SALMON METHODOLOGY REVIEW

Each year, the Scientific and Statistical Committee (SSC) completes a methodology review to help assure new or significantly modified methodologies employed to estimate impacts of the Council's salmon management use the best available science. This review is preparatory to the Council's adoption, at the November meeting, of all anticipated methodology changes to be implemented in the coming season, or in certain limited cases, of providing directions for handling any unresolved methodology problems prior to the formulation of salmon management options in March. Because there is insufficient time to review new or modified methods at the March meeting, the Council may reject their use if they have not been approved the preceding November.

This year the SSC is expected to report on a sensitivity analysis approach for the Fishery Regulation Assessment Model (FRAM) (Agenda Item D.1.a, Attachment 1), an updated Sacramento Index (SI) of fall Chinook abundance (Agenda Item D.1.a, Attachment 2), and an updated Sacramento Harvest Model (SHM) (Agenda Item D.1.a, Attachment 3).

Council Action:

1. **Approve methodology changes as appropriate for implementation in the 2009 salmon season.**
2. **Provide guidance, as needed, for any unresolved methodology issues.**

Reference Materials:

1. Agenda Item D.1.a, Attachment 1: Three Tests of a Potential Method for Development of a FRAM Sensitivity Analysis.
2. Agenda Item D.1.a, Attachment 2: The Sacramento Index.
3. Agenda Item D.1.a, Attachment 3: Preseason Report II Appendix D Sacramento River Fall Chinook Harvest Model (SHM).
4. Agenda Item D.2.b, Supplemental SSC Report.
5. Agenda Item D.2.c, Supplemental STT Report.
6. Agenda Item D.2.c, Supplemental SAS Report.

Agenda Order:

a.	Agenda Item Overview	Chuck Tracy
b.	Report of the Scientific and Statistical Committee	Steve Ralston
c.	Reports and Comments of Agencies and Advisory Bodies	
d.	Public Comment	
e.	**Council Action**: Adopt Final Methodology Changes for 2009 Salmon Seasons	

PFMC
10/15/08

Three Tests of a Potential Method for Development of a FRAM Sensitivity Analysis

Salmon Methodology Review

September 19, 2008

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Background

Sensitivity analysis (SA) of Chinook and Coho Fishery Regulation Assessment Models (FRAM) to major assumptions, including sensitivity to parameters related to mark-selective fisheries, has always been on the MEW "to do" list. At the April 2008 Pacific Fishery Management Council (Council) meeting this task was again discussed; however, it still wasn't clear what method would be most informative. In these discussions, the SSC emphasized a preference for a method utilizing a 'complete factorial design' approach. We left that meeting with the plan that the SSC would assist the MEW in designing these sensitivity analyses.

This is an exploratory report for one particular sensitivity analyses methodology. The level of parameter change is a topic for group discussion, as are all features of this exercise. The present purpose is to demonstrate this method and generate discussion.

Method

Bob Conrad (SSC) provided Chapter 8 of the 'Ecological Simulation Primer' (Swartzman and Kaluzny, 1987) as a good source of information and potential methods. This chapter is being mailed to all MEW members. The SA 'complete factorial design' method explored here is presented in pages 220-223. A model run is done for every varied parameter and all combinations of varied parameters. The number of model runs is m^n, with m being the number of levels examined and n being the number of parameters varied. The equations for calculating effects of parameter manipulation, as used here for model runs done with three parameters (n) at two levels (m) are presented in Table 1. These equations will change form according to the number of levels and parameters. Bob and I have discussed the limitations of this method but we believe it has merit because:

1) It captures the interaction of parameters being examined.
2) Flexibility in both parameters being examined and the model outputs chosen for evaluation.
3) A ranking of the effects is incorporated.
4) The output variables themselves can be evaluated for additional insight.
5) The number of model runs is not overwhelming.

Two of the limitations of this approach are that the choice of parameter levels is subjective, and while parameters can be ranked as to model sensitivity, that ranking is relative to the parameters (and the levels of adjustment) examined in the analysis.

Table 1. Equations used to calculate the "*effect statistic*" from model output results of varying parameters "a", "b", and "c", at two levels.

Perturbed Variable	Form of Equation for Effect Statistic: note that (1) designates the nominal condition
a	=(a+ab+ac+abc)/4 - ((1)+b+c+bc)/4
b	=(b+ab+bc+abc)/4 - ((1)+a+c+ac)/4
c	=(c+ac+bc+abc)/4 - ((1)+a+b+ab)/4
ab	=(abc+ab+c+(1))/4 - (ac+bc+a+b)/4
ac	=(abc+ac+b+(1))/4 - (ab+bc+a+c)/4
bc	=(abc+bc+a+(1))/4 - (ac+ab+b+c)/4
abc	=sum(a+b+c+ab+ac+bc)/6 – ((1)+abc)/2

Originally the FRAM was not set-up to model MSF. Thus, a FRAM sensitivity analysis should explore model functions without MSF as compared to model function when MSF are included. The model functions unique to only MSF add another component to the overall analysis. Thus, three sets of model runs are presented here:

1) General model function in standard non-MSF mode (Chinook series "1111").
2) General model function with significant level of fisheries converted to MSF (Chinook series "2222").
3) Specific model function of processes unique to MSF (coho series "2222").

Each series of eight model runs is presented with their own set of three tables.

For the Chinook exercises the three parameters manipulated were release mortality rates for: shaker release (**a**), legal size release (**b**), and drop-off and drop-out (**c**). These parameters were modeled at the nominal levels and at twice that level, for all FRAM fisheries. The standard Chinook legal size release mortality rate of 10% was doubled to 20%. The sub-legal release mortality rates and the drop-off/drop-out rates vary by fishery; the standard values and the doubled values can be seen in Appendix A. The two Chinook series were done with the same standardized set of recruit scalars and fishery effort scalars. Chinook series "2222" is simply a repeat of series "1111" but with all Puget Sound marine sport fisheries converted to Mark Selective Fisheries (MSF). An expanded set of Puget Sound marine sport fisheries was used to help demonstrate model functions; similarly the Puget Sound Chinook non-retention (CNR) fisheries were also expanded in area and time. The FRAM Chinook sensitivity analysis focused upon Puget Sound fisheries and stocks to take advantage of the experience gained with the MSFs already implemented in that region. .

The coho series used the 2007 pre-season final PFMC coho run (0714) to explore manipulation of three parameters input via FRAM's 'Selective Fishery Parameters' screen. The 'Mark Mis-ID', the 'UnMark Mis-ID', and the 'Drop-off' rates were modeled at nominal levels and at twice those values (Table 2). The manipulation of the coho MSF parameters was only applied to Council Area ocean fisheries.

Table 2 The standard Mark Selective Fishery input parameter values used in all Council area troll and sport fisheries, and the perturbed levels used for this coho MSF sensitivity analysis exercise.

Parameter Level	**Three MSF parameters manipulated in coho series "2222":**		
	Mark Mis-ID rate	**UnMarked Mis-ID rate**	**Drop-Off**
Standard values	0.06	0.02	0.05
Doubled values	0.12	0.04	0.10

In theory any model output variable could be evaluated for sensitivity to parameter manipulation. During the pre-season fishery planning process there is a focus on Exploitation Rates (ER) and natural stock escapement. The implementation of MSF will put more focus on hatchery stock escapements.

The Chinook sensitivity analysis "*effect statistic*" was calculated from model run outputs for natural stock preterminal ER (FRAM fisheries only) and escapement of hatchery and natural fish for two different Chinook stocks: Skagit summer/fall and Nisqually fall. These stocks were chosen because they have different patterns of pre-terminal fishery impacts, yet both would demonstrate effects from MSFs implemented in Puget Sound. Additional insight could be gained from looking at other model outputs. As a demonstration, three types of fishery mortality output (landed, shaker, and CNR) were used to calculate the effect statistic for a specific Chinook fishery (Area 9 sport).

The coho sensitivity analysis effect statistic was calculated from model run outputs of stock ER from NOF non-treaty troll fisheries, and from NOF plus Oregon area SOF sport fisheries. These fisheries were all MSF in the 2007 model. Four stocks were selected: Columbia River Marked and UnMarked, OCN UnMarked, and Thompson Wild. The three categories of fishery mortality were examined from the cumulative NOF non-treaty troll MSF (over all areas).

Results

Chinook Series "1111"

Table 3 (Skagit summer/fall Chinook) and Table 4 (Nisqually fall Chinook) present evaluated output and calculated effect statistics for pre-terminal ER, natural stock escapement, and hatchery stock escapement for these two Puget Sound Chinook stocks. Note that for change to a single parameter the effect statistic is the difference between the nominal run escapement output and perturbed parameter run escapement output. It is interesting to look at the change in output values resulting from these parameter manipulations and compare to the effect statistics to gage parameter inter-actions (or lack of).

Table 5 presents three types of fishery mortality output for the Area 9 sport fishery, by time step. Here it is interesting to observe the CNR mortality direct responsiveness to changes in the three mortality rate parameters. The 'effect statistic' for CNR mortality changes are perhaps easier to interpret than the effect statistic from other output variables. Referring to Table 5, Time Step Two Effects Statistic, the CNR Mortality for the nominal condition is 800 (600 shakers and 200 legal size mortalities). Doubling the shaker mortality rate adds 600 more mortalities, while doubling the legal size mortality rate adds 200 more. This is seen in both the Output and the Effect table columns. However, note that when both rates are doubled (command file "1ab1") although the Output CNR mortality increases by 800 total mortalities the Effect Statistic is “0” because there is no inter-action between the mortality rates in CNR fisheries where the model input is a fixed number of encounters. Note the output makes it obvious that the model does not apply ‘drop-off’ mortality rate to CNR fisheries.

It is not as transparent to interpret the corresponding effect statistic for Landed and Shaker mortalities. Here, as presented in Table 5, there appears to be a slight interaction between the three mortality rate input parameters. This interaction effect increases as the model progresses through the time steps and is seen as a cumulative effect in Table 5’s section for Time Step Two-Four (Time Step One output not presented here). This seems in conflict with the lack of inter-action for the examined parameters with the CNR fishery. The explanation is that, in this exercise, the input for retention fisheries are all in terms of ‘fishery scalars’ while the CNR inputs are fixed values. As the modeling progresses through time steps the stock abundances change in response to the release mortality rates, and ‘fishery scalar’ input produces fishery mortality that is responsive to changing abundance while fishery fixed value catch inputs are not responsive to abundance levels.

Chinook Series “2222”

The “2222” series is used to designate that MSF are included. Tables 6 and 7 correspond to Tables 3 and 4 presented for series “1111” above; and series “2222” Table 8 corresponds to Table 5.

Coho Series “2222”

With these coho runs we are focused upon the sensitivity of modeled MSFs to parameters unique to only MSF, thus there is no comparison to be made with retention fisheries. The tables follow the Chinook pattern of first looking at sensitivity of stock specific output (ER values) and then looking at mortality categories within a fishery. However, we deviate from the Chinook approach by looking only at ER values produced in the Council area MSF non-treaty troll (Table 9) and MSF sport fisheries (Table 10). The presented MSF effect statistics should not be confounded by including results from non-MSFs.

In Table 11 the three categories of fishery mortality are presented, for coho series “2222”, from the non-treaty NOF troll MSF fisheries (all areas combined). Here the effect statistics should not be confounded by changes in stock abundance over time (as seen above with Chinook fisheries modeled with effort scalars) as all the Council area coho fisheries are modeled with fixed catch inputs. Note however, Table 11 shows inter-action terms between all three manipulated parameters.

Discussion

There is plenty to sort out here. It is difficult to evaluate if the FRAM model is overly sensitive to any of the manipulated parameters; especially as the manipulation was a doubling of the standard values. But that has not been the purpose of this work. The evaluation of this particular type of sensitivity analysis methodology is the goal. Can this tool help the collective understanding of how the FRAM model operates and can it point to weakness in assumptions, areas of needed research, and even help find “model glitches”? Some of the hints from this evaluation are subtle, and should be explored beyond the scope of this presentation; some other issues are more clearly identified.

The presentation (in Tables 5, 8, and 11) of only three fishery mortality categories (landed, shaker, and CNR) is likely contributing to some confusion, as several types of mortalities are being combined to fit into those existing output report formats. In addition, there are differences in meaning between coho and Chinook "shaker" mortalities.

"Shaker" mortality is generally considered to be produced from the release of sub-legal fish, and this is the case in Chinook FRAM. However, in coho FRAM there are no sub-legal coho; coho "shakers" are release mortality from MSF. For both coho and Chinook, drop-off mortalities (legal sized Chinook only) are added to and reported as part of shaker mortality. Meanwhile, release mortalities from Chinook MSF (legal fish only) and coho MSF are summed into the CNR mortality category. Table 12 attempts to present how the various types of fishery related mortalities are categorized, and summed, for output reports.

'Landed' catch is straightforward and consistent between Chinook and coho FRAM.

Table 12. The assignment of various fishery mortality types to FRAM's output reporting categories.

Species	**The three fishery related mortality categories used in FRAM reports:**		
	Landed	**Shaker**	**Non-Retention (CNR)**
Coho	Landed or retained.	Drop-off mortality from both MSF and retention fisheries.	Release mortalities from non-retention (CNR).
			Release mortalities from MSF.
Chinook (legal size)	Landed or retained.	Drop-off mortality from both MSF and retention fisheries.	Release mortalities from non-retention (CNR).
			Release mortalities from MSF .
Chinook (sub-legal size)		Release mortalities from both MSF and retention fisheries.	Release mortalities from non-retention (CNR).
Notes:	1) For the same level of effort, the sub-legal release mortalities would be the same in a Chinook MSF as in a Chinook retention fishery.		
	2) FRAM does not calculate drop-off mortalities for either coho or Chinook CNR fisheries, but CNR input can be externally inflated to account for this.		
	3) FRAM does not apply a drop-off mortality rate to sub-legal Chinook encounters.		

Task Status

The MEW is exploring a potential tool for the FRAM sensitivity analysis task. The method presented here will be discussed and evaluated by a larger group at the October 15th Model Methodology Review Meeting. If this method is deemed worthwhile, then the MEW (preferably with input from the STT and SSC) can proceed to define a strategy to assess a larger set of parameters.

Parameters that potentially could be evaluated (under MSF and/or under retention fisheries) include: mortality rates, Chinook stock age structure, Chinook AEQ rates, and inter-actions between MSF specific parameters. Additional types of FRAM output should also be considered for evaluation. For example increasing the UnMarked Mis-Id rate (which would necessarily produce more dead Unmarked fish), in the presented coho MSF exercise, decreased the total MSF mortality; this result shifts the interest to the effect upon separated marked and unmarked mortality. In addition, FRAM output is apparently sensitive to whether catch input is provided as a ‘fishery effort scalar’ or as a ‘quota’; this issue also warrants further investigation.

Literature Cited

Swartzman G. L. and S. P. Kaluzny: Chapter 8 Simulation Model Evaluation, in *Ecological Simulation Primer*, Macmillan Publishing Company, New York, 1987, pp. 220-223.

Table 3. Results with three parameters at two levels, utilizing a complete factorial design focused on model output for Skagit Summer/Falls.

	Model Run	Evaluated Output:			Effect Statistic:		
.cmd	**parameter perturbed**	**PreTerm Nat ER**	**Nat Esc**	**Hat Esc**	**PreTerm Nat ER**	**Nat Esc**	**Hat Esc**
1**1**11	Standardized abundance & standardized fisheries (retention and CNR), standard release Mortality Rates	**0.4564**	**10978**	**427**			
1**a**11	1111 w/ doubled marine **shaker release Mortality Rate**	0.4769	10930	426	0.0202	-48	-2
1**b**11	1111 w/ doubled marine **legal-sized release Mortality Rate**	0.4594	10940	427	0.0030	-38	-1
1**c**11	1111 w/ doubled **drop-off Mortality Rate**	0.4682	10800	421	0.0116	-177	-7
1**ab**1	1111 w/ doubled shaker & legal-sized release Mortality Rates	0.4799	10892	425	0.0000	-1	0
1**ac**1	1111 w/ doubled shaker & drop-off release Mortality Rates	0.4882	10754	419	-0.0003	0	0
1**bc**1	1111 w/ doubled legal-sized & drop-off Mortality Rates	0.4713	10764	421	0.0000	0	0
1**abc**	1111 w/ doubled all three release Mortality Rates	0.4912	10715	418	0.0002	0	0

Table 4. Results with three parameters at two levels, utilizing a complete factorial design focused on model output for Nisqually Falls.

	Model Run	Evaluated Output:			Effect Statistic:		
.cmd	**parameter perturbed**	**PreTerm Nat ER**	**Nat Esc**	**Hat Esc**	**PreTerm Nat ER**	**Nat Esc**	**Hat Esc**
1111	Standardized abundance & standardized fisheries (retention and CNR), standard release Mortality Rates	**0.4993**	**872**	**4558**			
1a11	1111 w/ doubled marine **shaker release Mortality Rate**	0.5274	863	4499	0.0274	-9	-60
1b11	1111 w/ doubled marine **legal-sized release Mortality Rate**	0.5096	857	4446	0.0100	-15	-112
1c11	1111 w/ doubled **drop-off Mortality Rate**	0.5140	846	4373	0.0141	-26	-185
1ab1	1111 w/ doubled shaker & legal-sized release Mortality Rates	0.5373	848	4385	-0.0002	0	-1
1ac1	1111 w/ doubled shaker & drop-off release Mortality Rates	0.5411	838	4314	-0.0005	0	0
1bc1	1111 w/ doubled legal-sized & drop-off Mortality Rates	0.5241	831	4262	-0.0001	0	0
1abc	1111 w/ doubled all three release Mortality Rates	0.5508	822	4201	0.0005	0	0

Table 5. Results of a FRAM Sensitivity Analysis looking at three parameters at two levels, utilizing a complete factorial design focused on Chinook fishery mortality output from Area 9 sport fishery.

