PACIFIC SARDINE TEMPERATURE PARAMETER REVIEW

Background

In 1998, as part of Coastal Pelagic Species (CPS) Fishery Management Plan (FMP) Amendment 8, the Council adopted a precautionary approach to the management of the Pacific sardine resource in the U.S., linking annual harvest levels to sea surface temperature (SST). This was based on a mathematical relationship describing sardine recruitment with temperature, with lower temperatures resulting in less recruitment and vice versa. The FMP also established upper (15 percent) and lower (5 percent) bounds of harvest fraction. In warmer periods, the allowable harvest fraction is at the upper end of the range and in cooler periods, the harvest fraction is in the lower end of the range. The Scripps Institution of Oceanography (SIO) temperature times series has provided the SST for use in the harvest control rule.

Amendment 13 to the CPS FMP was adopted by the Council in 2011, to make the CPS FMP compliant with Magnuson-Stevens Act (MSA) requirements to adopt overfishing limits (OFL), annual catch limits (ACL), and other provisions to prevent overfishing. Amendment 13 established the current OFL control rule, which also incorporates temperature into the estimate of F_{msy}.

Divergent Temperatures

In recent years, the SIO temperature index has diverged from the broader Southern California Bight SST. In February 2013, the Council and the Southwest Fisheries Science Center sponsored a workshop of experts to consider whether there is a better SST index to be used for Pacific sardine management, and whether a new F_{msy}-temperature relationship should be used. The workshop participants recommended using the California Cooperative Oceanic Fisheries Investigations (CalCOFI) temperature index, and also endorsed a new F_{msy}-temperature index, as improved technical refinements independent of the policy choice of the harvest fraction range (currently 5-15 percent aligned along the SIO temperature index and related F_{msy} relationship).

Risk Assessment Framework

The report from Felipe Hurtado and Andre Punt is presented as Agenda Item I.1.b, Attachment 1, and includes stock and fishery performance measures of alternative OFL and harvest guideline control rules, sensitivity tests, and an assessment of changing to a new temperature recruit index. Twelve variants on fishery control rules are examined, including several different harvest fractions ranging from 0 percent to 20 percent. The report was first considered by the Council at its June 2013 meeting, with the recognition that a revised report would be necessary to correct elemental temperature data.

The revised report was considered at a January 7-9, 2014 meeting of the CPS Management Team (CPSMT). The CPSMT developed a report (I.1.c, CPSMT Report), which includes recommendations on use of the CalCOFI temperature index, the new F_{msy}-temperature relationship, and considerations for potential changes in the Pacific sardine harvest policy approach. In the context of technical refinements to temperature indexes and relationships and the aforementioned risk analysis, the CPSMT concluded a 10-20 percent harvest fraction best represents the new state of knowledge.

<u>Council Action</u>:

1. **Consider replacement of the existing SIO temperature index with the CalCOFI temperature index; and adoption of a new temperature-recruit relationship in the context of control rules for Pacific sardine management.**
2. **Provide guidance on potential policy changes regarding Pacific sardine harvest management.**

<u>Reference Materials</u>:

1. Agenda Item I.1.b, Revised Analysis: Revised Analyses Related to Pacific Sardine Harvest Parameters.
2. Agenda Item I.1.c, CPSMT Report.
3. Agenda Item I.1.d, Public Comment.

<u>Agenda Order:</u>

a. Agenda Item Overview — Kerry Griffin
b. Report on Pacific Sardine Temperature Parameters — Felipe Hurtado
c. Reports and Comments of Advisory Bodies and Management Entities
d. Public Comment
e. **Council Action**: Consider Technical Changes in Temperature and Stock Productivity Parameter Changes and Other Fishery Management Changes for Pacific Sardine

PFMC
02/14/14

Agenda Item I.1.b
Revised Analysis
March 2014

REVISED ANALYSES RELATED TO PACIFIC SARDINE HARVEST PARAMETERS

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EXCUTIVE SUMMARY

The analyses used to evaluate the performance of alternative candidate overfishing limit (OFL) and harvest guideline (HG) control rule variants are updated to reflect the recommendations of the Scientific and Statistical Committee (SSC), the Coastal Pelagic Species Advisory Subcommittee (CPSAS), the Coastal Pelagic Species Management Team (CPSMT), and the Pacific Fishery Management Council (Council) regarding performance measures, candidate control rules, and sensitivity tests.

INTRODUCTION

Amendment 8 to the Coastal Pelagic Species Fishery Management Plan (PFMC, 1998) established the following harvest control rule for Pacific sardine:

HG = (BIOMASS-CUTOFF) * FRACTION * DISTRIBUTION

where: HARVEST GUIDELINE is the target harvest level for each management year; BIOMASS is the annual population biomass estimate of sardine aged 1 and older; CUTOFF is 150,000 t, and is the threshold below which directed fishing is prohibited; FRACTION is a temperature-dependent exploitation fraction which ranges from 5% - 15%[1]; DISTRIBUTION is the average proportion of the coastwide biomass in U.S. waters, estimated at 0.87. MAXCAT is the maximum allowable catch regardless of biomass. MAXCAT is 200,000 t for Pacific sardine.

PFMC (2013) developed an initial risk assessment framework to evaluate the performance of alternative Overfishing Limit and Harvest Guideline control rules. This initial framework was based on representing the northern subpopulation of Pacific sardine using a population dynamics model that considers the entire population from northern Baja California (Mexico) to northern Vancouver Island (Canada) as a single fully-mixed population which is fished by a single fleet. Except for a small subset of sensitivity tests, and in common with the analyses on which Amendment 8 was based, the harvest by all fisheries is determined using a single harvest control rule (i.e., decision making in Mexico and Canada is not modelled explicitly).

Hurtado-Ferro and Punt (2013a) suggested changes to the specifications for the analyses developed during the harvest parameters workshop based on the results of initial analyses. They and Hurtado-Ferro and Punt (2013b) showed results for a set of candidate OFL and HG control rules. The results were presented to the Council at the April 2013 meeting, which led to recommendations for modifications to the management strategy evaluation framework. This document provides updated specifications for the analyses (Appendix A), shows the consequences of changing the metric used to define environmental forcing of recruitment on

[1] For ease of presentation, the document distinguishes between the FRACTION in HG control rule (“HG FRACTION”) and the FRACTION in the OFL control rule (“OFL FRACTION”).

historical harvest guidelines, and provides results obtained by applying the harvest control rule variants to the trials.

This document is an update of Hurtado-Ferro and Punt (2013c), which uses an updated standardized CalCOFI SST time series, provided by Kevin Hill, Ed Weber and Sam McClatchie (NOAA).

MANAGEMENT STRATEGY EVALUATION (MSE) FRAMEWORK

The specifications for the MSE framework on which the analyses of this document are based are given in Appendix A. The key differences between Appendix A and Appendix A of Hurtado-Ferro and Punt (2013a) is that the specifications for the sensitivity tests in Hurtado-Ferro and Punt (2013b) have been integrated, the performance statistics have been updated to reflect the recommendations of the SSC, the CPSMT and the CPSAS, and the table of specifications for the sensitivity tests has been updated.

CONTROL RULES

Figure 1a plots the current relationship between the OFL (the Acceptable Biological Catch [ABC] is 90.592% of the OFL) and 1+ biomass. Figure 1b shows the outcome of the HG control rule with HG FRACTION ranging between 0-15%, CUTOFF set to 150,000t and MAXCAT set to 200,000t when the ABC control rule is ignored, and Figure 1c show the HG when the constraint that the HG must be less than or equal to the ABC is applied based on the control rule from Amendment 13. Figure 2 shows the same information as Figure 1, except that the OFL and HG control rules are based on the CalCOFI-E_{MSY} relationship.

E_{MSY} ignoring the environmental effect

The "stochastic E_{MSY}" (SE_{MSY}) is here defined as the exploitation rate that maximizes the mean catch for the "All error" scenario[2,3] for a constant exploitation rate control rule when there is no observation error. SE_{MSY} (0.18) was calculated by projecting the operating model (OM) forward for 200,000 years (100 simulations × 2,000 years) for a range of values for FRACTION to guarantee equilibrium.

E_{MSY} accounting for an environmental effect

E_{MSY} is related to the environmental factor through the recruitment model; as temperature increases, E_{MSY} increases as well. Figure 3 illustrates this relationship. Figure 3 was calculated by projecting the operating model forward (with no process or observation error) for 5,000 years (sufficient to reach equilibrium) and a range of possible E_{MSY} values, while leaving temperature fixed to determine the relationship between E_{MSY} and temperature. This relationship was approximated using a polynomial equation (Figure 4).

Although the method used to estimate the relationship between temperature and E_{MSY} is similar to that used to estimate the current SIO-based temperature-E_{MSY} relationship in Amendment 8 (PFMC, 1998), the relationships differ for reasons other than the choice of environmental variable (CalCOFI vs. SIO). These reasons are: (a) the operating model for this analysis is age-structured and not a production model, and (b) the data used to estimate the relationship cover a different range of years (1984-2008 for CalCOFI vs. 1935-63 and 1986-90 for SIO). A unitless (i.e. in standard deviation space) comparison between the SIO- and

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[2] The value of E_{MSY} is 0.17 if expected yield is taken to be the median rather than the mean of the distribution.

[3] With variation in the environment, and recruitment given the environment.

CalCOFI-based relationships between SST and E_{MSY} is shown in Figure 5. Figure 5 also shows the relationship between E_{MSY} and temperature when the stock-recruitment relationship is fitted using CalCOFI data for 1984-2008 and the projections are based on the age-structured operating model to eliminate effects of these factors ("SIO recalculated" in Figure 5).

OFL, ABC and Harvest Guidelines

The OFLs, ABCs and the Harvest Guidelines are defined following the definitions in Amendment 13 (PFMC, 2010)[4]. Consistently with how OFLs have been calculated for the Pacific sardine, the OFL, defined as $OFL_y = E_{MSY}\left(I_y\right)\hat{B}_y^{1+}$ (eq. A5b), is bounded above by the catch corresponding to the E_{MSY} corresponding to the upper quartile of observed temperature. The ABC is defined as the OFL multiplied by an uncertainty buffer. The calculations of this report are based on the choice P^*=0.4. The harvest guideline, HG, is defined as $HG_y = \mathrm{DISTRIBUTION} \times \mathrm{HG\ FRACTION}_y (B_y^{1+} - \mathrm{CUTOFF})$, where the HG FRACTION is given by the polynomial approximation of the relationship between E_{MSY} and temperature. DISTRIBUTION is set equal to 1 (Figure 4). The HG is bounded below by the catch corresponding to E_{MIN} (i.e. the minimum value that HG FRACTION can take) and above by MAXCATCH.

Table 1 lists the full set of harvest control rule variants considered in this report. Taking harvest control rule variant "J" as a base-case (OFL FRACTION ranging between 0-25%; HG FRACTION ranging between 0-15%; CUTOFF set to 150,000t; MAXCAT set to 200,000t), the remaining variants differ from this base-case follows:

- Variant 4: No CUTOFF or MAXCAT, HG FRACTION is always set to 0.19.
- Variant 9: No MAXCAT, CUTOFF set to 20% of average unfished biomass ($0.2\overline{B_0}$)[5], HG FRACTION ranges from 5 to 18%.
- Variant 13: CUTOFF of 50,000t, HG FRACTION ranges between 11 and 18%.
- Variant 14: No MAXCAT, HG FRACTION set to 0.18, and a CUTOFF of 50,000t.
- Variant 15: HG FRACTION equal to 18%.
- Variant 16: HG FRACTION equal to 18% and no MAXCAT.
- Variant 17: As for harvest control rule variant 9, but with MAXCATCH set to 200,000t.
- Variant 18: OFL computed with an OFL FRACTION of 18% and the HG with a HG FRACTION of 15%.
- Variant 19: HG FRACTION is 15% and depends on the most recent year of the environmental variable instead of a 3-year average.
- Variant 20: HG FRACTION depends on the most recent year of the environmental variable instead of a 3-year average.
- Variant 21: No fishing
- Variant 22: HG FRACTION is 15%.

[4] The OFL as defined in Amendment 13 includes the DISTRIBUTION parameter, but DISTRIBUTION is assumed to be 1 for the bulk of the calculations reported here.

[5] $\overline{B_0}$ is here defined as the mean unfished biomass. Note that this definition of $\overline{B_0}$ is not the 'true B_0' of the stock, and is only used to define the CUTOFF parameter of the HG. The 'true' B_0 of the stock is not a static value but is instead related to the environment. Thus, the definition of B_0 being used here is not appropriate for defining an overfished threshold.

IMPACT OF CHANGING FROM SIO TO CalCOFI

Table 2 lists the estimates of 1+ biomass from the assessments for the last 10 years, the values for CalCOFI temperatures (SST_CC_ann), the values for the SIO temperatures and the resulting OFLs and harvest guidelines. The differences in HG are explained by the differences between the various time series (Figure 6), with the CalCOFI and SIO series having diverged since around 2000, with CalCOFI getting increasingly colder, while SIO has remained warm.

HGs and OFLs are calculated from the temperature and biomass for a given management year. Using management year 2000 as an example, the reference points are first calculated using SIO. From the relationship shown in the right panel of Figure 4, the E_{MSY} for an SIO SST of 18.08^{0}C is 66%, and the HG FRACTION is consequently 15% (HG FRACTION = max(E_{MSY}, HG FRACTION$_{max}$)) where OFL FRACTION$_{max}$ is the value of E_{MSY} at the upper quartile of observed SST, 17.76°C,. The OFL for 2000 using SIO temperature is equal to the biomass (1’581,346t) multiplied by the OFL FRACTION (44%, not shown in table; OFL FRACTION = max(E_{MSY}, OFL FRACTION$_{max}$), multiplied by DISTRIBUTION (0.87). The HG is equal to the biomass minus CUTOFF (150,000t), multiplied by HG FRACTION, and by DISTRIBUTION. The reference points using CalCOFI are calculated in a similar way, but the HG FRACTION and OFL FRACTION (OFL FRACTION$_{max}$ is 25% for CalCOFI, occurring at 16.16°C) are calculated using the relationship shown in the left panel of Figure 4.

RESULTS FOR A BASE-CASE OPERATING MODEL

The base-case operating model is defined in Table A4. Figure 7 shows the distributions of cumulative 1+ biomass and cumulative catch for the harvest control rule variant which most closely resembles the current HG control rule (harvest control rule variant “J” in Table 1), as well as those for the least (setting the harvest rate to DE_{MSY} with no CUTOFF or MAXCATCH; harvest control rule variant “M” in Table 1) and most (setting CUTOFF to $0.20\overline{B_0}$; harvest control rule variant 9 in Table 1) conservative harvest control rule variants. The catch for the OFL control rule is unbounded, whereas the catch for harvest control rule variants J and V4 do not allow the catch to exceed 200,000t (MAXCAT). Figure 8 shows 150-year time-trajectories of biomass for these three harvest control rule variants.

Table 4 lists the values for the performance measures for the harvest control rule variants in Table 1 (see Section 3 of Appendix A for definitions of the performance measures), highlighting those harvest control rule variants which perform best (green highlighted) and poorest (red highlighted) for each performance measure. No harvest control rule variant is always in the “best” group, indicating that there are trade-offs amongst the management objectives which underlie the performance measures. Some of the key trade-offs are illustrated in Figure 9. Best performance occurs in the top right corner of the left panel of Figure 9 (high average catches and 1+ biomasses) and in the top right corner of the right panel of Figure 9 (high probability that the catch is larger than 50,000t and the 1+ biomass exceeds 400,000t). Some of the harvest control rule variants (e.g. 4, “DE_{MSY}”) are “dominated” in Figure 9 (they achieve the same [or lower] average catch as another variant, but at lower average biomass). Harvest control rule variant 4 leads to a high proportion of years with no catch (Figure 9, right panel) and 1+ biomass values below 400,000t (Figure 9, right panel).

The current harvest control rule variant (“J” in Table 1, “6” in Figure 9), achieves amongst the lowest average catches, but performs best in terms of low catch variation and a low probability of the HG being zero (Table 4). This harvest control rule variant also leads to fairly high variation in 1+ biomass, but not as high as harvest control rule variant 18. However, 1+

biomass remains about 400,000t with high probability (~93% of years) under harvest control rule variant J. Harvest control rule variants 14 and 16, which both have no relationship between HG FRACTION and the environmental variable, lead to the highest average catches, but also to quite considerable between-year variation in catches and amongst the lowest probabilities of 1+ biomass dropping below 400,000t.

SENSTIVITY TO ALTERNATIVE SCENARIOS

Tables 5, 6 and 7 show the values for the performance measures for harvest control rule variant J, while the results of the sensitivity tests in the trade-off space are shown in Figure 10. Perhaps not surprisingly, variation in catch and biomass, as well as the probability of low (or zero) catches, is higher when the extent of recruitment variation is higher (case S2), and is lower when recruitment variation is lower (case S1). The same effect occurs when the extent of uncertainty in biomass estimates is changed (cases S3 and S4), although the size of the effect is less for cases S3 and S4 than for cases S1 and S2. The probability of low (or zero) catches is markedly higher when the number of years of poor environmental conditions is increased (case S6). In contrast, longer periods of good and poor environmental conditions (case S9), or a smoother (i.e. sine) underlying environmental signal (case S8) are relatively inconsequential. Overall, a slower decline in the environment (case S7) leads to better overall performance (higher average catches and higher average biomasses).

Less variation in the environment (case S10) leads to higher average catches and less between-year variation in catches, to a higher probability of biomass exceeding 400,000t and to a markedly lower probability of a zero catch. More variation in the environment leads to the opposite effects. The results are not very sensitive to time-varying selectivity and weight-at-age (cases S12, S13, S16 and S17) nor to hyper-stability in biomass estimates (Table 7). However, the results are sensitive to Mexico and Canada not following the US control rule (case S14 in Table 6). This is the only case in which the resource is rendered extinct. The results are more optimistic if only Canada does not follow the US control rule even though risks remain higher (case S15[6]). Risk is also much higher, and average catches lower and more variable, if natural mortality increases when the environment is declining (case S5).

The results are insensitive to basing the uncertainty between I and V on the variance between CC_SST_ann and ERSST_ann when the population dynamics are assumed to be driven by CC_SST_ann.

The results are generally more optimistic when the simulations are based on the ERSST series (higher average catches, lower probabilities of catches less than 50,000t and higher average biomasses), but the trade-offs achieved by the harvest control rule variants are similar to those from the simulations for the base case analysis (Table 8). This is because the ERSST series implies higher average biomasses given the fit of the environmental-recruitment model. Table 9 lists the estimates of 1+ biomass from the assessments for the last 10 years, the values for ERSST_ann, the values for the SIO temperatures and the resulting OFLs and harvest guidelines. It is important to keep in mind that the environmental-recruitment model based on CalCOFI (CC_SST_ann) fits the data better than the model based on ERSST_ann (Table 10). The relationship between ERSST and E_{MSY} is shown in Figure 11.

The results when simulations are based on the SIO_SST_ann time series show similar trade-offs as the base case, except for variant 4, which shows relatively higher catches than in the

[6] This sensitivity tests also captures some of the effects of there being two stocks with catches off Mexico coming from a southern subpopulation.

ERSST and base cases (Table 11). The recalculated relationship between SIO and E_{MSY} is shown in Figure 12. Table 12 lists the estimates of 1+ biomass from the assessments for the last 10 years, the values for the SIO temperatures and the resulting OFLs and harvest guidelines from changing the relationship between SST and E_{MSY}.

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Table 1. Harvest control rule variants. The numbers associated with each control rule variants are used in the figures. PFMC (2013) included a 15th variant, but this was equivalent to "HG Variant-1".

	Variants from Hurtado-Ferro and Punt (2013a)				
Variant	**M (4)**	**HG (J) (6)**	**HG Variant-3 (9)**	**Alt-3 (13)**	**Alt-4 (14)**
HG FRACTION (%)	DE_{MSY}	5-15	5- SE_{MSY}	11- SE_{MSY}	SE_{MSY}
CUTOFF	0	150	$0.20\overline{B_0}$	50	50
MAXCAT		200		200	-
	Additional analyses				
Variant	**New-1 (15)**	**New-2 (16)**	**New-3 (17)**	**New-4 (18)**	**New-5 (19)**
HG FRACTION (%)	Best fit	Best fit	5- SE_{MSY}	15*	15**
CUTOFF	150	150	$0.20\overline{B_0}$	150	150
MAXCAT	200	-	200	200	200
	Additional analyses				
Variant	**New-6 (20)**	**New-7 (21)**	**New-8 (22)**		
HG FRACTION (%)	5-15**	0	15		
CUTOFF	150	-	150		
MAXCAT	200	-	200		

* OFL/ABC = 0.18

** OFL/ABC based on E_{MSY} (0-0.26), linked to CC_SST_ann

Table 2. Impact of changing the environmental variable from SIO to CalCOFI, using both annual and 3-year averages.

Mgmt	Biomass	SIO				CalCOFI ann					CalCOFI 3-year average				
year	**(July)**	**SST**	**Fraction**	**HG**	**OFL**	**ann SST**	**Fraction**	**HG**	**Difference**	**OFL**	**3-y SST**	**Fraction**	**HG**	**Difference**	**OFL**
2000	1581346	18.08	0.15	186791	605339	15.28	0.11	141944	-44847	144549	16.28	0.15	186791	0	342567
2001	1182465	17.75	0.15	134737	433005	15.79	0.15	134737	0	195951	15.95	0.15	134737	0	226446
2002	1057599	17.24	0.15	118442	149081	15.55	0.15	118442	0	136744	15.54	0.15	118442	0	135077
2003	999871	17.31	0.15	110908	165969	14.94	0.06	43900	-67008	48895	15.43	0.14	100938	-9970	111214
2004	1090587	17.46	0.15	122747	246185	16.03	0.15	122747	0	223753	15.51	0.15	121863	-883	133783
2005	1193515	17.60	0.15	136179	346672	15.88	0.15	136179	0	215935	15.62	0.15	136179	0	165947
2006	1061391	18.03	0.15	118937	406300	15.46	0.14	111941	-6996	122575	15.79	0.15	118937	0	175969
2007	1319072	18.11	0.15	152564	504941	15.92	0.15	152564	0	245339	15.75	0.15	152564	0	210722
2008	832706	18.12	0.15	89093	318760	15.15	0.09	55526	-33567	62044	15.51	0.15	88560	-533	102291
2009	662886	17.83	0.15	66932	253753	15.27	0.11	50025	-16907	59538	15.45	0.14	62231	-4701	75513
2010	702024	17.84	0.15	72039	268735	15.36	0.13	60303	-11736	71210	15.26	0.11	53033	-19006	62055
2011	537173	17.90	0.15	50526	205630	15.55	0.15	50526	0	69334	15.39	0.13	44185	-6342	57163
2012	988385	17.64	0.15	109409	307746	15.56	0.15	109409	0	128999	15.49	0.15	106624	-2785	118718
2013	659539	17.35	0.15	66495	118854	15.32	0.12	53051	-13443	63508	15.48	0.14	63938	-2557	78025

Table 3. Values of biomass used in the harvest control rule variants (in '000 t).

Quantity	Value
$\overline{B_0}$	1572
0.33 $\overline{B_0}$	518.8
0.20 $\overline{B_0}$	314.4
0.10 $\overline{B_0}$	157.2

Table 4. Results of applying each of the harvest control rule variants to a base-case scenario (see Table A4 for specifications). The variants where the performance measure is within 5% of the best value are shaded in green and those for which the performance measure is within 5% of the poorest value are shaded in red (Variant 21 [no catch] not included in this calculation).

Scenario	M	HG J	HG Var3	Alt3	Alt4	New1	New2	New3	New4	New5	New6	New7	New8
Code	**4**	**6**	**9**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
OFL FRACTION (%)	0-25	0-25	0-25	0-25	0-25	0-25	0-25	0-25	18	0-25	0-25	-	0-25
HG FRACTION (%)	19	5-15	5-18	11-18	18	18	18	5-18	15	15	5-15	0.0	15
CUTOFF	0	150	$0.20\overline{B}_0$	50	50	150	150	$0.20\overline{B}_0$	150	150	150	-	150
MAXCAT	-	200	-	200	-	200	-	200	200	200	200	-	200
Performance Measure													
Mean catch all	108.5	105.8	133.9	113.2	149.3	110.9	146.1	100.8	111.0	102.3	101.7	0.0	106.6
SD catch all	158.3	72.5	165.1	73.2	164.1	73.3	163.6	76.6	69.6	72.9	73.6	0.0	71.5
Mean catch CO	144.9	110.9	148.3	117.8	155.5	116.4	153.5	111.2	113.6	113.0	112.3	0.0	111.7
SD catch CO	167.9	70.4	167.7	71.0	164.6	70.8	164.4	73.1	68.3	68.5	69.4	0.0	69.3
Mean B1+	571.7	1220.0	1177.8	1149.6	1033.2	1178.0	1072.9	1268.6	1148.4	1230.5	1239.0	1572.0	1207.7
SD B1+	747.4	888.1	755.8	888.9	750.1	890.2	757.7	876.0	916.2	888.9	885.6	907.6	892.8
Mean SSB	403.9	946.7	891.9	883.2	761.1	908.4	796.5	990.3	884.1	958.0	965.4	1304.3	936.0
SD SSB	554.3	757.0	588.9	756.9	578.0	758.2	586.1	747.4	777.8	759.7	757.2	805.5	760.6
%B1+>400	44.2	92.4	95.5	88.2	87.1	89.9	89.4	95.7	84.3	92.2	93.0	98.6	91.1
%No catch	25.1	4.7	9.8	4.0	4.0	4.8	4.9	9.5	2.3	9.7	9.7	100.0	4.7
%Catch<50	49.3	31.2	37.8	28.3	29.2	29.2	30.3	36.4	26.4	32.3	33.3	100.0	30.0
Median catch	51.9	97.4	81.7	109.3	100.9	104.8	97.2	88.5	104.3	92.8	92.2	0.0	97.7
Median B1+	300.5	991.8	994.5	911.7	847.3	943.5	885.7	1043.8	913.5	1012.1	1020.0	1401.8	980.0
Median SSB	205.7	742.1	747.2	671.4	617.1	698.5	650.3	789.7	671.8	761.4	768.3	1139.7	732.2
Mean pop age	1.81	2.83	2.77	2.76	2.62	2.79	2.66	2.88	2.76	2.84	2.85	3.29	2.82
Mean Catch Age	1.16	1.83	1.78	1.78	1.69	1.80	1.71	1.86	1.78	1.84	1.85	NA	1.82
%HCR min	NA	11.18	11.18	28.63	NA	NA	NA	11.18	NA	NA	16.65	NA	NA
%HCR max	NA	57.36	46.76	46.76	NA	NA	NA	46.76	NA	NA	56.64	NA	NA
Mean Yrs HCRmin	NA	2.58	2.58	4.37	NA	NA	NA	2.58	NA	NA	1.59	NA	NA
Mean Yrs HCRmax	NA	8.56	7.01	7.01	NA	NA	NA	7.01	NA	NA	3.58	NA	NA
Mean Yrs NoCatch	140.70	1.86	1.84	1.93	1.93	1.83	1.83	1.85	1.44	1.37	1.37	NA	1.84
% Collapses	44	0	0	0	0	0	0	0	0	0	0	0	0

Table 5. Results of applying harvest control rule variant J to a base-case scenario and nine of the sensitivity tests. Scenarios "σ_R=0.5" and "σ_R=0.9" refer to changing the assumed extent of recruitment variability; scenarios "σ_B=0.268" and "σ_B=0.5" refer to changing the assumed extent of uncertainty associated with biomass estimation; scenario "M&G" refers to time-varying natural mortality as a function of G; scenarios "G=a2","G=b", "G=c", and "G=d" refer to the shape of the underlying environmental signal, G, as described in Figure A1.

Scenario	**HG J**	**σ_R=0.5**	**σ_R=0.9**	**σ_B=0.268**	**σ_B=0.5**	**M&G**	**G=a2**	**G=b**	**G=c**	**G=d**
Code	**6**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
Performance Measure										
Mean catch all	105.8	112.1	101.0	108.0	101.8	95.9	87.9	116.1	107.5	105.4
SD catch all	72.5	71.5	73.2	71.8	73.7	76.2	70.5	71.1	68.6	73.2
Mean catch CO	110.9	116.7	106.9	112.7	108.0	105.9	93.8	120.1	110.6	110.8
SD catch CO	70.4	69.3	71.1	69.8	71.5	73.3	69.1	68.9	67.2	71.1
Mean B1+	1220.0	1241.1	1204.0	1213.8	1232.4	1099.5	1045.3	1304.2	1171.4	1214.7
SD B1+	888.1	718.2	1038.4	886.0	892.3	929.2	787.4	905.5	785.2	877.3
Mean SSB	946.7	959.8	936.8	940.1	959.7	842.5	812.7	1010.3	905.1	942.6
SD SSB	757.0	597.7	895.9	754.9	761.5	779.2	664.5	776.6	669.8	744.6
%B1+>400	92.4	97.4	88.3	92.6	92.3	78.9	89.2	94.3	94.3	91.5
%No catch	4.7	4.0	5.6	4.3	5.9	9.7	6.4	3.4	2.8	5.0
%Catch<50	31.2	27.4	34.2	29.7	34.1	39.1	41.1	25.1	27.1	32.0
Median catch	97.4	109.0	88.8	101.4	90.1	81.6	68.2	116.1	99.6	96.9
Median B1+	991.8	1064.8	929.0	983.1	1007.9	856.8	822.4	1091.3	978.5	988.6
Median SSB	742.1	800.1	693.6	734.2	757.6	629.2	625.5	810.5	731.1	740.4
Mean pop age	2.83	2.74	2.90	2.82	2.85	2.69	2.85	2.81	2.78	2.82
Mean Catch Age	1.83	1.77	1.88	1.82	1.84	1.74	1.84	1.82	1.79	1.82
%HCR min	11.18	11.18	11.18	11.18	11.18	11.18	15.09	8.37	7.49	11.52
%HCR max	57.36	57.36	57.36	57.36	57.36	57.36	45.21	64.49	59.61	56.97
Mean Yrs HCRmin	2.58	2.58	2.58	2.58	2.58	2.58	2.63	2.52	2.30	2.65
Mean Yrs HCRmax	8.56	8.56	8.56	8.56	8.56	8.56	6.12	9.93	7.19	8.97
Mean Yrs NoCatch	1.86	1.89	1.89	1.92	1.75	2.35	1.88	1.84	1.69	1.89
% Collapses	0	0	0	0	0	0	0	0	0	0

Table 6. Results of applying harvest control rule variant J to a base-case scenario and ten of the sensitivity tests. Scenarios “Amp=0.5” and “Amp=2” refer to changing the amplitude of the environmental signal; scenarios “Sel=Mex” and “Sel=PNW” refer to changing the selectivity of the fishery; scenarios “MF” and “MF=NoMex” refer to only the US following the US control rule; scenario “TV Selex” refers to time-varying selectivity; scenario “TV WaA” refers to time-varying weight-at-age; scenario “ERSST error” refers to variance in *I* equal to the variance between CC_SST_ann and ERSST_ann.

Scenario	**HG J**	**Amp = 0.5**	**Amp = 2**	**Sel=Mex**	**Sel=PNW**	**MF**	**MF=NoMex**	**TV Selex**	**TV WaA**	**ERSST error**
Code	**6**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**
Performance Measure										
Mean catch all	105.8	109.1	98.4	107.6	114.0	57.2	87.8	111.9	107.1	106.2
SD catch all	72.5	65.7	87.0	72.6	72.5	60.5	63.8	72.0	73.0	72.3
Mean catch CO	110.9	110.8	125.3	112.7	119.0	73.6	93.3	116.8	112.2	110.6
SD catch CO	70.4	64.8	79.7	70.4	70.0	59.6	61.9	69.7	70.8	70.5
Mean B1+	1220.0	1147.2	1443.5	1246.3	1337.3	716.0	1155.5	1299.0	1250.3	1218.3
SD B1+	888.1	711.5	1372.3	897.7	914.0	725.3	897.9	889.6	929.1	888.2
Mean SSB	946.7	883.9	1137.8	967.7	1054.6	493.7	880.7	1016.6	948.4	945.0
SD SSB	757.0	609.1	1168.3	766.9	789.0	534.4	753.2	763.2	762.5	757.1
%B1+>400	92.4	95.9	78.4	93.1	95.5	58.9	87.6	95.3	92.5	92.5
%No catch	4.7	1.6	21.8	4.6	4.3	22.8	6.0	4.3	4.7	4.0
%Catch<50	31.2	24.1	45.0	30.4	27.2	58.8	37.7	27.7	31.0	31.0
Median catch	97.4	100.8	81.5	100.6	112.7	32.9	77.8	108.5	99.4	97.7
Median B1+	991.8	977.4	1024.9	1018.1	1116.2	509.1	925.1	1082.5	1006.3	988.2
Median SSB	742.1	729.9	772.0	761.3	850.0	345.0	679.2	819.5	741.1	739.0
Mean pop age	2.83	2.75	3.08	2.84	2.69	2.18	2.60	2.72	2.84	2.83
Mean Catch Age	1.83	1.78	2.01	1.97	3.78	1.41	1.71	3.17	1.83	1.83
%HCR min	11.18	5.17	30.64	11.18	11.18	11.09	11.09	11.18	11.18	10.42
%HCR max	57.36	61.02	51.81	57.36	57.36	57.75	57.75	57.36	57.36	57.33
Mean Yrs HCRmin	2.58	1.95	5.42	2.58	2.58	2.61	2.61	2.58	2.58	2.59
Mean Yrs HCRmax	8.56	6.43	20.81	8.56	8.56	8.83	8.83	8.56	8.56	9.32
Mean Yrs NoCatch	1.86	1.50	3.63	1.87	1.88	4.14	1.94	1.88	1.86	1.82
% Collapses	0	0	0	0	0	14	0	0	0	0

Table 7. Results of applying harvest control rule variant J to five scenarios of the sensitivity test for hyper-stability in biomass estimates.

	g=210	*g*=320	*g*=400	*g*=500	*g*=620
Performance Measure					
Mean catch all	105.8	105.8	105.8	105.8	105.8
SD catch all	72.5	72.5	72.5	72.5	72.4
Mean catch CO	110.9	110.9	110.9	110.8	110.5
SD catch CO	70.4	70.4	70.4	70.5	70.5
Mean B1+	1220.0	1220.0	1220.0	1219.8	1217.4
SD B1+	888.2	888.2	888.2	888.3	889.1
Mean SSB	946.7	946.7	946.7	946.6	944.6
SD SSB	757.1	757.1	757.1	757.2	757.7
%B1+>400	92.4	92.4	92.4	92.4	92.1
%No catch	4.7	4.7	4.7	4.6	4.3
%Catch<50	31.2	31.2	31.2	31.2	31.3
Median catch	97.4	97.4	97.4	97.4	97.1
Median B1+	991.8	991.8	991.8	991.7	990.2
Median SSB	742.1	742.1	742.1	742.0	740.7
Mean pop age	2.83	2.83	2.83	2.83	2.83
Mean Catch Age	1.83	1.83	1.83	1.83	1.83
%HCR min	1.86	1.86	1.85	1.83	1.84
%HCR max	11.18	11.18	11.18	11.18	11.18
Mean Yrs HCRmin	57.36	57.36	57.36	57.36	57.36
Mean Yrs HCRmax	2.58	2.58	2.58	2.58	2.58
Mean Yrs NoCatch	8.56	8.56	8.56	8.56	8.56
% Collapses	0	0	0	0	0

Table 8. Results of applying each of harvest control rule variants to a model based on the ERSST time-series. The variants where the performance measure is within 5% of the best value are shaded in green and those for which the performance measure is within 5% of the poorest value are shaded in red (Variant 21 [no catch] not included in this calculation).