Model Run		TIME STEP TWO (MAY-JUNE)						TIME STEP THREE (JULY-SEPT)					
.cmd	parameter perturbed	Mortality Output			Effect Statistic			Mortality Output			Effect Statistic		
		Land	Shaker	CNR	Land	Shaker	CNR	Land	Shaker	CNR	Land	Shaker	CNR
1111	Standardized abundance & standardized fisheries (retention and CNR), standard release Mortality Rates	**565**	**159**	**800**				**4875**	**1458**	**700**			
1a11	1111 w/ doubled marine **shaker release Mortality Rate**	563	287	1400	-2	128	**600**	4830	2630	1100	-46	1171	400
1b11	1111 w/ doubled marine **legal-sized release Mortality Rate**	564	159	1000	-1	0	**200**	4857	1456	1000	-19	-2	300
1c11	1111 w/ doubled **drop-off Mortality Rate**	563	187	800	-2	28	**0**	4856	1699	700	-19	240	0
1ab1	1111 w/ doubled shaker & legal-sized release Mortality Rates	562	287	1600	0	0	0	4810	2629	1400	-1	0	0
1ac1	1111 w/ doubled shaker & drop-off release Mortality Rates	561	315	1400	0	0	0	4811	2869	1100	0	-1	0
1bc1	1111 w/ doubled legal-sized & drop-off Mortality Rates	563	187	1000	0	0	0	4838	1697	1000	0	0	0
1abc	1111 w/ doubled all three release Mortality Rates	560	315	1600	0	0	0	4792	2867	1400	0	1	0

Model Run		TIME STEP FOUR (OCT-APRIL)						TIME STEP TWO-FOUR sub-total					
.cmd	parameter perturbed	Mortality Output			Effect Statistic			Mortality Output			Effect Statistic		
		Land	Shaker	CNR	Land	Shaker	CNR	Land	Shaker	CNR	Land	Shaker	CNR
1111	Standardized abundance & standardized fisheries (retention and CNR), standard release Mortality Rates	**4838**	**3226**	**500**				**10278**	**4843**	**2000**			
1a11	1111 w/ doubled marine **shaker release Mortality Rate**	4730	6145	900	-108	2916	400	10122	9063	3400	-156	4215	1400
1b11	1111 w/ doubled marine **legal-sized release Mortality Rate**	4826	3226	600	-12	-1	100	10248	4841	2600	-31	-3	600
1c11	1111 w/ doubled **drop-off Mortality Rate**	4818	3466	500	-20	237	0	10237	5352	2000	-41	504	0
1ab1	1111 w/ doubled shaker & legal-sized release Mortality Rates	4719	6144	1000	1	0	0	10091	9060	4000	-1	-1	0
1ac1	1111 w/ doubled shaker & drop-off release Mortality Rates	4710	6379	900	0	-3	0	10082	9563	3400	1	-5	0
1bc1	1111 w/ doubled legal-sized & drop-off Mortality Rates	4806	3465	600	0	0	0	10207	5349	2600	0	-1	0
1abc	1111 w/ doubled all three release Mortality Rates	4699	6378	1000	0	2	0	10051	9559	4000	0	4	0

Table 6. Results with a **MSF background** utilizing three parameters at two levels, focused on model output for Skagit Summer/Falls.

Model Run		Evaluated Output			Effect Statistic		
.cmd	**parameter perturbed**	**PreTerm Nat ER**	**Nat Esc**	**Hatch Esc**	**PreTerm Nat ER**	**Nat Esc**	**Hatch Esc**
2222	Chinook series "1111" with Puget Sound marine sport fisheries converted to **Mark Selective Fishery**	**0.4078**	**11663**	**431**			
2**a**22	2222 w/ doubled marine **shaker release Mortality Rate,** MSF	0.4308	11614	428	0.0222	-46	-2
2**b**22	2222 w/ doubled marine **legal-sized release Mortality Rate,** MSF	0.4180	11536	430	0.0096	-124	-1
2**c**22	2222 w/ doubled **drop-off Mortality Rate,** MSF	0.4207	11478	424	0.0129	-187	-7
2**ab**2	2222 w/ doubled shaker & legal-sized release Mortality Rates, MSF	0.4395	11498	428	-0.0005	2	0
2**ac**2	2222 w/ doubled shaker & drop-off release Mortality Rates, MSF	0.4432	11431	422	0.0000	-3	0
2**bc**2	2222 w/ doubled legal-sized & drop-off Mortality Rates, MSF	0.4308	11353	423	0.0002	-3	0
2**abc**	2222 w/ doubled all three release Mortality Rates, MSF	0.4528	11303	421	0.0002	2	0

Table 7. Results with a **MSF background** utilizing three parameters at two levels, focused on model output for Nisqually Falls.

Model Run		Evaluated Output			Effect Statistic		
.cmd	**parameter perturbed**	**PreTerm Nat ER**	**Nat Esc**	**Hatch Esc**	**PreTerm Nat ER**	**Nat Esc**	**Hatch Esc**
2222	Chinook series "1111" with Puget Sound marine sport fisheries converted to **Mark Selective Fishery**	**0.3648**	**1053**	**4747**			
2a22	2222 w/ doubled marine **shaker release Mortality Rate,** MSF	0.4035	1045	4688	0.0335	-3	-56
2b22	2222 w/ doubled marine **legal-sized release Mortality Rate,** MSF	0.4076	995	4599	0.0377	-53	-145
2c22	2222 w/ doubled **drop-off Mortality Rate,** MSF	0.3829	1025	4561	0.0205	-34	-189
2ab2	2222 w/ doubled shaker & legal-sized release Mortality Rates, MSF	0.4305	1008	4553	-0.0048	5	3
2ac2	2222 w/ doubled shaker & drop-off release Mortality Rates, MSF	0.4208	1016	4502	0.0027	-6	-4
2bc2	2222 w/ doubled legal-sized & drop-off Mortality Rates, MSF	0.4251	967	4414	0.0028	-5	-3
2abc	2222 w/ doubled all three release Mortality Rates, MSF	0.4596	958	4354	-0.0005	4	3

Table 8. Results with a **MSF background** of a FRAM Sensitivity Analysis looking at three parameters at two levels, utilizing a complete factorial design focused on Chinook fishery mortality output from the Area 9 MSF sport fishery.

.cmd	Model Run parameter perturbed	TIME STEP TWO (MAY-JUNE) Mortality Output Land	Shaker	CNR	Effects: Land	Shaker	CNR	TIME STEP THREE (JULY-SEPT) Mortality Output Land	Shaker	CNR	Effects: Land	Shaker	CNR
2222	Chinook series “1111” with Puget Sound marine sport fisheries converted to **Mark Selective Fishery**	**366**	**160**	**821**				**3009**	**1463**	**894**			
2a22	2222 w/ doubled marine **shaker release Mortality Rate,** MSF	365	288	1421	-1	128	600	2980	2637	1292	-29	1173	398
2b22	2222 w/ doubled marine **legal-sized release Mortality Rate,** MSF	366	159	1041	-1	-1	220	2996	1461	1384	-13	-4	490
2c22	2222 w/ doubled **drop-off Mortality Rate,** MSF	365	188	821	-1	29	0	2998	1708	893	-11	243	-1
2ab2	2222 w/ doubled shaker & legal-sized release Mortality Rates, MSF	364	287	1641	0	0	0	2967	2634	1782	0	-1	-1
2ac2	2222 w/ doubled shaker & drop-off release Mortality Rates, MSF	364	316	1421	0	0	0	2969	2880	1292	0	-1	0
2bc2	2222 w/ doubled legal-sized & drop-off Mortality Rates, MSF	364	188	1041	0	1	0	2985	1704	1383	0	-1	-1
2abc	2222 w/ doubled all three release Mortality Rates, MSF	363	316	1641	0	0	0	2955	2875	1780	1	2	1

.cmd	Model Run parameter perturbed	TIME STEP FOUR (OCT-APRIL) Mortality Output Land	Shaker	CNR	Effects: Land	Shaker	CNR	TIME STEP TWO-FOUR sub-total (MAY-APRIL) Mortality Output Land	Shaker	CNR	Effects: Land	Shaker	CNR
2222	Chinook series “1111” with Puget Sound marine sport fisheries converted to **Mark Selective Fishery**	**3048**	**3229**	**684**				**6423**	**4852**	**2398**			
2a22	2222 w/ doubled marine **shaker release Mortality Rate,** MSF	2979	6149	1080	-69	2917	394	6324	9073	3793	-99	4217	1392
2b22	2222 w/ doubled marine **legal-sized release Mortality Rate,** MSF	3039	3228	965	-9	-2	279	6401	4848	3391	-22	-5	989
2c22	2222 w/ doubled **drop-off Mortality Rate,** MSF	3034	3471	683	-14	239	-1	6397	5367	2397	-26	510	-2
2ab2	2222 w/ doubled shaker & legal-sized release Mortality Rates, MSF	2970	6148	1358	0	0	-2	6302	9069	4780	0	0	-3
2ac2	2222 w/ doubled shaker & drop-off release Mortality Rates, MSF	2966	6385	1079	1	-3	0	6298	9581	3791	0	-4	0
2bc2	2222 w/ doubled legal-sized & drop-off Mortality Rates, MSF	3025	3469	964	0	-1	0	6375	5361	3388	0	-1	-1
2abc	2222 w/ doubled all three release Mortality Rates, MSF	2957	6383	1356	0	2	2	6275	9574	4777	1	4	3

Table 9. Results of a coho FRAM Sensitivity Analysis looking at three Mark Selective Fishery (MSF) parameters at two levels, utilizing a complete factorial design focused on Exploitation Rate (ER) in Ocean non-treaty NOF troll MSF for four coho stocks (86-92 Base Period as used in 2008).

MSF Model Run		Evaluated Output				Effect Statistic			
		ER in NOF NT Troll MSF for:							
		Columbia River		OCN	Thompson	Columbia River		OCN	Thompson
.cmd	parameter perturbed	Marked	UnMark	UnMark	Wild	Marked	UnMark	UnMark	Wild
C222	Pre-season 2007 abundance & 2007 fisheries (MSF and CNR), standard Mark Id Rates and Drop-off Rate	**0.0129**	**0.0051**	**0.0082**	**0.0041**				
C**a**22	C222 w/ doubled **Mark Mis-ID Rate**	0.0131	0.0054	0.0087	0.0044	0.0002	0.0003	0.0005	0.0002
C2**b**2	C222 w/ doubled **Unmark Mis-ID Rate**	0.0127	0.0052	0.0084	0.0044	-0.0002	0.0001	0.0001	0.0001
C22**c**	C222 w/ doubled **Drop-off Mortality Rate**	0.0134	0.0058	0.0093	0.0048	0.0006	0.0007	0.0012	0.0005
C**ab**2	C222 w/ doubled Mark & doubled Unmarked Mis-Id Rates	0.0129	0.0055	0.0088	0.0046	0.0000	0.0000	0.0000	0.0000
C**a**2**c**	C222 w/ doubled Mark Mis-ID & Drop-off Rates	0.0137	0.0061	0.0099	0.0050	0.0000	0.0000	0.0000	0.0000
C2**bc**	C222 w/ doubled Unmark Mis-ID & Drop-off Rates	0.0132	0.0058	0.0095	0.0048	0.0000	0.0000	0.0000	-0.0001
C**abc**	C222 w/ doubled all three release Mortality Rates	0.0135	0.0062	0.0100	0.0051	0.0000	0.0000	0.0000	0.0000

Table 10. Results of a coho FRAM Sensitivity Analysis looking at three Mark Selective Fishery (MSF) parameters at two levels, utilizing a complete factorial design focused on Exploitation Rate (ER) in Ocean sport MSF (NOF + SOF) for four coho stocks (86-92 Base Period as used in 2008).

MSF Model Run		Evaluated Output				Effect Statistic			
		ER in SOF & NOF Sport MSF for:							
		Columbia River		OCN	Thompson	Columbia River		OCN	Thompson
.cmd	parameter perturbed	Marked	UnMark	UnMark	Wild	Marked	UnMark	UnMark	Wild
C222	Pre-season 2007 abundance & 2007 fisheries (MSF and CNR), standard Mark Id Rates and Drop-off Rate	**0.3449**	**0.0836**	**0.0643**	**0.0091**				
C**a**22	C222 w/ doubled **Mark Mis-ID Rate**	0.3489	0.0890	0.0683	0.0096	0.0042	0.0061	0.0045	0.0007
C2**b**2	C222 w/ doubled **Unmark Mis-ID Rate**	0.3394	0.0883	0.0674	0.0096	-0.0059	0.0046	0.0029	0.0006
C22**c**	C222 w/ doubled **Drop-off Mortality Rate**	0.3614	0.1029	0.0788	0.0112	0.0169	0.0197	0.0148	0.0022
C**ab**2	C222 w/ doubled Mark & doubled Unmarked Mis-Id Rates	0.3429	0.0939	0.0714	0.0103	-0.0002	0.0001	0.0000	0.0000
C**a**2**c**	C222 w/ doubled Mark Mis-ID & Drop-off Rates	0.3665	0.1096	0.0838	0.0119	0.0005	0.0006	0.0005	0.0000
C2**bc**	C222 w/ doubled Unmark Mis-ID & Drop-off Rates	0.3556	0.1072	0.0815	0.0118	-0.0001	-0.0002	-0.0002	0.0000
C**abc**	C222 w/ doubled all three release Mortality Rates	0.3601	0.1140	0.0864	0.0124	-0.0001	-0.0003	-0.0002	0.0000

Table 11. Results of a coho FRAM Sensitivity Analysis looking at three parameters at two levels, utilizing a complete factorial design focused on fishery mortality output from non-treaty NOF Troll Mark Selective Fisheries.

Model Run		JULY TIME STEP						AUGUST TIME STEP					
.cmd	**parameter perturbed**	**Mortality Output:**			**Effect Statistic:**			**Mortality Output:**			**Effect Statistic:**		
		Land	**Shak**	**CNR**	**Land**	**Shak**	**CNR**	**Land**	**Shak**	**CNR**	**Land**	**Shak**	**CNR**
C222	Pre-season 2007 abundance & 2007 fisheries (MSF and CNR), standard Mark Id Rates and Drop-off Rate, MSF	**5748**	**530**	**1266**				**12857**	**1291**	**3374**			
Ca22	C222 w/ doubled **Mark Mis-ID Rate, MSF**	5748	567	1449	0	53	181	12857	1379	3824	0	127	440
C2b2	C222 w/ doubled **Unmark Mis-ID Rate, MSF**	5748	522	1221	0	-14	-47	12857	1265	3236	0	-43	-148
C22c	C222 w/ doubled **Drop-off Mortality Rate, MSF**	5748	1062	1266	0	544	1	12857	2585	3378	0	1323	4
Cab2	C222 w/ doubled Mark & doubled Unmarked Mis-Id Rates, MSF	5748	558	1400	0	-1	-3	12857	1347	3666	0	-4	-10
Ca2c	C222 w/ doubled Mark Mis-ID & Drop-off Rates, MSF	5748	1132	1450	0	17	0	12857	2758	3827	0	42	0
C2bc	C222 w/ doubled Unmark Mis-ID & Drop-off Rates, MSF	5748	1044	1222	0	-5	0	12857	2532	3239	0	-14	0
Cabc	C222 w/ doubled all three release Mortality Rates, MSF	5748	1113	1400	0	-7	2	12857	2697	3670	0	-16	6

Model Run		SEPTEMBER TIME STEP						JANUARY THROUGH DECEMEBER					
.cmd	**parameter perturbed**	**Mortality Output:**			**Effect Statistic:**			**Mortality Output:**			**Effect Statistic:**		
		Land	**Shak**	**CNR**	**Land**	**Shak**	**CNR**	**Land**	**Shak**	**CNR**	**Land**	**Shak**	**CNR**
C222	Pre-season 2007 abundance & 2007 fisheries (MSF and CNR), standard Mark Id Rates and Drop-off Rate, MSF	**3794**	**363**	**900**				**22399**	**2186**	**7094**			
Ca22	C222 w/ doubled **Mark Mis-ID Rate, MSF**	3794	387	1026	0	35	124	22399	2331	7854	0	215	746
C2b2	C222 w/ doubled **Unmark Mis-ID Rate, MSF**	3794	355	861	0	-12	-42	22399	2143	6873	0	-69	-237
C22c	C222 w/ doubled **drop-off Mortality Rate, MSF**	3794	726	903	0	372	3	22399	4374	7102	0	2238	8
Cab2	C222 w/ doubled Mark & doubled Unmarked Mis-Id Rates, MSF	3794	378	983	0	-1	-3	22399	2283	7603	0	-4	-15
Ca2c	C222 w/ doubled Mark Mis-ID & Drop-off Rates, MSF	3794	775	1031	0	12	0	22399	4666	7863	0	72	1
C2bc	C222 w/ doubled Unmark Mis-ID & Drop-off Rates, MSF	3794	713	864	0	-3	-1	22399	4287	6880	0	-23	-1
Cabc	C222 w/ doubled all three release Mortality Rates, MSF	3794	758	985	0	-5	2	22399	4569	7611	0	-30	10

APPENDIX TABLE A.

Standard and manipulated values of two parameters (Shaker mortality rate and Drop-off/Drop-out rate) examined in this Chinook sensitivity analysis.

Chinook Outfile: stk2008sfm56splitCVAEQfix.out		Standard Shaker Mortality by Time Step:				Sublegals encountered?			Doubled	Other Mortality by Fishery	
Fishery #	**Fishery Name**	**Step 1**	**Step 2**	**Step 3**	**Step 4**	**Step 2**	**Step**	**Steps 1&4**	**Shaker**	**Standard**	**Doubled**
Fishery 1	Southeast Alaska Troll	0.255	0.255	0.255	0.255	yes	yes	yes	0.5100	0.0080	0.0160
Fishery 2	Southeast Alaska Net	0.3	0.3	0.3	0.3	no	no	n.a.	0.6000	0.0300	0.0600
Fishery 3	Southeast Alaska Sport	0.123	0.123	0.123	0.123	yes	yes	yes	0.2460	0.0360	0.0720
Fishery 4	North/Central British Columbia Net	0.3	0.3	0.3	0.3	no	no	n.a.	0.6000	0.0300	0.0600
Fishery 5	West Coast Vancouver Island Net	0.3	0.3	0.3	0.3	no	no	no	0.6000	0.0300	0.0600
Fishery 6	Strait of Georgia Net	0.3	0.3	0.3	0.3	no	no	no	0.6000	0.0300	0.0600
Fishery 7	Canada Juan de Fuca Net (Area 20)	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0300	0.0600
Fishery 8	North/Central British Columbia Sport	0.123	0.123	0.123	0.123	yes	yes	yes	0.2460	0.0690	0.1380
Fishery 9	North/Central British Columbia Troll	0.255	0.255	0.255	0.255	yes	yes	yes	0.5100	0.0170	0.0340
Fishery 10	West Coast Vancouver Island Troll	0.255	0.255	0.255	0.255	yes	yes	yes	0.5100	0.0170	0.0340
Fishery 11	West Coast Vancouver Island Sport	0.123	0.123	0.123	0.123	yes	yes	yes	0.2460	0.0690	0.1380
Fishery 12	Strait of Georgia Troll	0.255	0.255	0.255	0.255	yes	yes	yes	0.5100	0.0170	0.0340
Fishery 13	North Strait of Georgia Sport	0.123	0.123	0.123	0.123	yes	yes	yes	0.2460	0.0690	0.1380
Fishery 14	South Strait of Georgia Sport	0.123	0.123	0.123	0.123	yes	yes	yes	0.2460	0.0690	0.1380
Fishery 15	BC Juan de Fuca Sport	0.123	0.123	0.123	0.123	yes	yes	yes	0.2460	0.0690	0.1380
Fishery 16	NT Cape Flattery-Quillayute Troll (Area 3-4)	0.255	0.255	0.255	0.255	yes	yes	n.a.	0.5100	0.0500	0.1000
Fishery 17	T Cape Flattery-Quillayute Troll (Area 3-4)	0.255	0.255	0.255	0.255	yes	yes	yes	0.5100	0.0500	0.1000
Fishery 18	Cape Flattery-Quillayute Sport (Area 3-4)	0.14	0.14	0.14	0.14	yes	yes	n.a.	0.2800	0.0500	0.1000
Fishery 19	Cape Flattery-Quillayute Net (Area 3-4)	0.3	0.3	0.3	0.3	no	no	n.a.	0.6000	0.0300	0.0600
Fishery 20	NT Grays Harbor Troll (Area 2)	0.255	0.255	0.255	0.255	yes	yes	n.a.	0.5100	0.0500	0.1000
Fishery 21	T Grays Harbor Troll (Area 2)	0.255	0.255	0.255	0.255	n.a.	yes	n.a.	0.5100	0.0500	0.1000
Fishery 22	Grays Harbor Sport (Area 2)	0.14	0.14	0.14	0.14	n.a.	yes	n.a.	0.2800	0.0500	0.1000
Fishery 23	NT Grays Harbor Net	0.3	0.3	0.3	0.3	n.a.	no	n.a.	0.6000	0.0300	0.0600
Fishery 24	T Grays Harbor Net	0.3	0.3	0.3	0.3	n.a.	no	n.a.	0.6000	0.0300	0.0600
Fishery 25	Willapa Net	0.3	0.3	0.3	0.3	n.a.	no	n.a.	0.6000	0.0300	0.0600

APPENDIX TABLE A (continued).

Standard and manipulated values of two parameters (Shaker mortality rate and Drop-off/Drop-out rate) examined in this Chinook sensitivity analysis.

Chinook Outfile: stk2008sfm56splitCVAEQfix.out		**Standard Shaker Mortality by Time Step:**				**Sublegals encountered?**			**Doubled**	**Other Mortality by Fishery**	
Fishery #	**Fishery Name**	**Step 1**	**Step 2**	**Step 3**	**Step 4**	**Step 2**	**Step 3**	**Steps 1&4**	**Shaker**	**Standard**	**Doubled**
Fishery 26	NT Columbia River Troll (Area 1)	0.255	0.255	0.255	0.255	yes	yes	n.a.	0.5100	0.0500	0.1000
Fishery 27	Columbia River Sport (Area 1)	0.14	0.14	0.14	0.14	yes	yes	n.a.	0.2800	0.0500	0.1000
Fishery 28	Columbia River Net	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0300	0.0600
Fishery 29	Buoy 10 Sport	0.14	0.14	0.14	0.14	n.a.	no	n.a.	0.2800	0.0500	0.1000
Fishery 30	Orford Reef-Cape Falcon Troll (Central OR)	0.255	0.255	0.255	0.255	yes	yes	yes	0.5100	0.0500	0.1000
Fishery 31	Orford Reef-Cape Falcon Sport (Central OR)	0.14	0.14	0.14	0.14	yes	yes	**no**	0.2800	0.0500	0.1000
Fishery 32	Horse Mountain-Orford Reef Troll (KMZ)	0.3	0.3	0.3	0.3	yes	yes	**no**	0.6000	0.0500	0.1000
Fishery 33	Horse Mountain-Orford Reef Sport (KMZ)	0.23	0.23	0.23	0.23	yes	yes	**no**	0.4600	0.0500	0.1000
Fishery 34	Southern California Troll	0.3	0.3	0.3	0.3	yes	yes	**no**	0.6000	0.0500	0.1000
Fishery 35	Southern California Sport	0.23	0.23	0.23	0.23	yes	yes	yes	0.4600	0.0500	0.1000
Fishery 36	Area 7 Sport	0.2	0.2	0.2	0.2	yes	yes	yes	0.4000	0.0500	0.1000
Fishery 37	NT San Juan Net (Area 6A,7,7A)	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0100	0.0200
Fishery 38	T San Juan Net (Area 6A,7,7A)	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0100	0.0200
Fishery 39	NT Nooksack-Samish Net	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400
Fishery 40	T Nooksack-Samish Net	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0100	0.0200
Fishery 41	T Juan de Fuca Troll (Area 5,6,7)	0.255	0.255	0.255	0.255	yes	yes	yes	0.5100	0.0500	0.1000
Fishery 42	Area 5/6 Sport	0.2	0.2	0.2	0.2	yes	yes	yes	0.4000	0.0500	0.1000
Fishery 43	NT Juan de Fuca Net (Area 4B,5,6,6C)	0.3	0.3	0.3	0.3	n.a.	yes	no	0.6000	0.0300	0.0600
Fishery 44	T Juan de Fuca Net (Area 4B,5,6,6C)	0.3	0.3	0.3	0.3	no	no	no	0.6000	0.0300	0.0600
Fishery 45	Area 8 Sport	0.2	0.2	0.2	0.2	yes	yes	yes	0.4000	0.0500	0.1000
Fishery 46	NT Skagit Net (Area 8)	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400
Fishery 47	T Skagit Net (Area 8)	0.3	0.3	0.3	0.3	no	no	no	0.6000	0.0200	0.0400
Fishery 48	Area 8D Sport	0.2	0.2	0.2	0.2	n.a.	**no**	n.a.	0.4000	0.0500	0.1000
Fishery 49	NT Stilly-Snohomish Net (Area 8A)	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400
Fishery 50	T Stilly-Snohomish Net (Area 8A)	0.3	0.3	0.3	0.3	no	no	no	0.6000	0.0200	0.0400
Fishery 51	NT Tulalip Bay Net (Area 8D)	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400

APPENDIX TABLE A (continued).

Standard and manipulated values of two parameters (Shaker mortality rate and Drop-off/Drop-out rate) examined in this Chinook sensitivity analysis.

Chinook Outfile: stk2008sfm56splitCVAEQfix.out		**Standard Shaker Mortality by Time Step:**				**Sublegals encountered?**			**Doubled**	**Other Mortality by Fishery**	
Fishery #	**Fishery Name**	**Step 1**	**Step 2**	**Step 3**	**Step 4**	**Step 2**	**Step 3**	**Steps 1&4**	**Shaker**	**Standard**	**Doubled**
Fishery 52	T Tulalip Bay Net (Area 8D)	0.3	0.3	0.3	0.3	no	no	no	0.6000	0.0200	0.0400
Fishery 53	Area 9 Sport	0.2	0.2	0.2	0.2	yes	yes	yes	0.4000	0.0500	0.1000
Fishery 54	NT Area 6B/9 Net used for Sport	0.2	0.2	0.2	0.2	yes	yes	yes	0.4000	0.0500	0.1000
Fishery 55	T Area 6B/9 Net	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400
Fishery 56	Area 10 Sport	0.2	0.2	0.2	0.2	yes	yes	yes	0.4000	0.0500	0.1000
Fishery 57	Area 11 Sport	0.2	0.2	0.2	0.2	yes	yes	yes	0.4000	0.0500	0.1000
Fishery 58	NT Area 10/11 Net	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400
Fishery 59	T Area 10/11 Net	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400
Fishery 60	NT Area 10A Net	0.2	0.2	**0.2**	0.2	n.a.	**yes**	no	0.4000	0.0200	0.0400
Fishery 61	T Area 10A Net	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400
Fishery 62	NT Area 10E Net	0.3	0.3	0.3	0.3	n.a.	**no**	**no**	0.6000	0.0200	0.0400
Fishery 63	T Area 10E Net	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400
Fishery 64	Area 12 Sport	0.2	0.2	0.2	0.2	yes	yes	yes	0.4000	0.0500	0.1000
Fishery 65	NT Hood Canal Net (Area 12,12B,12C)	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0100	0.0200
Fishery 66	T Hood Canal Net (Area 12,12B,12C)	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400
Fishery 67	Area 13 Sport	0.2	0.2	0.2	0.2	yes	yes	yes	0.4000	0.0500	0.1000
Fishery 68	NT Deep S. Puget Sound Net (13,13D-K)	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400
Fishery 69	T Deep S. Puget Sound Net (13,13D-K)	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400
Fishery 70	NT Area 13A Net	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400
Fishery 71	T Area 13A Net	0.3	0.3	0.3	0.3	n.a.	no	no	0.6000	0.0200	0.0400
Fishery 72	Freshwater Sport	0.2	0.2	0.2	0.2	n.a.	no	no	0.4000	0.0500	0.1000
Fishery 73	Freshwater Net	0.3	0.3	0.3	0.3	no	no	n.a.	0.6000	0.0200	0.0400

Agenda Item D.1.a
Attachment 2
November 2008

The Sacramento Index

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1 Introduction

Sacramento River fall Chinook (SRFC) have been the largest contributor to ocean salmon harvest off California and Oregon for several decades. At present, however, the stock appears to have collapsed as indicated by the 2006 and 2007 jack (estimated age-two) spawning escapement being the lowest on record (since 1970), and the 2007 adult (estimated age $\geq$ 3) escapement of 88,000 being the second lowest on record. Adding to the concern, the 2008 forecast escapement was 59,100 adults assuming all ocean salmon fisheries south of Cape Falcon, Oregon, and Sacramento River Basin fisheries impacting SRFC were closed in 2008. Given the stock's current status, and its 2008 forecast abundance, the U.S. Secretary of Commerce took the unprecedented step of closing all 2008 ocean Chinook fisheries south of Cape Falcon, and the California Fish and Game Commission took the equally unprecedented step of closing all 2008 Sacramento River Basin fisheries impacting SRFC. This report describes the data and methods used in 2008 to develop a historical index of SRFC adult ocean abundance and the forecast of this index abundance in 2008, which led to the forecast escapement of 59,100 adults. We begin with a brief synopsis of the methods used prior to 2008, and follow with a description of the methods proposed for use in 2009 and beyond.

1.1 Pre-2008 methods: Central Valley Index

In years prior to 2008, SRFC escapement projections were derived from forecasts of the Central Valley Index (*CVI*), which served as an index of abundance for the combined stocks of Central Valley Chinook, including SRFC, Sacramento River winter Chinook, Sacramento River late-fall Chinook, Central Valley spring Chinook, and San Joaquin River fall Chinook. The *CVI* is an annual index defined as the calendar year sum of Central Valley Chinook adult escapement (E_{CV}) and the ocean catch of Chinook (all stocks, including non-Central Valley) between Point Arena, California, and the U.S./Mexico border (C_{AM})

$$CVI = E_{CV} + C_{\mathsf{AM}}. \tag{1}$$

Linear regression of the *CVI* in year t against Central Valley Chinook jack spawning escapement in year t-1, with t = 1990–forward, was used to forecast the current year *CVI* based on the previous year's jack escapement (e.g., see PFMC 2007, Figure II-1).

SRFC adult escapement (E) was then forecast using the projected CVI, the anticipated CVI ocean harvest rate index ($h_{CVI} = C_{\mathsf{AM}}/CVI$), and the anticipated proportion (π) of E_{CV} that would be SRFC as

$$E = CVI \times (1 - h_{CVI}) \times \pi, \tag{2}$$

allowing for a pre-season evaluation of E relative to the SRFC escapement goal. In the most recent use of this model for forecasting purposes (2007), the previous year's h_{CVI} estimate, and the mean of the previous five years of π estimates, were used for these quantities in equation (2). Prior to 2008, stocks other than SRFC constrained ocean fisheries and a model more sophisticated than equation (2) was unnecessary for SRFC assessment.

1.2 2008 methods: Sacramento Index

There are several shortcomings to using the CVI to forecast SRFC escapement, including (1) the index itself is not SRFC-specific, (2) the index is calculated on a calendar year basis rather than on a biological year (between annual spawning events) basis, (3) ocean harvest north of Point Arena is not accounted for, and (4) river harvest is not accounted for. These shortcomings coupled with the critical status of SRFC in 2008 hastened the development of a new SRFC-specific abundance index (the *Sacramento Index*, *SI*) and a new SRFC-specific harvest model (the *Sacramento Harvest Model*, *SHM*).

The *SI* was similar in structure to the *CVI*:

$$SI = H_{o,S} + E, \tag{3}$$

where $H_{o,S}$ is the Sept. 1 through Aug. 31 (biological year) ocean harvest of SRFC south of Cape Falcon, and E is the SRFC adult escapement. Methods developed in 2008 provided estimates of SRFC ocean harvest in all time-area-fisheries south of Cape Falcon; a significant improvement in the extent, resolution, and specificity of SRFC ocean harvest information compared to that previously available. Like the *CVI* however, the *SI* defined in equation (3) does not include river harvest (although E implicitly depends on this harvest).

Based on a forecast of the *SI* and of the SRFC harvest expected in the ocean and river fisheries, the *SHM* provides a forecast of the current year SRFC adult escapement. The 2008 *SHM* did this by deducting the projected SRFC ocean harvest (a function of the *SI* and ocean fishery management measures) from the *SI* which yielded a forecast of SRFC adult escapement assuming a "typical" (largely unconstrained) SRFC river fishery (the type of fishery that generated the data from which the 2008 *SI* was constructed). To forecast the expected escapement under a constrained river fishery, the 2008 *SHM* first projected the SRFC adult river run abundance by dividing the projected escapement under a typical river fishery by (1 - average river harvest rate), and then multiplied this by (1 - constrained river harvest rate). For a complete description of the *SHM* see Mohr and O'Farrell (2008).

1.3 Post-2008 methods: Sacramento Index

As defined in 2008, the *SI* is an incomplete representation of SRFC adult ocean abundance, in part because it does not explicitly include the harvest of SRFC adults by the Sacramento River Basin recreational fishery. River harvest was not included in the 2008 formulation of the *SI* because of gaps in the historical time series of river harvest estimates. However, further analysis of the existing SRFC river harvest estimates derived from California Department of Fish and Game (CDFG) angler creel surveys, coupled with the methods described in this report, now allow for the hindcasting of river harvest for years in which survey estimates are unavailable, and this allows for a re-definition of the *SI* to explicitly include SRFC adult river harvest (H_r):

$$SI = H_{o,S} + H_r + E. \tag{4}$$

The addition of H_r to the *SI* also permits a more straightforward formulation of SRFC river harvest and escapement within the *SHM*.

This report describes in detail our assessment of the individual components of the *SI* as defined by equation (4). Section 2 documents how the $H_{o,S}$ estimates were derived. Section 3 details how the CDFG angler survey estimates, and hindcasts of H_r, were developed. Section 4 describes the escapement survey methods used to generate E. Section 5 presents the *SI* time series. Finally, Section 6 documents how the *SI* is annually forecast for use in the *SHM*.

2 Ocean Harvest

The ocean harvest of SRFC, $H_{o,S}$, is a key component of the *SI*, and for the purposes of the *SI*, is defined as the Sept. 1 through Aug. 31 SRFC ocean harvest south of Cape Falcon. Some SRFC have been harvested north of Cape Falcon, but this harvest was determined to be a small percentage of the SRFC overall ocean harvest (Appendix A). For years 1986–2007, the average proportion of the SRFC overall ocean harvest landed north of Cape Falcon was approximately two percent.

The *SI* is intended to be an index of SRFC *adult* ocean abundance. While direct measures are taken to ensure that only adults are included in the H_r and E estimates, directly restricting $H_{o,S}$ to include only age 3–5 SRFC is not possible given the limitations of available ocean harvest age composition data. However, few age-two Chinook are vulnerable to ocean fishing gear, and age-two Chinook are generally smaller than the minimum size-limits in ocean fisheries. For these reasons, the contribution of age-two fish to the ocean harvest is small. We thus consider the *SI* to be an index of SRFC adult ocean abundance, yet acknowledge that a small number of age-two fish may be harvested in ocean fisheries and therefore contribute to the index.

Estimation of $H_{o,S}$ from the mixed-stock ocean harvest presents challenges due to the limitations of the available data. In particular, the lack of age-specific SRFC harvest and escapement data precludes using cohort reconstruction methods to estimate SRFC ocean harvest (as is done, for example, with Klamath River fall Chinook, KRFC). The only data currently available for estimation of $H_{o,S}$ are the coded-wire tags recovered in ocean fisheries. We used these tag recoveries from ocean fisheries south of Cape Falcon, and the historical dominance of SRFC in the ocean harvest south of Point Arena, to estimate $H_{o,S}$ for all time-area-fisheries south of Cape Falcon. The remainder of Section 2 describes the details of this estimation methodology.

Table 1. Description of management areas south of Cape Falcon, Oregon. KMZ denotes the Klamath Management Zone which extends from Humbug Mountain, Oregon to Horse Mountain, California. "Falcon-to-Arena" is the region extending from Cape Falcon, Oregon to Point Arena, California, consisting of the {NO, CO, KO, KC, FB} areas. "Arena-to-Mexico" is the region extending from Point Arena, California, to the U.S./Mexico border, consisting of the {SF, MO} areas.

Area	*Abbreviation*	*Northern border*	*Major Ports*
Northern Oregon	NO	Cape Falcon, OR	Newport, Tillamook
Central Oregon	CO	Florence South Jetty, OR	Coos Bay
Oregon KMZ	KO	Humbug Mountain, OR	Brookings
California KMZ	KC	OR/CA border	Eureka, Crescent City
Fort Bragg	FB	Horse Mountain, CA	Fort Bragg
Falcon-to-Arena	FA		
San Francisco	SF	Point Arena, CA	San Francisco
Monterey	MO	Pigeon Point, CA	Monterey
Arena-to-Mexico	AM		

2.1 Data

Total Chinook (mixed-stock) harvest is estimated annually by management area $a \in$ {NO, CO, KO, KC, FB, SF, MO} (here confined to the areas south of Cape Falcon, see Table 1), month m, and fishery $x \in$ {Commercial, Recreational}. Summaries of this harvest can be found in PFMC (2008b, Appendix A). To obtain an estimate of $H_{o,S}$ from this mixed-stock harvest, two additional sources of information were required.

The first additional source of information required to derive $H_{o,S}$ was the estimated ocean harvest of KRFC in all time-area-fisheries south of Cape Falcon. These estimates were provided by the KRFC cohort reconstruction results which are available for brood years 1979–forward. The databases and methods used for KRFC cohort reconstruction are described in detail by Goldwasser et al. (2001) and Mohr (2006).