Scenario	**M**	**HG J**	**HG Var3**	**Alt3**	**Alt4**	**New1**	**New2**	**New3**	**New4**	**New5**	**New6**	**New7**	**New8**
Code	**4**	**6**	**9**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
FRACTION (%)	19	5-15	5-18	11-18	18	18	18	5-18	15	15	5-15	0	15
CUTOFF	0	150	0.20$\overline{B}_0$	50	50	150	150	0.20$\overline{B}_0$	150	150	150	-	150
MAXCAT	-	200	-	200	-	200	-	-	200	200	200	-	200
Performance Measure													
Mean catch all	183.6	138.3	172.5	142.7	182.9	141.8	181.7	132.6	146.3	133.7	133.0	0.0	139.2
SD catch all	161.3	61.2	160.4	59.7	153.2	60.0	153.4	65.8	58.1	63.7	64.6	0.0	59.8
Mean catch CO	184.4	138.5	174.1	142.8	183.0	141.9	181.9	133.6	146.5	135.7	135.0	0.0	139.3
SD catch CO	161.2	61.1	160.3	59.6	153.2	59.8	153.4	65.0	58.0	62.0	63.0	0.0	59.7
Mean B1+	965.8	1637.3	1537.2	1580.7	1389.2	1596.4	1415.6	1695.3	1540.8	1660.3	1669.4	2204.6	1624.3
SD B1+	711.1	875.2	733.3	880.1	731.6	879.2	735.1	864.0	898.2	875.8	873.1	892.6	879.0
Mean SSB	681.6	1272.8	1165.8	1222.8	1035.5	1236.5	1058.4	1324.6	1187.4	1295.1	1303.1	1829.6	1261.4
SD SSB	534.8	756.1	585.7	759.5	581.2	759.0	584.6	747.5	772.2	759.2	757.1	803.9	759.0
%B1+>400	80.5	99.6	99.8	98.9	98.6	99.2	99.0	99.9	98.3	99.5	99.7	100.0	99.4
%No catch	0.5	0.1	1.0	0.1	0.1	0.1	0.1	0.8	0.1	1.5	1.5	100.0	0.11
%Catch<50	12.8	11.0	17.6	9.1	10.3	9.3	10.7	15.5	7.8	13.3	14.4	100.0	9.63
Median catch	140.7	150.3	127.9	158.9	141.6	156.9	140.2	143.5	165.8	143.0	143.1	0.0	149.76
Median B1+	805.4	1450.4	1387.3	1393.2	1242.4	1409.2	1266.9	1508.4	1348.0	1479.4	1487.8	2048.7	1438.28
Median SSB	553.3	1093.6	1039.4	1043.4	912.0	1056.5	932.8	1146.9	1000.8	1120.9	1128.5	1676.7	1082.71
Mean pop age	2.31	2.75	2.66	2.71	2.56	2.72	2.58	2.78	2.68	2.76	2.77	3.21	2.74
Mean Catch Age	1.48	1.77	1.71	1.75	1.65	1.75	1.66	1.80	1.73	1.78	1.79	NA	1.77
%HCR min	NA	2.90	2.90	26.50	NA	NA	NA	2.90	NA	NA	9.30	NA	NA
%HCR max	NA	46.12	27.23	27.23	NA	NA	NA	27.23	NA	NA	47.33	NA	NA
Mean Yrs HCRmin	NA	1.74	1.74	3.19	NA	NA	NA	1.74	NA	NA	1.23	NA	NA
Mean Yrs HCRmax	NA	4.61	3.23	3.23	NA	NA	NA	3.23	NA	NA	2.30	NA	NA
Mean Yrs NoCatch	63.00	1.16	1.13	1.23	1.24	1.16	1.15	1.13	1.07	1.07	1.07	NA	1.16
% Collapses	1	0	0	0	0	0	0	0	0	0	0	0	0

Table 9. Impact of changing the environmental variable from SIO to ERSST_ann.

Mgmt	Biomass	SIO				ERSST ann					ERSST 3-year average				
year	(July)	SST	Fraction	HG	OFL	ann SST	Fraction	HG	Difference	OFL	3-y SST	Fraction	HG	Difference	OFL
2000	1581346	18.08	0.15	186791	605339	17.96	0.05	62264	-124527	39506	18.87	0.14	178836	-7955	197577
2001	1182465	17.75	0.15	134737	433005	18.76	0.13	114844	-19893	131529	18.57	0.10	91337	-43399	104607
2002	1057599	17.24	0.15	118442	149081	18.57	0.10	80636	-37806	93962	18.43	0.08	66319	-52123	77279
2003	999871	17.31	0.15	110908	165969	18.49	0.09	67125	-43784	78972	18.61	0.11	78843	-32066	92758
2004	1090587	17.46	0.15	122747	246185	19.08	0.15	122747	0	165874	18.71	0.12	99086	-23661	114888
2005	1193515	17.60	0.15	136179	346672	19.06	0.15	136179	0	178857	18.87	0.14	131001	-5178	149831
2006	1061391	18.03	0.15	118937	406300	18.89	0.15	116732	-2205	135944	19.01	0.15	118937	0	152007
2007	1319072	18.11	0.15	152564	504941	18.94	0.15	152564	0	176705	18.97	0.15	152564	0	180985
2008	832706	18.12	0.15	89093	318760	18.54	0.10	57766	-31327	70458	18.79	0.13	78462	-10631	95701
2009	662886	17.83	0.15	66932	253753	18.32	0.07	30881	-36051	39912	18.60	0.11	47004	-19927	60751
2010	702024	17.84	0.15	72039	268735	-	-	-	-	-	-	-	-	-	-
2011	537173	17.90	0.15	50526	205630	-	-	-	-	-	-	-	-	-	-
2012	988385	17.64	0.15	109409	307746	-	-	-	-	-	-	-	-	-	-
2013	659539	17.35	0.15	66495	118854	-	-	-	-	-	-	-	-	-	-

Table 10. Summary statistics for ln(R/S) models when fitting data from 1984-2008 only. Taken from PFMC 2013, Table App.E.6 and modified using the updated SST_CC_ann series

Series	AIC	R^2
SST_CC_ann	45.79	0.72
SIO_SST_ann	56.81	0.61
ERSST_ann	55.3	0.63

Table 11. Results of applying each of the harvest control rule variants to an operating model based on the SIO time-series. The variants where the performance measure is within 5% of the best value are shaded in green and those for which the performance measure is within 5% of the poorest value are shaded in red (Variant 21 [no catch] not included in this calculation).

Scenario	**M**	**HG J**	**HG Var3**	**Alt3**	**Alt4**	**New1**	**New2**	**New3**	**New4**	**New5**	**New6**	**New7**	**New8**
Code	**4**	**6**	**9**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
FRACTION (%)	19	5-15*	5-18*	11-18*	18	18	18	5-18*	15*	15**	5-15**	0	15
CUTOFF	0	150	$0.20\overline{B_0}$	50	50	150	150	$0.20\overline{B_0}$	150	150	150	-	150
MAXCAT	-	200	-	200	-	200	-	-	200	200	200	-	200
Performance Measure													
Mean catch all	132.8	87.7	93.8	91.4	105.5	90.8	104.5	80.9	115.6	85.5	84.4	0.0	89.2
SD catch all	118.8	66.8	110.4	67.5	110.7	67.2	109.8	67.4	61.7	68.1	68.7	0.0	66.1
Mean catch CO	134.5	94.0	101.7	97.9	113.0	97.2	111.9	87.6	116.1	98.0	96.7	0.0	95.5
SD catch CO	118.7	64.9	111.6	65.3	110.9	65.1	110.1	66.0	61.4	64.3	65.2	0.0	64.0
Mean B1+	698.9	1277.3	1274.4	1252.8	1202.8	1257.8	1210.5	1315.1	1076.7	1277.0	1284.9	1570.4	1267.5
SD B1+	525.9	594.4	541.7	593.9	538.5	594.5	540.3	592.0	623.7	600.7	599.0	647.9	596.1
Mean SSB	493.3	1005.5	998.4	982.6	931.2	987.2	938.4	1041.2	820.9	1007.0	1014.3	1302.9	996.4
SD SSB	395.3	511.3	446.6	511.4	443.9	511.7	445.3	509.3	527.1	521.7	520.3	582.8	512.9
%B1+>400	67.9	99.6	99.8	99.4	99.3	99.4	99.4	99.8	94.3	99.5	99.6	99.9	99.5
%No catch	1.2	6.8	8.0	6.7	6.7	6.8	6.8	7.9	0.4	13.0	13.0	100.0	6.8
%Catch<50	21.7	38.0	44.9	35.5	36.1	35.7	36.3	44.0	17.7	38.9	40.6	100.0	35.9
Median catch	101.3	71.9	58.7	76.8	74.7	76.0	74.1	60.6	109.2	71.8	69.0	0.0	74.9
Median B1+	580.9	1156.6	1170.6	1132.7	1100.2	1137.6	1107.2	1196.1	937.7	1157.2	1164.6	1456.9	1147.2
Median SSB	399.6	894.0	908.2	871.5	842.2	875.7	848.4	930.4	693.0	893.8	901.1	1191.4	885.0
Mean pop age	2.30	2.85	2.84	2.83	2.77	2.83	2.78	2.89	2.65	2.85	2.86	3.22	2.84
Mean Catch Age	1.47	1.84	1.83	1.82	1.78	1.83	1.79	1.87	1.71	1.84	1.85	NA	1.83
%HCR min	NA	2.19	1.99	2.20	NA	NA	NA	2.00	NA	NA	1.44	NA	NA
%HCR max	NA	28.68	28.68	63.46	NA	NA	NA	28.68	NA	NA	33.24	NA	NA
Mean Yrs HCRmin	NA	19.12	10.65	10.65	NA	NA	NA	10.65	NA	NA	25.32	NA	NA
Mean Yrs HCRmax	NA	3.79	3.79	7.65	NA	NA	NA	3.79	NA	NA	2.03	NA	NA
Mean Yrs NoCatch	NA	3.10	2.53	2.53	NA	NA	NA	2.53	NA	NA	1.77	NA	NA
% Collapses	3	0	0	0	0	0	0	0	0	0	0	0	0

Table 12. Impact of continuing to use SIO as the temperature index, but changing the relationship between SIO and E_{MSY}.

Mgmt year	Biomass (July)	SIO - current				SIO - recalculated relationship			
		SST	Fraction	HG	OFL	Fraction	HG	Difference	OFL
2000	1581346	18.08	0.15	186791	605339	0.15	186791	0	229754
2001	1182465	17.75	0.15	134737	433005	0.15	134737	0	164481
2002	1057599	17.24	0.15	118442	149081	0.09	74955	-43487	87343
2003	999871	17.31	0.15	110908	165969	0.10	76481	-34428	89979
2004	1090587	17.46	0.15	122747	246185	0.12	99833	-22914	115754
2005	1193515	17.60	0.15	136179	346672	0.14	127299	-8880	145597
2006	1061391	18.03	0.15	118937	406300	0.15	118937	0	154209
2007	1319072	18.11	0.15	152564	504941	0.15	152564	0	191648
2008	832706	18.12	0.15	89093	318760	0.15	89093	0	120984
2009	662886	17.83	0.15	66932	253753	0.15	66932	0	96311
2010	702024	17.84	0.15	72039	268735	0.15	72039	0	101997
2011	537173	17.90	0.15	50526	205630	0.15	50526	0	78046
2012	988385	17.64	0.15	109409	307746	0.15	106344	-3065	125371
2013	659539	17.35	0.15	66495	118854	-	-	-	-

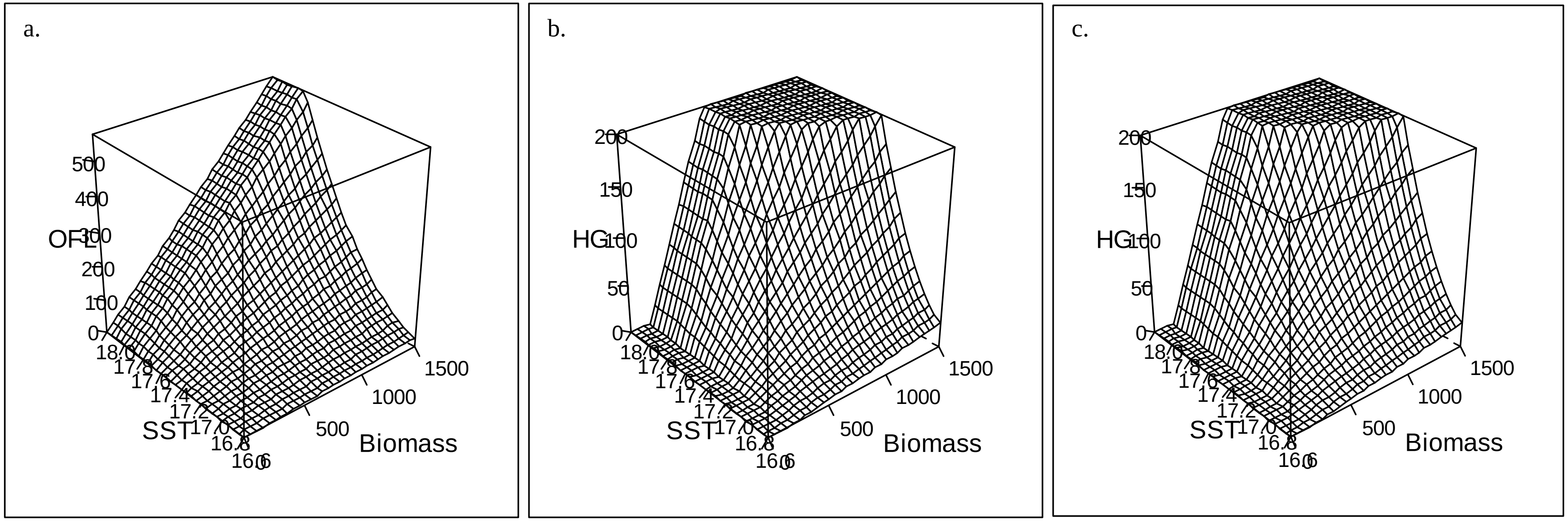


Figure 1. Current OFL control rule (a), HG control rule (b), and HG control rule when the constraint that the HG must be less than the ABC is imposed (c), across a range of 1+ biomass and temperature.

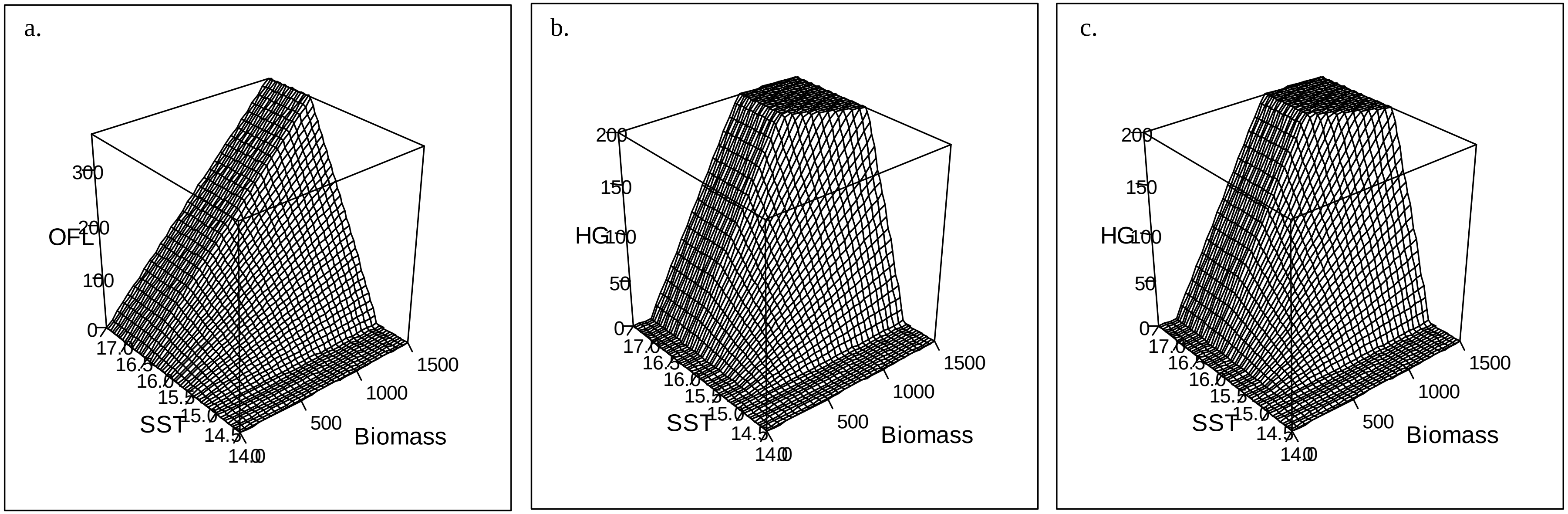


Figure 2. OFL control rule (a), HG control rule (b), and HG control rule when the constraint that the HG must be less than the ABC is imposed (c), across a range of 1+ biomass and temperature when temperature is based on the CalCOFI data.

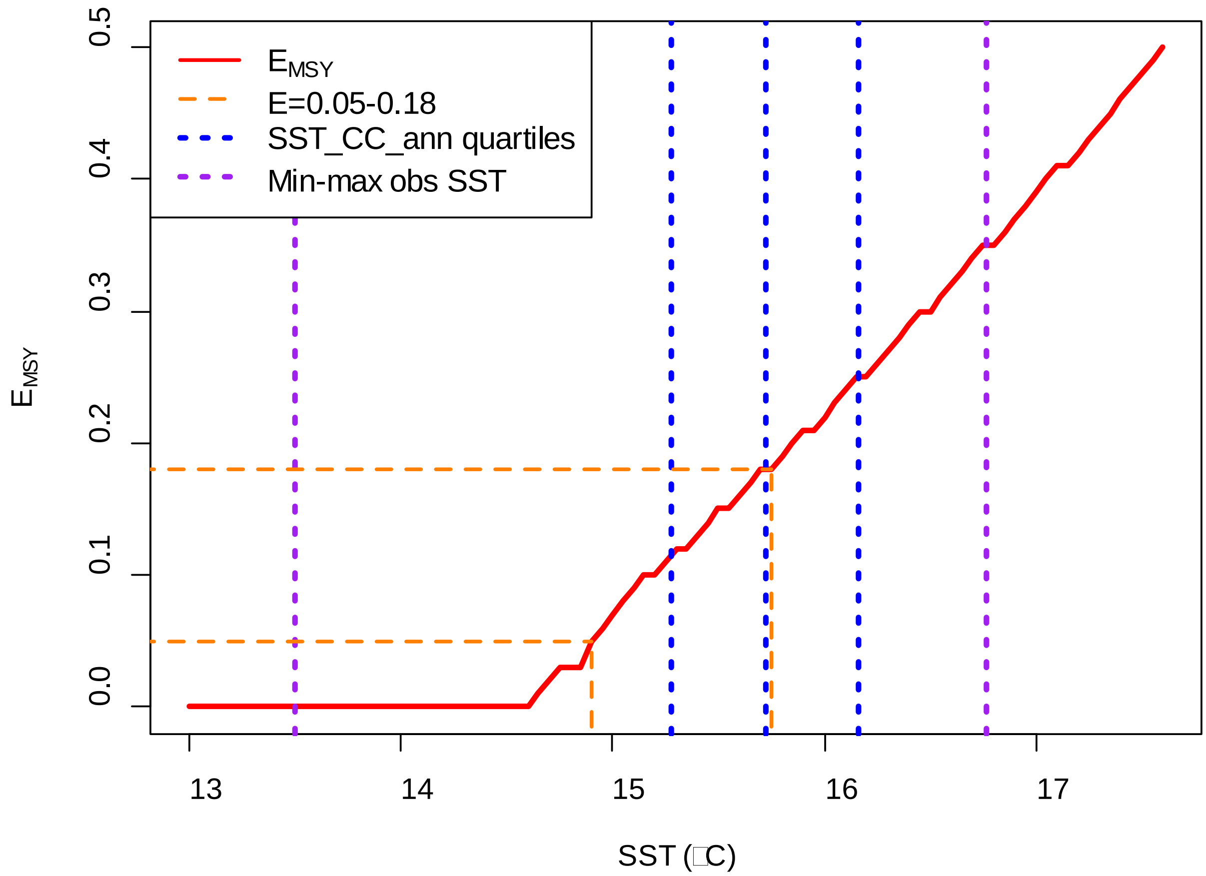


Figure 3. Relationship between CalCOFI SST and E_{MSY}, showing quartiles of observed SST in the SST_CC_ann time series.

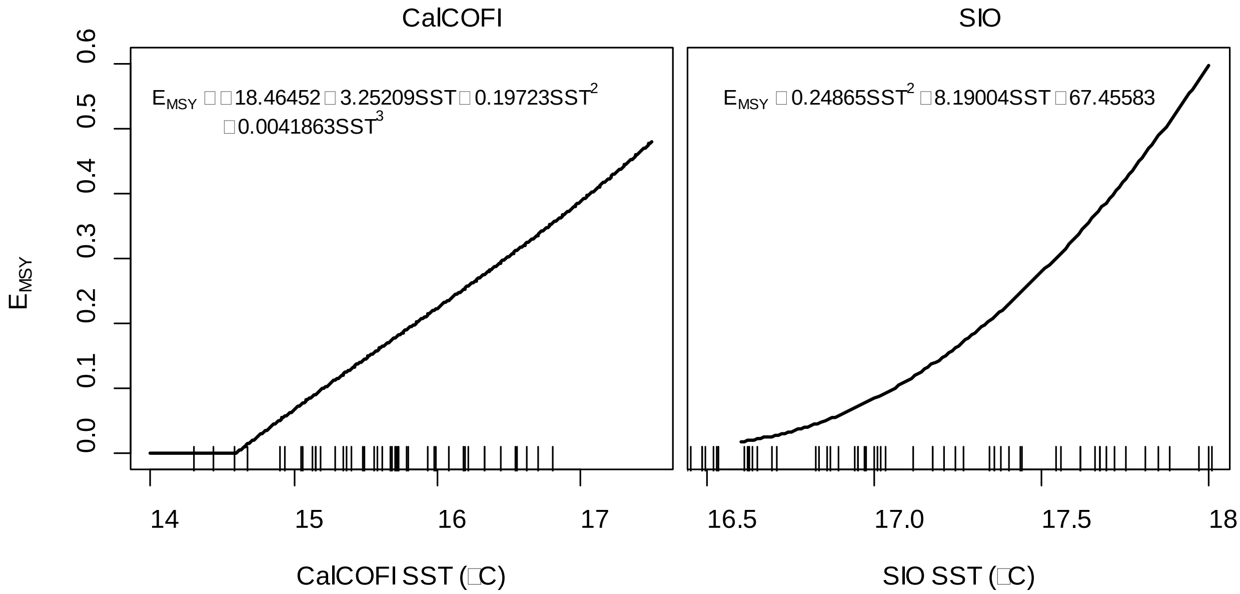


Figure 4. Polynomial approximation to the relationship between CalCOFI SST and E_{MSY} (left), and SIO SST and E_{MSY} (right). Marks at the bottom of each plot represent the spread of each series' SST data. Note that the scale in both plots is different.

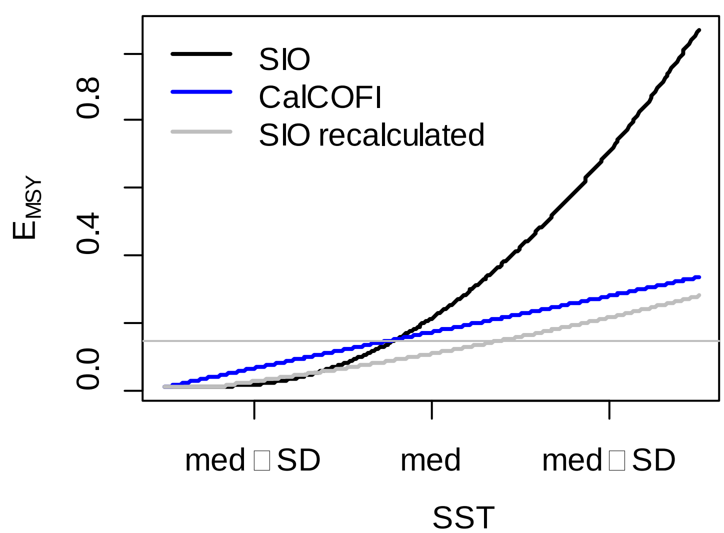


Figure 5. Unitless comparison between the SIO- and CalCOFI-based relationship between SST and E_{MSY}, centered around the median of the observed SST for each time series during the period 1984-2008. The gray horizontal line indicates 0.15.

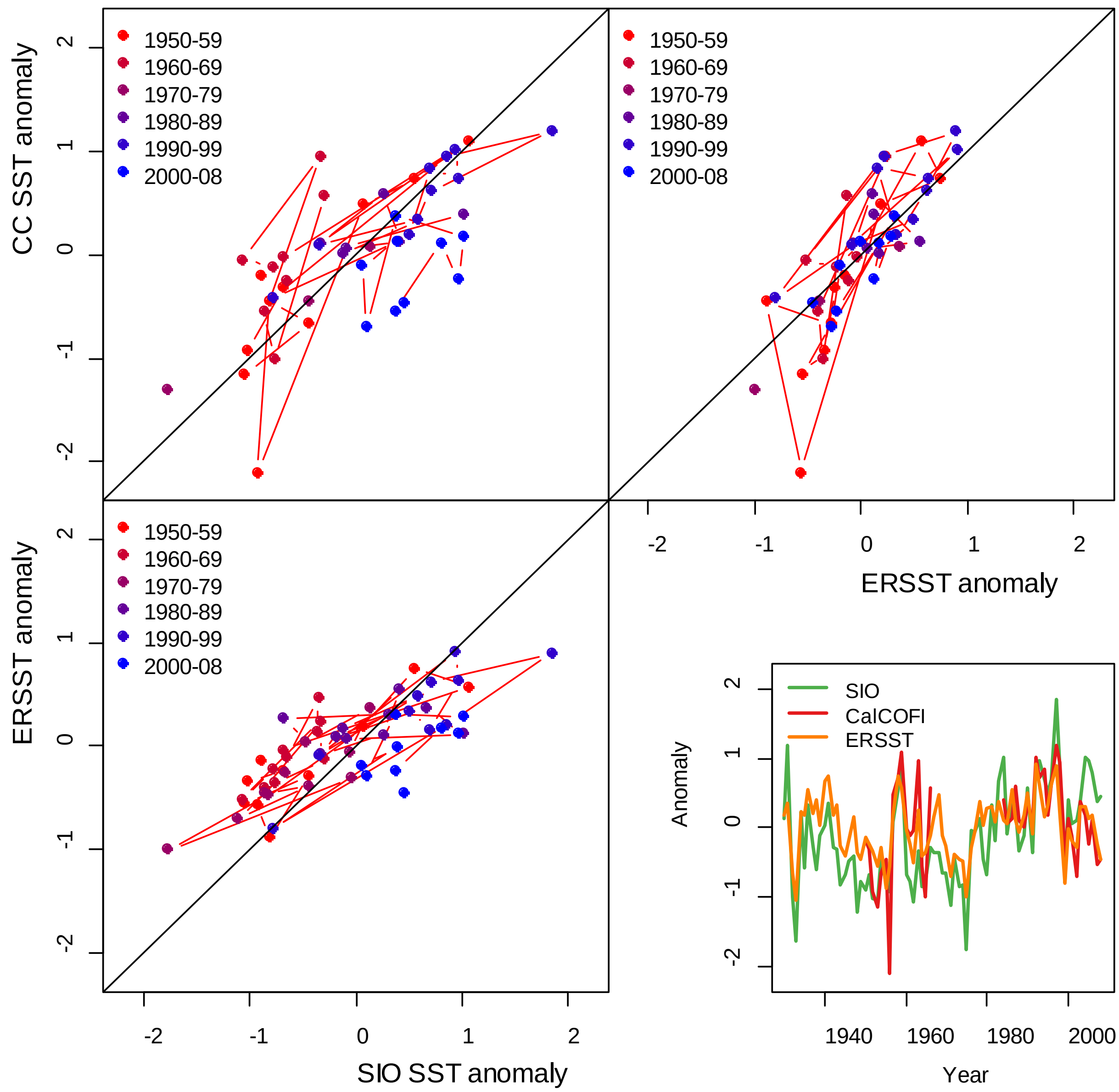


Figure 6. Comparison of the SIO_SST_ann, SST_CC_ann and ERSST_ann time series.

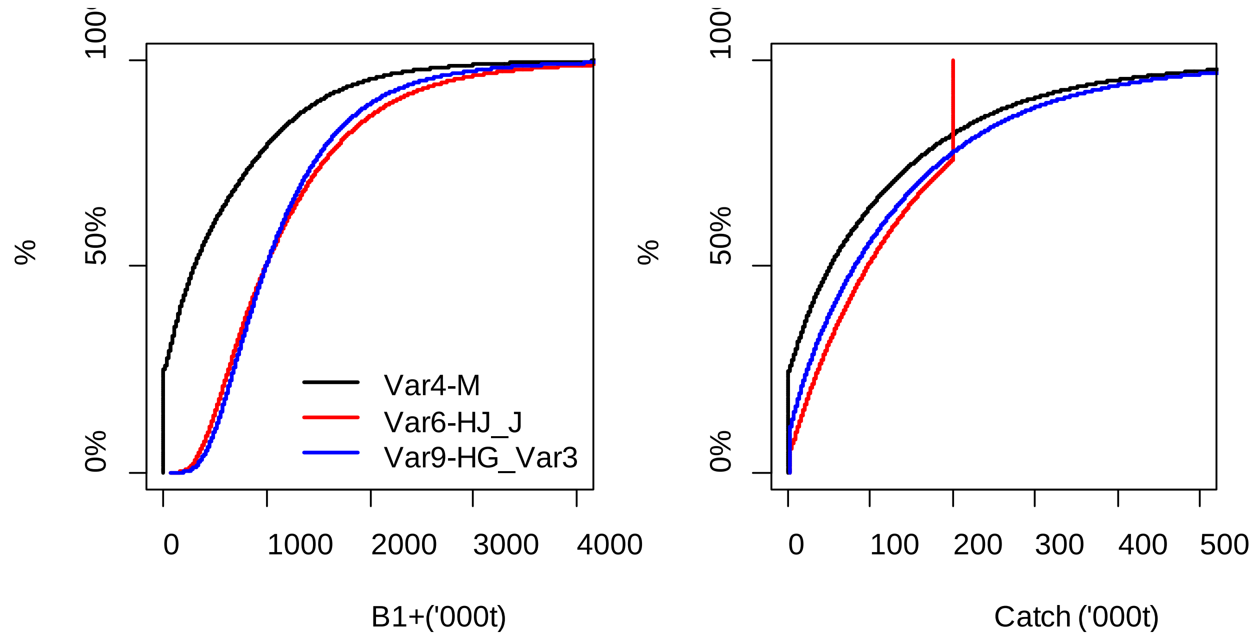


Figure 7. Cumulative distributions for biomass (1+) and catch for three harvest control rule variants.

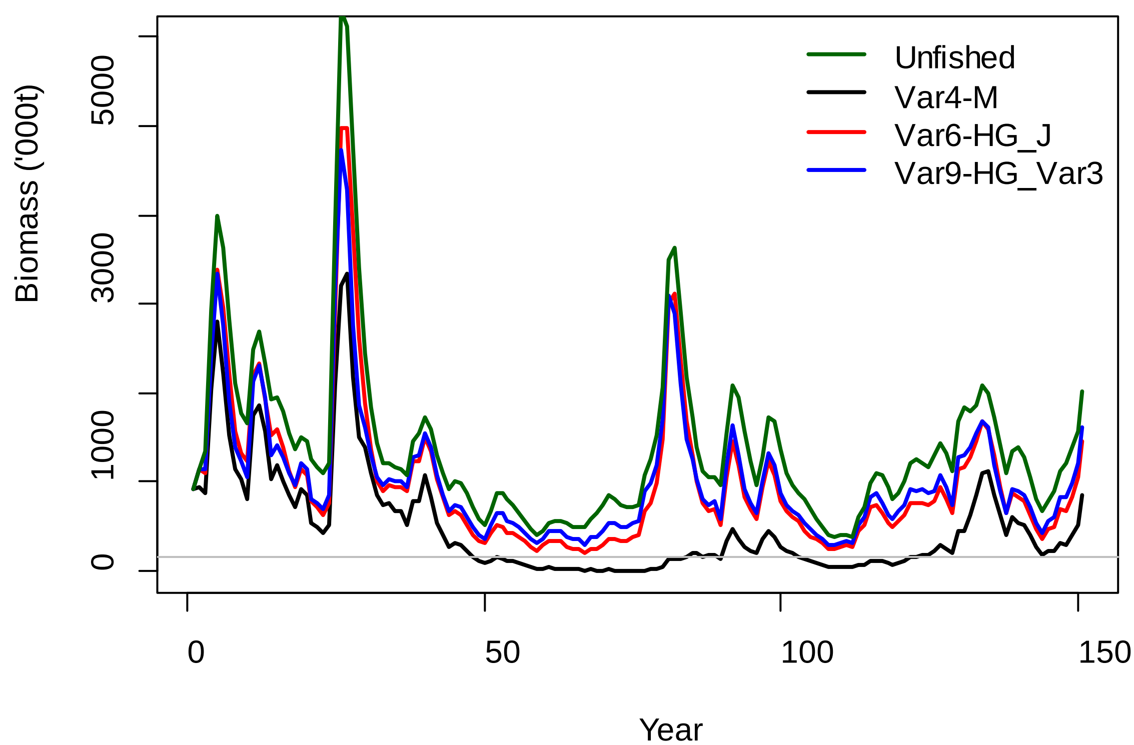


Figure 8. Example 150-year time-trajectories of 1+ biomass for three harvest control rule variants. The horizontal gray line indicates 150,000t.