The second additional source of information required to derive $H_{o,S}$ was the coded-wire tag recovery data from all Chinook stocks other than KRFC in all time-area-fisheries south of Cape Falcon (obtained from the Regional Mark Processing Center, http://www.rmpc.org). Coded-wire tags recovered in both commercial and recreational fisheries were expanded for the non-exhaustive sampling of ocean harvest to produce stock-specific estimates of the total number of coded-wire tagged fish harvested in all time-area-fisheries. These sample-expanded estimates were then further expanded to account for the hatchery mark-rate (tagged versus untagged) in order to estimate hatchery-specific ocean harvest by time-area-fishery. An exception to this procedure was used in the case of SRFC, where it was not feasible to expand for the hatchery mark-rate because of the low and variable tagging rates historically employed at SRFC-producing hatcheries. SRFC coded-wire tags were therefore only expanded for sampling.

2.2 Methods

Estimation of $H_{o,S}$ is performed by means of a two-part process that exploits the fact that SRFC dominate ocean Chinook harvest in the AM region. For each biological year t (m = Sept. 1, *t-1* through Aug. 31, t), for the areas south of Point Arena, $a \in \{\mathsf{SF}, \mathsf{MO}\}$, and in both the commercial and recreational fisheries, the time-area-fishery-specific ocean harvest of SRFC ($H_{o,S,a,m,x}$) was estimated by subtracting from the respective total Chinook harvest ($H_{o,T,a,m,x}$) the estimated harvest of all other stock groups that could be accounted for:

$$H_{o,S,a,m,x} = H_{o,T,a,m,x} - \sum_{g=K,V,N} H_{o,g,a,m,x}\,, \qquad \text{for} \quad a \in \{\mathsf{SF}, \mathsf{MO}\}. \tag{5}$$

$H_{o,K,a,m,x}$ is the estimated harvest of KRFC, hatchery- and natural-origin, derived from the KRFC cohort reconstruction. $H_{o,V,a,m,x}$ is the estimated harvest of all Central Valley hatchery-origin Chinook other than SRFC (including Sacramento River late-fall Chinook, Sacramento River winter Chinook, Central Valley spring Chinook, and San Joaquin River fall Chinook), as well as age-two SRFC coded-wire tagged groups (expanded for sampling only). $H_{o,N,a,m,x}$ is the estimated harvest of all non-Central Valley hatchery-origin Chinook stocks (excluding KRFC).

The summation term in equation (5) represents the best estimate of all known Chinook harvest in the SF and MO areas, other than age 3–5 SRFC. This expression omits the harvest of stocks without a coded-wire tagged hatchery component (e.g. some California Coastal Chinook), natural-origin fish from stocks with hatchery components (except for KRFC), and age-two SRFC natural- and untagged hatchery-origin fish. These omissions likely constitute a very small proportion of the total harvest in these southern areas.

To derive estimates of $H_{o,S,a,m,x}$ for the time-area-fisheries between Cape Falcon and Point Arena, we applied the ratio of SRFC harvest per SRFC coded-wire tag[1] observed south of Point Arena to the number of SRFC coded-wire tags recovered in the areas between Cape Falcon and Point Arena on a biological year basis as follows. Yearly SRFC ocean harvest in the region between Point Arena and the U.S./Mexico border (AM) was determined by summing $H_{o,S,a,m,x}$ over the SF and MO areas, over all months (Sept. 1 through Aug. 31), and over both fisheries:

$$H_{o,S,\mathsf{AM}} = \sum_{a=\mathsf{SF},\mathsf{MO}} \sum_{m,x} H_{o,S,a,m,x} \,. \tag{6}$$

The number of SRFC sample-expanded coded-wire tags recovered over this same subset of the harvest, $Z_{o,S,\mathsf{AM}}$, led to the ratio

$$\lambda = \frac{H_{o,S,\mathsf{AM}}}{Z_{o,S,\mathsf{AM}}}, \tag{7}$$

which represents the expected number of SRFC (hatchery- and natural-origin) harvested per SRFC coded-wire tag in the harvest, independent of month and fishery. For the time-area-fisheries between Cape Falcon and Point Arena, λ was then applied to the number of SRFC sample-expanded coded-wire tag recoveries, $Z_{o,S,a,m,x}$, to estimate the respective SRFC ocean harvest:

$$H_{o,S,a,m,x} = Z_{o,S,a,m,x} \times \lambda, \qquad \text{for} \quad a \in \{\mathsf{NO},\mathsf{CO},\mathsf{KO},\mathsf{KC},\mathsf{FB}\}. \tag{8}$$

With this two-part (north and south of Point Arena) method, the SRFC ocean harvest for each time-area-fishery south of Cape Falcon was estimated, and then aggregated for the SRFC overall ocean harvest,

$$H_{o,S} = \sum_{a,m,x} H_{o,S,a,m,x} \,. \tag{9}$$

The procedures described above parse each time-area-fishery Chinook total (T) harvest into two stocks (S and K) and two stock groupings (V and N). For the areas south of Point Arena, the sum of these four components, by construction, equaled the total harvest. However, for the

[1]In an attempt to constrain the estimate of $H_{o,S,a,m,x}$ to age 3–5 fish, we limited the coded-wire tag recoveries of SRFC used to estimate $H_{o,S,a,m,x}$ to age 3–5 fish. Hereafter, reference to "SRFC coded-wire tag" implies SRFC coded-wire tags from age 3–5 fish.

areas north of Point Arena, the estimated harvest of S, K, V, and N did not always sum to the total harvest. In these cases, the estimated component harvests were adjusted so that they did sum to the total harvest, using the methods described in Appendix B.

2.3 Results

For the region south of Point Arena, Table 2 displays the estimated SRFC ocean harvest, the number of age 3–5 SRFC sample-expanded coded-wire tags recovered, and their ratio for each biological year. Factors likely contributing to the observed annual variation in λ include variable SRFC natural-origin production, and variable tagging rates at SRFC-producing hatcheries. For example, while production levels at Coleman National Fish Hatchery have remained steady, the number of fish coded-wire tagged decreased sharply beginning with brood year 2002. It is likely that this reduction in tagging rate post-2002 at least partially accounts for the high λ values observed in 2005–2007.

Figure 1 displays total Chinook and SRFC ocean harvest estimates for the seven management areas south of Cape Falcon, 1983–2008. The proportion of total Chinook harvest attributed to SRFC is substantial for all areas, particularly in the south.

3 River Harvest

River harvest was not included in the 2008 formulation of the *SI* because of gaps in the historical time series of river harvest estimates. As a consequence, the *SHM's* 2008 escapement forecast was a function of the *SI* forecast, the $H_{o,S}$ forecast, and the average river harvest rate observed in past years compared to that expected in 2008 (PFMC 2008a, Appendix D). The approach used in the 2008 assessment to estimate this average river harvest rate is presented in this section, as well as an alternative river harvest rate model which depends nonlinearly on river run abundance.

The derived river harvest rate models are also used to hindcast the river harvest in years when angler surveys were not conducted based on (1) the escapement in that year, and (2) the river harvest rate expected at that level of escapement. These hindcast river harvest estimates for the

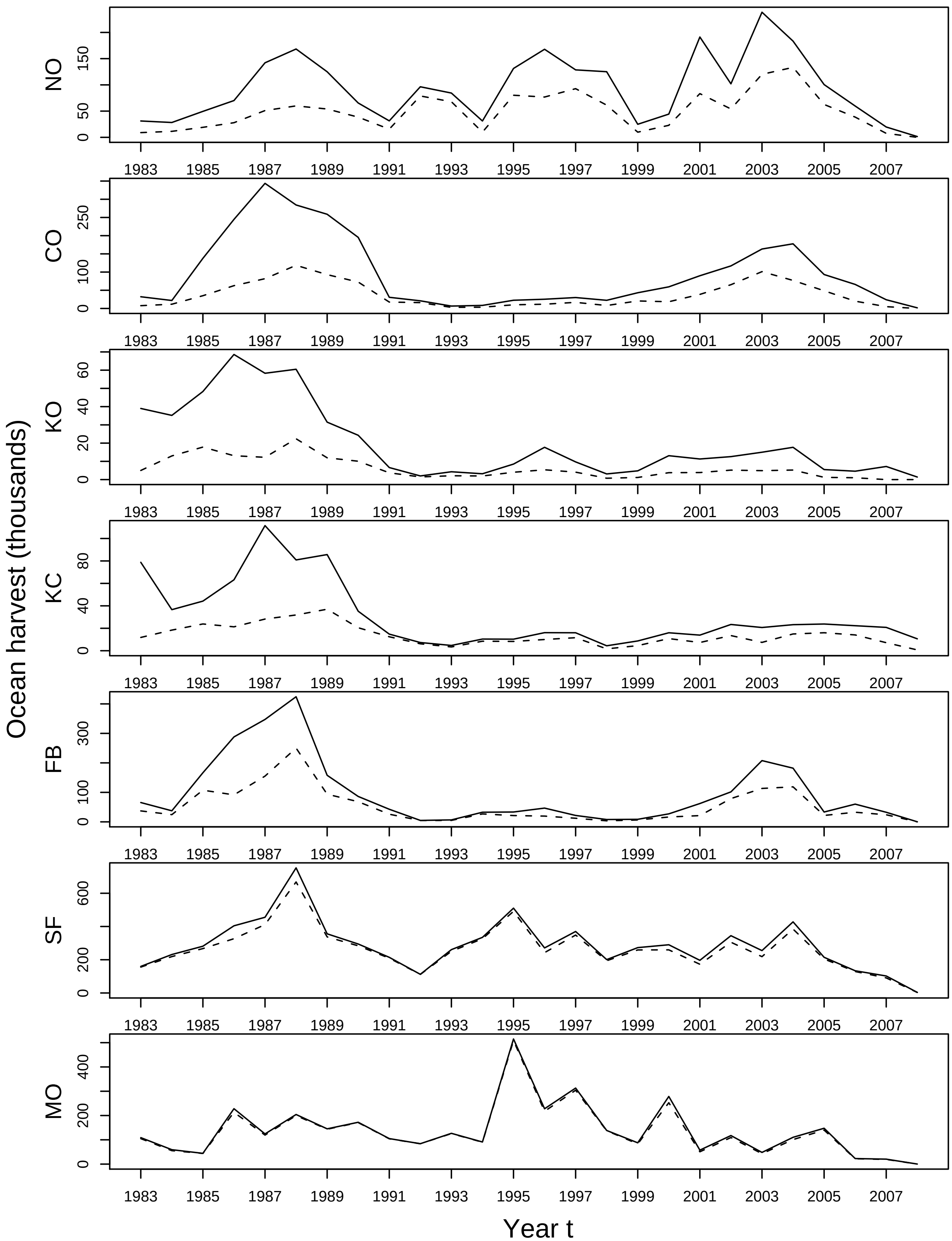

Figure 1. Estimated total Chinook (solid lines) and Sacramento River fall Chinook (dashed lines) ocean harvest for areas south of Cape Falcon, Oregon, for the Sept. 1, *t-1* through Aug. 31, *t* period, 1983–2008. Note that the y-axis scale differs for each management area.

Table 2. For the area south of Point Arena, estimated SRFC ocean harvest ($H_{o,S,\mathrm{AM}}$), number of SRFC age 3–5 sample-expanded coded-wire tags recovered ($Z_{o,S,\mathrm{AM}}$), and their ratio (λ, equation (7)), for the Sept. 1, *t-1* through Aug. 31, *t* period.

Year (t)	$H_{o,S,\mathrm{AM}}$	$Z_{o,S,\mathrm{AM}}$	λ
1983	260623	7981	32.66
1984	274200	5318	51.57
1985	311040	3314	93.90
1986	539879	8364	64.56
1987	530790	7192	73.80
1988	867888	15752	55.10
1989	480937	8077	59.56
1990	454626	8637	52.63
1991	313661	4771	65.75
1992	195500	1156	169.21
1993	376387	2903	129.70
1994	416422	2913	142.86
1995	999708	10256	97.47
1996	460311	13090	35.16
1997	652541	19004	34.34
1998	331319	17060	19.42
1999	342166	13258	25.81
2000	512112	4896	104.60
2001	223494	7565	29.54
2002	414641	10506	39.46
2003	261342	13156	19.86
2004	485356	16271	29.83
2005	344530	4212	81.83
2006	151140	1508	100.20
2007	110046	498	221.24

survey "gap" years, presented for the first time in this report, together with the harvest estimates for the survey years, provide a complete time series of H_r estimates, and it is this set of estimates that will be used for constructing the *SI* (equation (4)) in post-2008 assessments.

3.1 Data

Summary estimates of harvest and fishing effort, derived from the Sacramento River Basin angler surveys conducted by the California Department of Fish and Game (CDFG), were obtained from Dr. Robert G. Titus (CDFG, personal communication). SRFC river harvest and angler effort estimates exist for 1991–1994, 1998–2000, 2002, and 2007[2]. The proportion of jacks in samples of creel-surveyed fish in conjunction with the river harvest estimates allowed us to infer the adult harvest. The creel surveys were performed on eight sections of the Sacramento River, three sections of the American River, and three sections of the Feather River. Some additional surveys were conducted on the Yuba River, but survey effort there was much lower and estimated harvest (when surveys were conducted) was very low relative to the other surveyed rivers. For this reason, harvest and effort estimates from the Yuba River surveys were not included in the assessment. The estimated number of caught-and-released Chinook are available for the survey years, but were not used in the assessment.

In some years survey data were lacking for a particular month-stream-section, hence no estimates of harvest or effort were available. The methods employed to interpolate for these missing estimates are described in Appendix C. The effect of this interpolation was minor; the percent difference in the resulting river harvest estimate using the interpolated and non-interpolated datasets was less than four percent for all years.

3.2 Methods

For the surveyed years, Sacramento River Basin total annual river harvest of SRFC adults, H_r, was estimated as the sum of the estimated overall harvest (including jacks), H'_r, from each section k of streams $s \in \{\textsf{Sacramento, American, Feather}\}$, for months $m \in \{\textsf{Jun.}, \ldots, \textsf{Dec.}\}$, multiplied by

[2]Limited survey data exist for 2001 but these data were not used in the assessment since survey coverage in time and space was greatly reduced relative to the other years.

one minus the estimated proportion of jacks, p_J:

$$H_r = (1 - p_J) \sum_{m,s,k} H'_{r,m,s,k}. \tag{10}$$

All Chinook caught in these streams between the months of June and December were assumed to be SRFC. Adding H_r to the SRFC adult escapement estimate E yielded an estimate of the SRFC adult river run abundance,

$$R = H_r + E, \tag{11}$$

and in turn an estimate of the SRFC adult river harvest rate,

$$h_r = H_r / R. \tag{12}$$

For the 2008 SRFC assessment, the harvest in the largely unconstrained river fishery for previous years was modeled as being proportional to the river run abundance with an additive error term. The proportionality constant in this model is the mean harvest rate, $h_{r,mean}$:

$$H_r = h_{r,mean} R + \varepsilon. \tag{13}$$

The mean harvest rate was then estimated from the survey data using the ratio estimator

$$\hat{h}_{r,mean} = \bar{H}_r / \bar{R}, \tag{14}$$

where $\bar{H}_r$ and $\bar{R}$ denote the arithmetic mean of H_r and R over the survey years, respectively. The ratio estimator is the optimal estimator of the mean harvest rate under model (13) if the variance of ε increases in proportion to R (Thompson 2002).

For this report, we also consider an alternative model for the river harvest rate based on

$$h = f \times q, \tag{15}$$

where f is fishing effort in the Sacramento River Basin and q is the catchability coefficient. Equation (15) closely approximates the standard Type I fishery harvest rate model $h = 1 - e^{-qf}$ (Ricker 1975) for $h \leq 0.25$. We modeled f and q themselves as power functions of R:

$$\begin{aligned} f &= \alpha_f R^{\beta_f} e^{\theta_f}, \qquad \theta_f \sim N(0, \sigma_f^2), \\ q &= \alpha_q R^{\beta_q} e^{\theta_q}, \qquad \theta_q \sim N(0, \sigma_q^2), \end{aligned} \tag{16}$$

allowing these quantities to vary nonlinearly with river run abundance, which is appropriate for many fishery scenarios (Hilborn and Walters 1992). Equations (15) and (16) together imply that the harvest rate itself is a power function of R

$$h_r = \alpha_h R^{\beta_h} e^{\theta_h}, \qquad \theta_h \sim N(0, \sigma_h^2), \tag{17}$$

with $\alpha_h = \alpha_f \times \alpha_q$, $\beta_h = \beta_f + \beta_q$, and $\sigma_h^2 = \sigma_f^2 + \sigma_q^2$.

The parameters (α_f, β_f) and (α_q, β_q) were estimated using log-log ordinary least-squares regression (LL-OLS) on $\{f, R\}$ and $\{q, R\}$, respectively, for the survey years. The catchability coefficient was computed as $q = h_r/f$. Similarly, LL-OLS was used on $\{h_r, R\}$ to directly estimate (α_h, β_h), resulting in the fitted model

$$\hat{h}_{r,power} = \hat{\alpha}_h R^{\hat{\beta}_h}. \tag{18}$$

The fitted river harvest rate models were used to hindcast the SRFC adult river harvest for years in which angler surveys were not conducted, based on the relationship

$$\hat{H}_r = \hat{R} \times \hat{h}_r = (\hat{H}_r + E) \times \hat{h}_r, \tag{19}$$

noting that E is available for years 1970–forward. For the mean harvest rate model, solving (19) for $\hat{H}_r$ is straightforward. After changing the subscripts in (19) to reflect the mean model, we obtain

$$\hat{H}_{r,mean} = \frac{E \times \hat{h}_{r,mean}}{1 - \hat{h}_{r,mean}}. \tag{20}$$

For the power function harvest rate model, substitution of equation (18) into equation (19) yields

$$\hat{H}_{r,power} = \hat{\alpha}_h (\hat{H}_{r,power} + E)^{\hat{\beta}_h + 1}. \tag{21}$$

$\hat{H}_{r,power}$ cannot be solved for analytically in (21), however the unique value of $\hat{H}_{r,power}$ which satisfies the equality in (21) can be determined numerically (e.g., by minimizing the squared difference of the left and right hand sides of equation (21) subject to the constraint $\hat{H}_{r,power} \geq 0$).

Finally, in an attempt to reasonably bracket the river harvest hindcast estimates detailed above, the minimum and maximum harvest rates estimated over the survey years were substituted in place of $\hat{h}_{r,mean}$ in equation (20) to compute a minimum and maximum hindcast river harvest, respectively.

3.3 Results

The survey-derived f, H_r, R, and h_r are listed in Table 3. In addition, several model-derived harvest hindcasts for years with and without angler survey data, from 1970–2007, are listed in Table 3. Hindcast harvest estimates prior to 1991 assume that pre-1991 fisheries resembled post-1991 fisheries in terms of effort capacity, effort response to abundance, etc.

Figure 2 demonstrates the mean and power function models fitted to the harvest rate estimates derived from the survey. The solid line depicts the fitted mean model, which assumes that h_r is insensitive to river run abundance. The dashed line depicts the fitted power function model, which suggests that the river harvest rate may not be constant over the observed run sizes, but rather is higher (relative to the mean harvest rate) at low run sizes and lower at high run sizes. The power function estimated coefficient $\hat{\beta}_h$ is not significantly less than zero ($p = 0.122$). However, the residual pattern is more balanced for the power function model. At low river run abundance, the mean model residuals are nearly all positive, whereas the power function model residuals are both positive and negative, and the magnitude of the residuals is smaller for the harvest rate at the two highest levels of river run abundance.

Figure 3 provides additional support for the power function harvest rate model. The effort estimates derived from the angler survey appear to flatten somewhat at high run sizes, suggesting that there may be some limit to the effort capacity of the fishery. Conversely, the catchability coefficient appears to increase at an increasing rate as the river run abundance decreases, consistent with fishermen targeting a highly clumped abundance in areas where salmon are known to aggregate. The estimated power coefficients ($\hat{\beta}_f, \hat{\beta}_q$) were significantly greater than and less than zero, respectively ($p < 0.001$). The combination of the two relationships in Figure 3 results in the Figure 2 dashed line.

Hindcasted harvests derived from the mean and power function models, as well as minimum and maximum hindcast harvest brackets are plotted in Figure 4. Comparison of the model-derived harvest hindcasts to the survey-derived harvest estimates provides an indication of the accuracy of the river harvest hindcast method for the non-survey years. In general, the mean and power function models yield very similar results. In particular, the hindcasts from both models are very

Table 3. Sacramento River fall Chinook adult river return summary statistics and estimates, 1970–2007: escapement (E), angler effort (f), river run abundance (R), fishery harvest (H_r,$\hat{H}_{r,*}$), and harvest rate (h_r). Escapement estimates are sourced from PFMC (2008b, Tables B-1 and B-2); remaining estimates were developed as described in this report, with $\hat{H}_{r,min}$, $\hat{H}_{r,max}$, and $\hat{H}_{r,mean}$ derived from equation (20), and $\hat{H}_{r,power}$ derived from equation (21).

		Angler survey				Model-estimated harvest			
Year	E	f	H_r	R	h_r	$\hat{H}_{r,min}$	$\hat{H}_{r,mean}$	$\hat{H}_{r,power}$	$\hat{H}_{r,max}$
1970	157152	—	—	—	—	18291	26692	29941	47756
1971	154882	—	—	—	—	18027	26306	29572	47066
1972	92156	—	—	—	—	10726	15653	19010	28004
1973	220060	—	—	—	—	25613	37377	39894	66872
1974	202017	—	—	—	—	23513	34312	37087	61389
1975	155621	—	—	—	—	18113	26432	29692	47290
1976	167865	—	—	—	—	19538	28512	31672	51011
1977	164010	—	—	—	—	19089	27857	31051	49840
1978	126948	—	—	—	—	14775	21562	24965	38577
1979	169444	—	—	—	—	19722	28780	31925	51491
1980	142028	—	—	—	—	16531	24123	27469	43160
1981	174891	—	—	—	—	20355	29705	32798	53146
1982	163959	—	—	—	—	19083	27848	31043	49824
1983	109386	—	—	—	—	12731	18579	21994	33240
1984	158230	—	—	—	—	18416	26875	30116	48083
1985	238704	—	—	—	—	27783	40543	42760	72538
1986	238157	—	—	—	—	27719	40450	42676	72371
1987	194623	—	—	—	—	22652	33056	35927	59142
1988	224724	—	—	—	—	26156	38169	40614	68289
1989	151625	—	—	—	—	17648	25753	29042	46076
1990	104946	—	—	—	—	12215	17825	21232	31891
1991	117432	757901	26362	143794	0.183	13668	19946	23363	35685
1992	81145	440046	13876	95021	0.146	9444	13782	17061	24658
1993	135182	658570	28380	163562	0.174	15734	22960	26337	41079
1994	163631	870741	29548	193179	0.153	19045	27792	30990	49724
1995	295034	—	—	—	—	34339	50111	51234	89655
1996	299589	—	—	—	—	34869	50885	51908	91040
1997	342875	—	—	—	—	39907	58237	58249	104193
1998	238060	1375750	72342	310402	0.233	27708	40434	42661	72342
1999	395942	1491350	71115	467057	0.152	46084	67250	65868	120319
2000	416789	1433272	62005	478794	0.130	48510	70791	68821	126654
2001	546056	—	—	—	—	63555	92746	86700	165936
2002	775499	1866041	90260	865759	0.104	90260	131717	117053	235660
2003	521636	—	—	—	—	60713	88599	83374	158515
2004	283554	—	—	—	—	33003	48161	49527	86167
2005	394007	—	—	—	—	45858	66921	65593	119731
2006	267908	—	—	—	—	31182	45504	47185	81412
2007	87966	713323	15725	103691	0.152	10238	14941	18273	26731

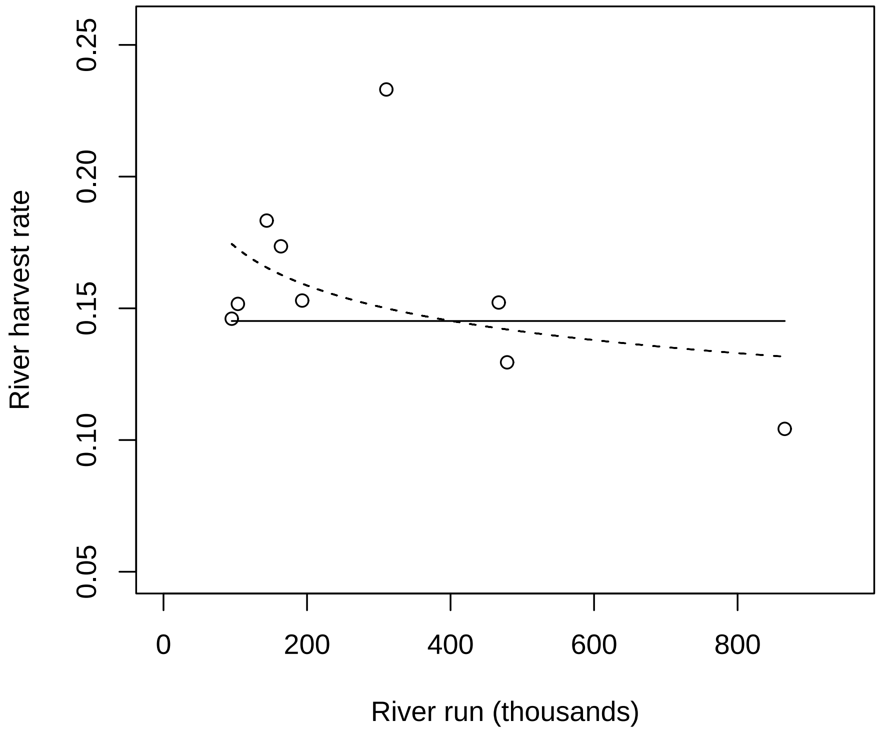

Figure 2. Estimated Sacramento River fall Chinook adult river harvest rate plotted as a function of the adult river run abundance. The solid line represents the fitted mean model, equation (14), with $\hat{h}_{r,mean} = 0.1452$. The dashed line represents the fitted power function model, equation (18), with $(\hat{\alpha}_h, \hat{\beta}_h) = (0.7515, -0.1274)$.

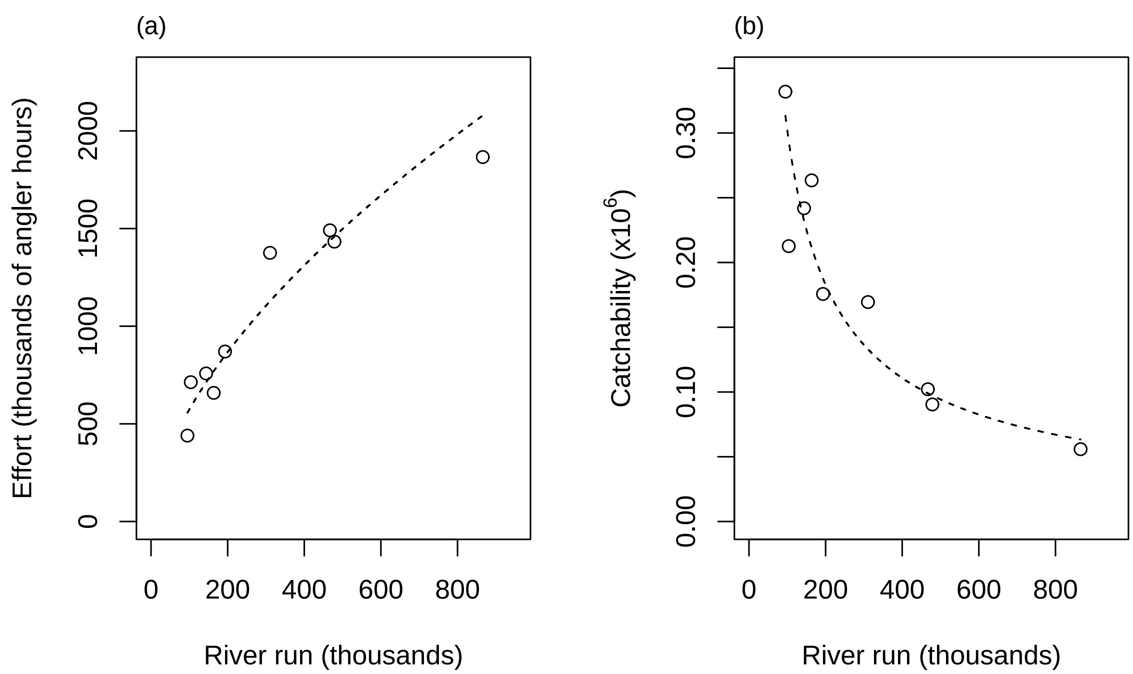

Figure 3. The relationships between adult river run abundance and (a) fishing effort (f) and (b) the catchability coefficient (q). Open circles are the survey-derived estimates; dashed lines depict the fitted models in (16) with $(\hat{\alpha}_f, \hat{\beta}_f) = (598.5711, 0.5963)$ and $(\hat{\alpha}_q, \hat{\beta}_q) = (0.0013, -0.7237)$.

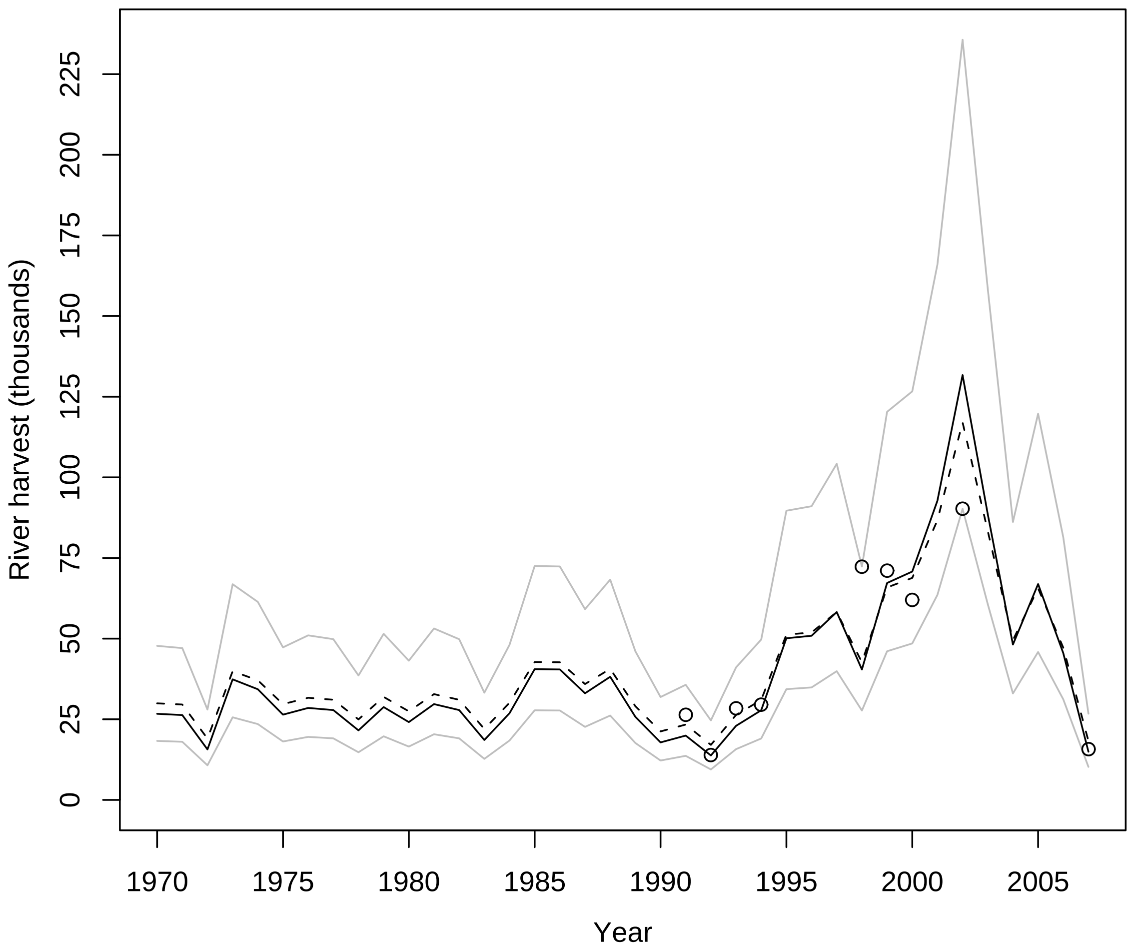

Figure 4. Estimated and hindcast river harvest of Sacramento River fall Chinook adults, 1970–2007. Circles are survey-derived estimates. The solid black line is the hindcasted harvest using the fitted mean harvest rate model. The dashed black line is the hindcasted harvest using the fitted power function harvest rate model. Solid grey lines depict the minimum and maximum hindcasted harvest, using the minimum and maximum harvest rates estimated over the nine survey years, respectively.

similar for years 1990–forward when angler surveys were not conducted (the "gap" years). Years 1990–forward are the years used for the *SI* forecast model (see Section 6). Further analysis (not shown) suggests that the choice between the power function harvest rate model-generated H_r and the mean harvest rate model-generated H_r has a negligible effect on the *SI* and the forecast of the *SI*. For this reason, and the simplicity of assuming a one parameter harvest rate model, the hindcasted H_r used in the remainder of this report and for post-2008 assessments will be $\hat{H}_{r,mean}$.

4 Escapement

SRFC escapement estimates are compiled annually from hatcheries and natural-area spawning surveys in the Sacramento River Basin. Tables B-1 and B-2 in PFMC (2008b) report natural-area and hatchery escapement, respectively, for Central Valley fall Chinook. The combined natural-area and hatchery escapement, both jacks and adults, for SRFC can be computed from these tables by summing the Sacramento River total adult (jack) escapement (located in Table B-1) and the total adult (jack) escapement from Sacramento hatcheries (located in Table B-2). In this report, Table 3 displays the combined natural-area and hatchery adult escapement of SRFC used for the construction of the *SI* (equation (4)).

Sacramento River Basin hatcheries, which include Coleman National Fish Hatchery (Battle Creek), Feather River Hatchery (Feather River) and Nimbus Hatchery (American River), enumerate jacks and adults separately as they enter the hatchery based on an established fork-length (FL) "cut-off" value (jack: FL $<$ cut-off; adult: FL $\geq$ cut-off). Since 1990, Coleman National Fish Hatchery has used a jack cut-off length of 65 cm and Nimbus Hatchery has used a 61 cm cut-off. At Feather River Hatchery, the jack cut-off was 61 cm from 1990–2005, and 65 cm thereafter.

Natural-area escapement estimates have been made using various means, including carcass surveys, aerial redd counts, ladder counts, weir counts and video monitoring (Table 4; also see CDFG (2007) for more information on the individual sampling programs). Jack and adult proportions are determined by a survey-specific fork-length cut-off value. For natural-area escapement surveys, this cut-off value has varied from 61–70 cm (Table 4). In some instances, the cut-off value has been arrived at empirically based on analysis of that year's length frequency distribution. More often, the cut-off value has been treated as a fixed constant across a series of years. For 1990–2007, all natural-area surveys in the American, Yuba, and Feather Rivers were carcass surveys employing mark-recapture estimation methods. The upper mainstem Sacramento River natural-area escapement estimates are a combination of individual survey-derived estimates performed on the Sacramento River mainstem, Battle Creek, Clear Creek, and other minor tributaries. Sampling in the minor tributaries (Deer, Mill, Butte, and Cottonwood Creeks) has been sporadic. However,

Table 4. Sacramento River fall Chinook natural-area escapement survey methods employed from 1990–2007. Cut-off: fork-length (FL) value used to distinguish a jack (FL < cut-off) from an adult (FL $\geq$ cut-off). R: Red Bluff Diversion Dam passage, May 15–Sept. 15 (upstream tributary escapements subtracted from passage to estimate mainstem escapement); S: carcass survey; V: video monitoring; C: carcass count; CDFG: California Department of Fish and Game; USFWS: United States Fish and Wildlife Service; DWR: Department of Water Resources.

			Jack Proportion		
System	*Years*	*Escapement Survey*	*Survey*	*Cut-off (cm)*	*Agency*
Mainstem	1990–2000	R	R	61	CDFG/USFWS
Sacramento	2001–2005	S	S	61	CDFG
River	2006	S	S	68	CDFG
	2007	S	S	67.5	CDFG
Clear Creek	1990–2007	S	S	61	CDFG
Battle Creek	1990–2005	S	S	61	CDFG/USFWS
	2006–2007	V	C	61	CDFG/USFWS
Deer Creek	1993–1994	S	S	61	CDFG
	1997–1998	S	S	61	CDFG
	2004–2007	S	S	61	CDFG
Mill Creek	1992–1994	S	S	61	CDFG
	1997–1998	S	S	61	CDFG
	2002–2007	S	S	61	CDFG
Butte Creek	1995–1998	S	S	61	CDFG
	2001–2005	S	S	61	CDFG
	2006–2007	S	S	65	CDFG
Yuba River	1990–2007	S	S	61	CDFG
Feather River	1990–1999	S	S	61	CDFG
	2000–2005	S	S	68	DWR
	2006–2007	S	S	65	DWR
American River	1990–2007	S	S	67–70	CDFG

since 2004, surveys have been conducted without interruption on Deer, Mill, and Butte Creeks, and sampling is expected to continue on these tributaries into the future. The 2004–2007 average annual escapement of these three tributaries was approximately six percent of the total natural-area escapement in the upper Sacramento River. Escapement to these minor tributaries represents a small fraction of the overall SRFC escapement.