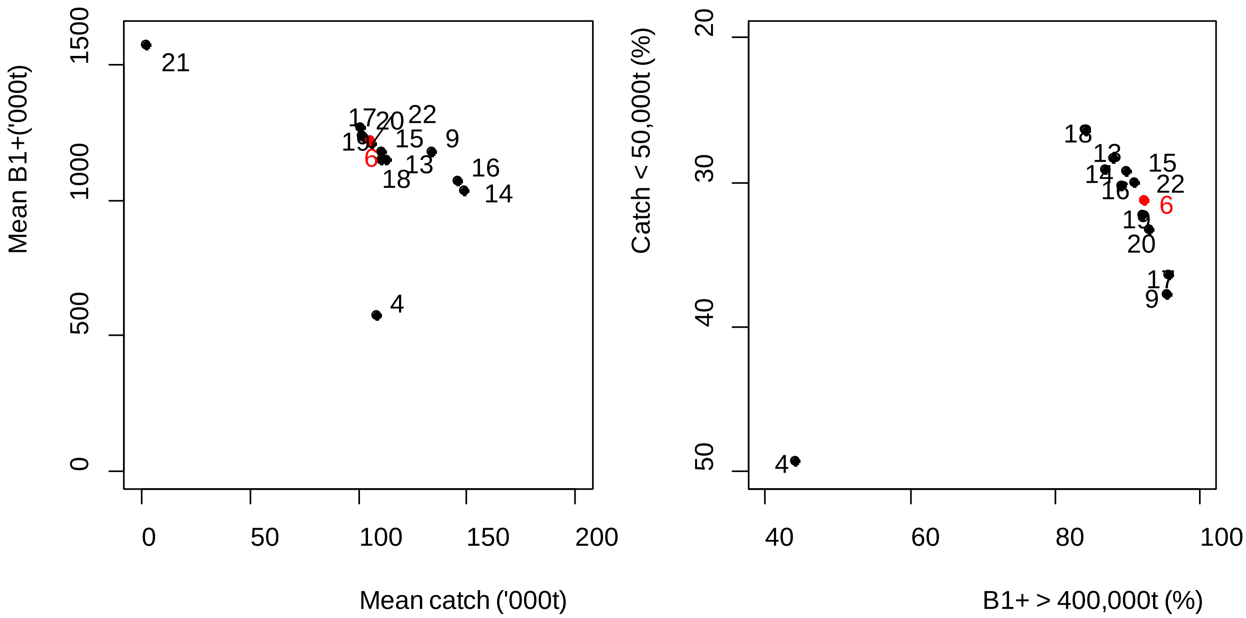


Figure 9. Trade-offs plots (mean annual catch when the catch is non-zero vs 1+ biomass [left]; and the probability of a catch < 50,000t vs. the probability of 1+ biomass exceeding 400,000t [right]) for the base-case scenario. The numbers denote the values used to refer to the harvest control rule variants (Table 1).

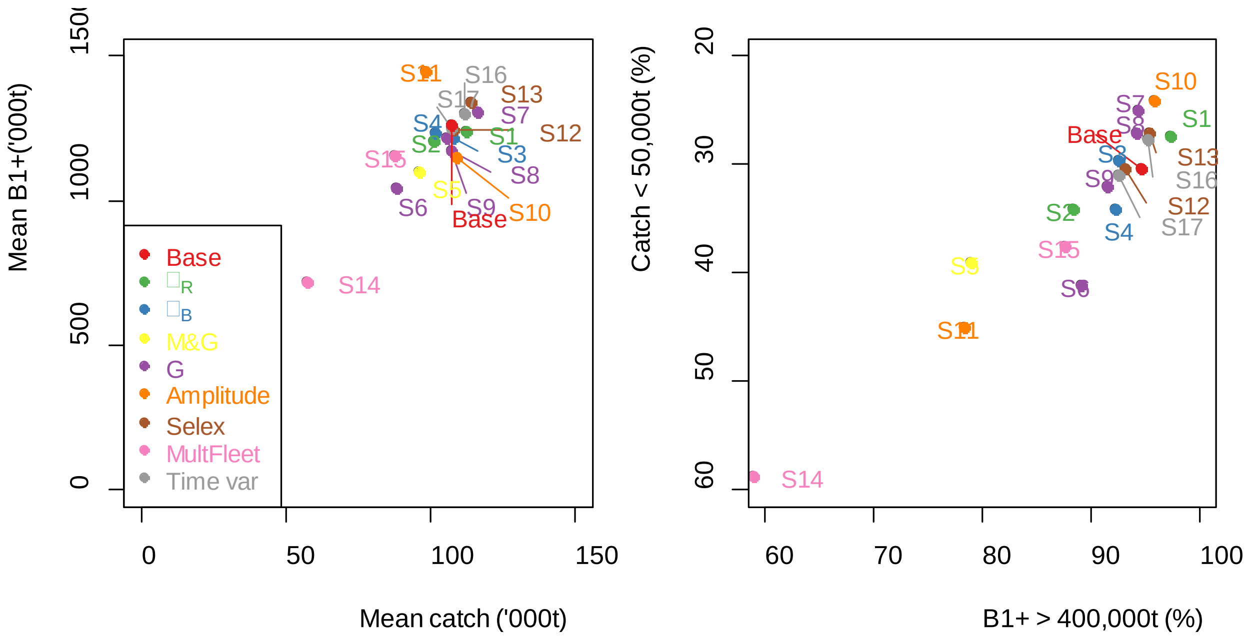


Figure 10. Trade-offs plots (mean annual catch when the catch is non-zero vs 1+ biomass [left]; and the probability of a catch < 50,000t vs. the probability of 1+ biomass exceeding 400,000t [right]) for the various sensitivity scenarios. The numbers denote the values used to refer to the sensitivity scenarios in Tables 5 and 6.

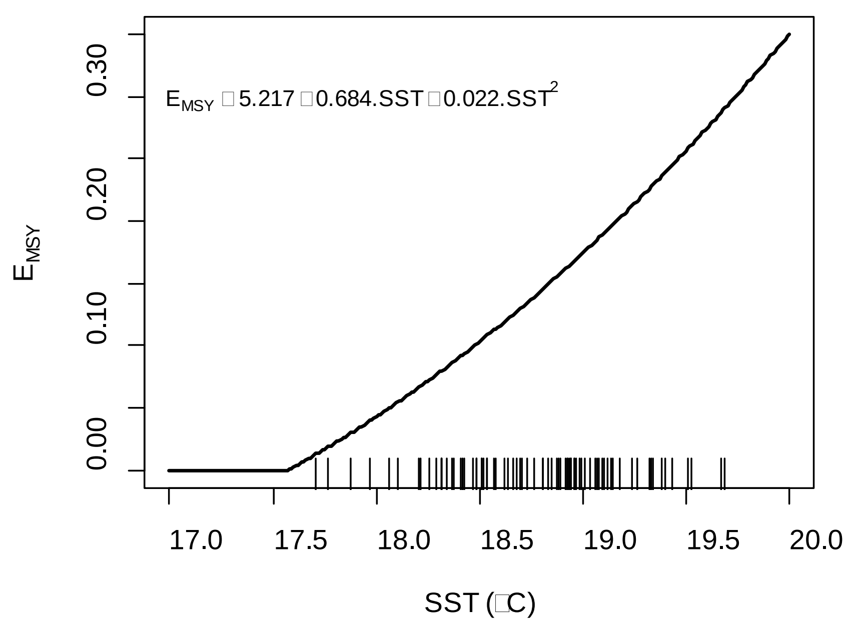


Figure 11. Polynomial approximation to the relationship between ERSST and E_{MSY}. Marks at the bottom of the plot represent the spread of ERSST data.

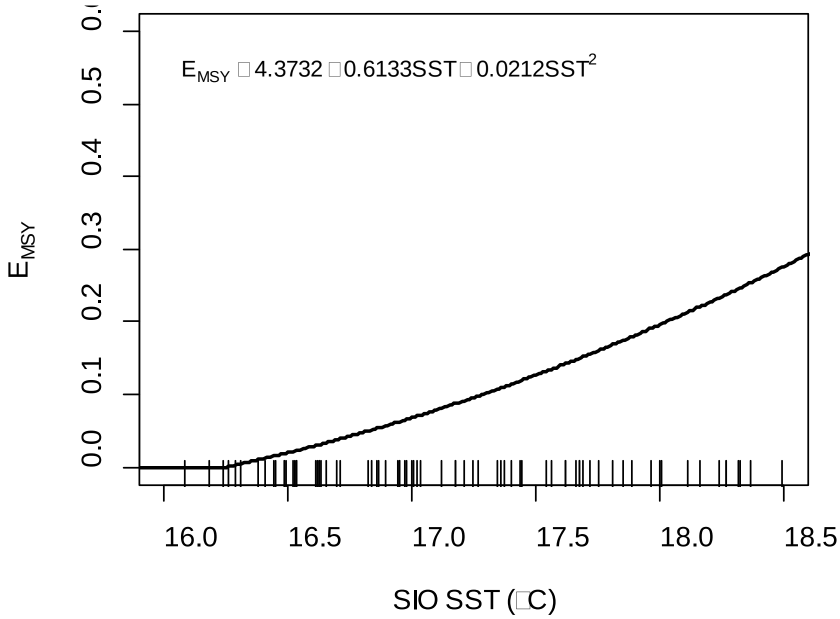


Figure 12. Polynomial approximation to the recalculated relationship between SIO and E_{MSY}. Marks at the bottom of the plot represent the spread of SIO data.

Appendix A. Specifications for Calculations to Evaluate Control Rules for Pacific Sardine

1. Basic dynamics

The operating model is age-structured, and recruitment is related to an environmental covariate (or driven on the assumption that recruitment is cyclic). The basic population dynamics are governed by the equation:

$$N_{y+1,a} = \begin{cases} R_{y+1} & \text{if } a = 0 \\ N_{y,a-1} e^{-M - S_{y,a-1} F_y} & \text{if } 1 \le a < x \\ N_{y,x-1} e^{-M - S_{y,x-1} F_y} + N_{y,x} e^{-M - S_{y,x} F_y} & \text{if } a = x \end{cases} \tag{A.1}$$

where $N_{y,a}$ is the number of animals of age a at the start of year y, M is the rate of natural mortality (assumed to be 0.4yr^{-1} for consistency with the stock assessment[7]), $S_{y,a}$ is the selectivity of the fishery on animals of age a during year y, F_y is the fully-selected fishing mortality during year y, and x is the maximum (plus-group) age.

Several fisheries (e.g. Ensenada, Southern California, Central California, Oregon, Washington, and Canada) operate on Pacific sardine. Rather than trying to model how the catch limit for the Pacific sardine fishery is allocated amongst those fisheries, selectivity-at-age is computed as a fishing mortality-weighted average selectivity from the most recent assessment (Table A.1, row “2011”).

Recruitment is governed by a stock-recruitment relationship with deviations which are autocorrelated and subject to a cyclic pattern.

$$R_y = f\left(SSB_y\right) e^{\varepsilon_y - \sigma_R^2/2} \tag{A.2a}$$

$$f\left(SSB_y\right) = SSB_y \exp\left(\alpha + \beta SSB_y + \phi V_y\right) \tag{A.2b}$$

$$\varepsilon_y = \rho_R \varepsilon_{y-1} + \sqrt{1-\rho_R^2}\,\eta_y \tag{A.2c}$$

$$\eta_y \sim N(0;\sigma_R^2); \tag{A.2d}$$

where $f(SSB_y)$ is the stock-recruitment relationship, α and β are the parameters of the stock-recruitment relationship (see Table A.2 for the base-case values for these parameters when the environmental is modelled based on the CalCOFI SST), SSB_y is spawning stock biomass in year y (age 2+ biomass), σ_R^2 is the extent of variation about the stock-recruitment relationship due to unmodelled white-noise processes, ρ_R determines the extent of auto-correlation in the deviations about the stock-recruitment due to white noise processes, ϕ determines the extent of the link to

[7] Sensitivity could be conducted to this assumption in future work, but this requires rerunning the stock assessment and repeating the stock-recruitment analyses.

the environmental variable, and V_y is the value of the environmental variable in future year *y*. V_y is assumed to be cyclic and temporally auto-correlated, i.e.:

$$V_y = \rho_V V_{y-1} + (1-\rho_V)G_y + \sqrt{1-\rho_V^2}\,\nu_y \tag{A.3a}$$

$$G_y = -\psi \frac{\sin(2\pi(y-\bar{y})/p)}{\left|\sin(2\pi(y-\bar{y})/p)\right|} \tag{A.3b}$$

$$\nu_y \sim N\left(0;\sigma_\nu^2\right) \tag{A.3c}$$

where ρ_V is the extent of auto-correlation in the environmental variable, ν_y is the deviation in the environmental variable about its expected value, G_y is the underlying signal in the environmental variable (Figure A.1), ψ is the amplitude of the underlying signal, $\bar{y}$ is a reference year, and *p* is the period of the wave.

The catch during (future) year *y* is determined using the equation:

$$C_y = \sum_{a=0}^{x} \tfrac{w_{y,a+1/2}\, S_{y,a}F_y}{M+S_{y,a}F_y} N_{y,a}(1-e^{-M-S_{y,a}F_y}) \tag{A.4}$$

where $w_{y,a+1/2}$ is weight-at-age in the middle of year *y*. The catch includes age-0 fish even through the HCRs are based on estimates of the biomass of fish of age 1 and older (see below).

The initial numbers-at-age are taken from the 2012 stock assessment (Hill *et al*., 2012; Model X6e), along with the values of the parameters determining fecundity-at-age and weight-at-age (Table A.3, row “1991-2010”).

2. Potential control rules

2.1 OFL control rule

One possible OFL control rule is:

$$OFL_y = E_{MSY}\,\hat{B}_y^{1+} \tag{A.5a}$$

where B_y^{1+} is the estimate of 1+ biomass at the start of fishing season, and E_{MSY} is the proxy for F_{MSY}. Given the structure of Equation A.5a, here F_{MSY} is an exploitation rate, E_{MSY}, rather than a fishing mortality. This structure is consistent with the way the current OFL and HG control rules were developed (PFMC 1998), and also avoids the need to generate estimates of the population age-structure at the start of year *y* (the error structure for which could be complicated).

Selection of a value for E_{MSY} in equation A.5a is based on projecting the operating model forward for 20 replicates of 1,000 years for a range of values for E_{MSY} assuming that B_y^{1+} is log-normally distributed about the true 1+ biomass. E_{MSY} is computed for various choices for V_y to allow a relationship between F_{MSY} and V_y to be determined, i.e. :

$$OFL_y = E_{MSY}(I_y)\,\hat{B}_y^{1+} \tag{A.5b}$$

where I_y allows for error in the measuring the "true" value of the environmental variable[8], i.e. E_{MSY} would not be based on V_y but rather an estimate of V_y which is subject to error, i.e.:

$$I_y = V_y + \varsigma_y\,;\ \varsigma_y \sim N(0, \sigma_\varsigma^2) \tag{A.6}$$

where σ_ς determines the extent of measurement error.

2.2 Potential Harvest Guideline control rules
The general form of the harvest guideline (HG) control rule is:

$$HG_y = \text{DISTRIBUTION}\,x\,\text{FRACTION}_y(B_y^{1+} - \text{CUTOFF}) \tag{A.8}$$

where HG_y is the harvest guideline for year *y*, DISTRIBUTION is the proportion of the stock in US waters, FRACTION_y is the proportion of the stock above the cutoff which is taken in all fisheries during year *y*, and CUTOFF is the biomass level below which no directed fishing is permitted. Given that the purpose of this analysis is to analyse stockwide harvest, DISTRIBUTION is set to 1 (except for a small subset of the sensitivity runs). The value of the harvest guideline is constrained to be less than the ABC (the OFL multiplied by a buffer based on a P* of 0.4, which consistent with the way the Council have selected the ABC for the 2012 and 2013 fisheries) and the maximum catch (MAXCAT). FRACTION depends on the environmental variable for some of the harvest control rule variants.

The catch is always assumed to be at least 2,000t to cover catches in the live bait fishery.

3. Performance measures
The performance measures are:

- Average catch (abbreviation "Mean catch") [all years]
- Standard deviation of catch (abbreviation "SD catch") [all years]
- Average catch (abbreviation "Mean catch") [all years for which the catch is non-zero]
- Standard deviation of catch (abbreviation "SD catch") [all years for which the catch is non-zero]
- Mean biomass (SSB and 1+ biomass) (abbreviations "Mean B1+" and "Mean SSB")
- Standard deviation (SSB and 1+ biomass) (abbreviations "SD B1+" and "SD SSB")
- Percentage (1+) biomass > 400,000t (abbreviation "%B1+>400,000t")
- Percentage of years with no catch (or catch below a threshold value) (abbreviations "% No catch" and "%Catch < 50,000t")
- Median catch (abbreviation "Median catch") [all years]
- Median biomass (SSB and 1+ biomass) (abbreviations "Median B1+" and "Median SSB")
- Cumulative distribution for catch
- Cumulative distribution for biomass
- Average number of consecutive years with zero catch (abbreviation "Mean Yrs No Catch")

[8] It is best not to think of SST or any other real-world measurement as being *V*. The real *V* is probably unmeasurable (it may be most related to some property of the flow of the California Current), and the best we can do is to use a proxy for it, such as SST. For that reason there is error associated with the connection between *V* and *I*.

- How often the HCR sets FRACTION to its minimum value (abbreviation "%HCR min")
- How often the HCR sets FRACTION to its maximum value (abbreviation "%HCR max")
- Average number of consecutive years FRACTION equals its minimum value (abbreviation "Mean Yrs HCR min")
- Average number of consecutive years FRACTION equals its maximum value (abbreviation "Mean Yrs HCR max")
- Mean age of the population (abbreviation "Mean Pop Age")
- Mean age of the catch (abbreviation "Mean Catch Age")
- Mean and maximum number of consecutive years in which catch < 50,000t
- Mean and maximum number of consecutive years in which 1+ Biomass < 400,000t.

4. Sensitivity analyses

There are many factors (apart from the parameters of the OFL and HG control rules; Table 1) which could be varied to explore the robustness of candidate control rule variants. Table A.4 lists the factors which define the operating model, along with base-case values for the parameters of the operating model. Table A.5 lists the sensitivity runs which are used to explore the robustness of the results to changes to the specifications of the operating model.

Multiple fleets

For this sensitivity test, the OFL and HG were computed based on a value for DISTRIBUTION of 0.87, the catch by Canada was computed using the Pacific Northwest selectivity pattern and a fully-selected fishing mortality of 0.1y^{-1}, and the catch by Mexico was computed using the MexCal selectivity pattern and a fully-selected fishing mortality of 0.2yr^{-1}, i.e. the fully-selected fishing mortality for the whole fishery was computed as:

$$C_y = \sum_{a=0}^{x} \frac{w_{y,a+1/2} S_{y,a} F_y}{Z_{y,a}} N_{y,a} (1 - e^{-Z_{y,a}}) \tag{A.9}$$

where $Z_{y,a} = M + S_{y,a} F_y + S_a^{\text{MexCal}} 0.2 + S_a^{\text{PNW}} 0.1$ and C_y was set to the US harvest guideline.

Time varying selectivity

For this sensitivity test, the age-specific selectivity pattern is:

$$S_{y,a} = J_y S_{y,a}^{\text{MexCal}} + (1 - J_y) S_a^{\text{PNW}} \tag{A.10a}$$

where $J_y = \max(0, \min(1, a + bV_y))$ and a and b are selected so that $J_{1985} = 0$ and $J_{2011} / (1 - J_{2011})$ matches the ratio of the fully-selected Fs for the MexCal area to the PNW. The selectivity-at-age for the MexCal fleet is:

$$S_{y,a}^{\text{MexCal}} = L_y S_a^{\text{MexCal-1}} + (1 - L_y) S_a^{\text{MexCal-2}} \tag{A.10b}$$

where $L_y = \max(0, \min(1, c + dV_y))$ and c and d are selected so that $L_{1996} = 1$ and $L_{2006} = 0$. $S_a^{\text{MexCal-1}}$ is the F-weighted selectivity-at-age (between seasons) for the MexCal area for 1993-

1999 and $S_a^{\text{MexCal-2}}$ is the F-weighted selectivity-at-age (between seasons) for the MexCal area for 2000-2011 (Table A.6).

Time-varying weight-at-age
The weight-at-age for year y is:

$$w_{y,a} = Q_y w_a^{1981-1993} + (1-Q_y) w_a^{2000-2011} \tag{A.11}$$

where $Q_y = \max(0, \min(1, e + fV_y))$ and e and f are selected so that $Q_{1987} = 1$ and $Q_{2006} = 0$. The weight-at-age used when computing 1+ biomass for use in the HCR was set to the average weight-at-age.

Hyper-stability in biomass estimates
Hyper-stability in biomass estimates is modelled by modifying the way $\hat{B}_y^{1+}$ is set in the operating model. In the base-case model, $\hat{B}_y^{1+} = B_y^{1+} e^{\psi}; \psi \sim N(0, \sigma_B)$, which was modified to:

$$\hat{B}_y^{1+} = q_y B_y^{1+} e^{\psi}; \psi \sim N(0, \sigma_B) \tag{A.12a}$$

$$q_y = \max\left(g\left(B_y^{1+}\right)^{-0.5}, 1\right), \tag{A.12b}$$

where g is a scaling parameter set at 620, 500, 400, 320 and 210, so that biomass is overestimated when the true 1+ biomass is below 400 000t, 250 000t, 150 000t, 100 000t and 50 000t respectively.

Table App.A.1. Fleet-averaged selectivity (computed using the output of model X6e of Hill *et al*. [2012]). Results are shown for 2011, 2007-2011, and 2002-2011.

Year Range	Age (yr) 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2011	0.263	1.000	1.000	0.669	0.471	0.390	0.358	0.345	0.339	0.335	0.333	0.332	0.332	0.331	0.331	0.331
2007-11	0.245	0.962	1.000	0.713	0.539	0.468	0.440	0.428	0.423	0.420	0.418	0.417	0.417	0.417	0.416	0.416
2002-11	0.218	0.918	1.000	0.741	0.578	0.511	0.485	0.475	0.470	0.467	0.466	0.465	0.464	0.464	0.464	0.464

Table App.A.2. Parameter values for the recruitment model

Parameter	Value
α	-13.423
β	-0.001186
ϕ	1.047

Table App.A.3. Vector of weights-at-age

Year Range	Age (yr) 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1981-90	0.014	0.081	0.134	0.160	0.172	0.177	0.179	0.179	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180
1991-2010	0.015	0.067	0.130	0.163	0.178	0.184	0.187	0.188	0.188	0.188	0.188	0.188	0.188	0.188	0.188	0.188

Table App.A.4. Values for the specifications on the base-case analyses.

Factor	Base-Case Value	Notes
Recruitment variation, σ_R	0.752	Hill *et al.* (2012)
Auto-correlation in recruitment deviations, ρ_R	0.091	
Assessment SE(log), σ_B	0.36	Ralston *et al.* (2011)
Auto-correlation in assessment error, ρ_B	0.707	
Future correlation between M and V_y	None	
Variance of the measurement error associated with the environmental index, σ_ς	0.374	
Nature of the environmental variable	Square Wave with period of 60 years (equal periods of high and low values)	See Figure App.1a1
Auto-correlation in the environmental variable, ρ_v	0.343	
Variance of the environmental variable about its expectation, σ_v	0.490	
Amplitude of the underlying environmental signal, ψ	0.469	
Scaling parameter, ϕ	1.047	
Center of wave	1975	
Selectivity	Set to average values	
Hyper-stability of biomass estimates	None	

Table App.A.5. Specifications for the sensitivity tests.

Factor (abbreviation)	Specification	Justification / reference
Lower variation in recruitment (**σ_R=0.5**)	$\sigma_R = 0.5$	
Higher variation in recruitment (**σ_R=0.9**)	$\sigma_R = 0.9$	
Lower variation in estimated biomass (**σ_B=0.268**)	$\sigma_B = 0.268$	0.268 is the CV of ending biomass from the 2012 assessment
Higher variation in estimated biomass (**σ_B=0.5**)	$\sigma_B = 0.5$	
Lower auto-correlation in assessment error (**ρ_B=0.5**)	$\rho_B = 0.5$	
Natural mortality increases when the environment is trending downwards **(M&G)**	[M=0.4 yr^{-1} when $\Delta G>0$; M=0.8 yr^{-1} when $\Delta G<0$]	Murphy (1966) suggested that *M* increase while the population as declining
Nature of the environmental variable		
Square wave, with unequal periods of good and poor recruitment **(G=a2)**	Figure App.A.1a2	
Square wave, with equal periods of good and poor recruitment but the environment declines more gradually than for the base case **(G=b)**	Figure App.A.1b	
Sine wave with period of 60 years (equal periods of high and low values **(G=c)**	Figure App.A.1c	
Square wave with period of 100 years (equal periods of high and low values) **(G=d)**	Figure App.A.1d	
The environment fluctuates less than for the base-case **(Amp=0.5)**	$\psi = 0.217$	
The environment fluctuates more than for the base-case **(Amp=2)**	$\psi = 0.868$	
Future selectivity matches that for PNW **(Sel=PNW)**	Table App.A.6	
Future selectivity matches that for Mexico **(Sel=Mex)**	Table App.A.6	
Only the US follows the US control rule **(MF)**	Equation A.9	
Only the US follows the US control rule (catch by Mexico is zero) **(MF=NoMex)**	Equation A.9 but the *F* for Mexico is 0	
Time-varying selectivity **(TV Selex)**	Equation A.10	
Time-varying weight-at-age **(TV WaA)**	Equation A.11	
Hyper-stability in biomass estimates **(HS)**	Equation A.12; g=210,320,400,500,620	Five versions of the test depending on the value of *g*
ERSST drives recruitment, but the CalCOFI index is used in the HCR **(ERSST error)**		
Analysis is based on the ERSST time-series **(ERSST)**		

Table App.A.6. Selectivities-at-age for sensitivity analyses (computed using the output of model X6e of Hill *et al*. [2012]).

	Age (yr)															
Pattern	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$S^{MexCal-1}$	0.118	0.793	1	0.749	0.496	0.339	0.254	0.207	0.182	0.166	0.158	0.152	0.149	0.148	0.146	0.145
$S^{MexCal-2}$	0.212	1	0.864	0.444	0.221	0.132	0.097	0.082	0.075	0.07	0.069	0.067	0.066	0.066	0.066	0.064
S^{PNW} (2011)	0.001	0.077	0.377	0.695	0.867	0.94	0.97	0.984	0.991	0.994	0.997	0.998	0.999	0.999	0.999	1
S^{PNW} (2007-11)	0.001	0.077	0.377	0.695	0.867	0.94	0.97	0.984	0.991	0.994	0.997	0.998	0.999	0.999	0.999	1

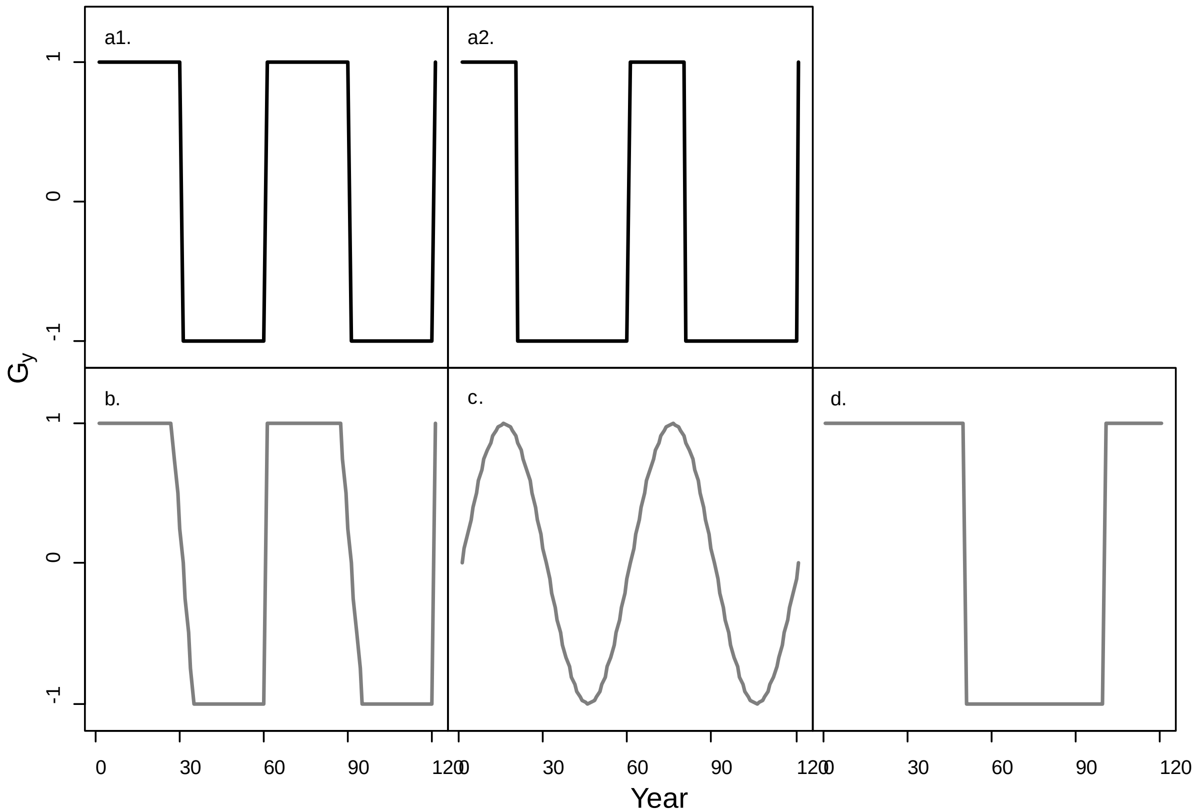


Figure App.A.1. Defined shapes for the environmental signal G_y. a1) is the base case; a2), b), c) and d) are sensitivity tests.

Appendix B. Update to fitting environmental data to the chosen model

The Pacific sardine harvest control rule parameters workshop decided that the values for the parameters of the environmental model in the sardine OM would be estimated by fitting it to the ERSST_ann data, since the ERSST_ann time-series is long and likely more reliable than the SST_CC_ann time series (which was used to fit the stock-recruitment relationship). The methods and parameter estimates are described in Adjunct B of Appendix J of PFMC (2013) for the analyses based on the ERSST_ann time series. However, ERSST_ann was not an ideal choice to model the environmental variable because (1) the biomass cycles observed in projections were not of the desired amplitude, with the lowest simulated biomasses being around 1,000,000 t in the absence of harvest; and (2) the OM unable to reproduce the observed SST data.

The parameters for the environmental variable were re-estimated by applying the methods described in Adjunct B of Appendix J of PFMC (2013) to the SST_CC_ann time series. The estimates of amplitude and σ_V based on the SST_CC_ann data are larger than those based on the ERSST_ann data, while the estimate of ρ_V is smaller. The revised parameter estimates are shown in Table App.B.1, while Table App.B.2 shows the results from the fit to the ERSST_ann data (repeated from Adjunct B for convenience). Figures App.A.1 and App.A.2 show the fits and residuals for the SST_CC_an data.

Using the parameter values in Table App.B.1 improves model performance in terms of the problems described above, but also introduces a new problem: the high value of σ_V. The SST_CC_an temperatures during 1957, 1958, 1959, 1963, and 1995 were high even though these years correspond to the 'cold period' (i.e. pre-1975). Three of these years (1957, 1965, and 1966) coincided with El Nino events, and removing these years could lead to an improved OM. The results removing the 3 El Nino outliers are shown in Table App.B.3, and Figures App.B.3 and App.B.4. The results removing all five unusual years are given in Table App.B.4, and Figures App.B.5 and App.B.6.

Table App.B.1. Estimated parameters and AIC for each model fit for SST_CC_ann data.

Model	Amplitude	σ_V	ρ_V	AIC
SQ	0.320	0.620	-	5.99
SQ with AC	0.327	0.608	0.207	6.23
Sin	0.388	0.632	-	7.78

Table App.B.2. Estimated parameters and AIC for each model fit for ERSST_ann data.