5 *SI* Time Series

The resulting *SI* time series and its components are listed in Table 5 and displayed graphically in Figure 5 for the period 1983–2007. Both the *SI* and the relative contribution of its components have varied over this time period. The lowest level of the *SI*, by a significant margin, occurred in 2007, but the *SI* was also relatively low in 1983–1984 and in the early 1990s. Similarly, the high *SI* levels that occurred during the 2000–2005 period are comparable to the levels of the late 1980s, although the relative contribution of the *SI* components in these two periods differs (a shift in the relative contributions occurred in the mid- to late-1990s). Prior to 1998, the fraction of the *SI* taken as ocean harvest averaged about 0.74, whereas since then it has averaged about 0.51. The escapement fraction averaged about 0.22 prior to 1998, and about 0.41 since that time. The contribution of river harvest to the *SI* has been consistently small relative to the ocean harvest and escapement components. The contrast between the time series of SRFC abundance (as indexed by the *SI*) and the time series of SRFC escapement is striking. In particular, the anomalously high escapement levels in years 1999–2003 were due, at least in part, to the reduced ocean harvest fraction over this period. High levels of the *SI* in the mid- to late-1980s did not translate into comparable high levels of escapement due to the relatively high fraction of fish removed by ocean fisheries during this period.

The *SI* is plotted against the *CVI* in Figure 6). The two indices of abundance are highly correlated ($R^2 = 0.93$). This is not surprising given the dominance of SRFC relative to other Central Valley Chinook stocks in both escapement and ocean harvest in the AM region over the 1983–2007 period. The 1:1 line plotted in Figure 6 highlights the fact that the *SI* exceeded the *CVI* in all years

Table 5. Sacramento River fall Chinook ocean harvest ($H_{o,S}$), river harvest (H_r), escapement (E), and the Sacramento Index (SI) as defined in equation (4), 1983–2007. $H_{o,S}$ is for the Sept. 1, $t-1$ through Aug. 31, t period.

	$H_{o,S}$					
Year (t)	*Commercial*	*Recreational*	*Total*	H_r	E	SI
1983	245156	86149	331305	18579	109386	459270
1984	266162	86978	353140	26875	158230	538245
1985	355388	158895	514283	40543	238704	793530
1986	618726	137543	756269	40450	238157	1034876
1987	686093	173155	859248	33056	194623	1086927
1988	1162584	188275	1350859	38169	224724	1613752
1989	611420	159180	770600	25753	151625	947978
1990	514202	150520	664722	17825	104946	787493
1991	298804	90161	388965	26362	117432	532759
1992	232456	70143	302599	13876	81145	397620
1993	342422	115345	457767	28380	135182	621329
1994	302329	164730	467059	29548	163631	660238
1995	735704	387895	1123598	50111	295034	1468743
1996	426719	156978	583696	50885	299589	934170
1997	579731	210240	789971	58237	342875	1191083
1998	292840	113886	406726	72342	238060	717128
1999	308096	76600	384696	71115	395942	851753
2000	431354	153174	584528	62005	416789	1063322
2001	284414	93450	377864	92746	546056	1016666
2002	447624	184062	631686	90260	775499	1497445
2003	501864	106456	608319	88599	521636	1218554
2004	621935	212601	834536	48161	283554	1166251
2005	367740	127065	494805	66921	394007	955733
2006	149910	107653	257562	45504	267908	570974
2007	120953	32821	153774	15725	87966	257465

over this period (except 2000), due primarily to the inclusion of FA-region ocean harvest and river harvest in the *SI*.

6 *SI* Forecast

The *SHM* forecast of SRFC harvest and escapement is based on that year's *SI* forecast. The *SI* forecast in turn is based on the previous year's jack (*J*) spawning escapement using a statistical model relating *J* in year *t-1* to the *SI* in year *t*. *SI* estimates from 1990–forward are used to fit the

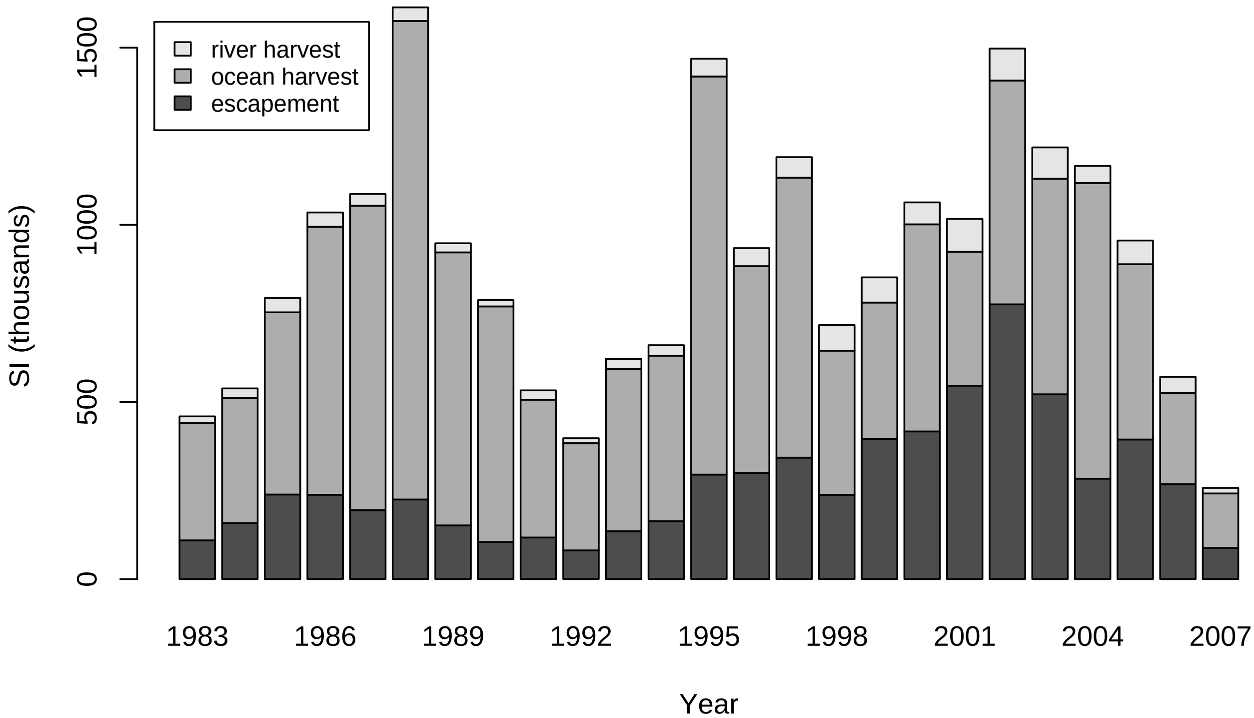

Figure 5. The Sacramento Index (SI) and the relative levels of its components, 1983–2007.

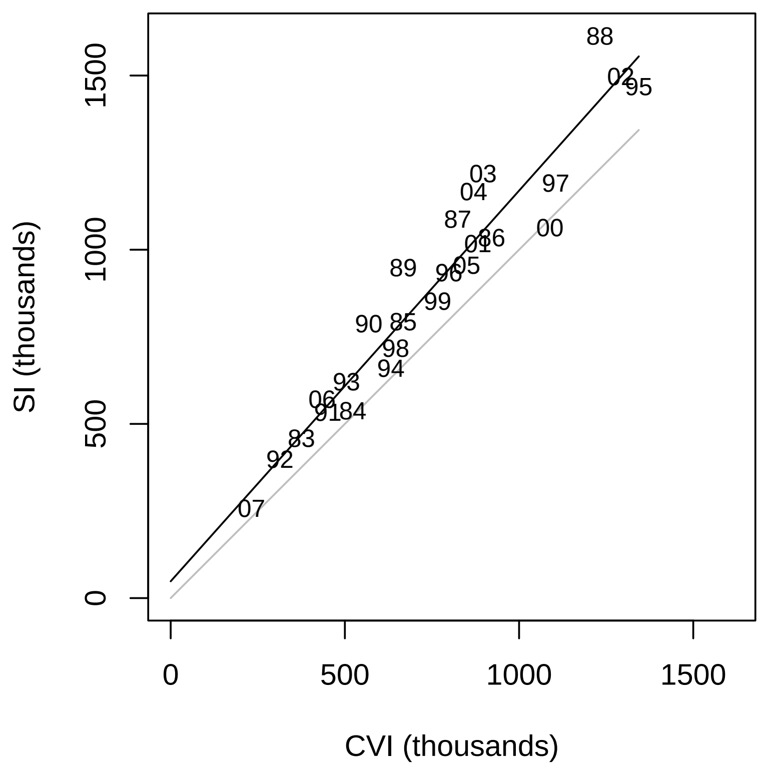

Figure 6. The Sacramento Index (*SI*) and the Central Valley Index (*CVI*) from 1983–2007 plotted on equal scales. The black line is the least-squares regression line for the *SI* and *CVI* ($R^2 = 0.93$). The grey line is the 1:1 line (*SI* = *CVI*).

model, even though estimates of the SI are available back to 1983. Use of this particular range of years is consistent with the range of years used to fit the CVI forecast model in the pre-2008 SRFC assessments. For both the CVI and the SI, their relationship to the previous year's jack escapement is markedly different before and after 1990. While the mechanism underlying this shift in the relationship is not known, limiting the data to the 1990–forward period improves the performance of these forecast models under current conditions.

For the 2008 assessment, with the SI defined as in equation (3), a variety of statistical models relating the SI in year t to J in year $t\text{-}1$ were examined (see PFMC 2008a, Appendix C). Ultimately, a linear model with zero-intercept and additive errors was most strongly supported

$$SI = \beta_{SI} J + \varepsilon, \tag{22}$$

and the ratio estimator

$$\hat{\beta}_{SI} = \bar{SI}/\bar{J} \tag{23}$$

was judged to be the optimal estimator of β_{SI}. Figure 7 displays the fitted model with slope $\hat{\beta}_{SI} = 28.766$, and the forecasted SI value used for the 2008 SRFC assessment. Use of the zero-intercept model for the 2008 assessment was particularly justified given the very low jack escapement in 2006 and the very low levels of $H_{o,S}$ and E in 2007, all indicating a particularly weak 2004 year class that would contribute little 4-year-old carryover to the SI in 2008. The 2005 data point was excluded from the fitting of the model because it was uninformative with respect to forecasting the 2008 SI given the record low 2007 jack escapement, and because of its excessive leverage on the overall fit of the model (PFMC 2008a, Appendix C).

Figure 8 shows the zero-intercept linear model fitted to the reformulated SI (equation (4)) data. Including the river harvest in the SI results in an increased slope estimate ($\hat{\beta}_{SI} = 30.525$) and thus a higher SI forecast, relative to the SI definition that did not include river harvest, but no change is evident in the displayed pattern of the data points. The data, estimates, and models used for the SRFC annual assessment are carefully evaluated each year and modifications to the methods of assessment are proposed as warranted. We emphasize that the reformulated SI, and the fitted model displayed in Figure 8, were not used for the 2008 SRFC assessment.

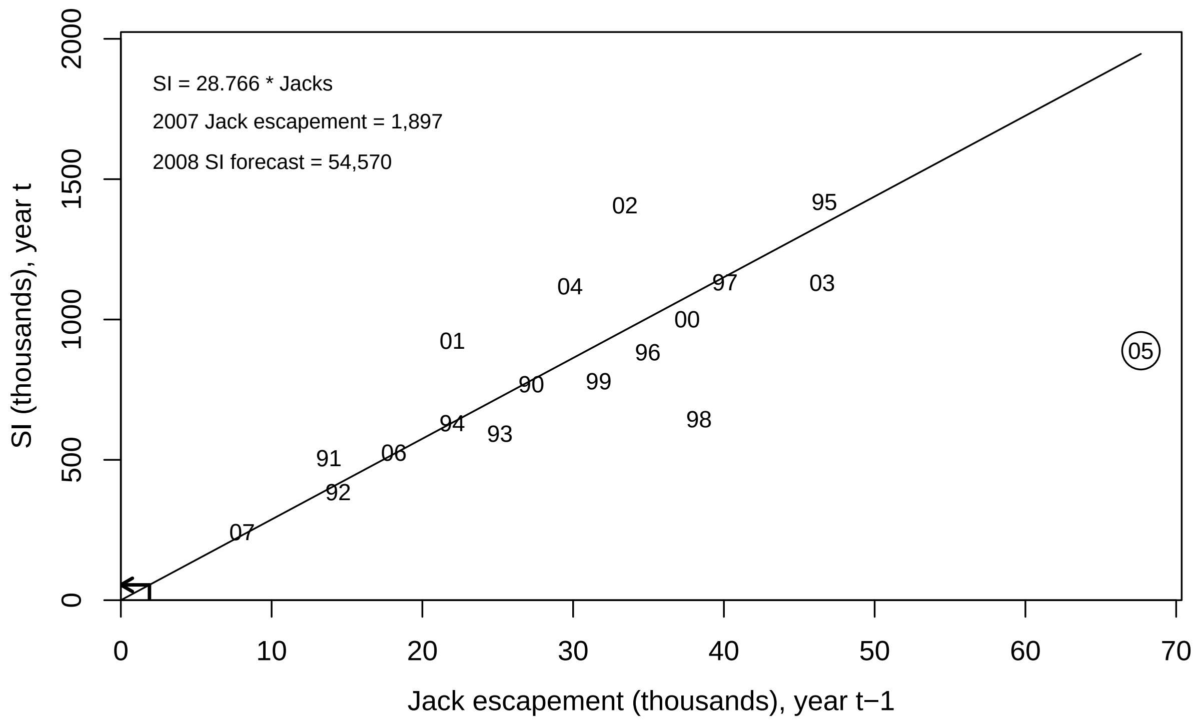

Figure 7. The Sacramento Index (*SI*) forecast model in the 2008 assessment. Arrow traces the 2007 jack escapement to the forecast *SI* for 2008.

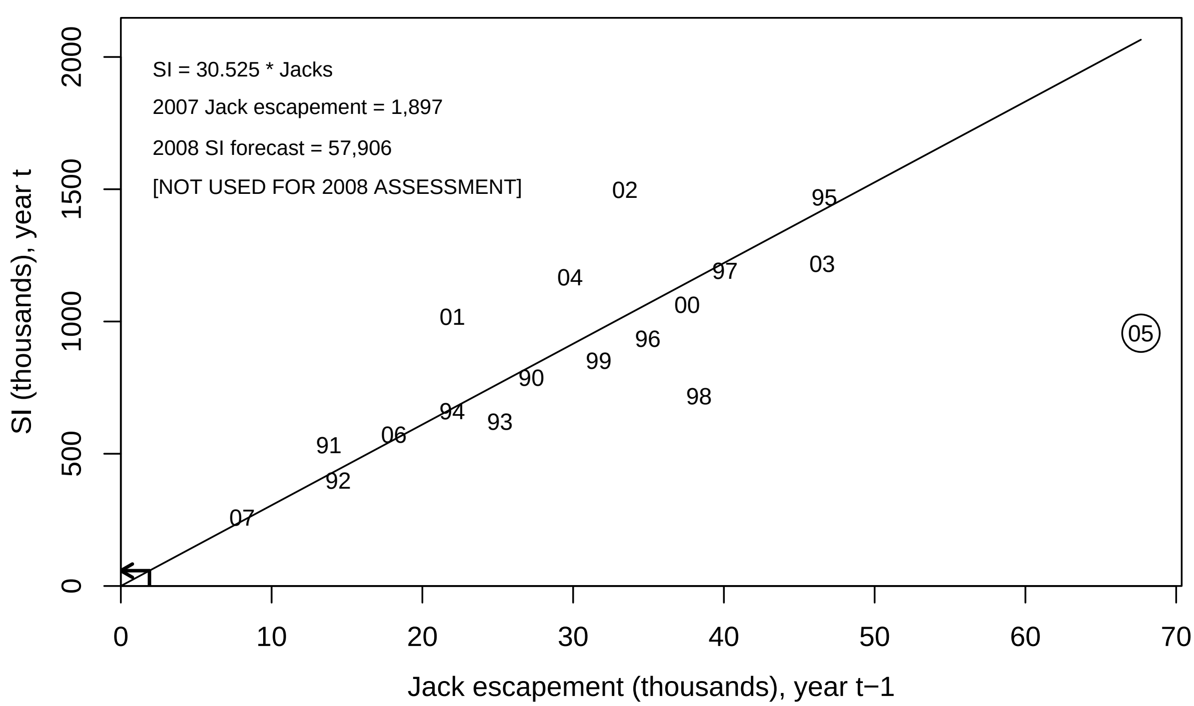

Figure 8. The Sacramento Index (*SI*) forecast model for the reformulated *SI* that includes river harvest, equation (4). Arrow traces the 2007 jack escapement to the forecast *SI* for 2008 under the equation (4) definition of the *SI*. This forecast was not used for the 2008 SRFC assessment.

7 Conclusions

Novel methods were required for the development of the *SI*, particularly for the estimation of SRFC ocean harvest in all time-area-fisheries south of Cape Falcon. Inclusion of SRFC river harvest in the *SI* has provided a more complete index of SRFC adult ocean abundance, and has resulted in a more straightforward formulation of SRFC river harvest and escapement within the *SHM* (Mohr and O'Farrell 2008). Together, the *SI* and *SHM* have significantly advanced the extent, resolution, and specificity of the SRFC assessment framework. It is now possible to directly evaluate the effects of proposed fishery management measures on SRFC expected ocean harvest by time-area-fishery, river harvest, and spawning escapement. This was not possible within the previous *CVI*-based assessment framework.

We recommend that the *SI* be reported in place of the *CVI* in all Pacific Fishery Management Council (PFMC) salmon reports issued in the future, at least in so far as the *CVI* has been used to represent and evaluate the status of the SRFC stock. In particular, we recommend that Table 5 of this report, which lists the *SI* time series and that of its components, replace PFMC Preseason Report I (PFMC 2008a) Table II-1 (analogous listing of the *CVI* and its components). We also recommend that Figure 5 of this report, a graphical presentation of the *SI* time series and that of its components, replace PFMC Preseason Report I Figure II-2 (time-series of SRFC spawning escapement). Finally, we recommend that Figure 8 of this report, a graphical depiction of the *SI* forecast model, replace PFMC Preseason Report I Figure II-1 (*CVI* forecast model).

8 Acknowledgements

We thank Rob Titus, CDFG Anadromous Resource Assessment Unit, for providing us access to the Sacramento River Basin angler survey data, and his willingness to discuss with us the particulars of the survey design, data, and estimates. We also thank all of those responsible for the ocean harvest, river harvest, and escapement monitoring programs that produced the data used in this report.

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Appendix A Harvest North of Cape Falcon

The ocean harvest component of the *SI* includes SRFC harvest from Cape Falcon to the U.S./Mexico border, but not SRFC harvest north of Cape Falcon (NF). The proportion of the SRFC overall ocean harvest landed in the NF region was previously estimated and published in PFMC (2008a, Appendix B). In that document, the mean proportion of the SRFC overall ocean harvest landed in the NF region was estimated to be approximately one half of one percent over the 1986–2007 period. Subsequent to publication of PFMC (2008a), further analysis indicated that this estimate was likely too low.