Model	Amplitude	σ_V	ρ_V	AIC
SQ	0.181	0.393	-	-64.4
SQ with AC	0.193	0.364	0.372	-74.6
Sin	0.222	0.404	-	-60

Table App.B.3. Parameters removing the thee El Nino years

Model	Amplitude	σ_V	ρ_V	AIC
SQ	0.383	0.592	-	1.939
SQ with AC	0.396	0.574	0.298	1.213
Sin	0.496	0.600	-	3.062

Table App.B.4. Parameters removing all five unusual years

Model	Amplitude	σ_V	ρ_V	AIC
SQ	0.457	0.510	-	-10.267
SQ with AC	0.469	0.490	0.342	-11.336
Sin	0.637	0.499	-	-11.956

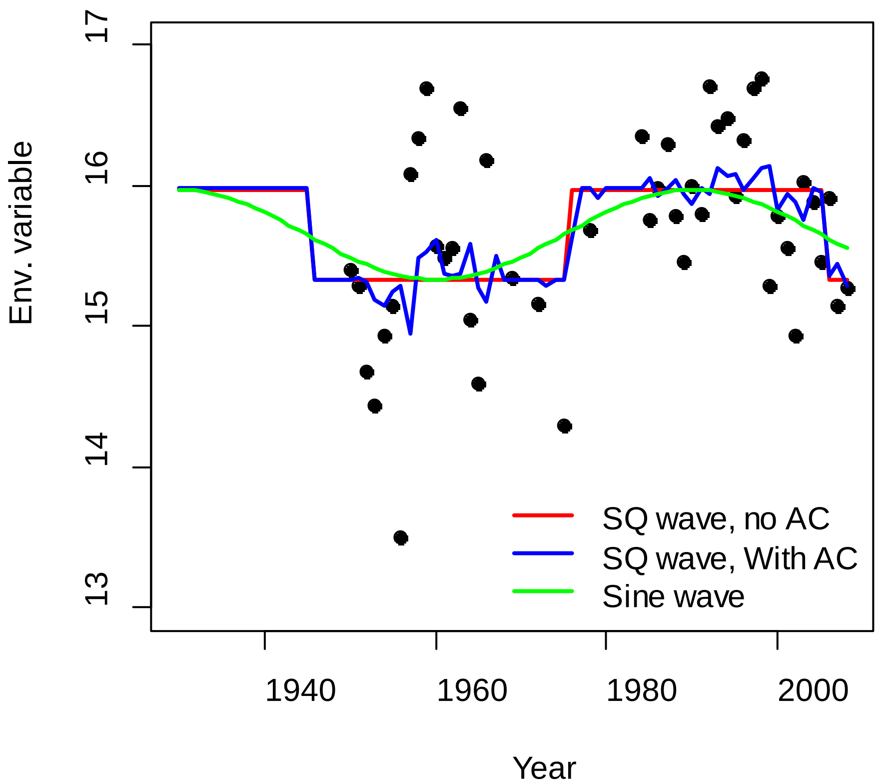


Figure App.B.1. Fits of each model to the SST_CC_ann data

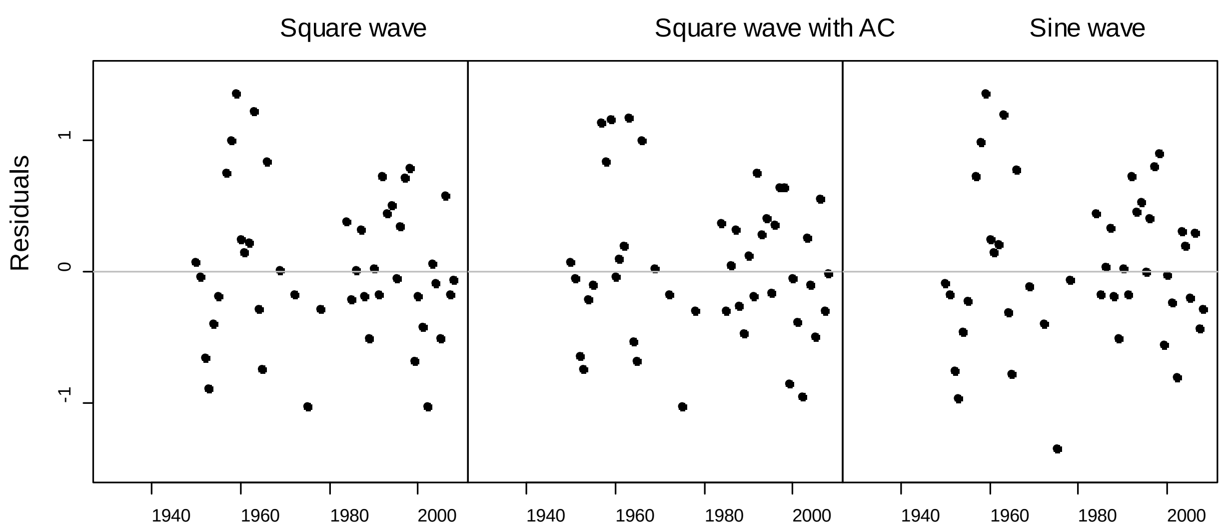


Figure App.B.2. Residual plot for the three models

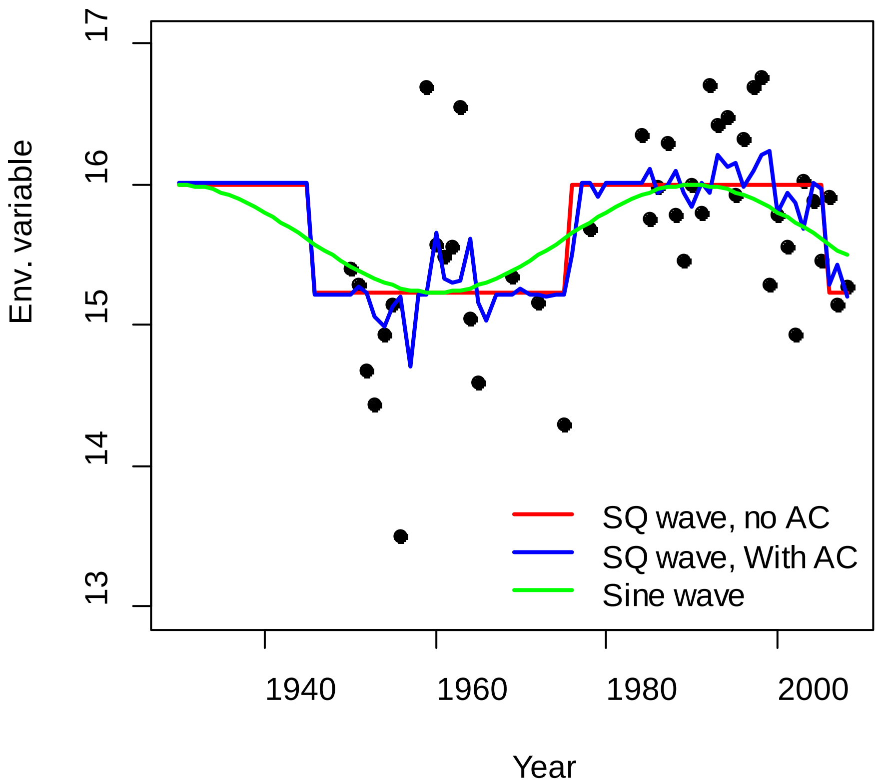


Figure App.B.3. Fits of each model to the SST_CC_ann data removing the three El Nino years

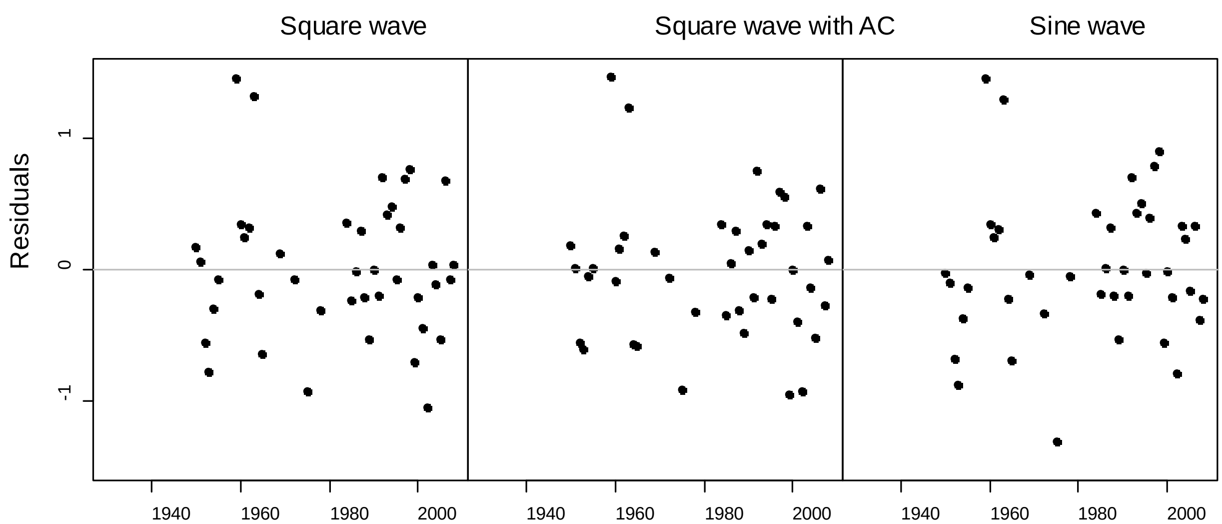


Figure App.B.4. Residual plot for the three models removing the three El Nino years

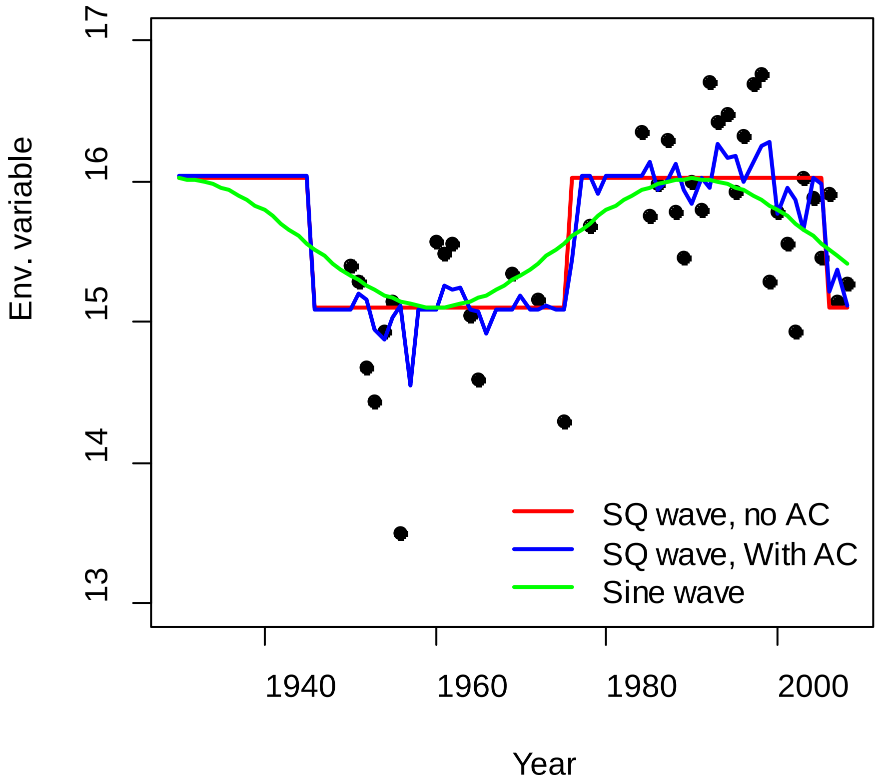


Figure App.B.5. Fits of each model to the SST_CC_ann data removing all five unusual years

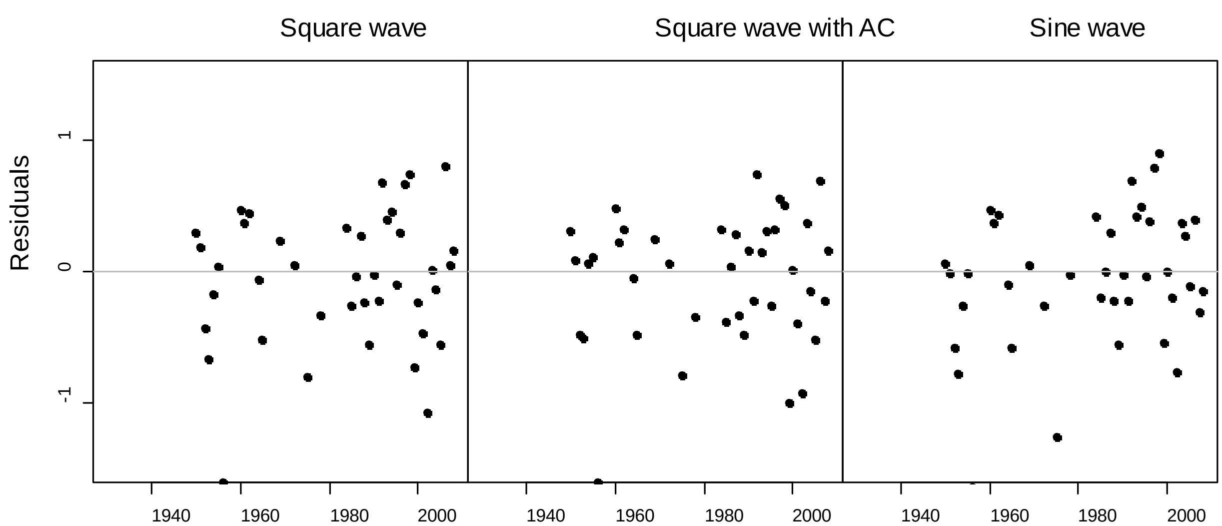
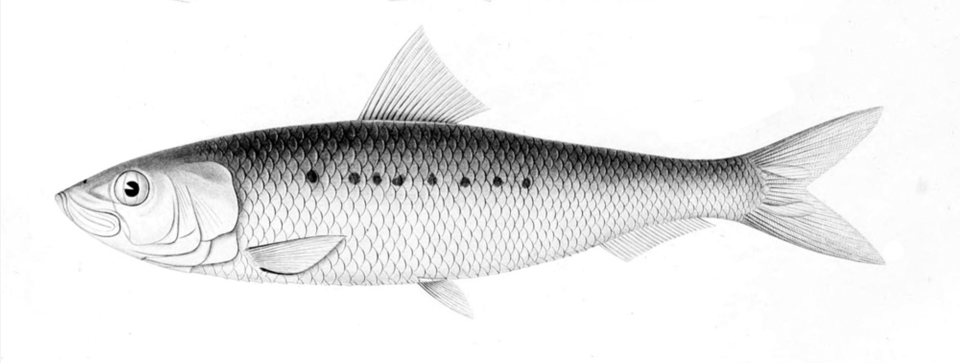


Figure App.B.6. Residual plot for the three models removing all five unusual years

REVISED ANALYSES RELATED TO EVALUATING PARAMETER VALUE CHOICES FOR PACIFIC SARDINE



Felipe Hurtado-Ferro and André E. Punt

School of Aquatic and Fishery Sciences, University of Washington

SUMMARY

- Context
- Environmental index
- Recalculated relationship and new harvest control rule
- Simulation testing of the harvest control rule
- Sensitivities

CONTEXT

Pacific Sardine: Management Process

(Amendment 8 & 13)

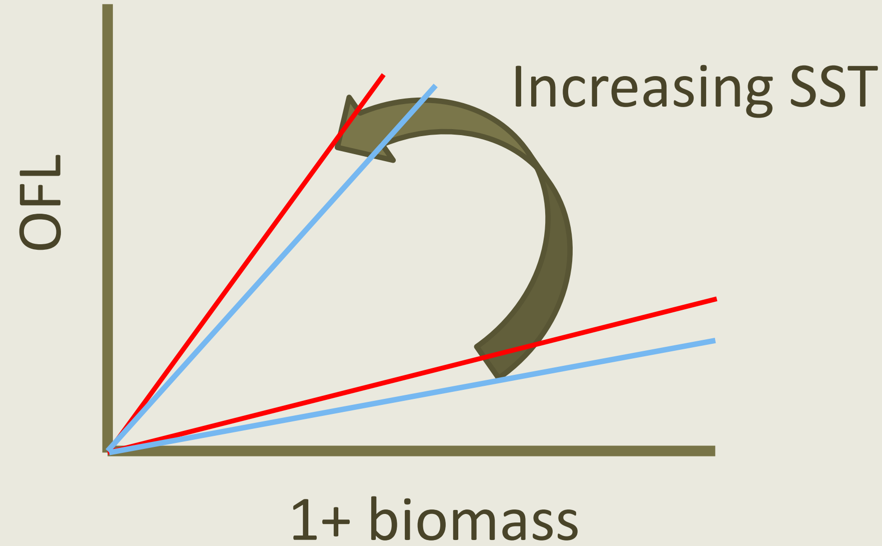
Overfishing Level (OFL)

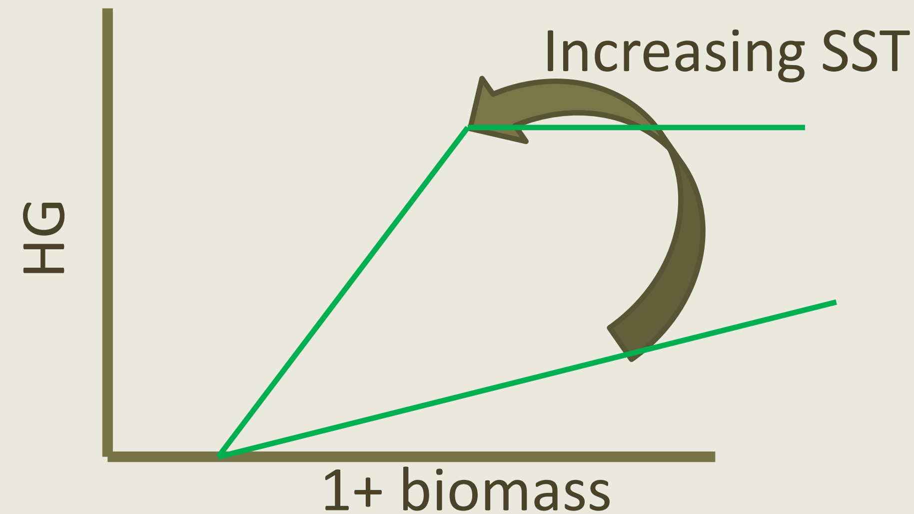
↓ *P**

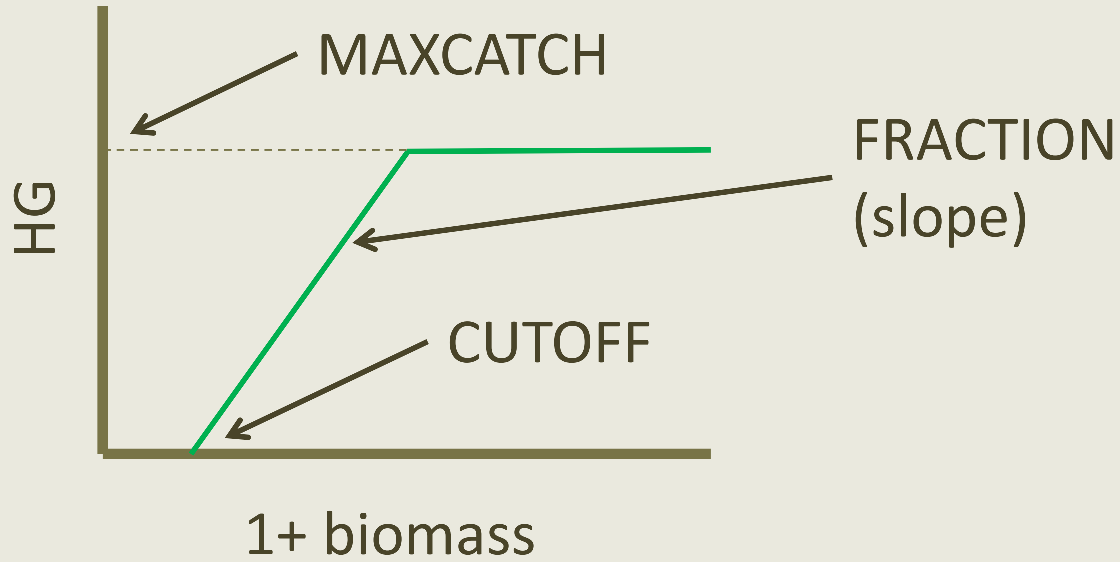
Acceptable Biological Catch (ABC)

↓

Harvest Guideline (HG)







ISSUE:

- Value for MAXCATCH?
- Value for CUTOFF?
- Relationship between FRACTION and an environmental variable?
- What environmental variable to use?

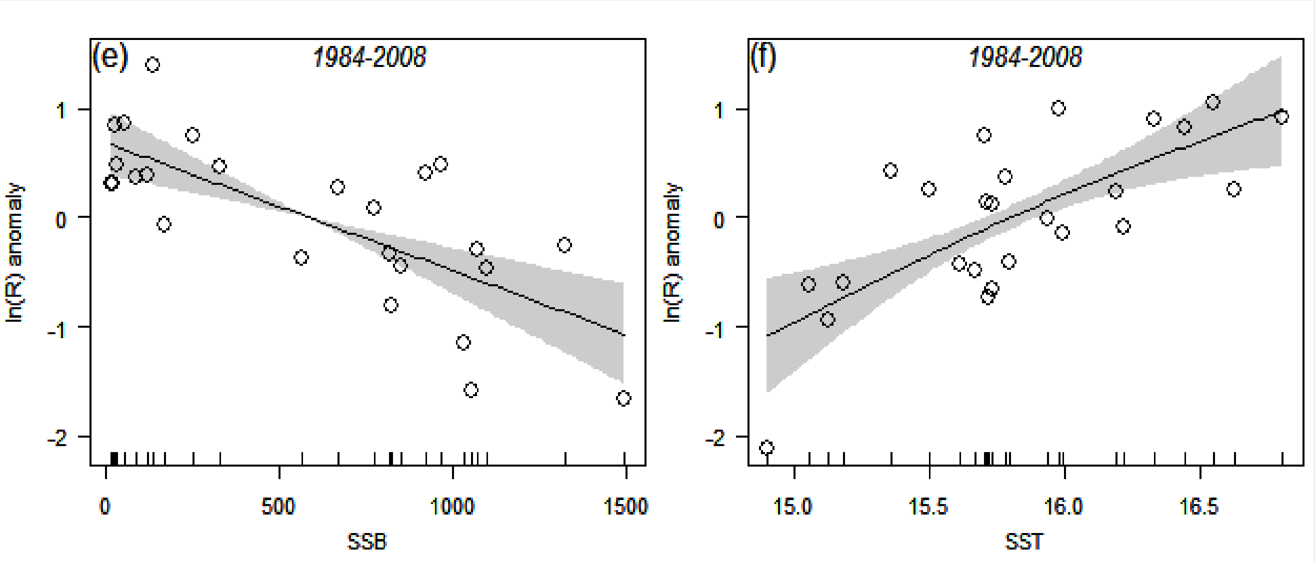
Background

- In Amendment 8 to the CPS FMP, FRACTION is a function of 3-year average sea surface temperature (SST) at Scripps Pier (SIO) (bounded by 5 and 15%).
- McClatchie et al. (2010)* reanalysed the data on which the SST-recruitment relationship was based and found the relationship was no longer significant.

*McClatchie, S., Goericke, R., Auad, G., and Hill, K. 2010. *Canadian Journal of Fisheries and Aquatic Sciences* **67**: 1782–1790.

ENVIRONMENTAL INDEX

Recruitment is related to both environment and spawning biomass



The relation between several environmental indices and recruitment was evaluated.

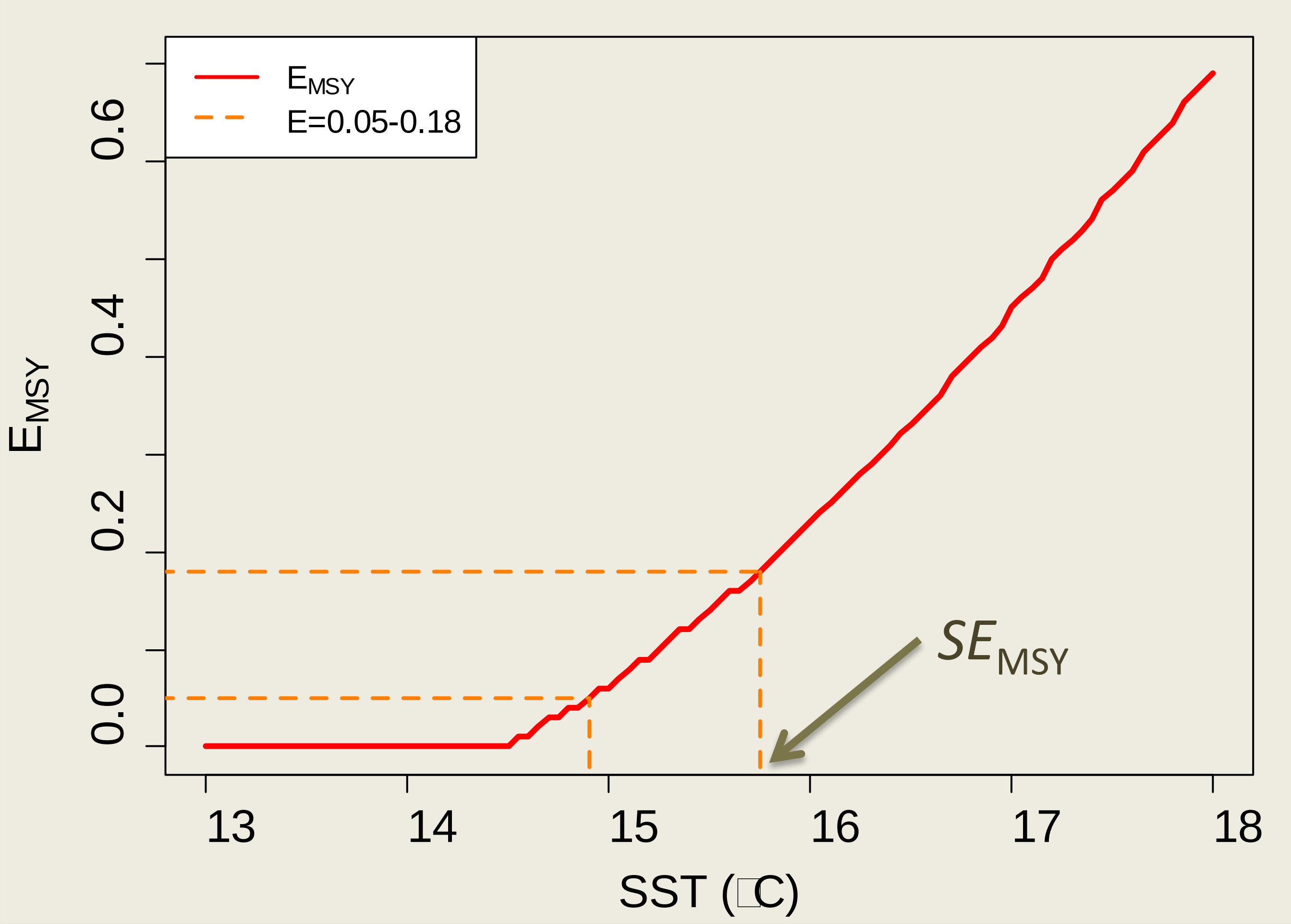
CalCOFI SST provides a better fit than SIO or ERSST to the stock-recruitment data for 1984-2008

Series	AIC	R^2
SST_CC_ann	45.79	0.72
SIO_SST_ann	56.81	0.61
ERSST_ann	55.3	0.63

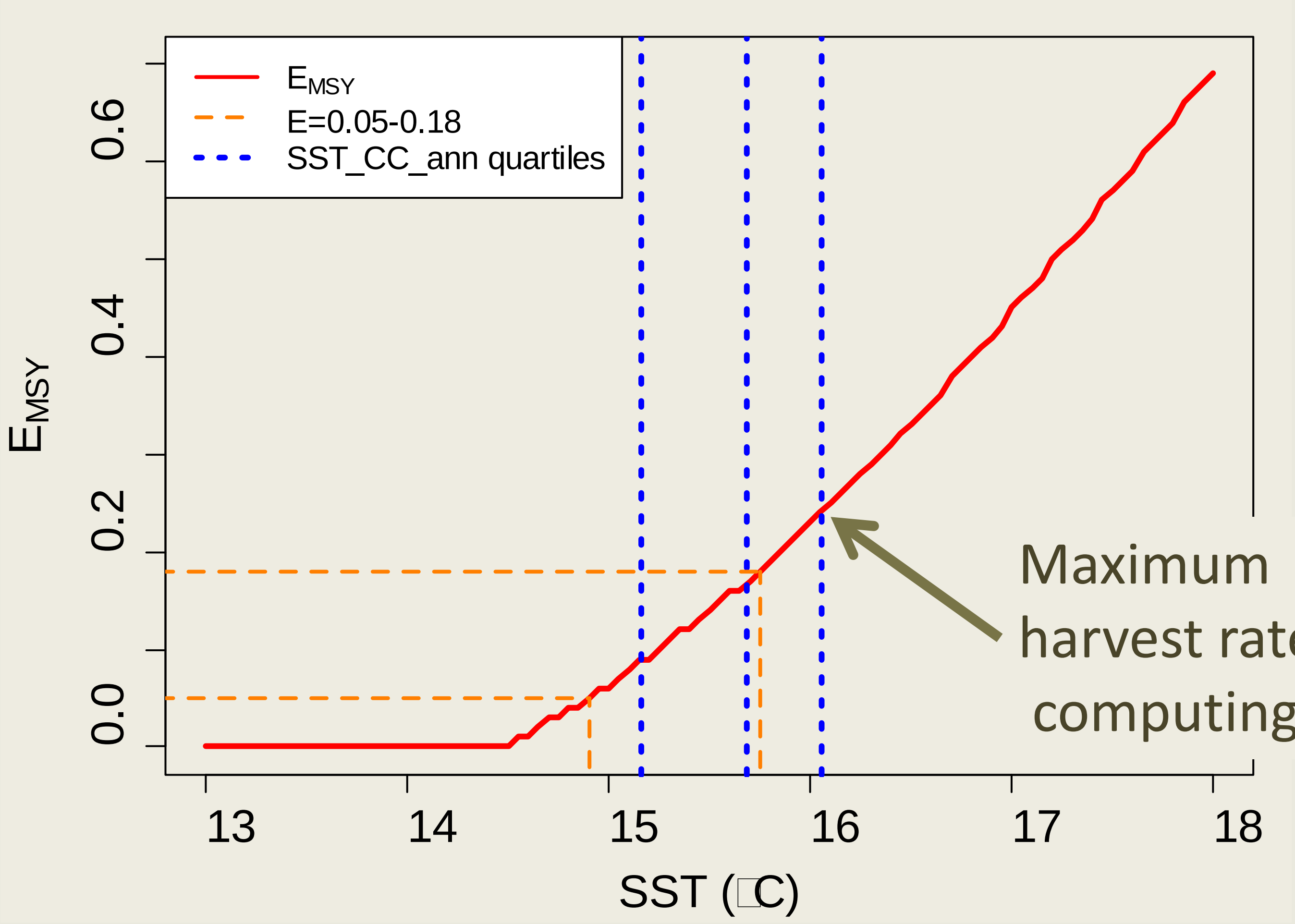
From PFMC 2013, Table App.E.6

RECALCULATED RELATIONSHIP BETWEEN ENVIRONMENT AND E_{MSY}

Calibrating the “CalCOFI” HG control rule



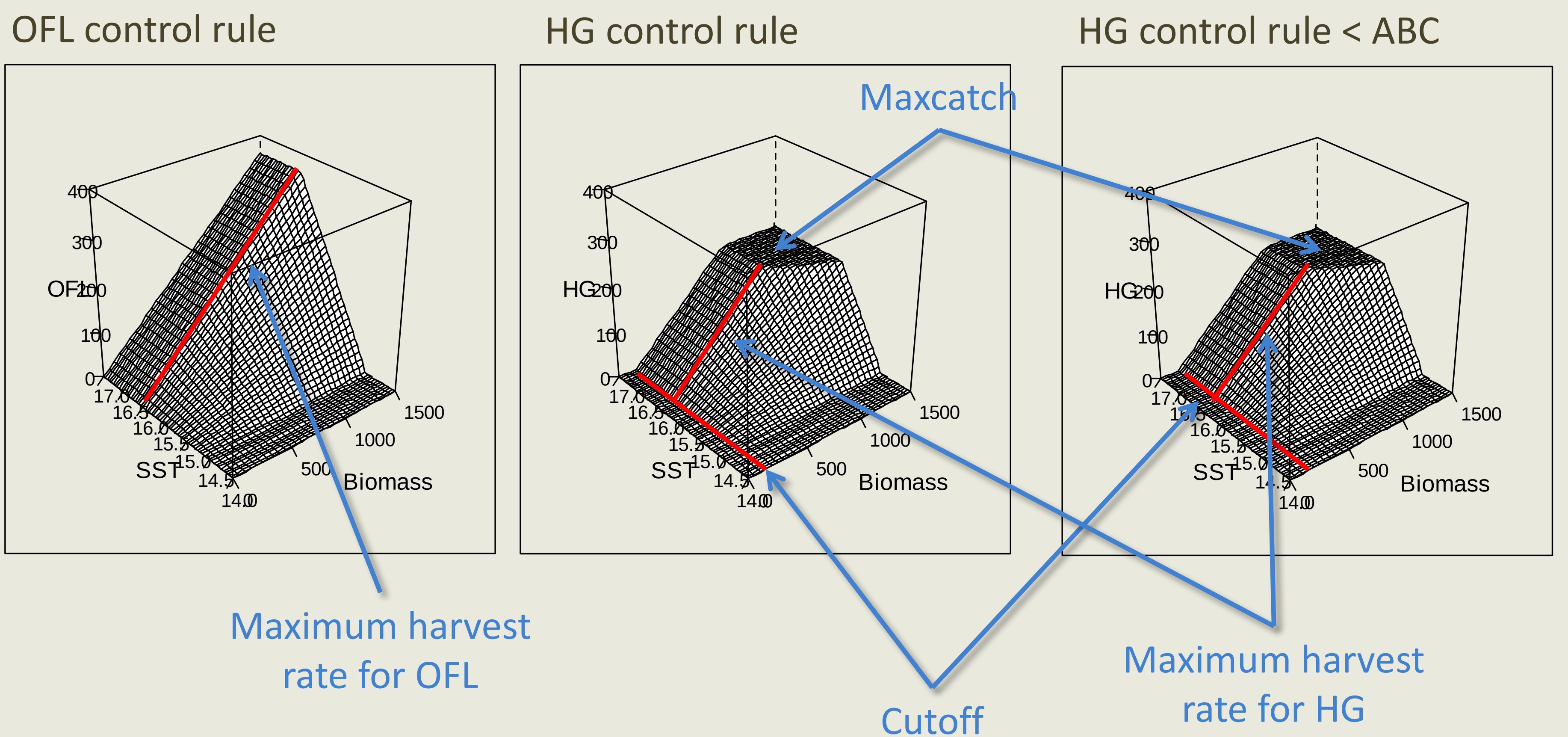
Calibrating the "CalCOFI" HG control rule



Maximum harvest rate for computing OFL

CalCOFI-based harvest control rule

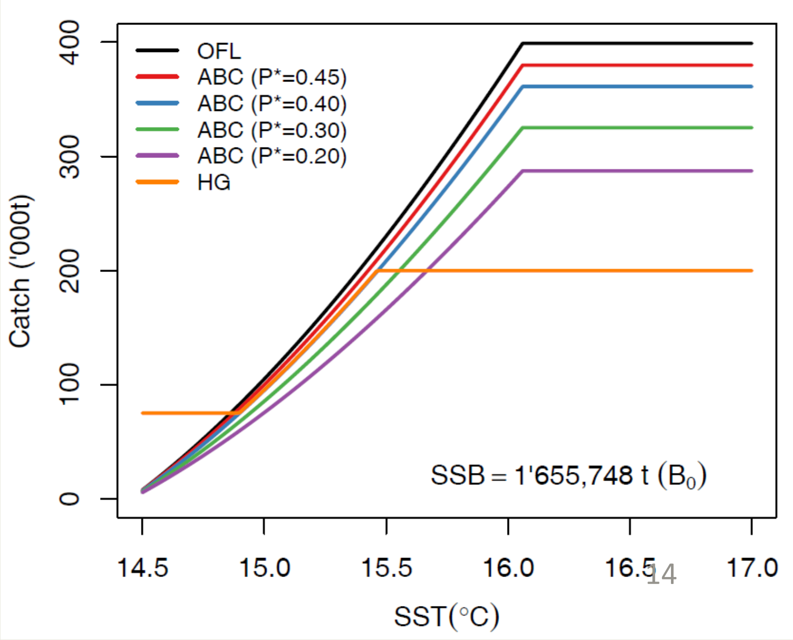
The harvest control rule depends on both the 1+ biomass and the CalCOFI SST



SIMULATION TESTING OF THE HARVEST CONTROL RULE

Harvest Control Rule variants

- Different choices for FRACTION, CUTOFF and MAXCAT
- FRACTION :
  - can be a constant (e.g. E_{MSY}) or
  - can be related to the environmental variable (e.g. 5% at 14.89^{0}C and E_{MSY} at 15.47^{0}C)
- Note: results are provided for illustrative "harvest policy variants".

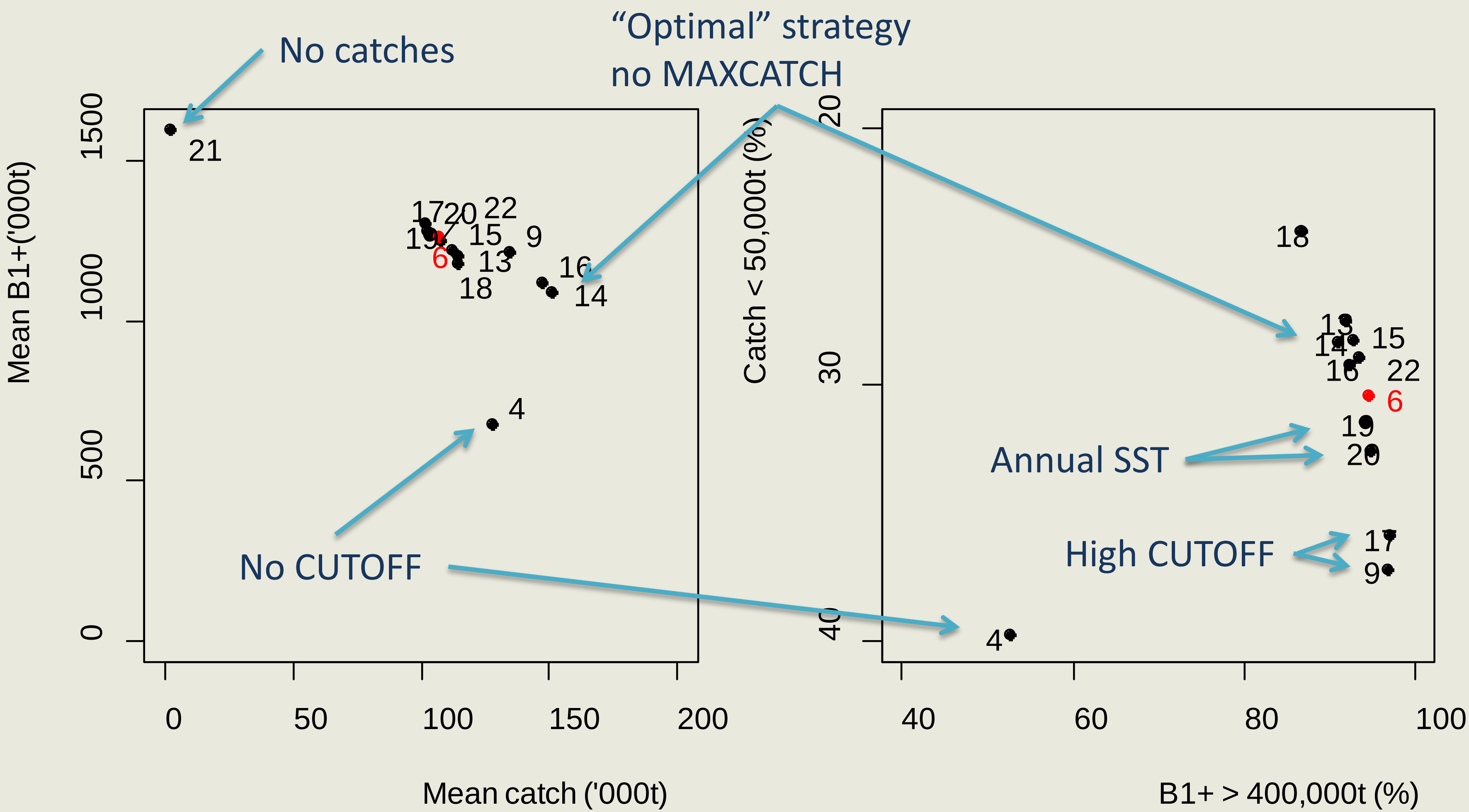


Quantifying trade-offs between different HCR variants: Biomass vs. catch

The performance measures are selected to quantify performance relative to [some] management goals.

- Average catch (total)
- Average population size (1+ biomass)
- Probability [total] catch is less than some threshold (e.g. 50,000t)
- Probability 1+ biomass is below a threshold.

Quantifying trade-offs between different HCR variants: Biomass vs. catch



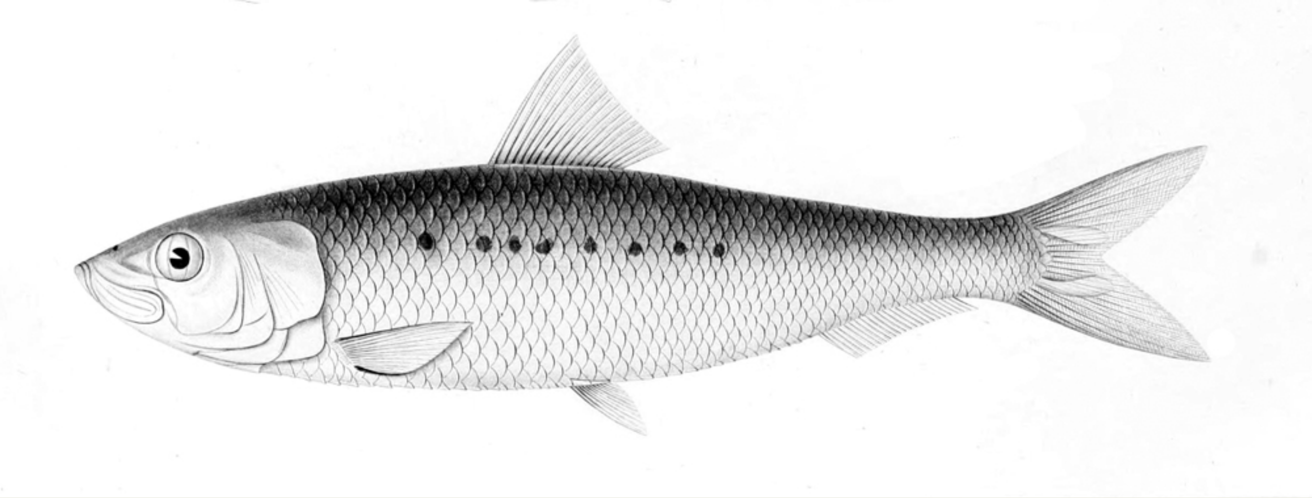
CONCLUSIONS

- There is a trade-off between catch and biomass: maintaining higher biomass levels imply having lower catches.
- Higher cutoffs have higher probability of low catches. However, including a cutoff results in higher mean catches and higher mean biomass than not doing it.
- With the exception of variant 4, all variants explored produce mean biomass at or above ~70% of unfished biomass.
- Using an annual index increases catch variance.

SENSITIVITIES

Sensitivity analyses allow to evaluate the HCR under alternative assumptions

- Lower environmental variability leads to higher, more stable catches.
- Results are not sensitive to changes in selectivity, growth, natural mortality or to hyper-stability in biomass estimates.
- Results are very sensitive to Mexico and Canada not following the US control rule.
- Results are robust to the use of alternative environmental indices (e.g. ERSST or SIO).



Questions?

Technical assistance: Kerry Griffin, Joshua Lindsay, Kevin Hill, Richard Parrish, Kirk Lynn, Ed Weber, Sam McClatchie

COASTAL PELAGIC SPECIES MANAGEMENT TEAM REPORT ON SARDINE HARVEST PARAMETERS CHANGES

Executive Summary

The CPSMT met January 7-9, 2014 to discuss the ramifications of a new sea surface temperature (SST) index for the harvest control rule for Pacific sardine. The team discussed the effects of the new index and the revised productivity relationship with environment on the performance of sardine management harvest control rules (HCR). The purpose of the discussion was to evaluate if, or how, changing the temperature index informing FRACTION would maintain or deviate from established policy for the sardine management.

The HCR for sardine includes a SST-dependent parameter that has been measured off Scripps Institution of Oceanography (SIO) pier, adopted with Amendment 8 and maintained in Amendment 13. McClatchie et al. (2010) found that SSTs at the SIO no longer reflected ocean SSTs off southern California. As an interim measure, Hill (2011) estimated F_{msy} independent of temperature to determine the overfishing limit (OFL) for Pacific sardine management until a new SST environmental index could be identified. Subsequently, Lindegren and Checkley (2013) found SST averaged over the present California Cooperative Oceanic Fisheries Investigations (CalCOFI) surveys more accurately reflected SSTs off California and explained a significant amount of sardine recruitment variability.

Hurtado-Ferro and Punt (2013) developed a simulation model to enable the examination of the risks associated with the current harvest control rules using the CalCOFI SST index, with regard to jeopardizing the long-term stock productivity of sardine. They ran many scenarios that used the CalCOFI SST Index and varied harvest control rule parameter values for OFL E_{msy}, HG FRACTION, CUTOFF, and MAXCAT. These scenarios (along with some additional requested scenarios) were reviewed by the CPSMT at the January 2014 meeting.

Based on the review of the new CalCOFI temperature time-series and the resulting change in the E_{msy} relationship, the CPSMT recommended that to maintain consistency with the current harvest policy and control rule, the CalCOFI temperature index should be used in the HCR to manage sardine. The CPSMT also identified the need for a slight modification to the FRACTION component of the HG rule. The CPSMT investigated a number of performance measures for model scenarios that allowed for a thorough examination of the biological and economic outcomes produced using the current harvest control rules. These outcomes included mean biomass of age 1+ sardines (B1+ biomass), mean Spawning Stock Biomass (SSB), depletion, percent years the stock would collapse, percent years with no commercial catch, percent years when the catch was greater than 50,000 mt, and median catch (Tables 1 and 2).

Based on the information available and its evaluation, the CPSMT concluded that a HCR change to the CalCOFI index and FRACTION range of 10-20 (Scenario K) best represented the SST data and new knowledge of stock productivity. This option preserves current policy by permitting harvest rates to take advantage of periods when biomass and productivity are high, but restricts harvest when biomass and productivity are low. This protects the long-term productive capacity and ability of the stock to recover from a series of poor unproductive time periods.

COASTAL PELAGIC SPECIES MANAGEMENT TEAM REPORT ON SARDINE HARVEST PARAMETERS CHANGES

Introduction

At its January 7-9, 2014 meeting, the CPSMT discussed analyses examining a new ocean sea surface temperature (SST) index for the harvest control rule (HCR) for sardine. The CPSMT discussed and evaluated the effects of the new SST index and revised productivity relationships with environment and its use in Pacific sardine management harvest control rules.

A Maximum Sustainable Yield (MSY) Control Rule and the Harvest Guideline (HG) for Pacific sardine were first established by Amendment 8 of The Coastal Pelagic Species Fishery Management Plan (FMP) (PFMC 1998). The HG includes a term, FRACTION, which is a proxy for E_{msy} [1]and specifies how much of the sardine stock is available for harvest when the biomass is above CUTOFF. Since the adoption of Amendment 8 FRACTION has been dependent on a linear relationship between temperature and stock productivity. The productivity of the sardine is related to southern California ocean temperatures, with sardines being more productive at higher ocean temperatures (Jacobsen and MacCall 1995). As described in the FMP, this relationship is presently calculated using a three-year running average SST taken at the Scripps Institution of Oceanography (SIO) pier to represent ocean temperatures.

When the SIO time series was updated with recent data, McClatchie et al. (2010) found that the sardine stock–recruit and temperature–recruit relationships underpinning the FRACTION term in the sardine HG formula were no longer valid. As an interim measure, Hill (2011) estimated E_{msy} independent of temperature to manage Pacific sardine until a new environmental index was developed. The result, a stochastic E_{msy} of 18%, was used to calculate OFL and ABC control rules in 2012 and 2013; calculation and output of the HG FRACTION remain unchanged during this period.

In February 2013, the Pacific Fishery Management Council (Council) and the Southwest Fisheries Science Center hosted a Pacific sardine management workshop to initiate a review and risk assessment of harvest control rule parameters. The workshop, among other things, was tasked to evaluate alternative estimates or times series for SST and stock distribution policies congruent with current harvest policy. At this meeting, Martin Lindegren and David M. Checkley, Jr. presented information that demonstrated the CalCOFI temperature time series is a better indicator of ocean temperature off southern California than those collected at SIO and a

[1] As a point of clarification, Over Fishing Levels (OFLs) for CPS are based on F_{msy} or E_{msy} proxy harvest rates applied to the best available estimate of biomass. F_{msy} is an instantaneous measure of fishing mortality rate for deterministic equilibrium MSY. In reality, an annual exploitation rate, E_{msy}, is used as a proxy for F_{msy} as the appropriate measure of fishing mortality for a particular year. E_{msy} is used to determination of OFL and is also equal to FRACTION in the Harvest Control Rule.

better predictor of Pacific sardine recruitment/productivity (Lindegren and Checkley 2013). However, the workshop found no information on alternative stock distribution estimates that were conclusive, but recommended all available data be gathered for future review.

At the behest of the Council, Felipe Hurtado-Ferro developed a new simulation harvest guideline model and conducted an analysis of sardine management scenarios (Hurtado-Ferro, unpublished). These scenarios were presented at the April 2013 Council meeting. The Council and advisory bodies requested additional model runs and additional fishery performance measures to further examine the potential effects of using the CalCOFI SST data. The CPSMT and the Scientific and Statistical Committee's CPS Subcommittee (SSC CPSS) met jointly in May 2013 to discuss the analyses and develop recommendations for the June 2013 Council meeting. Following discovery that temperature data in the analysis included some erroneous values, full Council discussion was postponed to provide time to rerun the model and evaluate the model scenarios using corrected data. The Council requested that the evaluation include socio-economic impacts and model sensitivity to stock distribution.

In January 2014, the CPSMT met to assess the revised management scenarios. The purpose of the assessment was to evaluate if, or how, changing the temperature index which determines FRACTION would maintain or deviate from established policy for the management of sardine. This report presents a synthesis of these analyses and an assessment of the risks associated with replacing SIO pier SST with CalCOFI SST as the index for environmental conditions.

How This Report is Organized

In examining the various harvest scenarios presented in this report, it is first necessary to recognize that there are underlying differences in management and the scientific analyses framing the discussions now as compared to Amendment 8. These differences are summarized in the following two sections. Next, the harvest policy scenarios are then described and the CPSMT recommendation presented. Finally, the model sensitivity to stock distribution is addressed.

Harvest Policy under Amendment 8

The Pacific sardine harvest guideline control rule as defined in Amendment 8 reduces the exploitation rate as biomass declines:

HG = (BIOMASS – CUTOFF) • FRACTION • DISTRIBUTION

Where: HG = Harvest Guideline, Biomass= estimated 1+ sardine biomass (from stock assessment), CUTOFF = 150,000 mt, FRACTION = 5-15% and depends on SST, and DISTRIBUTION = 87%.

The purpose of CUTOFF is to protect the stock when biomass is low. The purpose of FRACTION is to specify how much of the stock is available to the fishery when BIOMASS exceeds CUTOFF. FRACTION is dependent on oceanographic conditions and is a proxy for E_{msy}. If BIOMASS falls as low as CUTOFF, the harvest rate is reduced to zero. CUTOFF thus provides a buffer for the spawning stock that is protected from fishing and available to rebuild if the stock biomass is low. Another parameter used in the harvest policy is MAXCAT, the maximum level of harvest that is allowed under any stock abundance. The purpose of MAXCAT is to guard against extremely high catch levels due to errors in estimating biomass, to reduce year-to-year variation in catch levels, and to avoid overcapitalization during short periods of high biomass and high potential harvest. To account for its transboundary status, DISTRIBUTION sets sardine harvest levels for US fisheries by prorating the portion of the entire stock that resides in US waters.

For Amendment 8, several options for a MSY control rule were evaluated in which FRACTION was a time-varying estimate of the MSY exploitation rate estimated from SST data. The values for CUTOFF and MAXCAT also varied among the options. The purpose of these simulations was not to find the combination of FRACTION, CUTOFF, and MAXCAT that was optimal, but rather the results were used to find MSY control rules and parameters that gave good results for most performance measures. The simulation model was not useful for estimating or predicting exact quantities, but useful to evaluate the relative difference among options. The simulation results for various performance measures were compared for thirteen options and the Council selected Option J (CPS Amendment 8, Appendix B, Table 4.2.5-1, page B-99), to best meet the relevant CPS FMP goals:

1. Promote efficiency and profitability in the fishery, including stability of catch.
2. Achieve optimum yield.
3. Provide adequate forage for dependent species.
4. Prevent overfishing.

What is Different from Amendment 8 Harvest Policy Analysis?

First, adoption of Amendment 13 to the CPS FMP resulted in the implementation of essentially three control rules: OFL, Acceptable Biological Catch (ABC) and HG. From Amendment 8 through Amendment 13, the HG functioned as the sole control rule and exceeding it was equated with overfishing. The new OFL and ABC control rules set a level of annual catch to define overfishing and buffer for scientific uncertainty, respectively. Analyses conducted during the Amendment 13 scoping process revealed that the ABC output fell below the HG at some P* (probability of overfishing) values during regimes with lower SSTs. This outcome is in part due to fixing the lower bound for FRACTION in the HG rule. Amendment 13 implemented a control rule policy that specifies the lower of the two would serve as the annual management target or ACT. The result was that sardine management post-Amendment 13 became more precautionary, particularly in cooler and low biomass conditions. This policy of using the lower of the two control rules is included in the current simulation work.

Second, a new simulation model is used for these analyses. The new operating model (age-structured) is structurally different than the simulation model used in Amendment 8 (production model), and incorporates a revised recruitment time series that better represents sardine population dynamics over the past several decades. The updated model produces a higher stochastic E_{msy} (SE_{msy}) than Amendment 8 (0.18 vs 0.12) due to the bulk of the intermediate and low biomass years when Amendment 8 was developed and a period when sardine biomass was declining because of the numerous cold water years. The new time series with more recent data includes a large number of years at low and intermediate biomass levels when the biomass was expanding because it was a warm water period (Dr. Richard Parrish, pers.comm.).

Finally, the 1984-2008 CalCOFI SST time series replaces the 1916-1998 SIO SST used in the Amendment 8 model and in the relationship to define E_{msy} (F_{msy}). The CalCOFI SST time series provides the best fit for the sardine recruitment – environment relationship, as indicated by R^2 of 0.72 from Table 10 in the Hurtado-Ferro and Punt report (Agenda Item I.1.b, Attachment 1). The E_{msy} -SST relationship based on SIO data differs from the CalCOFI E_{msy}-SST relationship (Figure 5, Attachment 1, Agenda Item I.4.b, June 2013).

Harvest Policy Scenarios

The CPSMT reviewed all the various model harvest scenarios (Appendix Table 1) conducted by Hurtado-Ferro and Punt (2013) and also requested other scenarios. For the purposes of this report, the CPSMT selected a subset of scenarios and performance measures to provide clarity on the implications of the new model and on the management implications of various harvest and management strategies. Included in the subset are scenarios that contrast broadly different values for HCR parameters (Table 1) and ones that vary only in the values informing the FRACTION parameter (Table 2).

All the scenarios used a three-year averaged CalCOFI SST time series because this reduces the variation in FRACTION and large inter-annual fluctuations in harvest. A three-year average also spans temperature conditions from the year preceding spawning, the birth year and the year prior to recruitment to the adult population. This is consistent with present policy for FRACTION, which currently uses a three-year average temperature variable, but from SIO temperatures. For the purpose of analysis Hurtado-Ferro and Punt (2013) set DISTRIBUTION to 1.0, as was done originally in Amendment 8, and thus was not a factor in the scenarios.

Scenarios Illustrating Broadly Contrasting Policy/Management Strategies

Table 1 shows seven sardine harvest scenarios (A-H) that vary significantly in their harvest/population implications depending on four variables: OFL E_{msy}, HG Fraction, CUTOFF and MAXCAT. These represent broad harvest policies ranging from the current harvest policy, to static (true MSY-type policies), to ones that create high catches but pulse fisheries. The intent of this table to highlight the general theory behind the current control rule and that the theory still holds with the updated model. (Similar to Table 4.2.3.3-1, page B-95; Amd. 8).

Table 1. The results of modeling seven harvest control rule scenarios by varying E_{MSY}, FRACTION, CUTOFF OR MAXCAT on biological and economic performance measures for the Pacific sardine population and fishery.

Scenario	A	B	C	D	E	F	G	H
Variant Code	21	6	28	24	26	4	14	23
Scenario Description	No fishing	Base Case - "HG J" from Amendment 8	High CUTOFF, Pulse Fishery	Maximize catch, high FRACTION and high CUTOFF	Static MSY	E_{msy} - No CUT OFF or MAXCAT, HG FRACTION is always set to 0.19.	No MAXCAT, HG FRACTION set at 0.18, Small CUTOFF	Temperature/ productivity varying E_{MSY}
CalCOFI	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave
OFL E_{MSY} (%)	-	0-25	0-25	45	Emsy	0-25	0-25	0-25
HG FRACTION (%)	0	5-15	5-15	45	Emsy	19	18	0-25
CUTOFF	-	150	640	0.33 * B0	0	None	50	0
MAXCAT	-	200	200	-	-	None	None	-
Performance Measure								
Biological								
Mean B1+ (SD)	1572 (907.6)	1220 (888.1)	1370.5 (868.0)	864.8 (613.9)	671.6 (780.9)	571.7 (747.4)	1033.2 (750.1)	962.9
Mean SSB (SD)	1304.3 (805.5)	946.7 (757)	1088.9 (741.1)	594.2 (391.4)	479.0 (586.7)	403.9 (554.3)	761.1 (578)	701.6
%B1+>400	98.6	92.4	97.75	83.3385	51.5945	44.2	87.1	695.3
Depletion (B1+ % of Unfished B1+)	-	0.78	0.87	0.55	0.427	0.36	0.66	524.9
								85.3
Economic								
%No catch	100	4.7	23.8	36.7	16.8	25.1	4	4.0
%Catch<50	100	31.2	48.5	47.0	42.3	49.3	29.2	29.4
Median catch	0	97.4	54.1	65.7	70.1	51.9	100.9	102.3
Mean catch all (SD)	0 (0)	105.8 (72.5)	79.18 (75.7)	184.3 (304.6)	120.9 (158.4)	108.5 (158.3)	149.3 (164.1)	158.8 (183.7)

Scenario B (Base Case) is very similar to the selected option from Amendment 8, including using a 5-15% HG FRACTION. The only difference is the use of the new CalCOFI SST index for Scenario B. What are noteworthy are the percent time with no catch (4.7%), the relatively high $B1^+$ abundance (1,220,000 mt), and a high Depletion value (78%). Depletion refers to the portion of the population remaining after harvest (i.e., the percentage of fish left in the ocean after harvest). Thus high depletion values, as in Scenario B (Base Case) are good.

Scenario A (No Fishing) shows that without fishing mean biomass (B1) is 1,572,000 mt. If OFL E_{msy} and HG FRACTION are both set to E_{msy} (18%) and without a CUTOFF or MAXCAT as in Scenario E, then mean B1+ biomass and depletion decrease significantly. Mean catch increases, but there is no fishery 16.8% of the time and the population collapses 30% of the time. If a CUTOFF of 50,000 mt is added to this scenario (Variant G) the population never collapses but the depletion is relatively low (0.66), and standard deviation of catch is above mean catch, indicating a pulse commercial fishery. If OFL E_{msy} and HG FRACTION are allowed to vary from 0-25% and there is no CUTOFF or MAXCAT (Scenario H), mean and median catch go up compared to the Base Case, but the standard deviation of catch is high and there is no fishery 4% of the time.

If OFL E_{msy} and HG FRACTION are set very high, at 45%, and CUTOFF is also set very high, at 33% of B_0 (i.e. 1,572,000 mt) (Scenario D), depletion is again low and while catch is high, it is highly pulsed (high SD) and there is no catch 36.7% of the time (Scenario D). Finally, if CUTOFF is set at a high level (640,000 mt), 40% B_0 but with status quo FRACTION and MAXCAT, mean biomass and the depletion rate increase, but there is also no catch 24% of the time (Scenario C). These different scenarios clearly show the value of CUTOFF and/or non-stochastic catch levels in protecting the stock. HCRs with high CUTOFF generally produce a strongly pulsed fishery that is frequently closed, without dramatic gains in biomass.

Very high FRACTION rates or static FRACTION rates, with no CUTOFF, produce lower overall population abundance and no fishery. Simply increasing CUTOFF does maintain a high B1+ biomass but also increases the number of years with no fishery. After analyzing these scenarios, the CPSMT determined that large changes in the harvest control rules were contrary to Amendment 8 policies, which identified the importance of a relative high B1+ abundance and a consistent commercial fishery.

Scenarios Evaluating FRACTION

Table 2 includes seven scenarios (B, I-O) that employ different values or ranges only for FRACTION while the parameters are the same for OFL E_{msy}, CUTOFF and MAXCAT (except for Scenario O with an OFL E_{msy} of 18). For ease of comparison, Scenario B (Base Case) is repeated from Table 1. The purpose of this comparison was to evaluate candidate bounds for FRACTION under the new CalCOFI temperature time-series and the resulting change in the E_{msy} relationship.

Scenarios B, I, K, and L vary in the range of values for FRACTION, whereas Scenarios M and N use a constant HG FRACTION. Scenario O has a constant OFL E_{msy} and HG FRACTION. Even with these differences, biological performance measures across all seven model simulations are similar. All have a population biomass over 400,000 mt more than 84 percent of the time and depletion rates that exceed 73%. Likewise, economic performance indicators are generally comparable. None of the scenarios had less than five percent of years with no catch (i.e., no fishery) and the percent of years with catch <50 mt ranged from 26.4 to 31.2. Median catch is useful to determine fishery stability or how constant catch might be over the long term because mean catch can mask very high or very low catches averaged over the long term. Consistency in catch is also reflected when median and mean catch values are similar. Fishery stability is realized in all the scenarios in Table 2.

Table 2. The results of modeling seven harvest control rule scenarios by varying FRACTION on biological and economic performance measures for the Pacific sardine population and fishery.

Scenario	B	I	K	L	M	N	O
Variant Code	6	25	31	32	15	22	18
Scenario Description	Base Case - "HG J" from Amendment 8	HG FRACTION bounded at 5-18	HG FRACTION bounded at 10-20	HG FRACTION bounded at 10-25	HG FRACTION set at 18%	HG FRACTION set at 15%	OFL set at 18% and HG FRACTION set at 15%
CalCOFI	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave
OFL E_{MSY} (%)	0-25	0-25	0-25	0-25	0-25	0-25	18
HG FRACTION (%)	5-15	5-18	10-20	10-25	18	15	15
CUTOFF	150	150	150	150	150	150	150
MAXCAT	200	200	200	200	200	200	200
Performance Measure							
Biological							
Mean B1+ (SD)	1220 (888.1)	1196.6 (884.1)	1182.0 (883.3)	1170.3 (879)	1178 (890.2)	1207.7 (892.8)	1148.4 (916.2)
Mean SSB (SD)	946.7 (757)	924.6 (753.7)	911.4 (752.9)	900.3 (750)	908.4 (758.2)	936 (760.6)	884.1 (777.8)
%B1+>400	92.4	91.9	91.2	91.0	89.9	91.1	84.3
Depletion (B1+ % of Unfished B1+)	0.78	0.76	0.75	0.74	0.75	0.77	0.73
Economic							
%No catch	4.7	4.7	4.7	4.7	4.8	4.7	2.3
%Catch<50	31.2	30.8	30.5	30.4	29.2	30	26.4
Median catch	97.4	104.2	106.6	110.0	104.8	97.7	104.3
Mean catch all (SD)	105.8 (72.5)	109.8 (74.5)	111.6 (74.9)	113.4 (75.8)	110.9 (73.3)	106.6 (71.5)	111 (69.6)

CPSMT Recommendations

It is important to note that the Council's policy choice for the current HG FRACTION control rule is based on analyses that used the SIO index (CPS FMP Amendment 8) whereas these scenarios addressed above are based on the newer CalCOFI index. Recall, the two are not directly comparable when using this new relationship to determine the HG FRACTION calculation.

The CPSMT supports the inclusion of temperature as an environmental variable in the harvest guideline (HG) for sardine management, since it as an indicator of stock productivity. The CPSMT recognizes the CalCOFI index is the most appropriate indicator of sardine recruitment/productivity and recommends its use. Use of the CalCOFI temperature time series, along with the change from a production to age-structured model, maintains a precautionary management policy. The CPSMT notes that the depletion rate (% mean biomass compared to the unfished case) for Scenario B (Base Case) rises from 0.64 in Amendment 8 to 0.78 in the current analysis. Since SIO temperatures have increased and CalCOFI temperatures have decreased in recent years, use of a CalCOFI index results more frequently in lower FRACTION values and more conservative harvest control rules (see Table 4) for these years.

The choice of values used to define or bound the HG FRACTION is a policy decision. The status quo would be to continue to use SIO and FRACTION bounded at 5-15%. Another option is to use CalCOFI and FRACTION bounded at 5-15% (Scenario B). However, if CalCOFI is used going forward, and with the calculated E_{msy} changing from 0.12 (using SIO SST) to 0.18 (using CalCOFI SST), the CPSMT believes it appropriate to adjust the HG FRACTION bounds accordingly. The increase in E_{msy} reflects statistically identified increased productivity and therefore a higher fishing rate at MSY that maximizes mean catch. The original intent of the HG under the CPS FMP was to have a FRACTION that varied based on temperature to allow more catch during good conditions and less during unfavorable conditions.

The CPSMT examined the effects of extreme values for various parameters to confirm the current model was operating correctly and producing expected outcomes (Table 1). After reviewing the new model, the increase in stochastic E_{msy}, and the shift of where those FRACTIONs fall on curve, the CPSMT is recommending revising the bounds of FRACTION to a range of 10-20%. The results of this potential change are shown in Scenario K, which includes a temperature-dependent OFL FRACTION of 0-25, an HG FRACTION of 10-20, and CUTOFF and MAXCAT at status quo (**Table 3**).

Table 3. A comparison between two HG scenarios that the CPSMT considered to most likely to meet the goals of Amendment 8.

Scenario	**B**	**K**
Variant Code	6	31
Scenario Description	Base Case - "HG J" from Amendment 8	HG FRACTION bounded at 10-20
CalCOFI	3 yr ave	3 yr ave
OFL E_{MSY} (%)	0-25	0-25
HG FRACTION (%)	5-15	10-20
CUTOFF	150	150
MAXCAT	200	200
Performance Measure		
Biological		
Mean B1+ (SD)	1220 (888.1)	1182.0 (883.3)
Mean SSB (SD)	946.7 (757)	911.4 (752.9)
%B1+>400	92.4	91.2
Depletion (B1+ % of Unfished B1+)	0.78	0.75
Economic		
%No catch	4.7	4.7
%Catch<50	31.2	30.5
Median catch	97.4	106.6
Mean catch all (SD)	105.8 (72.5)	111.6 (74.9)

One reason for the shift to a higher HG FRACTION range (5-15 to 10-20) is the increase from stochastic F_{msy} of 0.12 in Amendment 8 to 0.18 based on updated analysis/new model (Hurtado-Ferro and A. E. Punt. 2013). Additionally, a FRACTION that ranges from 10-20% also better reflects the mid-range of temperature vs E_{msy} and aligns with CalCOFI temperatures in manner that is similar to the where the 5-15% range fell relative to SIO temperatures. To illustrate, Figure 1 which depicts the current policy from Amendment 8, using SIO temperature and FRACTION bounded at 5-15 can be compared to Figure 2 which depicts FRACTION bounded at 5-15 and 10-20 using CalCOFI temperature.

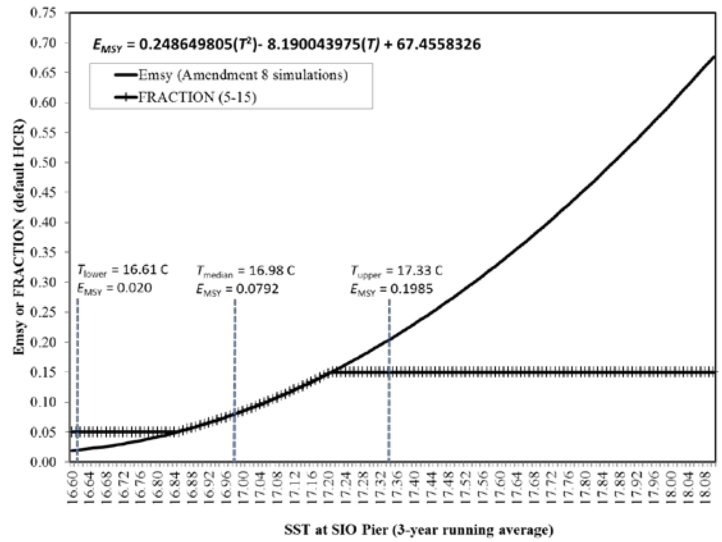


Figure 1. E_{msy} and FRACTION based on SST at SIO Pier; Amendment 8

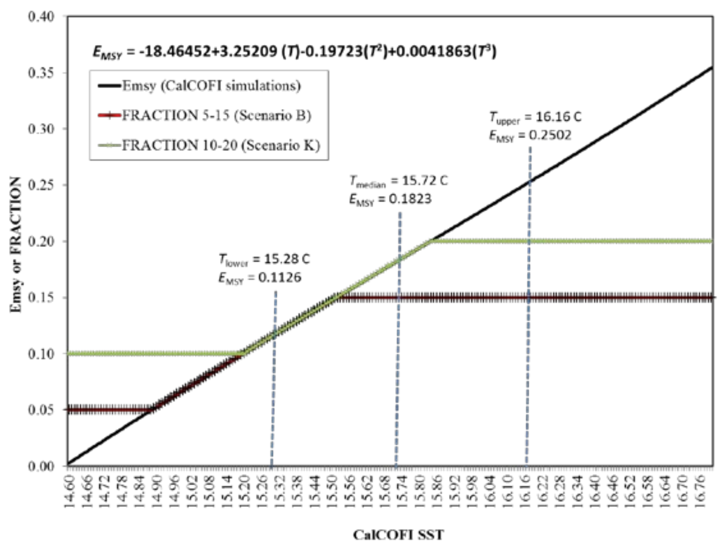


Figure 2. CalCOFI SST and Emsy from Hurtado; FRACTION bounded at 5-15 (Scenario B) and at 10 -20 (Scenario K).