For this report, SRFC harvest in the NF region was estimated following the same methods that were used in the FA region. SRFC coded-wire tags recovered in the NF region were expanded for sampling and multiplied by λ to estimate the SRFC harvest, as in equation (8). The Sept. 1 through Aug. 31 SRFC harvest for the NF region was then divided by the Sept. 1 through Aug. 31 SRFC overall ocean harvest to obtain the proportion of SRFC overall ocean harvest landed in the NF region. Figure 9 displays this proportion for the years 1986–2007. The proportion was less than or equal to five percent in all but one year (2005), and averaged 2.37 percent over this time period.

Appendix B Ocean Harvest Estimate Adjustment Methods

For the Cape Falcon to Point Arena region (FA), the time-area-fishery estimated harvest of the four components (S, K, V, N) did not always sum to the total harvest, likely due to a combination of factors such as sampling error, incomplete data for all stocks that contribute to the harvest in these areas, and variation in the distribution of untagged stocks that contribute to the λ expansion factors. For notational simplicity, we omit all harvest (H) subscripts in this Appendix other than those denoting the stock components (S, K, V, N) and total (T), noting that these methods are applied at the year-time-area-fishery level of stratification. For the FA region, over the period 1983–2007, there were a total of 1446 year-time-area-fishery strata. The sum of the component groups' harvest was less than the total harvest in 875 of these strata, and greater than the total

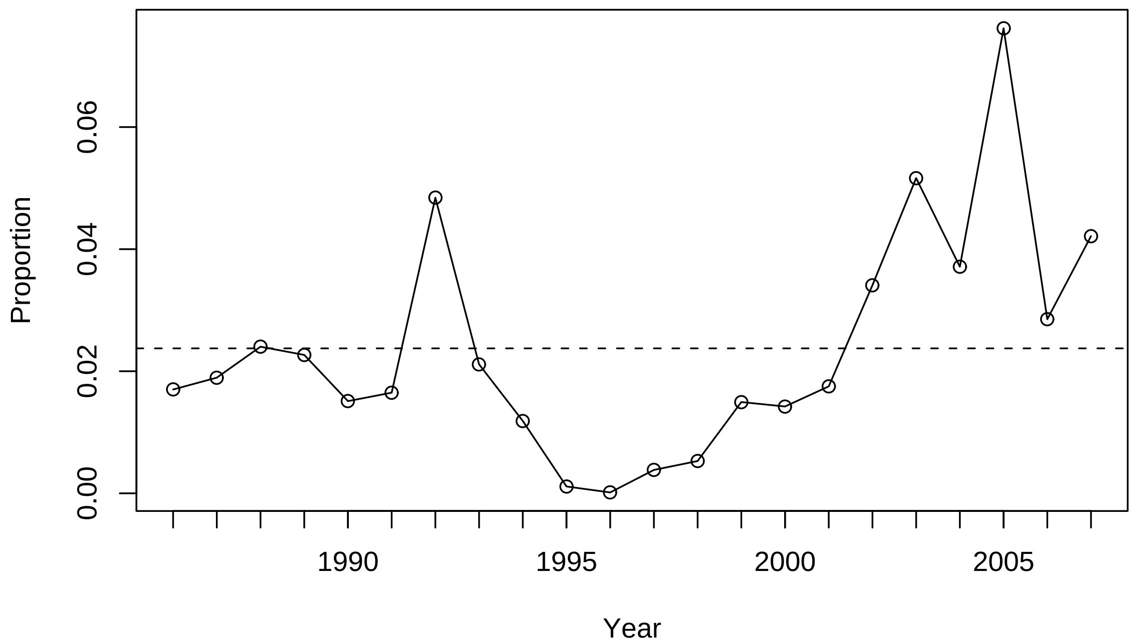

Figure 9. Proportion of Sacramento River fall Chinook overall ocean harvest landed north of Cape Falcon, Oregon, 1986–2007. Dashed line depicts the mean proportion.

harvest in 266 of these strata. For those strata in which there was a difference between the group sum and total harvest, the magnitude of the difference (Δ) was

$$\Delta = |(H_S + H_K + H_V + H_N) - H_T|.$$

The methods used to adjust the component harvests depend on whether their sum was (1) less than or (2) greater than the total harvest, as described below.

B.1 Under-accounted: $H_S + H_K + H_V + H_N < H_T$

The rationale underlying the adjustments in this case was the following. The KRFC harvest estimates are based on expansion of recovered coded-wire tags by well-determined sampling and mark rates, and well-quantified hatchery-to-natural production values, obtained through stock-level cohort analysis. Thus, H_K was not adjusted. H_V and H_N are likely minimum estimates since they do not account for the natural production of these stock groups and were thus adjusted. H_S estimates were not adjusted, and therefore the *SI* is unaffected. The magnitude of the difference, Δ, was prorated to H_V and H_N unless $H_V + H_N = 0$, in which case Δ was allocated to H_N if the area was off Oregon ($a \in \{\mathsf{NO},\mathsf{CO},\mathsf{KO}\}$) (harvest of N more likely there), or allocated to H_V if the area was off California ($a \in \{\mathsf{KC},\mathsf{FB}\}$) (harvest of V more likely there). This set of adjustments is codified below, with $\tilde{H}$ denoting the adjusted harvest:

$$\tilde{H}_K = H_K$$

$$\tilde{H}_S = H_S$$

$$\tilde{H}_V = \begin{cases} H_V + \Delta[H_V/(H_V+H_N)] & : \quad H_V + H_N > 0 \\ \Delta & : \quad H_V + H_N = 0 \quad \text{and} \quad a \in \{\mathsf{KC},\mathsf{FB}\} \\ 0 & : \quad H_V + H_N = 0 \quad \text{and} \quad a \in \{\mathsf{NO},\mathsf{CO},\mathsf{KO}\} \end{cases}$$

$$\tilde{H}_N = \begin{cases} H_N + \Delta[H_N/(H_V+H_N)] & : \quad H_V + H_N > 0 \\ \Delta & : \quad H_V + H_N = 0 \quad \text{and} \quad a \in \{\mathsf{NO},\mathsf{CO},\mathsf{KO}\} \\ 0 & : \quad H_V + H_N = 0 \quad \text{and} \quad a \in \{\mathsf{KC},\mathsf{FB}\}. \end{cases}$$

B.2 Over-accounted: $H_S + H_K + H_V + H_N > H_T$

The rationale underlying the adjustments in this case was the following. The KRFC harvest estimates are based on expansion of recovered coded-wire tags by well-determined sampling and mark rates, and well-quantified hatchery-to-natural production values, obtained through stock-level cohort analysis. Thus, H_K was not adjusted. (In no instance did H_K exceed H_T.) H_V and H_N are likely minimum estimates since they do not account for the natural production of these stock groups, and thus H_S was reduced first to make up for the overage (down to zero if need be). If the H_S adjustment was insufficient to make up for the overage, and the area was off Oregon ($a \in \{\mathsf{NO},\mathsf{CO},\mathsf{KO}\}$), then H_V was reduced (down to zero if need be) followed by H_N, if necessary. (The latter ordering reflects the supposition that off Oregon, harvest of N is more likely than V.) If the H_S adjustment was insufficient to make up for the overage, and the area was off California ($a \in \{\mathsf{KC},\mathsf{FB}\}$), then H_N was reduced (down to zero if need be) followed by H_V, if necessary. (The latter ordering reflects the supposition that off California, harvest of V is more likely than N.) This set of adjustments is codified below, with $\tilde{H}$ denoting the adjusted harvest:

$$\tilde{H}_K = \quad H_K$$

$$\tilde{H}_S = \begin{cases} H_S - \Delta & : \quad \Delta \leq H_S \\ 0 & : \quad \text{otherwise} \end{cases}$$

$$\tilde{H}_V = \begin{cases} H_V & : \quad \Delta \leq H_S \\ H_V - (\Delta - H_S) & : \quad H_S < \Delta \leq H_S + H_V \quad \text{and} \quad a \in \{\mathsf{NO}, \mathsf{CO}, \mathsf{KO}\} \\ H_V - (\Delta - H_S - H_N) & : \quad H_S + H_N < \Delta \leq H_S + H_V + H_N \quad \text{and} \quad a \in \{\mathsf{KC}, \mathsf{FB}\} \\ 0 & : \quad \text{otherwise} \end{cases}$$

$$\tilde{H}_N = \begin{cases} H_N & : \quad \Delta \leq H_S \\ H_N - (\Delta - H_S) & : \quad H_S < \Delta \leq H_S + H_N \quad \text{and} \quad a \in \{\mathsf{KC}, \mathsf{FB}\} \\ H_N - (\Delta - H_S - H_V) & : \quad H_S + H_V < \Delta \leq H_S + H_N + H_V \quad \text{and} \quad a \in \{\mathsf{NO}, \mathsf{CO}, \mathsf{KO}\} \\ 0 & : \quad \text{otherwise} \end{cases}$$

The *SI* was reduced by this set of adjustments since $\tilde{H}_S < H_S$. The unadjusted SRFC harvest ($H_{o,S}$), adjusted SRFC harvest ($\tilde{H}_{o,S}$), and their ratio, are shown in Table 6 for years 1983–2007. In general, the differences between the adjusted and unadjusted harvest estimates were small.

Appendix C River Harvest Data Interpolation Methods

In some years harvest estimates do not exist for a particular stratum (month-stream-section), either because the fishery was closed, or because the fishery was open but it lacked sample coverage. For strata in which the fishery was closed, harvest and angler effort were assumed to be zero. For strata in which the fishery was open but data were lacking, harvest and angler effort were interpolated for using data from the same stratum (month-stream-section) in other years that had a similar level of overall harvest, effort, and escapement.

Table 6. Sacramento River fall Chinook unadjusted ocean harvest ($H_{o,S}$), adjusted ocean harvest ($\tilde{H}_{o,S}$), and their ratio, for the Sept. 1, *t-1* through Aug. 31, *t* period.

Year (t)	$H_{o,S}$	$\tilde{H}_{o,S}$	$\tilde{H}_{o,S}/H_{o,S}$
1983	348120	331305	0.95
1984	356894	353140	0.99
1985	522224	514283	0.98
1986	758670	756269	1.00
1987	879384	859248	0.98
1988	1353463	1350859	1.00
1989	777520	770600	0.99
1990	689658	664722	0.96
1991	397231	388965	0.98
1992	357954	302599	0.85
1993	469881	457767	0.97
1994	480313	467059	0.97
1995	1126329	1123599	1.00
1996	584578	583697	1.00
1997	793131	789971	1.00
1998	406883	406726	1.00
1999	386280	384696	1.00
2000	595698	584528	0.98
2001	380465	377864	0.99
2002	640127	631686	0.99
2003	625738	608320	0.97
2004	894762	834536	0.93
2005	519337	494805	0.95
2006	272500	257563	0.95
2007	186277	153774	0.83

Two “eras” were defined for the purpose of the interpolation. The “low harvest” era consisted of years 1991–1994 and 2007, characterized by relatively low harvest, effort, and escapement. The “high harvest” era consisted of years 1998–2000 and 2002, characterized by relatively high harvest, effort, and escapement.

Interpolation of missing estimates from a particular strata of the angler survey was performed by taking the mean of estimated harvest and effort in the same month-stream-section for the years in the era of the missing estimate. The use of this method may best be illustrated with an example. For September 1999, harvest and effort estimates were unavailable for the Feather River, section 12.1. To interpolate for the missing harvest estimate, we first noted that 1999 was included in the high harvest era. The harvest estimate for this stratum was then computed in the following manner:

$$H'_{r,\mathsf{Sept.,Feather,12.1}} = \frac{1}{3} \times \sum_{t=98,00,02} H'_{r,\mathsf{Sept.,Feather,12.1}}(t), \tag{24}$$

where the years t are denoted by their last two digits. This method takes advantage of the relative similarity in harvests for the two distinct eras.

This interpolation method assumes that run timing and the spatio-temporal allocation of angler effort is consistent across years in the same stream and section. As such, the method is not able to account for year-effects, where harvest and effort levels may vary due to particular circumstances that occur in a given year (e.g., an abundance of good weather in a particular year results in increased harvest and/or effort).

The interpolation method described above differs slightly from the method used for the 2008 assessment. For that assessment, we used a wider variety of interpolation techniques, including nearest neighbor and averaging between sections of a stream within a given year. The differences between the two methods in terms of harvest and effort estimates are minor. In this report, all figures and Table 3 include estimates based on the interpolation methods described above. For comparison, the estimated average harvest rate with these interpolation methods is $\hat{h}_{r,mean} = 0.1452$, while for the 2008 assessment it was $\hat{h}_{r,mean} = 0.1449$. The small difference in these two values is due to the use of the different interpolation methods.

PRESEASON REPORT II

APPENDIX D

SACRAMENTO RIVER FALL CHINOOK HARVEST MODEL (SHM)

The model previously used by the STT to forecast the impacts of ocean and river fisheries on SRFC escapement has a number of significant limitations: (1) It is not a dynamic model, (2) it is not based directly on SRFC fishery impact data, (3) it does not directly account for north of Point Arena ocean fishery impacts, and river fishery impacts (although SRFC escapement implicitly depends on these impacts), and (4) it is incapable of modeling the effect of variation in management measures for the ocean fishery north of Point Arena, and for the river fishery. SRFC have not been a constraining stock for fishery management for the past 15 years and this model, despite its limitations, was sufficient for management purposes. However, the 2008 SRFC stock status demanded development of a more refined harvest model in order to meet current management needs. In response, a new “Sacramento Harvest Model” (SHM) was developed to rectify all but the first limitation listed above. The SHM is described below.

Given the SRFC ocean harvest $H_o(x)$ for all time/area fisheries (x) for the September – August period and the *SI* (APPENDIX C), define the SRFC ocean harvest rate index as $h_o(x) = H_o(x)/SI$. Summing these quantities across all time/area fisheries gives the overall harvest and harvest rate index for the September - August period: $H_o = \sum H_o(x)$ and $h_o = \sum h_o(x)$, respectively. By definition of the *SI*, the SRFC spawning escapement assuming an unrestricted river fishery is

$$E_u = SI - H_o = SI(1-h_o).$$

This escapement thus results from a river run size of

$$R = E_u/(1-h_{r,u}) = SI(1-h_o)/(1-h_{r,u}),$$

where $h_{r,u}$ is the unrestricted river harvest rate. For a restricted river fishery with harvest rate h_r, the SRFC escapement would thus be

$$E = R(1-h_r) = SI(1-h_o)(1-h_r)/(1-h_{r,u}).$$

If fishery impacts are not equal to fishery harvest, for example with non-retention fisheries, the above formula for *E* would apply with the impact rate i_o substituted for h_o, and i_r substituted for h_r:

$$E = SI(1-i_o)(1-i_r)/(1-h_{r,u}).$$

Forecasting the SRFC escapement *E* thus requires forecasts of the components *SI*, i_o, and i_r, along with an estimate of $h_{r,u}$. The component *SI* is forecast as described in APPENDIX C. The component $i_o = \sum i_o(x)$, and the $i_o(x)$ quantities are forecast as follows. For seasonal retention fisheries $i_o(x) = h_o(x)$, and $h_o(x)$ is modeled as a linear function of the expected effort, $f(x)$.

A ratio estimator was used to fit these time/area fishery-specific relationships to the historical $(h_o(x), f(x))$ data, 1986-forward, with the historical $h_o(x) = H_o(x)/SI$ estimated based on SRFC coded-wire tag recoveries as described in APPENDIX C. These data and fitted relations are depicted for the January - August period in Figure D-1 for the commercial fishery and Figure D-2 for the recreational fishery. For the previous September - December (fall) fishery period, since these fisheries have occurred prior to model application, $H_o(x)$ is estimated directly from the observed coded-wire tag recoveries for that period. The forecast effort $f(x)$ is provided by the KOHM effort submodel and is a linear function of the number of days open. For a quota fishery, the harvest rate index is forecast as $h_o(x) = Q(x)\pi(x)/SI$, where *Q(x)* is the quota and $\pi(x)$ is the proportion of SRFC expected in the catch. In the case of non-retention fisheries, $i_o(x)$ is forecast as $h_o(x)s_o(x)$, where $h_o(x)$ is the expected harvest rate were it a retention fishery, and $s_o(x)$ is the hook-and-release mortality rate. The time/area fishery-specific ocean harvests and impacts are forecast as the respective harvest and impact rate index forecasts multiplied by the forecast *SI*.

For a retention river fishery $i_r = h_r$, and h_r is forecast as Q_r / R for quota-restricted fishery, and as $h_{r,u}$ for an unrestricted fishery. The quantity $h_{r,u}$ was estimated to be 0.1449 based on the available river fishery harvest survey data, as shown in Figure D-3. For a non-retention river fishery, i_r is forecast as $h_r s_r$, where h_r is the expected harvest rate were it a retention fishery, and s_r is the hook-and-release mortality rate (0.10). The river fishery harvest and impacts are forecast as the respective harvest and impact rate forecasts multiplied by the forecast river run size.

FIGURE D-1 SRFC ocean commercial harvest rate index versus effort for each month/port-area. The dots are the historical data, 1986 forward, and the line depicts the ratio estimator predictor.

FIGURE D-2 SRFC ocean recreational harvest rate index versus effort for each month/port-area. The dots are the historical data, 1986 forward, and the line depicts the ratio estimator predictor.