Table 4 shows the current SIO HG harvest control rule with: the current rule using the CalCOFI index (Scenario B: HG FRACTION bounded from 5-15%), and the recommended CalCOFI policy (Scenario K which bounds FRACTION at 10-20) for the 2000-2013 management years.

The HGs for the recommended policy, Scenario K, can exceed those for Scenario B, the current rule using the CalCOFI index. However, the recommended policy is more conservative than the SIO rule when considering the range of HG FRACTION bounds (10-20%) relative to SE_{msy} (0.18), and due to the fact that depletion increases from the Amendment 8 base case level of 0.64 to the Scenario K value of 0.75.

Table 4. Difference in Pacific sardine Harvest Guideline control rule using two different temperature indices: Scripps Institution of Oceanography (SIO) pier and the California Cooperative Oceanic Fisheries Survey (CalCOFI). HG $FRAC_B$ = HG FRACTION using Scenario B; HG_B = Harvest Guideline using Scenario B; similarly for Scenario K.

		SIO				CalCOFI					
Year	Biomass (1+)	SST	E_{msy}	HG FRAC	HG	SST	E_{msy}	HG $FRAC_B$	HG_B	HG $FRAC_K$	HG_K
2000	1,581,346	18.08	0.660	0.150	186,791	16.28	0.269	0.150	186,791	0.200	249,054
2001	1,182,465	17.75	0.421	0.150	134,737	15.95	0.217	0.150	134,737	0.200	179,649
2002	1,057,599	17.24	0.162	0.150	118,442	15.54	0.154	0.150	118,442	0.154	121,816
2003	999,871	17.31	0.191	0.150	110,908	15.43	0.137	0.137	100,938	0.137	100,938
2004	1,090,587	17.46	0.259	0.150	122,747	15.51	0.149	0.149	121,863	0.149	121,863
2005	1,193,515	17.60	0.334	0.150	136,179	15.62	0.166	0.150	136,179	0.166	150,737
2006	1,061,391	18.03	0.618	0.150	118,937	15.79	0.193	0.150	118,937	0.193	152,802
2007	1,319,072	18.11	0.685	0.150	152,564	15.75	0.187	0.150	152,564	0.187	190,001
2008	832,706	18.12	0.693	0.150	89,093	15.51	0.149	0.149	88,560	0.149	88,560
2009	662,886	17.83	0.477	0.150	66,932	15.45	0.139	0.139	62,231	0.139	62,231
2010	702,024	17.84	0.483	0.150	72,039	15.26	0.110	0.110	53,033	0.110	53,033
2011	537,173	17.90	0.522	0.150	50,526	15.39	0.131	0.131	44,185	0.131	44,185
2012	988,385	17.64	0.358	0.150	109,409	15.49	0.146	0.146	106,624	0.146	106,624
2013	659,539	17.35	0.207	0.150	66,495	15.48	0.144	0.144	63,938	0.144	63,938

Distribution

Although sensitivity analyses of the new operating model indicate that fishing by Canada and Mexico strongly affects model results (i.e., the sardine stock experiences collapses when catch by these countries is not constrained by the HCR), sensitivity tests, as well as the primary analysis completed, were not intended to analyze the DISTRIBUTION parameter of the sardine Harvest Guideline control rule. Moreover, the results of the sensitivity analysis of multiple fleets (where essentially fishing pressure by Mexico and Canada is static and remains relatively high during all years and conditions), are not unexpected. Other control rule runs also show that the model is sensitive to invariable catch levels and catch occurring at very low biomass levels.

Discussion at the February 2013 workshop on sardine harvest parameters noted the innate difficulties in calculating a DISTRIBUTION parameter and the proportion of Pacific sardine, and all CPS stocks, in U.S. waters. CPS stock abundance within each country fluctuates annually and seasonally and is the result of a variety of factors. This is highlighted in the Harvest Parameters Workshop Report (PFMC 2013) with the statement "There will be times when all of the sardine stock is in U.S. waters and times when this proportion is much less." This is part of the reason why the DISTRIBUTION parameter is intended to represent an average condition both within and among years. In fact, when the DISTRIBUTION parameter (derived from fish spotter data from 1964 through 1992, a time when biomass was very low) was developed for Amendment 8, it was predicted that "in years with medium to high biomass the proportion of sardine in US waters would be higher."

Amendment 8 acknowledges that when the DISTRIBUTION parameter was developed it would not protect this stock against high combined catches: "Prorating total harvest….will not protect CPS stocks against high combined … harvest rates if harvest rates are too high in Mexico, but harvest in U.S. waters will automatically decrease if biomass decreases." However, the FMP also states the "primary advantage of prorating the total target harvest level (i.e. DISTRIBUTION) to obtain harvest guidelines or quotas for U.S. fisheries is that U.S. fisheries can be managed unilaterally, in a responsible manner that is consistent with the Magnuson-Stevens Act."

Amendment 8 and discussions at the workshop identified alternative control rule approaches or variants on the current control policy may exist to account for some level of biomass of sardine residing off other countries and subject to fishing. However, to fully explore and evaluate these would require investment of additional time and resources to accomplish.

Conclusion

The CPSMT reiterates the foresight of the HG rule in Amendment 8. The adoption of Amendment 13 added OFL and ABC control rules to the management of sardine, which increased the precautionary approach, particularly at lower temperatures. As noted earlier in this report, the ABC control rule under cooler regimes can produce an annual catch limit that falls below the HG. The recommend policy option (Scenario K) preserves current policy by permitting higher harvest rates to take advantage of periods when biomass and productivity are high and restricting harvest when biomass and productivity are low, to protect long-term productive capacity and help to rehabilitate the stock. Information presented on the

DISTRIBUTION parameter of the HCR at the February workshop did not support a change in this term and the CPSMT is unaware of any new data to indicate that the current value should be changed or that would support a change at this time.

Finally, the CPSMT is aware that issues with rule-making timelines, i.e. implementing the new HCR in time for the fishing season beginning July 1, 2014, may arise with the new temperature index, and that further consideration by the Council may also be required to accomplish changes to the HG rule. However, the CPSMT notes that although it may not be possible to implement changes to the HG rule in time for the 2014-2015 fishing season, the new E_{msy} relationship may be used in the calculation of OFL and ABC immediately, because OFL decisions are under the purview of the SSC.

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Appendix Table 1. Results of applying 21 variations to the harvest control rule base-case scenario (Scenario HG J).

Scenario	Request 1	Request 2	Request 3	Request 4	Request 5	Request 6	Request 7	Request 8	New7
Variant Code	24	25	26	27	28	29	30	31	21
Variant Description	OFL no max catch, relatively high cutoff		msy		High Cutoff				No fishing
CalCOFI	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave
OFL E_{MSY} (%)	45	0-25	Emsy	0-25	0-25	0-25	0-25	0-25	-
HG FRACTION (%)	45	5- Emsy	Emsy	5-15	5-15	5-15	5-15	10-20	0
CUTOFF	0.33 * B0	150	0	150	640	640	150	150	-
MAXCAT	-	200	-	300	200	300	150	200	-
Performance Measure									
Biological									
Mean B1+ (SD)	864.8 (613.9)	1196.6 (884.1)	671.6 (780.9)	1180.8 (856.6)	1370.5 (868.0)	1346.0 (844.6)	1256.0 (907.9)	1182.0 (883.3)	1572 (907.6)
Mean SSB (SD)	594.2 (391.4)	924.6 (753.7)	479.0 (586.7)	904.6 (716.3)	1088.9 (741.1)	1061.8 (709.7)	987.7 (782.3)	911.4 (752.9)	1304.3 (805.5)
%B1+>400	83.3385	91.9205	51.5945	92.2465	97.75	97.724	92.7085	91.2055	98.6
Depletion (B1+ % of Unfis	0.55	0.76	0.427	0.75	0.87	0.86	0.80	0.75	-
Economic									
%No catch	36.7	4.7	16.8	4.7	23.8	24.1	4.6	4.7	100
%Catch<50	47.0	30.8	42.3	31.7	48.5	49.2	30.5	30.5	100
Median catch	65.7	104.2	70.1	94.2	54.1	52.1	101.7	106.6	0
Mean catch all	184.3	109.8	120.9	119.9	79.1	89.4	92.7	111.7	0
SD catch all	304.6	74.5	158.4	97.0	75.7	97.1	55.5	74.9	0
Mean catch CO	289.9	115.2	145.3	125.7	103.1	117.1	97.1	117.1	0
SD catch CO	340.7	72.3	163.1	95.7	71.3	96.1	53.0	72.6	0
Median B1+	709.8	961.6	427.3	965.0	1168.4	1153.5	1027.3	945.1	1401.8
Median SSB	503.6	714.3	295.6	719.1	908.8	894.8	774.4	699.3	1139.7
Mean pop age	2.44	2.81	2.04	2.78	3.00	2.96	2.88	2.79	3.29
Mean Catch Age	1.56	1.81	1.30	1.79	1.94	1.92	1.86	1.80	NA
%HCR min	100.00	11.18	NA	11.18	11.18	11.18	11.18	25.21	NA
%HCR max	100.00	46.76	NA	57.36	57.36	57.36	57.36	39.64	NA
Mean Yrs HCRmin	NA	2.58	NA	2.58	2.58	2.58	2.58	3.98	NA
Mean Yrs HCRmax	NA	7.01	NA	8.56	8.56	8.56	8.56	5.97	NA
Mean Yrs NoCatch	2.37	1.86	131.43	1.86	2.28	2.27	1.86	1.84	NA
% Collapses	0	0	30	0	0	0	0	0	0

Scenario	HG J	M	New8	New6	HG Var3	New3	Alt3	Alt4	New1	New2	New4	New5	ABC
Variant Code	6	4	22	20	9	17	13	14	15	16	18	19	23
Variant Description	Base - case	Emsy No CUTOFF or MAXCAT, HG FRACTION is always set to 0.19.	HG FRACTION is 15%. Constant	HG FRACTION ranges 5-15% and depends on the most recent year of the environmental variable instead of a 3-year average	No MAXCAT, CUTOFF set to 20% of average unfished biomass (0.2(B_0) HG FRACTION ranges from 5 to 18%.	Same as 9, but with MAXCAT set to 200,000t	CUTOFF of 50,000t, HG FRACTION ranges between 11 and 18%.	No MAXCAT, HG FRACTION set to 0.18, and a CUTOFF of 50,000t	HG FRACTION equal to 18%.	HG FRACTION equal to 18% and no MAXCAT	OFL computed with an OFL FRACTION of 18% and the HG with a HG FRACTION of 15%	HG FRACTION is 15% constant and depends on the most recent year of the environmental variable instead of a 3-year average	
CalCOFI	3 yr ave	3 yr ave	3 yr ave	Annual	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	Annual	
OFL E_{MSY} (%)	0-25	0-25	0-25	0-25	0-25	0-25	0-25	0-25	0-25	0-25	18	0-25	0-26
HG FRACTION (%)	5-15	19	15	5-15	5-18	5-18	11-18	18	18	18	15	15	0-26
CUTOFF	150	None	150	150	0.20(B_0)	0.20(B_0)	50	50	150	150	150	150	0
MAXCAT	200	None	200	200	None	200	200	None	200	None	200	200	-
Performance Measure													
Biological													
Mean B1+ (SD)	1220 (888.1)	571.7 (747.4)	1207.7 (892.8)	1239 (885.6)	1177.8 (755.8)	1268.6 (876)	1149.6 (888.9)	1033.2 (750.1)	1178 (890.2)	1072.9 (757.7)	1148.4 (916.2)	1230.5 (888.9)	962.8532382
Mean SSB (SD)	946.7 (757)	403.9 (554.3)	936 (760.6)	965.4 (757.2)	891.9 (588.9)	990.3 (747.4)	883.2 (756.9)	761.1 (578)	908.4 (758.2)	796.5 (586.1)	884.1 (777.8)	958 (759.7)	701.5835996
%B1+>400	92.4	44.2	91.1	93	95.5	95.7	88.2	87.1	89.9	89.4	84.3	92.2	695.3185621
Depletion (B1+ % of Unfis	0.78	0.36	0.77	0.79	0.75	0.81	0.73	0.66	0.75	0.68	0.73	0.78	524.85
													85.3
Economic													
%No catch	4.7	25.1	4.7	9.7	9.8	9.5	4	4	4.8	4.9	2.3	9.7	4.028
%Catch<50	31.2	49.3	30	33.3	37.8	36.4	28.3	29.2	29.2	30.3	26.4	32.3	29.421
Median catch	97.4	51.9	97.7	92.2	81.7	88.5	109.3	100.9	104.8	97.2	104.3	92.8	102.31452
Mean catch all	105.8	108.5	106.6	101.7	133.9	100.8	113.2	149.3	110.9	146.1	111	102.3	158.7974256
SD catch all	72.5	158.3	71.5	73.6	165.1	76.6	73.2	164.1	73.3	163.6	69.6	72.9	183.6664263
Mean catch CO	110.9	144.9	111.7	112.3	148.3	111.2	117.8	155.5	116.4	153.5	113.6	113	165.3783036
SD catch CO	70.4	167.9	69.3	69.4	167.7	73.1	71	164.6	70.8	164.4	68.3	68.5	184.5914234
Median B1+	991.8	300.5	980	1020	994.5	1043.8	911.7	847.3	943.5	885.7	913.5	1012.1	788.04902
Median SSB	742.1	205.7	732.2	768.3	747.2	789.7	671.4	617.1	698.5	650.3	671.8	761.4	565.558785
Mean pop age	2.83	1.81	2.82	2.85	2.77	2.88	2.76	2.62	2.79	2.66	2.76	2.84	2.556783715
Mean Catch Age	1.83	1.16	1.82	1.85	1.78	1.86	1.78	1.69	1.8	1.71	1.78	1.84	1.641779844
%HCR min	11.18	NA	NA	16.65	11.18	11.18	28.63	NA	NA	NA	NA	NA	3.4295
%HCR max	57.36	NA	NA	56.64	46.76	46.76	46.76	NA	NA	NA	NA	NA	25.6795
Mean Yrs HCRmin	2.58	NA	NA	1.59	2.58	2.58	4.37	NA	NA	NA	NA	NA	1.87455589
Mean Yrs HCRmax	8.56	NA	NA	3.58	7.01	7.01	7.01	NA	NA	NA	NA	NA	4.035436474
Mean Yrs NoCatch	1.86	140.7	1.84	1.37	1.84	1.85	1.93	1.93	1.83	1.83	1.44	1.37	1.940737172
% Collapses	0	44	0	0	0	0	0	0	0	0	0	0	0

COASTAL PELAGIC SPECIES ADVISORY SUBPANEL REPORT ON PACIFIC SARDINE TEMPERATURE PARAMETER REVIEW

The Coastal Pelagic Species Advisory Subpanel (CPSAS) received a briefing from Ms. Lorna Wargo on the Coastal Pelagic Species Management Team (CPSMT) analyses and recommendations regarding sardine harvest parameters. The CPSAS commends the CPSMT for their work and supports the conclusions of the CPSMT report.

Achieving optimum yield requires balance between fishery opportunities, economic stability, and ecosystem and forage needs. The recommendations included in the CPSMT report help to maintain the goals and objectives of the CPS Fishery Management Plan, namely to:

1. Promote efficiency and profitability in the fishery, including stability of catch
2. Achieve optimum yield
3. Provide adequate forage for dependent species
4. Prevent overfishing

The CPSAS concurs with the CPSMT recommendation to use Harvest Policy Scenario K, outlined in Tables 2 and 3 of, Agenda Item I.1.c CPSMT Report. Although the CPSAS has concerns regarding the truncated time series available under California Cooperative Oceanic Fisheries Investigations (CalCOFI) (because there is lack of data on historic biomass), the CPSAS unanimously supports transitioning to the use of a 3-year average of the CalCOFI index. The CPSAS also concurs with the Harvest Parameters Workshop recommendation to conduct periodic review of the environmental proxy.

Integral to the use of the CalCOFI index is the adoption of FRACTION values that are consistent with Amendment 8. We support the CPSMT conclusion that an harvest control rule change to the CalCOFI index and FRACTION range of 10-20 best represent the sea surface temperature data and new knowledge regarding stock productivity. This option preserves current policy by permitting harvest rates to take advantage of periods when biomass and productivity are high, but restricts harvests when biomass and productivity are low.

The CPSAS notes that under Amendment 13 sardine management became even more precautionary, with the addition of the overfishing limit and acceptable biological catch control rules in addition to the harvest guideline control rule. Under Amendment 13, the lowest control rule prevails to determine annual management measures. The reanalysis conducted during the harvest parameters workshop, with the addition of recent data, produced a higher stochastic E_{msy}. The higher productivity (E_{msy} of 0.18 vs. 0.12) means that the depletion level (biomass remaining after accounting for the fishery) is significantly higher (above 70 percent) compared to the 64 percent depletion from Amendment 8 Option J.

In conclusion, the CPSAS supports the CPSMT recommended policy option, Scenario K, as the best option to preserve balance between fishing opportunity and ecosystem needs.

PFMC
03/11/14

Agenda Item I.1.c
Supplemental CPSMT PowerPoint
March 2014

Coastal Pelagic Species Management Team

Report on

Sardine Harvest Parameter Changes

Pacific Fishery Management Council
March 11, 2014
Sacramento, California

Background

- Sardine harvest control rules (HCR) include a temperature-dependent parameter; index used sea surface temperatures from Scripps Pier

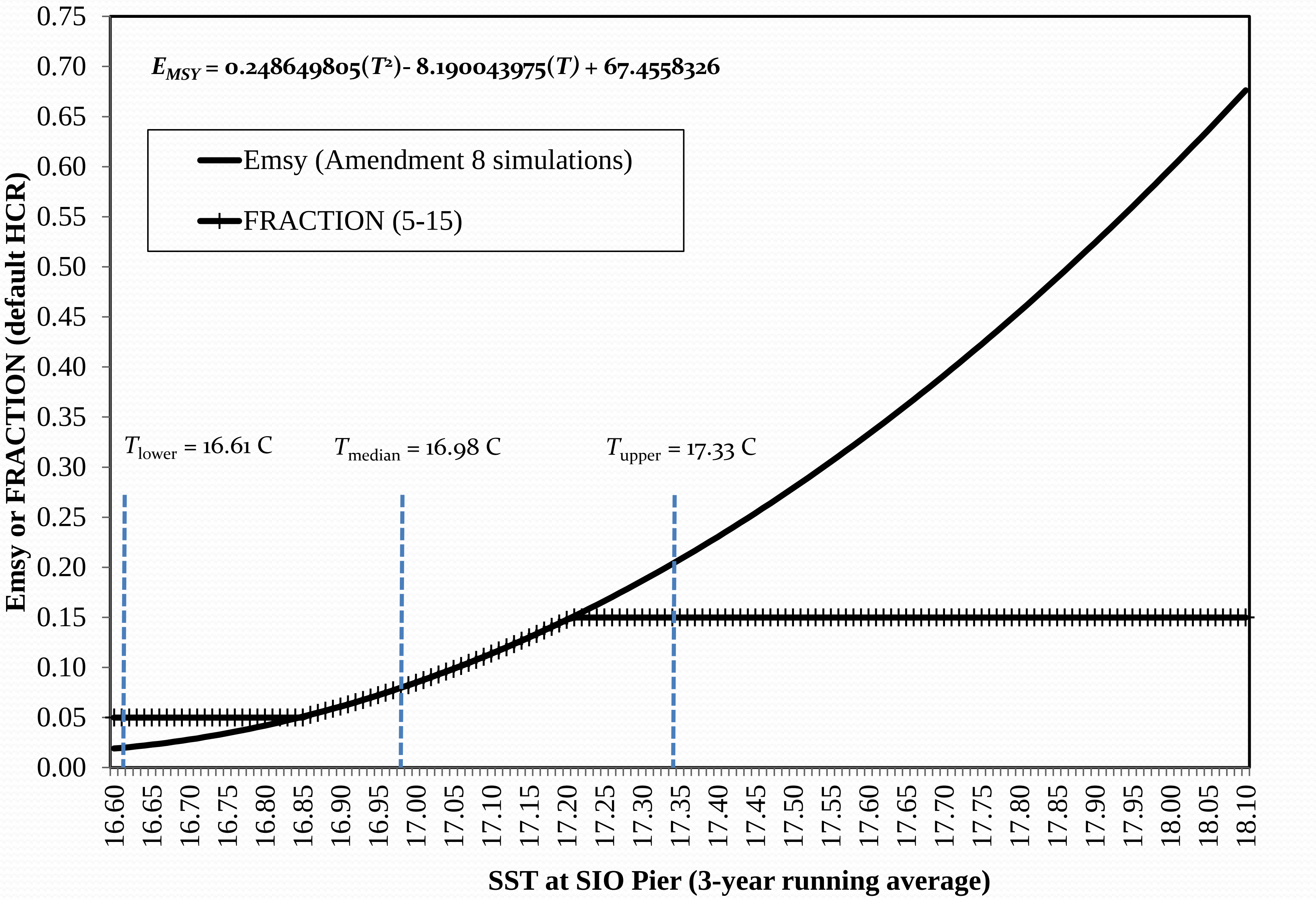
- 2010 – McClatchie et. al.
  Sea surface temperatures (SST) at Scripps Pier no longer represented ocean temperature

- 2013 – Lindegren and Checkley:
  SST from CalCOFI surveys explained sardine recruitment variability; and
  Harvest Parameter Workshop agreed

- 2013-14 Hurtado-Ferro and Punt :
  New simulation model, management scenarios

- 2014 – CPSMT Meeting and Harvest Parameter Report

Figure 1. E_{MSY} and FRACTION based on SST at SIO Pier



Purpose of report

- February 2013 workshop recommended that CalCOFI SSTs are the best choice for a relationship between an environmental variable and FRACTION

- CPSMT reviewed harvest scenarios to evaluate:

  If, or how, changing the temperature index from Scripps Pier to CalCOFI maintains or deviates from established management policy

  Model sensitivity to stock distribution

Current Policy

- OFL = BIOMASS * E_{MSY} * DISTRIBUTION
  ABC = OFL * BUFFER

- Harvest Guideline
  (HG) = (BIOMASS – CUTOFF) * FRACTION * DISTRIBUTION

- ACT = HG or ABC, whichever is lower

- HG FRACTION bounded at 5 – 15

Table 1. Scenarios Illustrating Broadly Contrasting Strategies

Scenario	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Variant Code	21	6	28	24	26	4	14	22
Scenario Description	No fishing	Base Case - "HG J" from Amendment 8	High CUTOFF, Pulse Fishery	Maximize catch, high FRACTION and high CUTOFF	Static MSY	E_{msy} - No CUT OFF or MAXCAT, HG FRACTION is always set to 0.19	No MAXCAT, HG FRACTION set at 0.18, Small CUTOFF	Temperature/ productivity varying E_{MSY}
CalCOFI	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave
OFL E_{MSY} (%)	-	0-25	0-25	45	Emsy	0-25	0-25	0-25
HG FRACTION (%)	0	5-15	5-15	45	Emsy	19	18	0-25
CUTOFF	-	150	640	0.33 * B0	0	None	50	0
MAXCAT	-	200	200	-	-	None	None	-
Performance Measure								
Biological								
Mean B1+ (SD)	1572 (907)	1220 (888)	1371 (868)	865 (613)	672 (780)	572 (747)	1033 (750)	963 (702)
Mean SSB (SD)	1304 (805)	945	1089 (741)	594 (391)	479 (586)	403 (554.3)	761 (578)	695 (525)
%B1+>400	99	92	98	83	52	44	87	85
Depletion (B1+ % of Unfished B1+)	-	78%	87%	55%	43%	36%	66%	61%
Economic								
%No catch	100	4.7	23.8	36.7	16.8	25.1	4.0	4.0
%Catch<50	100	31	49	47	42	49	29	29
Median catch	0	97	54	66	70	52	101	102
Mean catch all (SD)	0 (0)	106 (73)	79 (76)	184 (304)	121 (158)	108 (158)	149 (164)	158 (184)

Table 2. Scenarios Varying Fraction

Table 2. The results of modeling seven harvest control rule scenarios by varying FRACTION on biological and economic performance measures for the Pacific sardine population and fishery.

Scenario	B	I	K	L	M	N	O
Variant Code	6	25	31	32	15	22	18
Scenario Description	Base Case - "HG J" from Amendment 8	HG FRACTION bounded at 5-18	HG FRACTION bounded at 10-20	HG FRACTION bounded at 10-25	HG FRACTION set at 18%	HG FRACTION set at 15%	OFL set at 18% and HG FRACTION set at 15%
CalCOFI	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave	3 yr ave
OFL E_{MSY} (%)	0-25	0-25	0-25	0-25	0-25	0-25	18
HG FRACTION (%)	5-15	5-18	10-20	10-25	18	15	15
CUTOFF	150	150	150	150	150	150	150
MAXCAT	200	200	200	200	200	200	200
Performance Measure							
Biological							
Mean B1+ (SD)	1220 (888)	1197 (884)	1182 (883)	1170 (879)	1178 (890)	1208 (893)	1148 (916)
Mean SSB (SD)	947 (757)	925 (754)	911 (753)	900 (750)	908 (758)	936 (761)	884 (778)
%B1+>400	92	92	91	91	90	91	84
Depletion (B1+ % of Unfished B1+)	78%	76%	75%	74%	75%	77%	73%
Economic							
%No catch	4.7	4.7	4.7	4.7	4.8	4.7	2.3
%Catch<50	31	31	30	30	29	30	26
Median catch	97	104	107	110	105	98	104
Mean catch all (SD)	106 (73)	110 (75)	112 (75)	113 (76)	111 (73)	107 (72)	111 (70)

Figure 1. E_{MSY} and FRACTION based on SST at SIO Pier

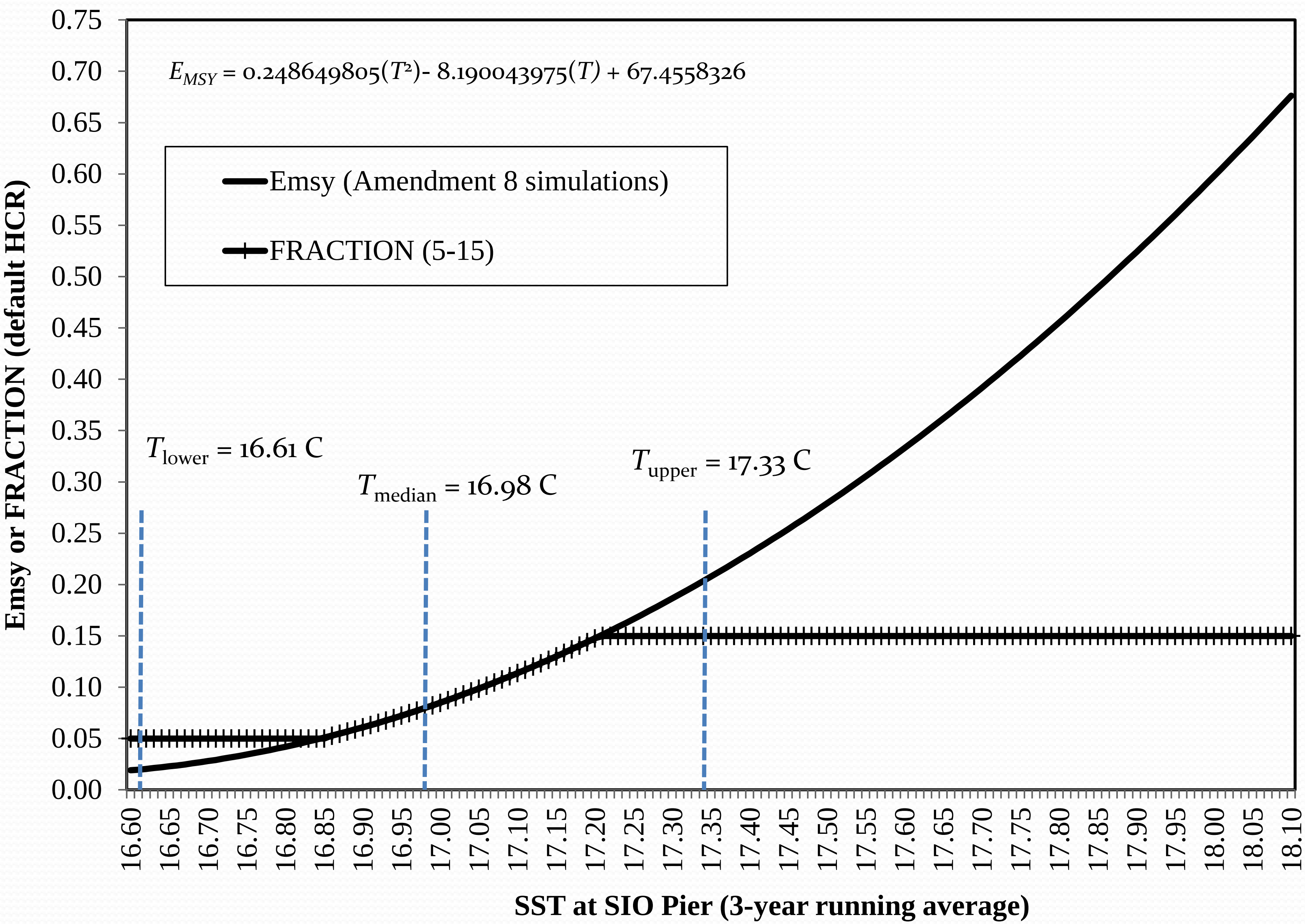


Figure 2. CalCOFI SST and E_{MSY} from Hurtado-Ferro; FRACTION 5-15

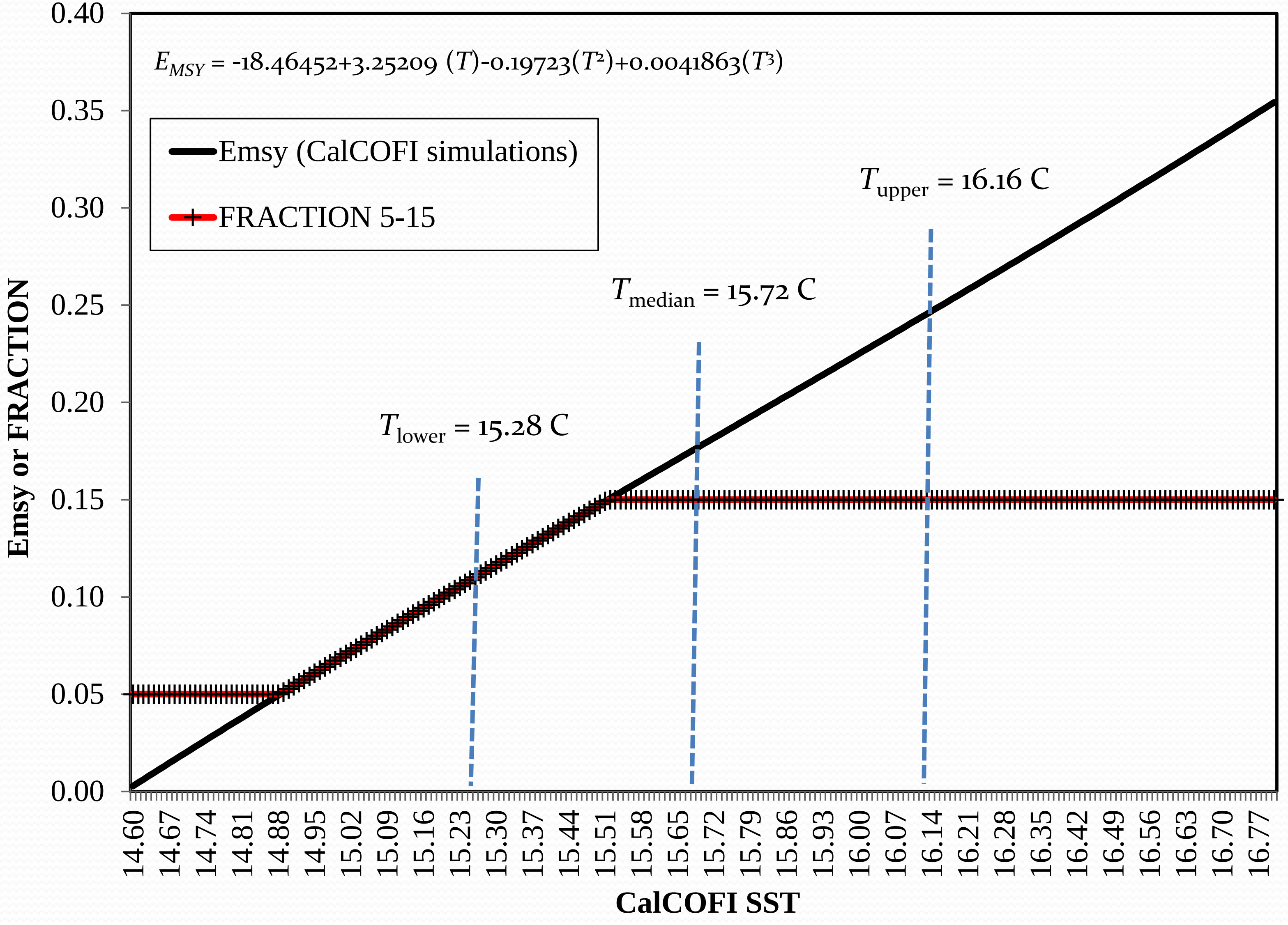


Figure 2. CalCOFI SST and E_{MSY} from Hurtado-Ferro; FRACTION 10-20

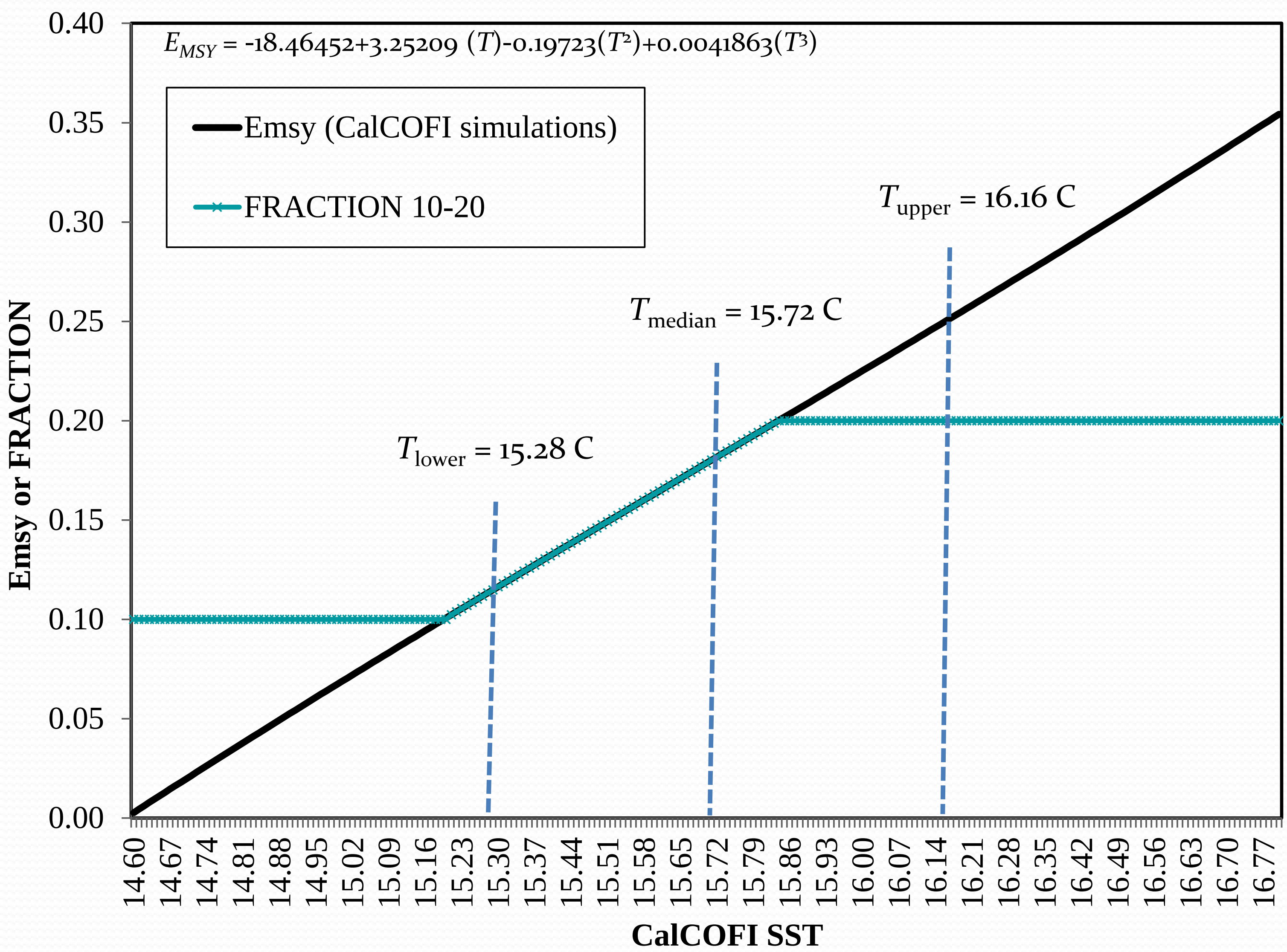


Figure 2. CalCOFI SST and E_{msy} from Hurtado-Ferro FRACTION 5-15 and 10-20

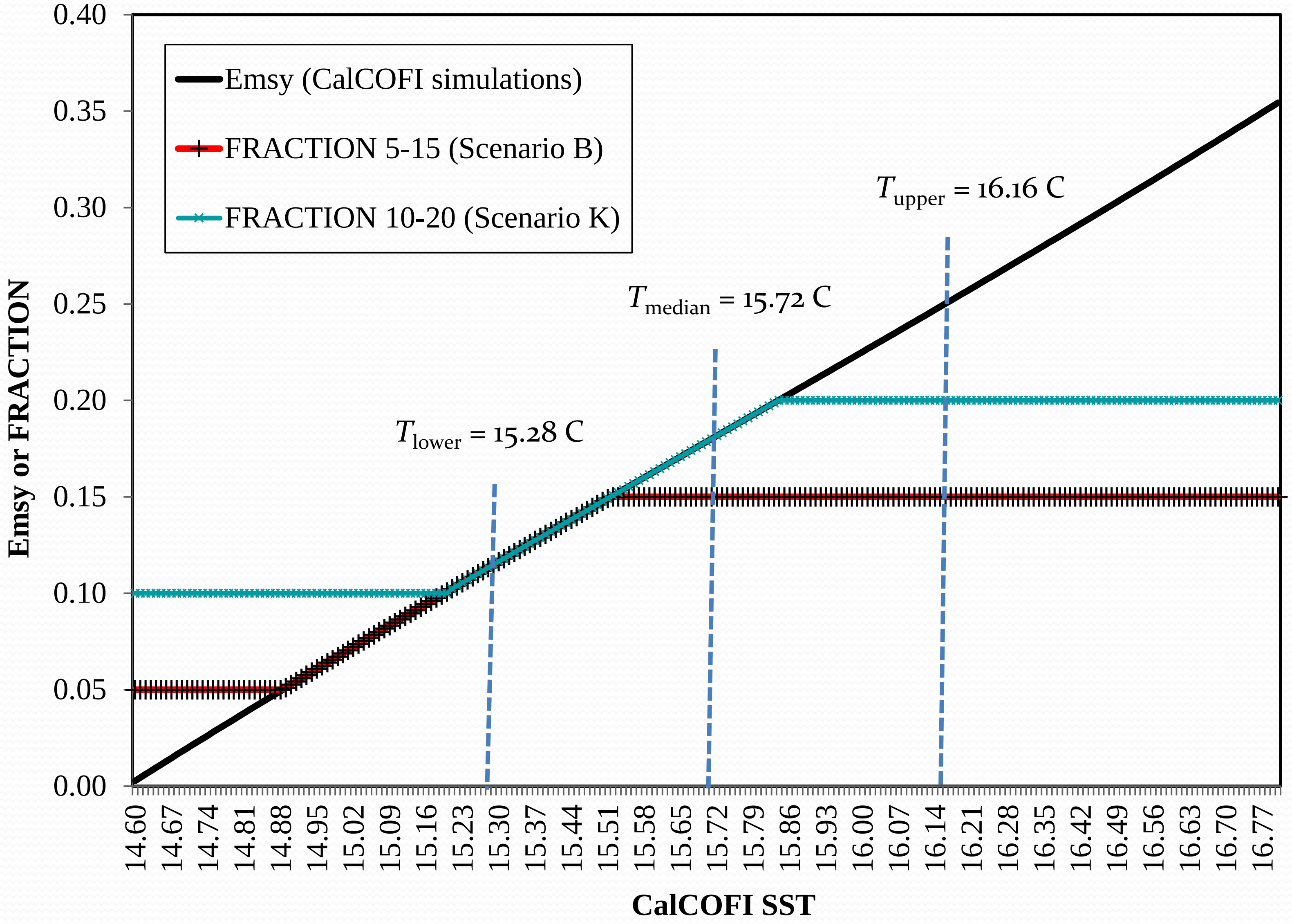
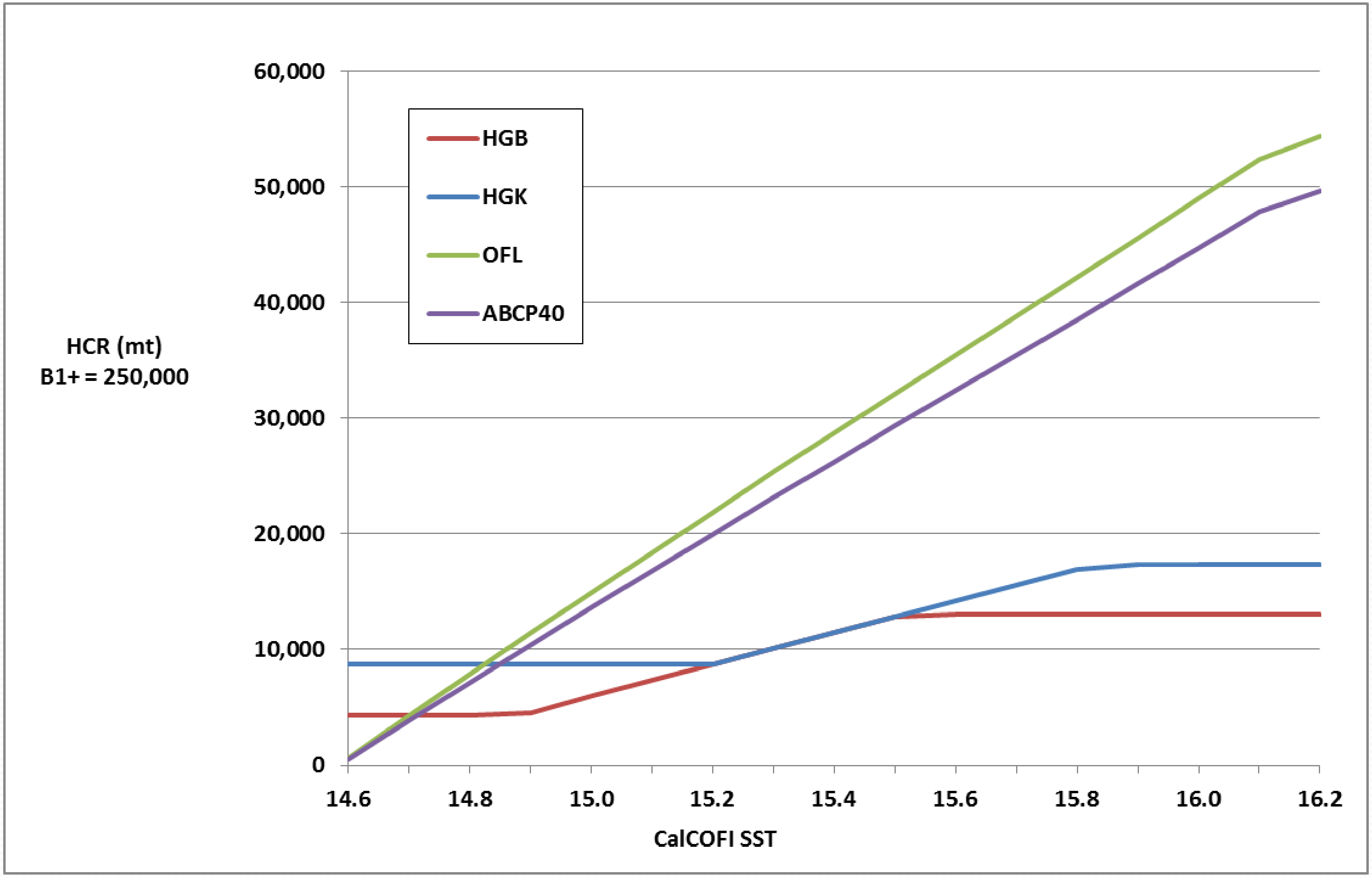


Table 3. Scenarios B (base case) and K (recommended)

Scenario	**B**	**K**
Variant Code	6	31
Scenario Description	Base Case - "HG J" from Amendment 8	HG FRACTION bounded at 10-20
CalCOFI	3 yr ave	3 yr ave
OFL E_{MSY} (%)	0-25	0-25
HG FRACTION (%)	5-15	10-20
CUTOFF	150	150
MAXCAT	200	200
Performance Measure		
Biological		
Mean B1+ (SD)	1220 (888)	1182 (883)
Mean SSB (SD)	945 (757)	911 (753)
%B1+>400	92	91
Depletion (B1+ % of Unfished B1+)	78%	75%
Economic		
%No catch	4.7	4.7
%Catch<50	31	30
Median catch	97	107
Mean catch all (SD)	106 (73)	112 (75)

Figure 3. Illustration of Harvest Control Rules at Low Biomass
OFL, ABC P*40, HG with FRACTION 5-10, HG with FRACTION 10-20



Distribution

- Operating Model Sensitivity

  Expected where fishing pressure by Mexico and Canada is static and remains relatively high during all years and conditions

- Distribution Parameter in Amendment 8

  Represent an average condition both within and among years

- Alternative approaches

Conclusion

- Current policy aims to:

  support higher harvest rates to take advantage of periods when biomass and productivity are high, and

  restrict harvest when biomass and productivity are low

- Current policy combines HCRs from Amendment 8 and 13

  Defaults to lowest HCR: OFL/ABC or HG
  Harvest Guideline is zero when biomass at CUTOFF

- Operating model sensitive to fixed catches
  no new information to update Distribution parameter

- Recommended HG FRACTION of 10-20 is consistent with policy

Don’t Get High-Centered

Acknowledgements:

Kirk Lynn, Josh Lindsay, Felipe Hurtado, CPSMT members, NMFS staff, SWFSC staff

Questions?

SSC REPORT ON PACIFIC SARDINE TEMPERATURE PARAMETER REVIEW

Dr. André Punt provided the Scientific and Statistical Committee (SSC) with a presentation on the report entitled "Revised Analyses Related to Pacific Sardine Harvest Parameters" (Agenda Item I.1.b). The report includes updated Management Strategy Evaluation analyses using revised California Cooperative Oceanic Fisheries Investigations (CalCOFI) temperature index data, and incorporates advisory body input regarding performance measures, candidate control rules, and sensitivity tests. The revised oceanographic data appear to have little influence on the results.

The SSC noted that the MSE results pertain to long-term (1000 year) estimates. Since the sardine population is currently in a relatively low portion of its cyclical variation, the next 10-year average harvests could likely be substantially lower than the mean annual harvests presented in the document.

The SSC recommends that overfishing limits (OFLs) for the northern subpopulation of Pacific sardine be based on an E_{msy} proxy derived from the relationship between estimated E_{msy} and the 3-year moving average of the CalCOFI temperature index, restricted to an E_{msy} range of 0-25 percent (Figure 4 of Agenda Item I.1.b – CalCOFI).

The SSC also reviewed the Coastal Pelagic Species Management Team's (CPSMT's) "Report on Sardine Harvest Parameters Changes", presented by Ms. Lorna Wargo, co-chair of the CPSMT. The CPSMT discussed the effects of the new CalCOFI temperature index and the revised temperature productivity relationship on the performance of potential sardine management harvest control rules (HCRs). Scenarios included, among others, evaluating FRACTION ranges of 5-15 percent and 10-20 percent, and consequent effects on HCRs. The SSC noted that, given the SSC's decision on OFLs (above), options D, E, and O of the CPSMT no longer apply. The SSC recognized that the choice of any particular range of the FRACTION parameter is primarily a matter of policy; however, the CPSMTs proposals are logical. In particular, the proposed change to a 10-20 percent range is intended to allow the harvest rate at the median observed temperature index to reflect the calculated relationship between the temperature index and E_{msy}.

Overall, the SSC finds that the revised analyses represent the best available science to guide Council decisions, and the CPSMT's recommendations provide useful guidance on potential policy changes regarding Pacific sardine harvest management.

The SSC recommends that the ability to change Pacific sardine HCRs should be frame-worked into the CPS Fishery Management Plan, as is currently the case for groundfish, making the process more flexible for future management.

PFMC
03/10/14

Comments on the Sardine Re-analysis.
Richard Parrish
February 12, 2014

Submitted to the Pacific Fishery Management Council for the March Briefing Book

Results from January 2014 CPSMT Meeting:

The Coastal Pelagic Species Management Team met in La Jolla in January 2014 to review the revised sardine population analysis (Hurtado-Ferro and Punt. 2013). Several different management policies, in addition to those in the above report, were examined.

The review focused on the shorter time series from the CalCOFI surveys (CC SST) and did not consider simulations using the Scripps Pier (SIO SST) or Extended Reconstructed (ERSST) time series. The revised analysis predicts a much smaller and more productive sardine population than the Amendment 8 analysis. Average unfished biomass is about 50% lower and average productivity is about 50% higher than the earlier analysis: (i.e. 1572 TMT vs 3050 TMT: and Emsy = 0.18 vs 0.12). The 2014 analysis predicts a population with much higher density-dependence than the earlier analysis.

A comparison of the policies from Amendment 8 and those in the CPSMT Report shows that HG J is a much more conservative a policy with the revised analysis. In the Amendment 8 analysis average depletion was 64% and the fishery was closed 1 year in 200. In the revised analysis the values are 78% and 1 year in 21. The CUTOFF was at about 5% of Bo in Amendment 8 and about 10% in the revised analysis.

The smaller biomass and higher productivity in the revised sardine analysis produces significant differences in the results predicted for the current harvest guideline (HG J) and other policies examined by the CPSMT (i.e. their Tables 1 and 2). The Amendment 8 analysis had an OFL policy (i.e. maximum long-term catch) that produced a pulse fishery closed just under 1 year in 2, an average catch of 208 TMT and an average depletion of 43%. The equivalent policy with the revised analysis (Scenario D) has the fishery shut down about 1 year in 3, an average catch of 184 TMT and an average depletion of 55%.

There has been little discussion in any of the recent sardine analyses regarding the optimum depletion level for sardine – one that balances ecosystem values with socio-economic values. The revised analysis shows that the sardine population is considerably more productive than earlier thought, as seen in the large increase in average depletion with the HG J (i.e. Scenario B; 64% to 78%.) The reference depletion level usually used in West Coast fishery management is the level that is produced by the Fmsy (or Emsy) policy. With the revised analysis this would be a depletion of 36% (Scenario F).

Scenario G with an average depletion of 66% most closely approaches the depletion level of HG J in the Amendment 8 analysis (i.e. 64%). However, it has a median catch (101 TMT) that is only 55% of the HG J Amendment 8 value of 182 TMT. The scenarios in the CPSMT's

Table 2 have a very narrow range of options with no change in either CUTOFF or MAXCAT. The average depletion in these scenarios range from 73% (Scenario O) to 78% (Scenario B). The median catch for these scenarios range from 97-110 TMT; all well below the 182 TMT predicted in Amendment 8. There was no attempt to develop a policy with higher median catch; this would require reductions in MAXCAT and possibly CUTOFF. Therefor I would not personally recommend any of the proposed policies. However, I note that the CPS management team attempted to strike a balance by recommending the harvest fraction range in Scenario L (10-20%) to account for higher productivity.

The bottom line is that all of the scenarios in the CPSMT's Table 2 are much more conservative than HG J in Amendment 8; median catch levels are far lower and average depletion levels are considerably higher.

Predictions for the Future of the Sardine Fishery:

There have been numerous predictions made by several NGOs, and others, that the sardine population is going to collapse in a manner similar to the collapse that occurred in the mid-1900s. In addition, it has been suggested that the Scripps Pier sea temperatures are no longer a predictor of reproductive success in sardine. This report is an attempt to place the present situation in context with what is known about the northern population of sardine in the California Current. Note that if the Scripps Pier sea surface temperatures are still a predictor of reproductive success in sardine the argument that we are presently going through a collapse 'like the one' in the mid-1900s is difficult to defend.

Stock Structure:

First we need to understand the stock structure of the sardine (*Sardinops sagax*). Genetic, morphometric and meristic studies show that there are five genetic stocks of sardine in the world (Parrish et al. 1989). One of these stocks occurs in the California Current and Gulf of California and it is known that this stock has extremely low genetic variation and 'almost no variation among populations in the frequencies of allozymes' (Hedgecock et al 1989). Hedgecock et al. also reported that biological data (i.e. growth rates) can safely be used for area-specific fishery models.

It has been generally accepted that the California Current sardine stock can be divided into three fishery stocks (Clark 1947, Felix-Uraga et al 2005). Recent evidence (Felix-Uraga et al. In Press) confirms that there are three fishery stocks; two in the California Current (i.e. the northern or 'cold' stock and the southern or 'temperate' stock) and one in the Gulf of California (i.e 'warm" stock).

Distribution:

The distribution of the northern sardine stock and its relationship with the stock in Baja California was described by Murphy (1966), the year I first started working on sardine.

> "Vrooman (1964) reports that the population of sardines is made up of three races. One in the Gulf of California, is apparently restricted and is not involved in

> the Pacific Coast fisheries. The other two are involved. The southern race has been identified from southern Baja California to San Pedro; those in the northern race, from San Quintin in northern Baja California to Monterey. The apparent wide overlap in distribution of these races is due to integration over time. Apparently their north-south movements are synchronous because they have not been found overlapping during any particular survey."

In the early California Current sardine fishery (i.e. prior to 1920) sardines were caught from British Columbia to southern California and the Canadian fishery reached 86,340 tons in the 1929-30 season (Murphy, 1966). However, the Oregon-Washington fishery did not get started until the mid-1930s. During the peak of the fishery (1926-27 to 1946-47) when the fishery was never below 200,000 tons per season, there were extensive landings from British Columbia to Southern California.

During the period of 1981-2012 sardine landings totaled 8,833,602 mt; 18.3% from the 'cold' stock, 16.0% from the 'temperate' stock and 65.7% from the 'warm' stock (Felix-Uraga et al. In Press). The dividing line between the northern and southern stocks is in the Southern California Bight and it moves seasonally in association with the 17 C isotherm. The 1981-2012 landings data in the above study suggest that 65.3% of the Ensenada, Mexico landings and 35.1% of the landings in Southern California were from the 'temperate' stock.

History of Exploitation and Collapse of the Northern Sardine Stock:

Parrish et al (1989) reported that the major sardine stocks have extensive latitudinal changes in their distribution that is associated with population size. Sardines expand their range into higher latitudes during periods of high biomass and abandon these high latitude areas during periods of low biomass. The pattern of collapse in the northern stock of California sardine, described below, was one of the major pieces in the Parrish et al report.

The US sardine fishery first exceeded 50,000 mt in the 1917-18 season; the Canadian fishery exceeded 50,000 mt in the 1927-28 season and the northern Baja California fishery did not exceed 50,000 mt until 1997 (Murphy 1966, Hill et al. 2011). The maximum observed sardine biomass, 3.894 million tons, occurred at the start of the 1931-32 fishing season (MacCall 2013) and the peak fishery occurred in the 1936-7 season when 791,334 tons were landed in the US and Canadian fisheries (Murphy 1966).

The second peak in sardine landings occurred in the 1941-2 season with an age 2+ biomass of 2.458 million tons. Over the two decades there was no regulation of either total catch or effort and by the end of the 1962-3 season the biomass fell to 0.021 million tons (Figure 1). The exploitation rate over this period averaged 43% with a maximum of 87% in the 1961-2 season. MacCall (1979) used a simple, but logical, population analysis to show that the sardine population would not have gone below about 1 million tons if it had been fished at a constant fishing mortality rate of F=0.25 (i.e. an exploitation rate of 22.1%) or a constant annual catch of 300,000 tons.

Hill (2013) reported that the total exploitation rate of age 0+ sardines ranged from 10.43% to 24.98% during calendar years 2000-12; and the average for these years was 13.63%; the corresponding values for the US portion of the fishery was 5.57% to 14.85% and 7.84%. A moderate portion of the 200-2012 landings were southern stock sardine so the actual average coastwise exploitation rate is undoubtedly somewhere between the 7.84% and 13.63% values.

It therefore appears that the exploitation rate on the northern stock during the 2000-12 period was less than one quarter of the rate observed during the historical collapse of the sardine.

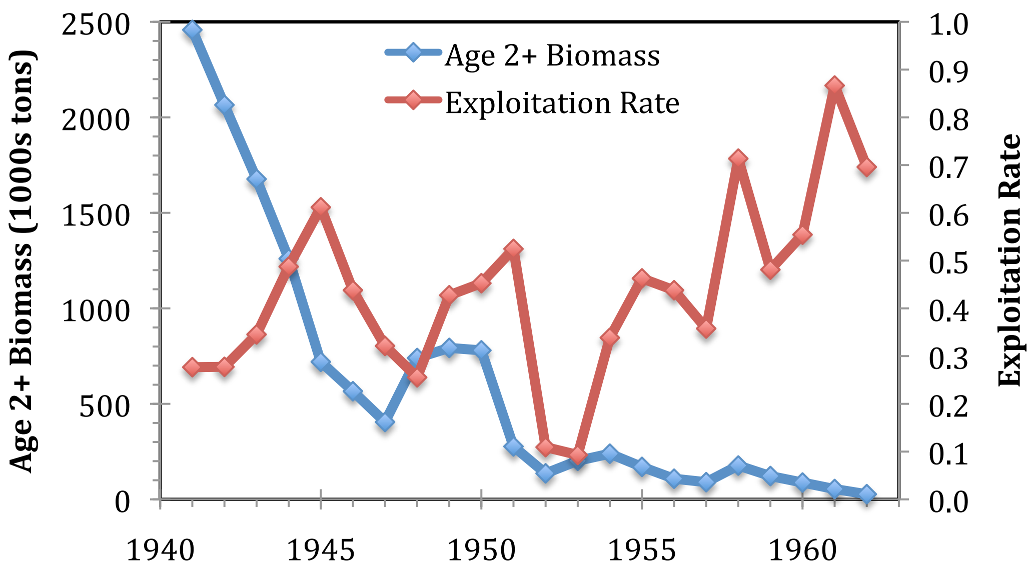


Figure 1. Sardine age 2+ biomass and exploitation rates from the second peak of the population in the 1942-3 season until the stock declined by 99% in at the end of the 1962-3 season. (Biomass in thousands of tons from MacCall 2013, landings from Murphy 1966).

Management:

The historical collapse of the Pacific sardine fishery occurred during a period when there was no regulation of annual landings or fishing effort. The present US fishery is regulated with both limited entry and an annual catch quota that automatically reduces the exploitation rate when the biomass decreases or cold environmental conditions in the southern nearshore area (i.e. Scripps Pier). The Canadian fishery is managed with an annual quota based on in-year biomass surveys and the Mexican fishery is primarily based on the southern (temperate) and Gulf of California (warm) stocks.

Environmental Conditions:

The large recent effort to re-assess sardine management was caused by the fact that environmental variable in the current harvest guideline rule (sea surface temperature at

Scripps Pier) became suspect. MacCall (2013) re-analyzed the environmental-dependent spawner-recruit relationships using a number of environmental variables. The two environmental series that can be used to assess the long-term (N= 61 years) SST in the sardine's spawning grounds are the Scripps Pier SST (SIO SST) and the Extended Reconstructed SST (ERSST). The Amendment 8 sardine analyses and the current Harvest Guideline include a 3 year running mean of the SIO SST, therefore the comparisons uses the 3 year average SST for both time series (i.e SIO SST T3 and ERSST T3 in Macall 2013).

Although the correlation between the two SST time series is R=0.72, the two time series have very major differences (Figure 2). The ERSST time-series has multi-year periods above and below the mean and little long-term trend. The SIO time-series has only minor excursions above the mean in the 1931-1980 period; but it never goes under the mean after 1980. The SIO series is colder than the ERSST time series for most of the time before 1976 and warmer than the ERSST series in most of the years since 1976.

The two time-series represent different geographical areas and the 1931-2008 average Scripps Pier SST (17.15 C) shows that is 1.62 degrees C colder than the ERSST average (18.77).

Has time invalidated the original (Jacobson and MacCall 1995) temperature-dependent spawner-recruit model? MacCalls (2013) R- non-linear and linear fits to the ln(R/S) model with SIO SST T3 both have an R-squared of 0.39 with 61 years of data. The same model with the ERSST time series has an R-squared of 0.27. The original linear fit to the ln(R/S) model had an R-squared of 0.27 with 34 years of data (Jacobson and MacCall 1995). Clearly the new Scripps Pier time series is a better descriptor of sardine recruitment than either the original, shorter time series, or ERSST the other long-term SST time series examined.

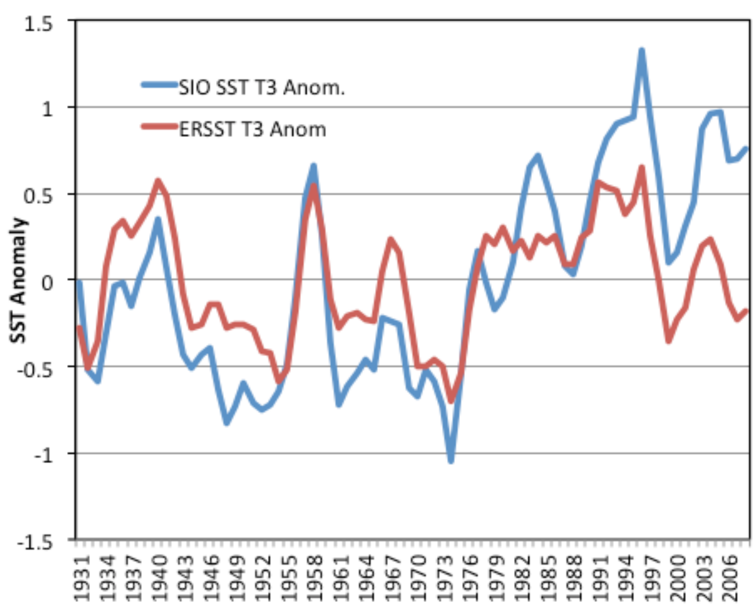


Figure 2. SST anomalies for 3 year average Scripps Pier and Extended Reconstructed sea surface temperatures (1931-2008. (Data from MacCall 2013)

Obviously the claims that the original model has been ‘debunked’ are not valid and in fact the statistical fit with the new, and much longer time series, are considerably better than the original.

It is also clear that the SST at Scripps Pier was considerably colder during the collapse of the sardine that occurred in the late 1940s and early 1950s than it is at present and the ERSST had a more extensive negative SST anomaly during the 1943-56 period when the stock collapsed.

References:

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Agenda Item I.1.d
Supplemental Public Comment PowerPoint
March 2014

Pacific Sardine Harvest Parameters

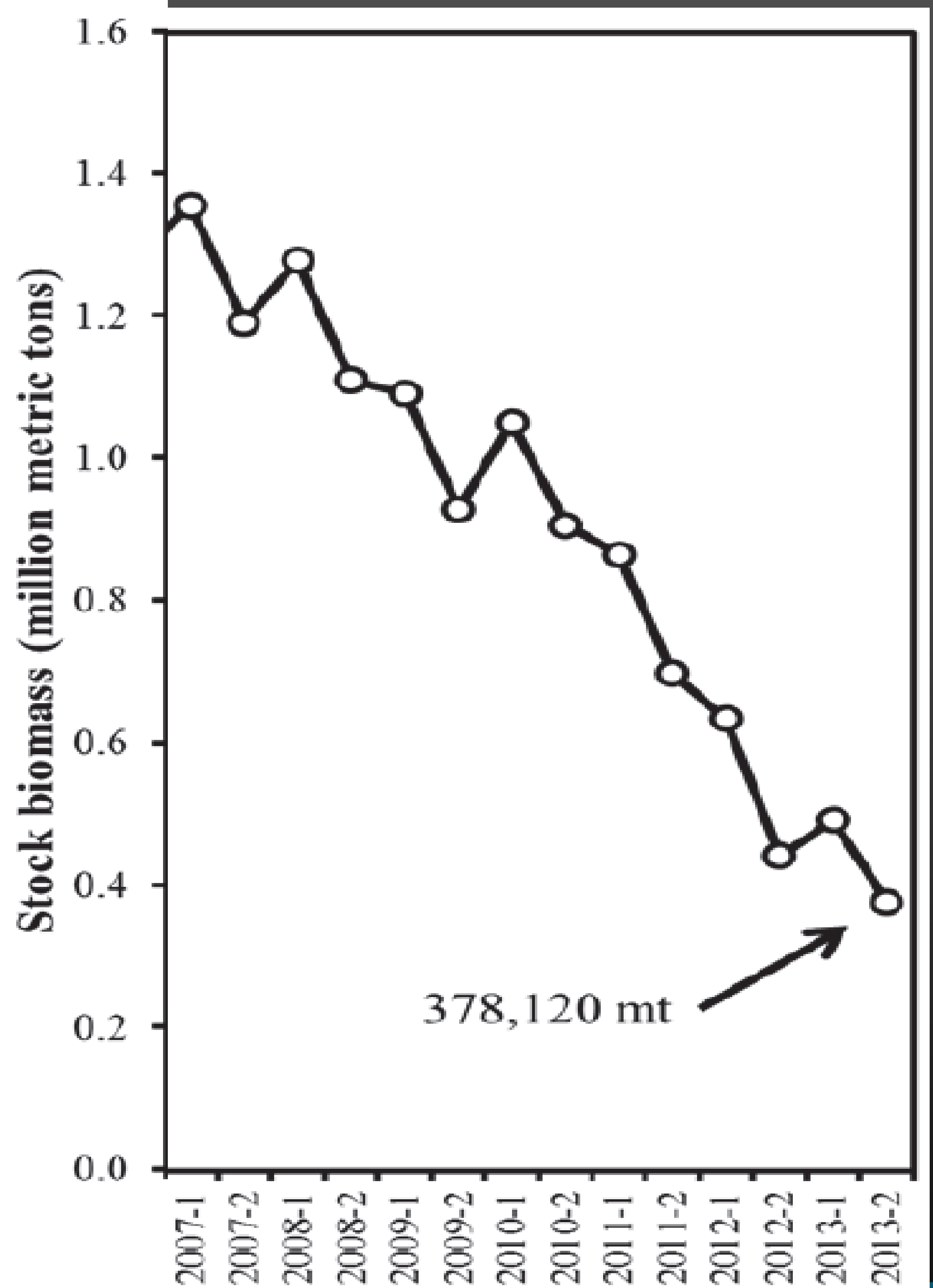
Geoff Shester, Ph.D.
California Campaign Director

OCEANA

Summary of Requests

- Do not change FRACTION range at this time (keep bounded at 5-15%)
- Adopt the CalCOFI temperature index (3-year moving average) for setting FRACTION in the Harvest Guideline
- Agendize consideration of full revision of Harvest Guideline (CUTOFF, DISTRIBUTION, etc.)