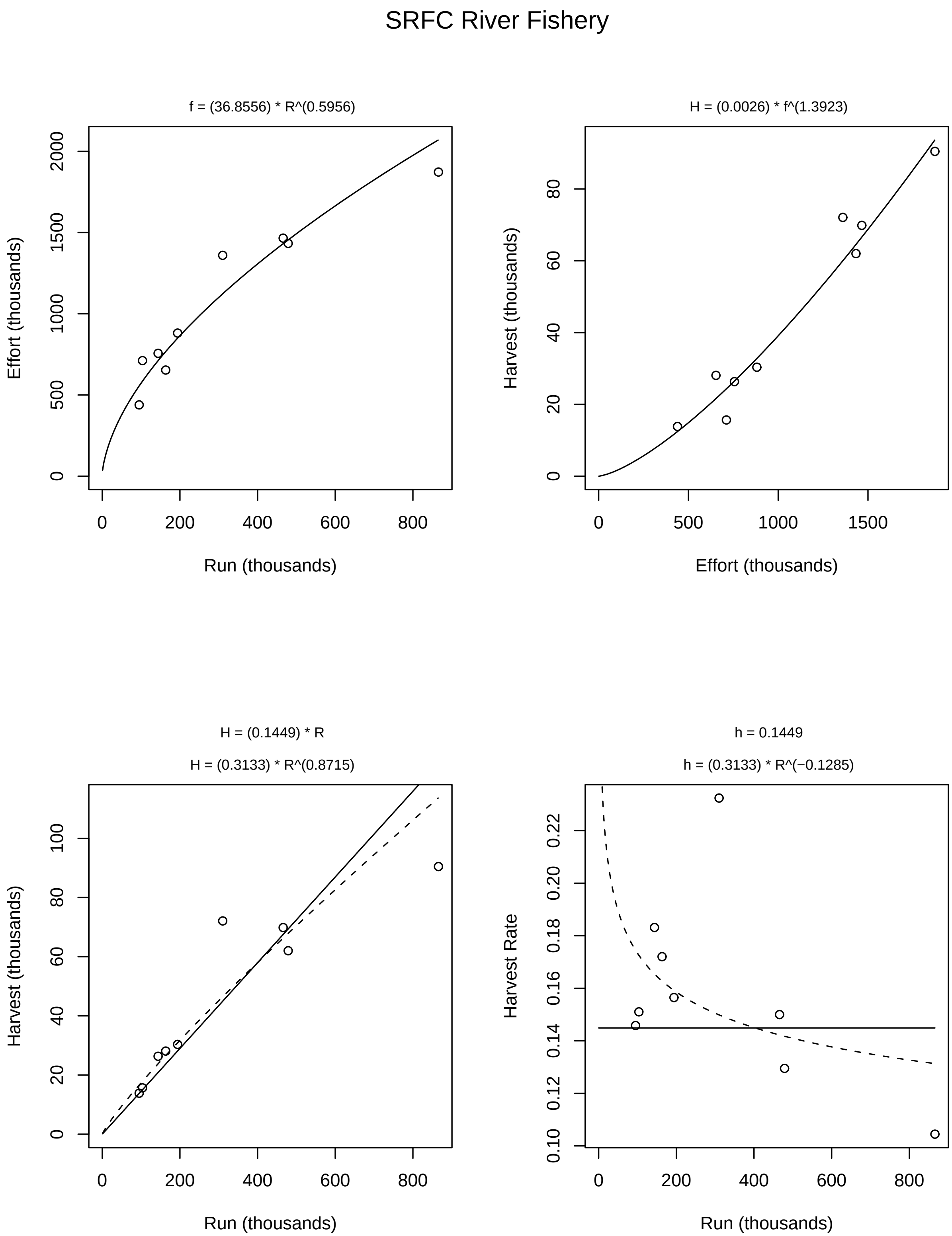

FIGURE D-3 SRFC river fishery available survey data. Top-left panel: effort versus run size; top-right panel: harvest versus effort; bottom-left panel: harvest versus run size; bottom-right panel: harvest rate versus run size. Solid line in bottom-left panel depicts the ratio estimator fit with slope 0.1449, and this value was considered the best estimate of the average unrestricted river fishery harvest rate. The ratio estimator is depicted in the bottom-right panel as a solid horizontal line with intercept 0.1449.

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON 2008 METHODOLOGY REVIEW

The Salmon Subcommittee of the Scientific and Statistical Committee (SSC), the Salmon Technical Team (STT), and the Model Evaluation Workgroup (MEW) met at the Marriott Courtyard Portland Airport on October 15, 2008, to review the three salmon methodology items identified by the Council at the September meeting:

- Development of a new stock abundance forecast for Sacramento River fall Chinook.
- Harvest forecast model for Sacramento River fall Chinook.
- Sensitivity analysis of Chinook and Coho Fishery Regulation Assessment Models (FRAM) to major assumptions including sensitivity to parameters related to mark-selective fisheries.

Presentations on each of the items were given to the full SSC at the November meeting.

Development of a New Stock Abundance Forecast for Sacramento River Fall Chinook

Dr. Michael O'Farrell presented a review of the updated Sacramento River fall Chinook (SRFC) abundance forecast data and methods using a new Sacramento Index (SI) methodology. The SI was initially developed for the 2008 preseason management process in response to the decline of the SRFC stock and to address management limitations of the Central Valley Index (CVI) used in previous seasons. Dr. O'Farrell noted the updated SI now includes a more complete accounting of SRFC adult ocean abundance and a straightforward accounting of river harvest and escapement of SRFC, resulting in an advance in the extent, resolution, and specificity of the SRFC assessment framework

The SSC agrees that the SI is a more appropriate index than the CVI for representing the status of the SRFC stock. The updated SI represents a substantial improvement over the CVI and the SI used in 2008. The SSC recommends that the updated SI be reported in place of the CVI in future Council salmon reports to represent the status of the SRFC stock.

Bias in the estimate of the potential escapement of SRFC is possible because of: (1) the simplifying assumptions when accounting for ocean harvest, (2) not accounting for natural mortality between the time of harvest and escapement, and (3) drop-off mortality. The SSC agrees with the working group that bias from these factors is likely small under recent Council management. A simple length cutoff for separating jacks from adults in returns to Sacramento River Basin hatcheries has probably introduced errors in jack counts and could reduce the accuracy of forecasts of SRFC adult abundance from jack returns; the SSC understands from the discussion that coded-wire-tag (CWT) marking has been recently initiated at these hatcheries, in part to correct this deficiency. Further work on the age composition of hatchery returns will be useful in reducing forecast error.

Harvest Forecast Model for Sacramento River Fall Chinook

Dr. Michael O'Farrell presented a review of the Sacramento Harvest Model (SHM). The SHM was developed in 2008 in concert with the Sacramento Index (SI) in response to the need to model Sacramento River Fall Chinook (SRFC) distinct from the Central Valley combined stocks. In particular, the Sacramento Index (SI) directly accounts for harvest north of Point Arena and river harvest. Using the SHM it is now possible to evaluate the effect of variation in management measures. The SHM is not age structured, because adequate age data are not available.

The SHM considers harvest during a "biological year" (September 1 – August 31), rather than the calendar year of the CVI model. September – December harvest is estimated from fishery data using the same method used for calculating the SI. January - August harvest is projected using harvest rates predicted from expected effort by area and month using the Klamath Ocean Harvest Model and the expected numbers of adult SRFC in the ocean. River harvest is modeled as well, which was not done in the Central Valley modeling.

The SSC considers the SHM an improvement in modeling the harvest of SRFC, and endorses it for Council use. The SSC compliments the authors presenting the SI methodology and SHM for providing thorough and comprehensive documentation for review which greatly facilitated the review process.

Sensitivity Analysis of Chinook and Coho Fishery Regulation Assessment Models

Mr. Andy Rankis presented "Three tests of a potential method for development of a FRAM sensitivity analysis". The methodology incorporates a "complete factorial design" to examine a model's sensitivity to manipulation of selected parameters and to guage interaction among those parameters. For Chinook FRAM, the sensitivity analysis examined the model function in regard to manipulating the release mortality rates for: drop-off/out, legal size Chinook, and sub-legal size Chinook. Two Chinook analyses included the doubling of these parameters for all FRAM fisheries; the first analysis had no mark selective fisheries, the second analysis was based upon a relatively large Puget Sound sport fishery converted into a selective fishery. A third analysis tested the coho FRAM selective fishery parameters of: mark misidentification rate, unmark misidentification rate, and drop-off mortality rate. By running the model with the Council-adopted rates and double these rates they were able to characterize the relative importance of these factors and show how the factors interacted in the model.

The first Chinook analysis demonstrated that the model seems to be working correctly (for the three selected parameters) and is not overly sensitive to the key mortality rate parameters that largely determine the non-landed portion of total fishery related mortality; and in combination, the second Chinook analysis demonstrates that the model continued to function in a consistent manner when a relatively large selective fishery replaced a previously non-selective fishery. The third analysis showed that in the relatively low-intensity coho selective fisheries that were modeled, the interaction effects of the three selective fishery parameters are explainable and minor.

The SSC agrees that the proposed approach is useful and encourages the MEW to conduct a thorough sensitivity analysis with the framework that has been proposed. Because of the large number of parameters to be examined, the SSC recommends a partial factorial design instead of a full factorial for future sensitivity analyses. Also, future analyses should examine three levels of the parameters being examined: the nominal level, something less than the nominal level, and something greater than the nominal level. This will allow analysts to determine if the effects of some of the parameters are non-linear. Finally, future sensitivity analyses should define the objective of the analyses presented. For example, (1) model performance, (2) identification of key parameters that affect key model outputs used for management, and (3) how uncertainty in key model inputs affects key model outputs used for management.

Chinook Selective FRAM

At the September meeting the Council expressed renewed interest in obtaining SSC approval of Chinook selective FRAM as a management tool for use in Council fisheries.

The selective fishery version of the Chinook FRAM was first presented to the SSC in 2002. At that time the SSC could not evaluate the suitability of the model because it was poorly documented and lacked validation. Based on the complex Chinook life cycle (compared with the relatively simpler life cycle of coho salmon) and concern that errors could become very large, the SSC concluded, in part, that:

"2. ...the SSC cannot support the use of the modified Chinook FRAM to evaluate mark-selective fishery proposals in 2003.

3. If the Council chooses to use the modified Chinook FRAM to evaluate mark-selective fishery proposals in 2003, the SSC supports the STT recommendation to establish buffers for management targets to compensate for the increased bias and uncertainty of model estimates..." (Exhibit C.4.b, Supplemental SSC Report, November 2002).

Subsequently, an attempt to compare model predictions with fisheries-based field studies in 2003 -2004 in Washington Marine Catch Areas 5 and 6 in the Strait of Juan de Fuca was reviewed by the SSC. After that review the SSC concluded:

"Overall results indicated that FRAM produced reasonably good predictions for encounter rates. However, the fisheries were too small and the data too variable to reach any firm conclusions about stock-specific predictions of impacts. Also, it is not possible to assess model predictions of non-landed mortalities with this comparison. The SSC is no closer to being able to recommend adoption of the mark-selective version of Chinook FRAM for use in evaluating Council fisheries than it was two years ago." (Agenda Item D.2.b. Supplemental SSC Report, November 2004).

As a result of SSC recommendations in 2002, the MEW was formed. The first task of the MEW was to produce documentation for the FRAM models. This task has been substantially completed and reviewed by the SSC. Documentation includes: (1) an Overview, (2) a User Manual, (3) Technical Documentation, (4) a Programmers Guide, and (5,6) Base Period documentation for Chinook and Coho FRAMs. After reviewing the documentation the SSC now has a better understanding of the modeling framework in general and Chinook selective FRAM in particular.

Based upon increased understanding of Chinook selective FRAM during the last several years due to the new documentation and additional analyses (such as the preliminary sensitivity analysis), the SSC concluded that the Chinook selective FRAM is suitable for modeling mark-selective fisheries of low intensity, with “low intensity” provisionally defined as those fisheries with fishery-specific exploitation rates on marked stocks of less than 10 percent and overall selective fishery exploitation rates of less than 30 percent. However, the Salmon Technical Team should further valuate the appropriateness of the 10 percent/30 percent provisional guidelines and make recommendations to the Council.

The values of 10 percent and 30 percent are not arbitrary – they are based on precautionary application of modeling results presented by Lawson and Sampson (1996) for coho salmon. These results are based on simulations that show that selective fisheries do not harvest all stocks at an equal rate, but remove marked fish from a population more rapidly, thereby changing the stock composition and progressively increasing encounters (and consequent mortalities) on unmarked fish. As a result, unmarked fish mortalities increase exponentially, rather than linearly with exploitation rate and the effect can be quantified. This effect is negligible at low harvest rates, which makes the current linear models adequate to model low intensity fisheries, but exploitation rates for higher intensity fisheries will be biased low.

Similar results are likely to apply to Chinook given that the same fishery dynamics apply. Chinook cohort sizes are re-estimated annually similarly to coho, so modeling errors are unlikely to propagate from year to year. Because the intensity of mark-selective fisheries on marked hatchery stocks will be used to determine if a fishery is low intensity, the exploitation rate on marked hatchery stocks will now need to be monitored during the management process.

Lawson, Peter W. and David B. Sampson. 1996. Gear related mortality in selective fisheries for ocean salmon. North American Journal of Fisheries Management 16:512-520.

PFMC
11/02/08

MODEL EVALUATION WORKGROUP REPORT ON SALMON METHODOLOGY REVIEW

This past summer the Model Evaluation Workgroup (MEW) has made progress on two tasks:

1) Three reports of the Fishery Regulation Assessment Model (FRAM) documentation set have been updated with details relating to the addition of new Chinook stocks to the Chinook FRAM model.
2) A potential methodology for a FRAM sensitivity analysis was identified and three sets of analyses were completed as an exploratory use of this tool.

At the Salmon Methodology Review meeting in October, the MEW presented their FRAM sensitivity analysis work to the Salmon Subcommittee of the Scientific and Statistical Committee (SSC) and the Salmon Technical Team (STT) in a paper entitled "Three Tests of a Potential Method for Development of a FRAM Sensitivity Analysis." This write-up is available as Agenda Item D.1.a, Attachment 1. A complete sensitivity analysis would consider model functions with a wide range of FRAM parameters in both the retention fishery and selective fishery modes. This type of effort has not yet been attempted. Our understanding of this sensitivity analysis methodology is still developing.

The three completed methodology tests included:

1) Examination of Chinook FRAM (retention fisheries) sensitivity to manipulations of release mortality rates for: legal size fish, sub-legal size fish, and for drop-off/drop-out.
2) A repeat of the above test but with a robust mark selective fishery replacement.
3) Using coho FRAM, a manipulation of only mark selective input parameters.

The results of these tests were encouraging. Expected FRAM model functions were confirmed and illustrated with the manipulations of the examined parameters. The model was shown to not be overly sensitive to input release mortality rates. This was important as in selective fisheries the mortality of wild fish is determined by these rates.

Additional questions were raised that can also be explored with this tool; for example, model function related to the form of catch input i.e., "quota" catch input versus a "fishery scalar" catch input. How the age structure of a Chinook stock influences that stock's exploitation rate also needs to be better understood.

The MEW does not consider the FRAM sensitivity analysis task as being completed. Progress was made, but we would like to continue this effort with a comprehensive study design that includes input from the SSC, the STT, and others.

At the Methodology Review meeting the topic of exploitation rates in potential Chinook mark selective fisheries was discussed. The MEW will explore the development of exploitation rate thresholds for Chinook mark selective fisheries.

PFMC
10/28/08

SALMON ADVISORY SUBPANEL REPORT ON SALMON METHODOLOGY REVIEW

1. Sensitivity analysis of Chinook and Coho Fishery Regulation Assessment Models (FRAM) to major assumptions, including sensitivity to parameters related to mark-selective fisheries.
   - Salmon Advisory Subpanel (SAS) is encouraged by the preliminary results of the FRAM sensitivity analysis and supports continuation of the FRAM sensitivity analysis.
   - Some parameter estimates used in the FRAM deserve further refinement, in particular, net fishery drop-out rates are based on Alaskan ocean fisheries, and are probably too high for inland fisheries such as Puget Sound and Columbia River.

2. Sacramento River fall Chinook
   - The SAS feels it important to highlight the fact that the Sacramento Harvest Model is based on an index and not a full run reconstruction like the Klamath Ocean Harvest Model. Furthermore we recognize the difficulties the team faces in trying to develop this model before data from the constant fractional marking program becomes available.
   - Until the cause of the recent collapse of the Sacramento River fall Chinook is fully understood and is quantified, use of this model and the ocean abundance estimates may be difficult to predict and should be highlighted as such.
   - The SAS recommends the Council proceed with caution in implementing the Sacramento Index and Sacramento Harvest Model for ocean management.

PFMC
11/02/08

SALMON TECHNICAL TEAM
REPORT ON SALMON METHODOLOGY REVIEW

The Salmon Technical Team (STT) met on October 15 with the Scientific and Statistical Committee's (SSC) Salmon Subcommittee and the Model Evaluation Workgroup to review the Sacramento Index (SI), the Sacramento Harvest Model (SHM), and a proposed methodology for sensitivity analysis of the modifications made to the Fishery Regulation Assessment Model (FRAM) to model mark-selective Chinook fisheries.

Sacramento Index and Sacramento Harvest Model

Since the March 2008 SSC evaluation of the SI and the SHM, and the 2008 Sacramento River fall Chinook assessment, the SI and SHM have been modified to explicitly include river recreational harvest. The STT believes that the SI and SHM are a substantial improvement over the Central Valley Index (CVI) and the CVI-based harvest model which has previously been used to evaluate the impacts of management measures on Sacramento fall Chinook, and that the explicit inclusion of river recreational harvest is a further improvement over the SI and SHM as used in the 2008 preseason process. The STT recommends the use of the SI and SHM in their current form for future assessments of Sacramento River fall Chinook.

FRAM Sensitivity Analysis

The sensitivity analysis of the mark-selective FRAM focused on interpretation of the outputs of cursory runs intended to evaluate effects and interactions of perturbations to three parameters using a full-factorial design. There were no unexpected results or surprises about the performance of FRAM in modeling mark-selective fisheries. The STT continues to support the use of FRAM to evaluate mark-selective fisheries for both Chinook and coho, as long as the total mortality rates in mark-selective fisheries remain relatively low.

PFMC
10/27/08

Agenda Item D.1.c
Supplemental Tribal Comments
November 2008

Salmon Methodology Review

While the Scientific and Statistical Committee (SSC) statement on Chinook selective Fishery Regulation Assessment Model (FRAM) did not raise any major red flags, work on model evaluation needs to continue. The Council must be confident that this tool is adequate for assessing fishery impacts from the suite of fisheries that we ultimately recommend for adoption.

Washington Department of Fish and Wildlife (WDFW) has stated that it is their intent to put more mark-selective fisheries on the water. As prudent managers, we need to begin discussion on what constitutes low intensity or low levels of mark-selective fisheries that the SSC and Salmon Technical Team (STT) have alluded to in their reports. What levels of exploitation does the SSC's "provisional" low intensity threshold for marked fish translate into for the associated populations of unmarked fish? Where are we relative to this threshold for the coho and Chinook mark-selective fisheries that are already on the water?

After reviewing the SSC comments, I am concerned whether the FRAM model calculates the information necessary to monitor the impact or intensity levels of mark-selective fisheries. Currently, we monitor impacts to natural, unmarked fish stocks, but the SSC's threshold is expressed as the exploitation rates exerted by mark-selective fisheries on marked fish stocks. The STT should be tasked with providing the Council with their recommendations on what metric should be utilized to monitor the impact or intensity levels of mark-selective fisheries. If these recommendations are for a metric currently not contained within the current FRAM reports, then the appropriate modifications should be made so that they are included. Completion of this work is essential, if the Council is to continue to fulfill its obligation to constrain fishery impacts to sustainable levels on stocks of concern.

PFMC
11/02/08