OCEANA



Do Not Increase Fraction Range

- Current Fraction Range: 5-15%
- 10-20% is a more aggressive harvest range resulting in lower biomass (CPSMT Rpt, Table 3)
- Temperature index and Fraction range are two distinct, separate decisions
- Now is not the time to be fishing sardines more aggressively:
  - HG has been overestimating productivity (73% stock decline in 7 years; low recruitment)

Source: Hill et al. 2013. Pacific sardine biomass projection in 2013; November 2013, E.5.b

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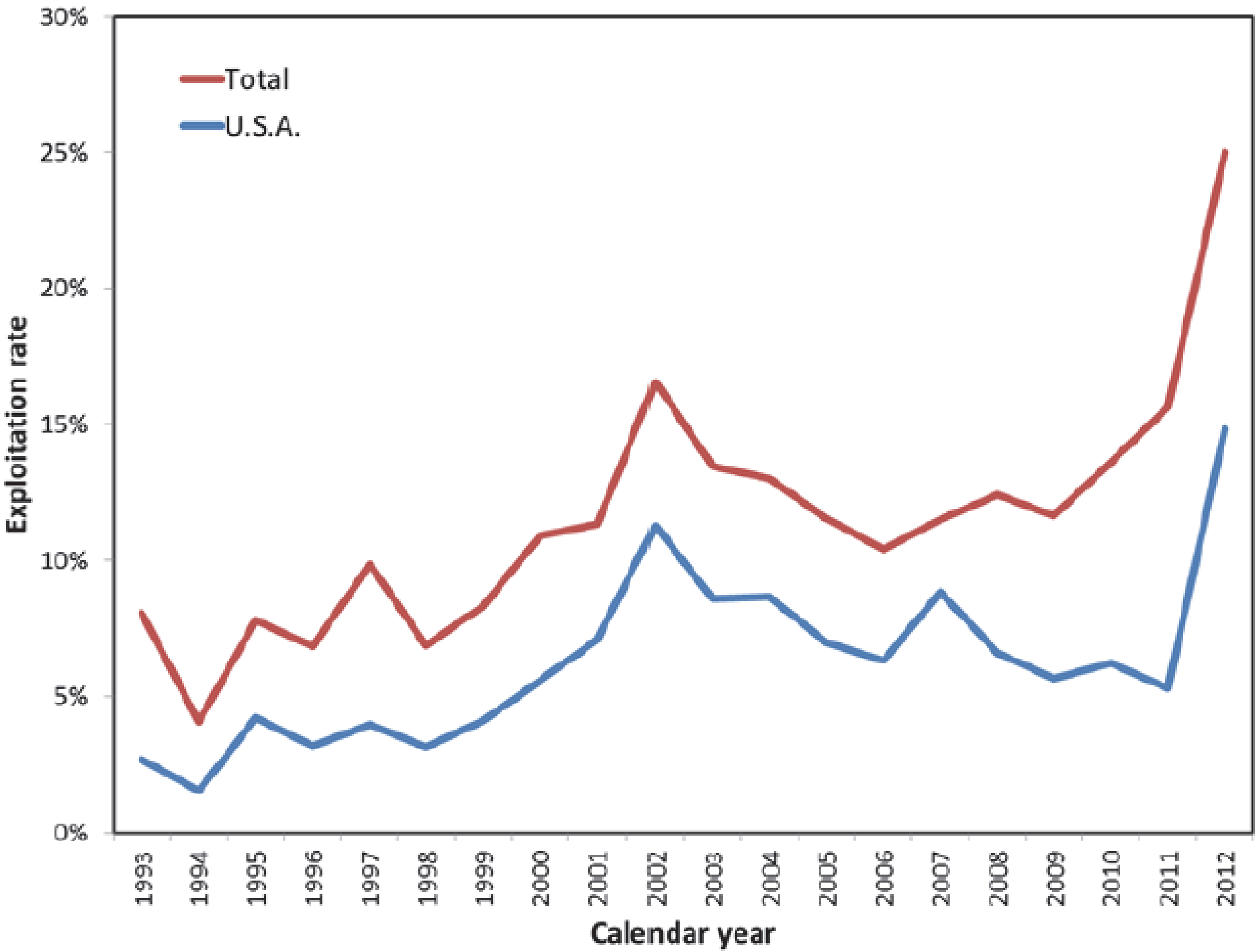
Sardine Overfishing Occurred in 2012

(Overfishing Limit Set at 18%)



Calendar year	U.S.A.	Total
2000	5.57%	10.91%
2001	7.07%	11.34%
2002	11.26%	16.55%
2003	8.59%	13.46%
2004	8.68%	13.02%
2005	6.99%	11.53%
2006	6.33%	10.43%
2007	8.85%	11.50%
2008	6.59%	12.43%
2009	5.64%	11.64%
2010	6.23%	13.59%
2011	5.30%	15.63%
2012	14.85%	24.98%

Source: Hill et al. 2013. Pacific sardine biomass projection in 2013; November 2013, E.5.b

New Evidence of Inadequate Forage

Specifically Sardine and Anchovy

- **California Sea Lions** –
  Unusual Mortality Event
  (Melin et al., NOAA, 2014)

Ingrid Overgard/TMMC

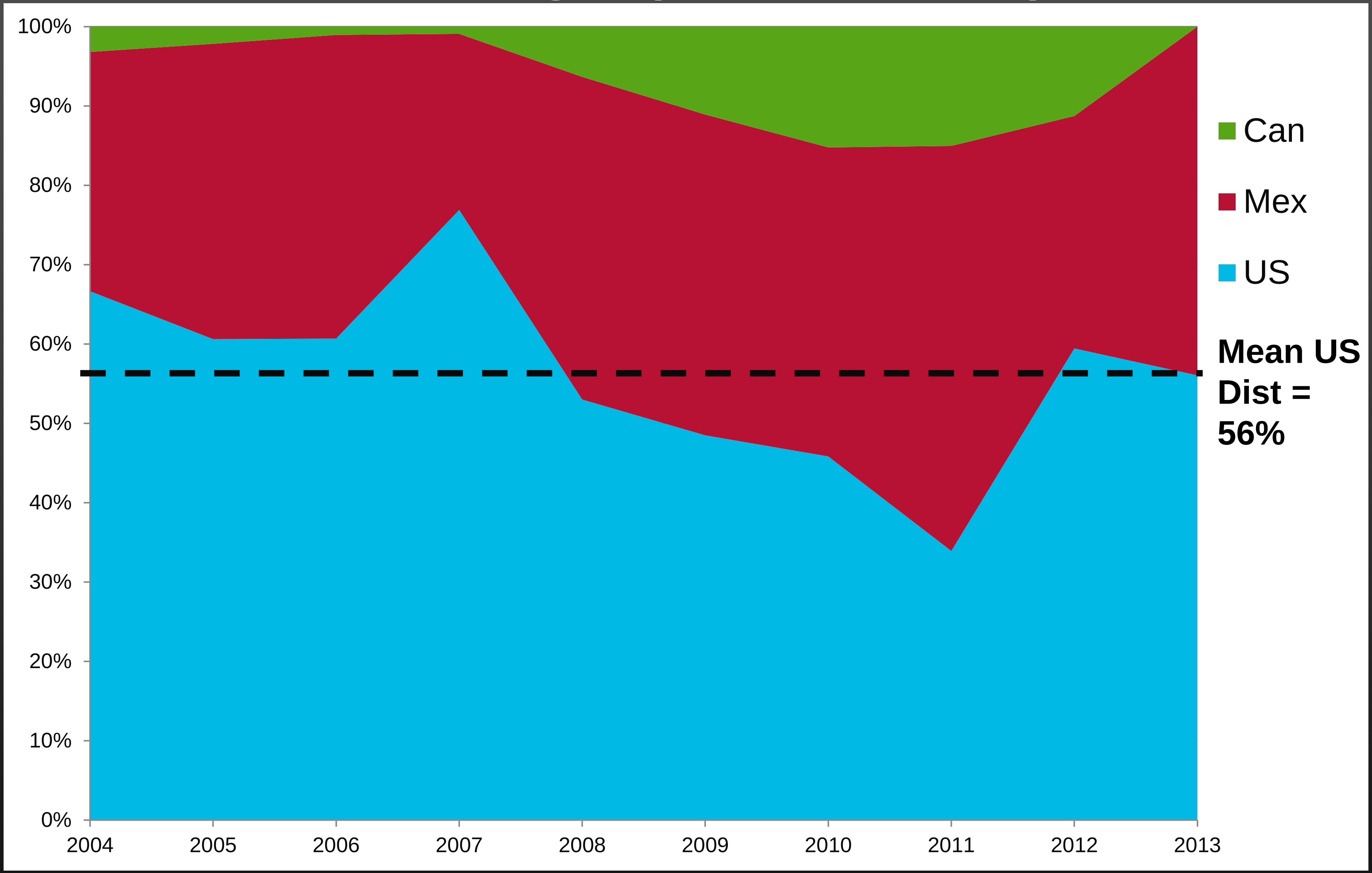
- **Brown Pelicans** –
- Nesting Failures (Harvey 2013)

Ingrid Taylar

- **Tufted Puffins** –
  ESA Listing Petition (NRDC 2014)

Geoff Shester/Oceana

Actual Distribution of Pacific Sardine Landings (2004-2013)



Source: Hill 2013. Pacific sardine biomass projection in 2013; November 2013, E.5.b

OCEANA

Three Ways to Fix DISTRIBUTION

When Mexico and Canada Aren't Following the US Harvest Guideline

- Set HG and OFL based on coastwide assessment then subtract most recent year's landings from Canada and Mexico

- Estimate the portion of the sardine stock in US waters (recommended in CPS FMP) in the stock assessment

- Use CUTOFF to account for foreign catch

OCEANA

Oceana’s Proposal

Parameters	Current HG	Oceana Proposed Harvest Control Rule
CUTOFF (B1+, mt)	150,000	640,000
FRACTION	5-15% (SIO index)	5-15% (CalCOFI index)
MAXCAT (mt)	200,000	300,000
DISTRIBUTION (U.S.)	87% of TOTAL HG	TOTAL HG - Lmexico - Lcanada
MSST (1+, mt)	50,000	640,000
OFL (TOTAL)	18% of Biomass (1+)	Emsy (0-25%) based on CalCOFI
OFL (US)	87% of TOTAL OFL	TOTAL OFL - Lmexico - Lcanada

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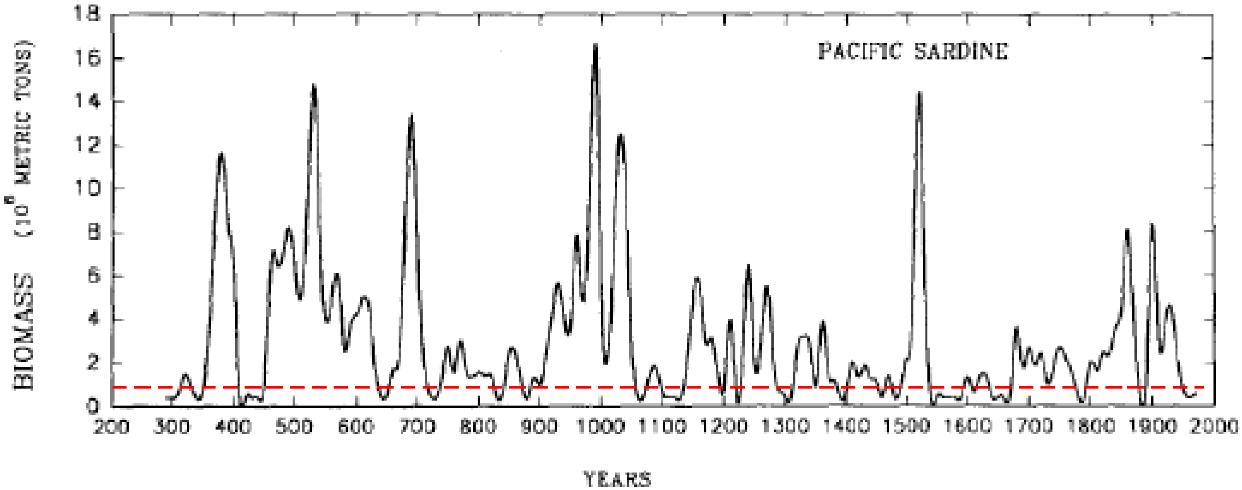
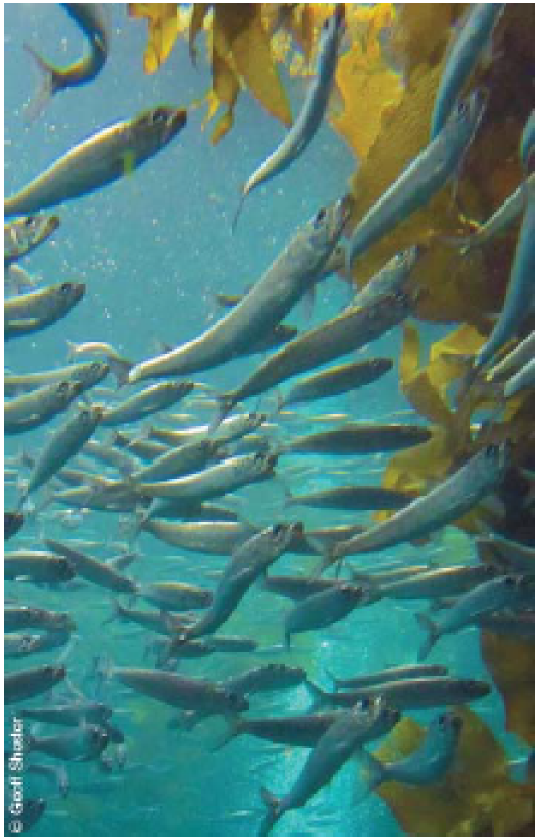
Pacific Sardine

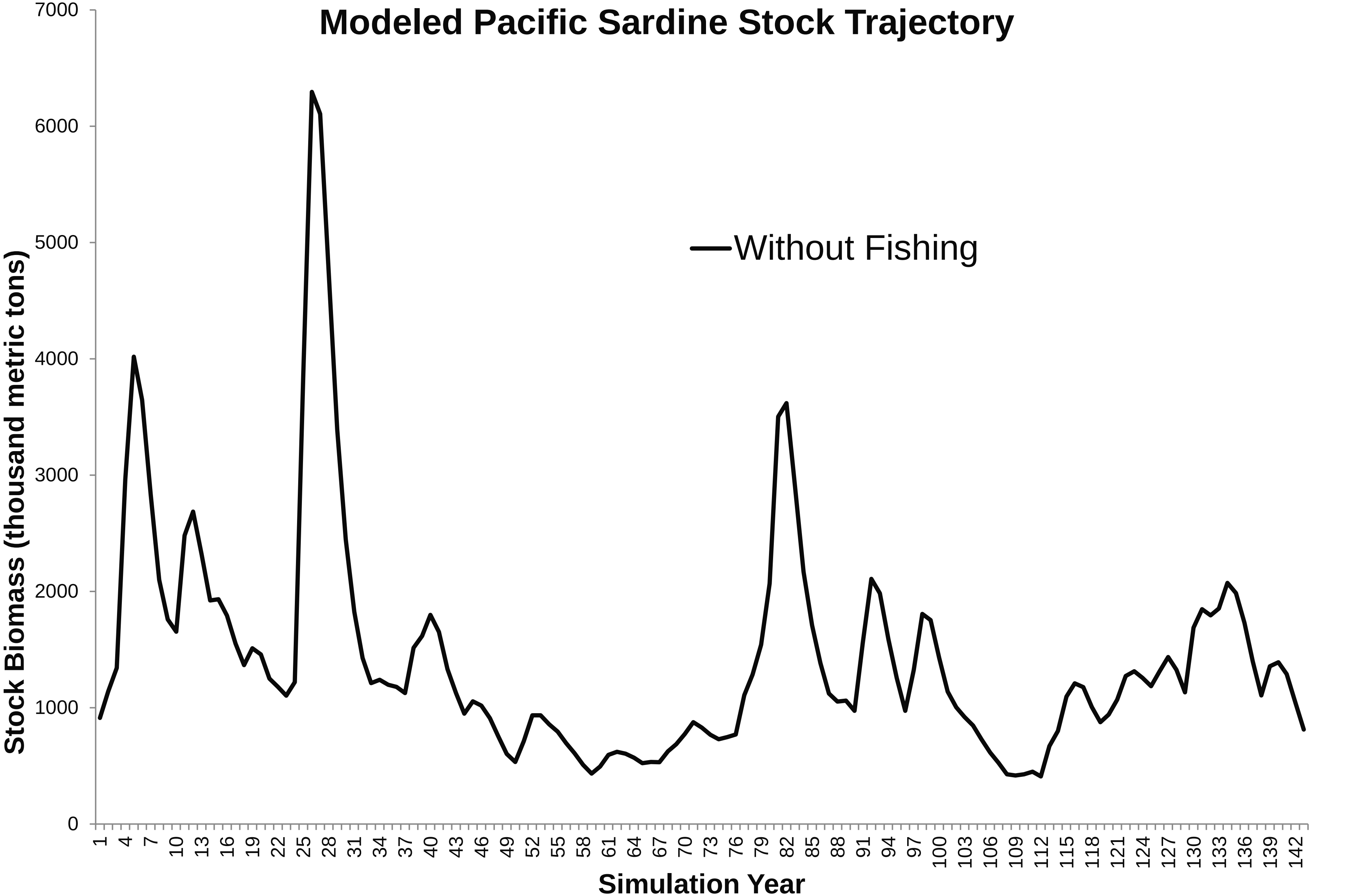
1700-yr hindcast series of Pacific sardine using fish-scale-deposition rates from sediments in the Santa Barbara Basin



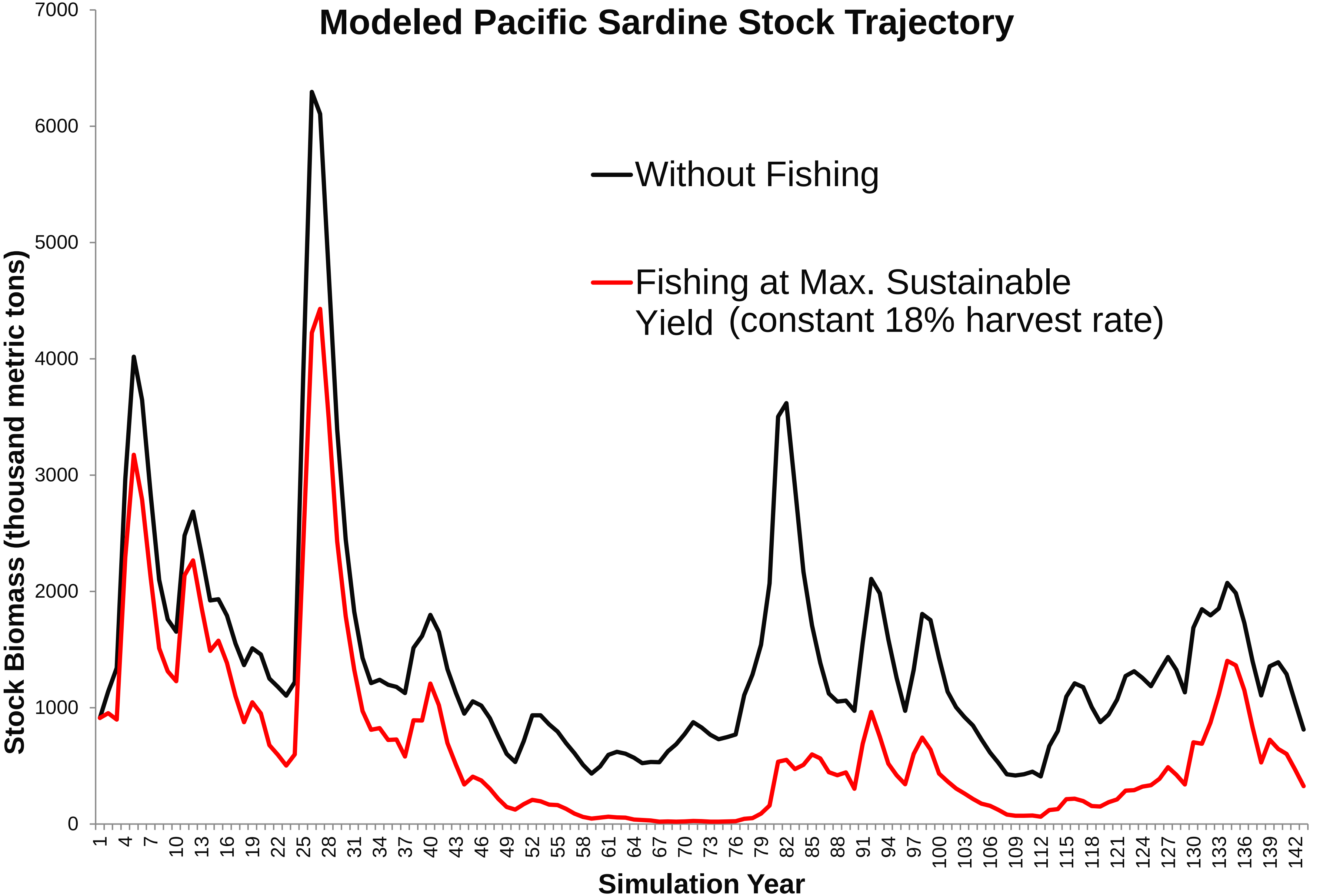


Collapse: less than 1 million tons
Recovery: greater than 4 million tons

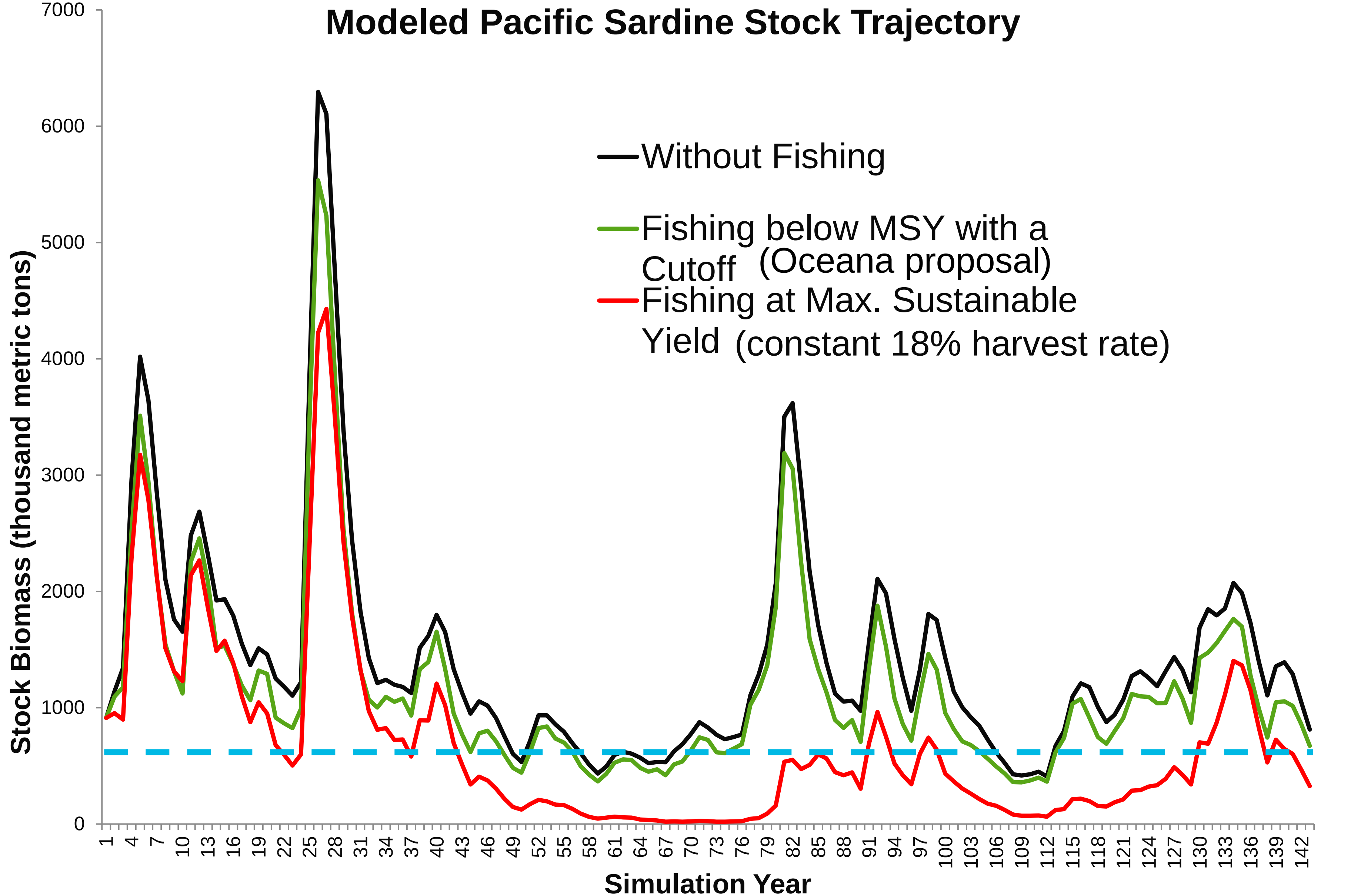
Baumgartner et al. (1992)



Trajectories based on 2013 Hurtado & Punt model



Trajectories based on 2013 Hurtado & Punt model



Trajectories based on 2013 Hurtado & Punt model

New Operating Model Results

	Oceana proposed *("Request 6")*	Option J assuming Mex/Can follow US HG *("Option J")*	Option J with only US following US control rule *("MF")*
Mean B1+	**1,346**	**1,220**	**716**
% of unfished B1+	**0.86**	**0.78**	**0.46**
% years with B1+>400,000 t	**97.75**	**92.4**	**58.9**
Mean catch (all years)	**89.4**	**105.8**	**57.2**
% years with catch<50,000 t	**49.2**	**31.2**	**58.8**

From CPSMT March 2014 Report and Hurtado-Ferro and Punt (2014).

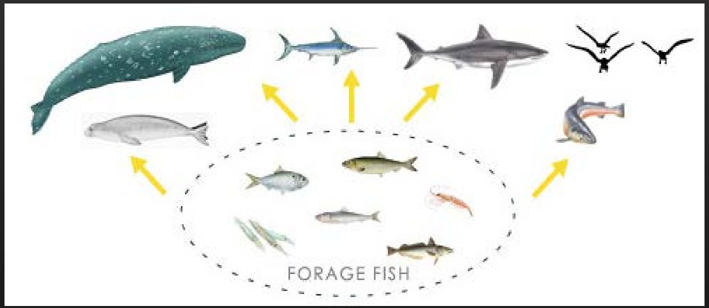
OCEANA

CUTOFF is Critical

- CUTOFF must explicitly be used to provide adequate forage to dependent predators (this is a goal of the CPS FMP)
- Current CUTOFF not high enough to:
  - Reduce stock risk
  - Increase biomass
  - Provide forage production
  - Address uncontrolled Mex/Can landings

Conclusion

- New data and experience since Amendment 8 show we need more precautionary HCR
- Do not adopt more aggressive HCR (10-20% is more aggressive); but use CalCOFI index to set HG FRACTION
- Overhaul of Sardine HCR required to:
  - Provide adequate forage
  - Prevent overfishing
  - Address international dilemma



- Consider & Adopt Oceana's proposed HCR

Agenda Item I.1.d
Supplemental Public Comment 2
March 2014

California Wetfish Producers Association
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March 12, 2014

Ms. Dorothy Lowman, Chair
And Members of the Pacific Fishery Management Council
7700 NE Ambassador Place #200
Portland OR 97220-1384

RE: Agenda Item I.1. Pacific Sardine Temperature Parameter Review

Dear Ms. Lowman and Council members,

I am Executive Director of the California Wetfish Producers Association (CWPA), representing the majority of coastal pelagic species 'wetfish' fishermen and processors in California. I appreciate your consideration of the following points in the continuing discussion whether and how to modify the sardine harvest control rule to address ocean temperature as the proxy for environmental conditions influencing sardine recruitment. This letter is an extension of our earlier comments, submitted in June, 2013, as Supplemental Public Comment 2, after attending the sardine harvest parameters workshop and subsequent CPS management team meetings, including the most recent CPSMT meeting held in January 2014.

Re: changing the environmental proxy from Scripps Pier sea surface temperature (SIO SST) to Cal-COFI 5–15 meter temperature, which measures mid-water depths that track on average about 2 degrees colder than the surface, I'd appreciate the Council's reconsideration of the following excerpts from my June 2013 comments:

- While CalCOFI midwater temperatures appeared to be the best fit to the data in the recent period (1984-2008), analysis showed that "[the NOAA Extended reconstructed sea surface temperature] ERSST_T5 (i.e., a five-year running mean starting and ending two years before and after the recruitment event) was the most significant variable for recruitment and recruitment success for the entire data set [which encompassed both cold and warm periods over time (1935-63 and 1986-90)], including output from three stock assessments (i.e., Murphy, 1966; MacCall, 1979; Hill et *al.*, 2010). **ERSST_T5 and SIO_SST_T5 were the most significant variables for recruitment and recruitment success, respectively, when missing data were excluded. "** The sardine workshop report noted that new indices are under development (I.1.b_ATT1_SARDINE_WKSHP_RPT_APR2013BB) and recommended **"... that the Council consider developing procedures which allow a regular (every 5-7 years perhaps) evaluation of whether the selected environmental variable remains the best predictor of recruitment success. "**

We again encourage the Council to act on that recommendation.

- The sardine workshop recommended using an **annual** CalCOFI 5-15 meter temperature average as the environmental proxy, but the management team recognized that a **3-year mean** temperature is better for management because it smoothes the "ups and downs" of harvest fractions.

We continue to agree that a three-year mean temperature parameter is best to maintain stability in the fishery. Fishery economics require the ability to forecast in business plans.

Representing California's Historic Fishery

• And again, we ask the Council to consider that achieving **OY requires balance: considering both fishery opportunity and economic stability as well as forage needs.**

With that preamble, I appreciate the Council's consideration of the following information specific to the recent reanalysis of the Amendment 8 HCR provided by Dr. Richard Parrish, an architect of the original sardine HCR who attended both the workshop and subsequent CPSMT meetings. I have highlighted some key points, and attached for reference his complete letter to the Council. Dr. Parrish has also submitted his comments independently.

EXCERPTS

Comments on the Sardine Re-Analysis

Richard Parrish (I.1.d, Public Comment, March 2014)

(Please note that direct quotes are highlighted in italics. Emphasis added.)

Results from January 2014 CPSMT Meeting:

• *"There has been little discussion in any of the recent sardine analyses regarding the optimum depletion level for sardine – one that balances ecosystem values with socio-economic values.* ***The revised analysis shows that the sardine population is considerably more productive than earlier thought, as seen in the large increase in average depletion with HG J [Amendment 8] (i.e. Scenario B Base Case; 64% to 78%.) …"***

• . "*The scenarios in the CPSMT's Table 2 have a very narrow range of options with no change in either CUTOFF or MAXCAT. The average depletion in these scenarios range from 73% (Scenario O) to 78% (Scenario B). The median catch for these scenarios range from 97-110 TMT; all well below the 182 TMT predicted in Amendment 8. There was no attempt to develop a policy with higher median catch; this would require reductions in MAXCAT and possibly CUTOFF. Therefore I would not personally recommend any of the proposed policies.* ***However, I note that the CPS management team attempted to strike a balance by recommending the harvest fraction range in Scenario L (10-20%) to account for higher productivity."***

"The bottom line is that all of the scenarios in the CPSMT's Table 2 are much more conservative than HG J in Amendment 8; median catch levels are far lower and average depletion levels are considerably higher."

Predictions for the Future of the Sardine Fishery

" There have been numerous predictions made by several NGOs, and others, that the sardine population is going to collapse in a manner similar to the collapse that occurred in the mid-1900s. In addition, it has been suggested that the Scripps Pier sea temperatures are no longer a predictor of reproductive success in sardine. This report is an attempt to place the present situation in context with what is known about the northern population of sardine in the California Current. "

Stock Structure:

"It has been generally accepted that the California Current sardine stock can be divided into three fishery stocks (Clark 1947, Felix-Uraga et al 2005). Recent evidence (Felix-Uraga et al. In Press) confirms that there are three fishery stocks; two in the California Current (i.e. the northern or 'cold' stock and the southern or 'temperate' stock) and one in the Gulf of California (i.e 'warm" stock)."

Distribution:

"During the period of 1981-2012 sardine landings totaled 8,833,602 mt; 18.3% from the 'cold' stock, 16.0% from the 'temperate' stock and 65.7% from the 'warm' stock (Felix-Uraga et al. In Press). The dividing line between the northern and southern stocks is in the Southern California Bight and it moves seasonally in association with the 17 C isotherm. The 1981-2012 landings data in the above study suggest that 65.3% of the Ensenada, Mexico landings and 35.1% of the landings in Southern California were from the 'temperate' (i.e. southern) stock."

History of Exploitation and Collapse of the Northern Sardine Stock:

"The maximum observed sardine biomass, 3.894 million tons, occurred at the start of the 1931-32 fishing season (MacCall 2013) and the peak fishery occurred in the 1936-7 season when 791,334 tons were landed in the US and Canadian fisheries (Murphy 1966).

The second peak in sardine landings occurred in the 1941-2 season with an age 2+ biomass of 2.458 million tons. ***Over the two decades there was no regulation of either total catch or effort and by the end of the 1962-3 season the biomass fell to 0.021 million tons (Figure 1). The exploitation rate over this period averaged 43% with a maximum of 87% in the 1961-2 season****. MacCall (1979) used a simple, but logical, population analysis to show that the sardine population would not have gone below about 1 million tons if it had been fished at a constant fishing mortality rate of F=0.25 (i.e. an exploitation rate of 22.1%) or a constant annual catch of 300,000 tons. "*

"Hill (2013) reported that the total exploitation rate of age 0+ sardines ranged from 10.43% to 24.98% during calendar years 2000-12; and the average for these years was 13.63%; the corresponding values for the US portion of the fishery was 5.57% to 14.85% and 7.84%. ***A moderate portion of the 200-2012 landings were southern stock sardine so the actual average coastwise exploitation rate is undoubtedly somewhere between the 7.84% and 13.63% values.***

It therefore appears that the exploitation rate on the northern stock during the 2000-12 period was less than one quarter of the rate observed during the historical collapse of the sardine. "

Management:

"The historical collapse of the Pacific sardine fishery occurred during a period when there was no regulation of annual landings or fishing effort. The present US fishery is regulated with both limited entry and an annual catch quota that automatically reduces the exploitation rate when the biomass decreases or cold environmental conditions in the southern nearshore area (i.e. Scripps Pier). *The Canadian fishery is managed with an annual quota based on in-year biomass surveys and the Mexican fishery is primarily based on the southern (temperate) and Gulf of California (warm) stocks. "*

Environmental Conditions:

"Has time invalidated the original (Jacobson and MacCall 1995) temperature-dependent spawner-recruit model? MacCalls (2013) R- non-linear and linear fits to the ln(R/S) model with SIO SST T3 both have an R-squared of 0.39 with 61 years of data. The same model with the ERSST time series has an R-squared of 0.27. The original linear fit to the ln(R/S) model had an R-squared of 0.27 with 34 years of data (Jacobson and MacCall 1995). Clearly the new Scripps Pier time series is a better descriptor of sardine recruitment than either the original, shorter time series, or ERSST the other long-term SST time series examined. "

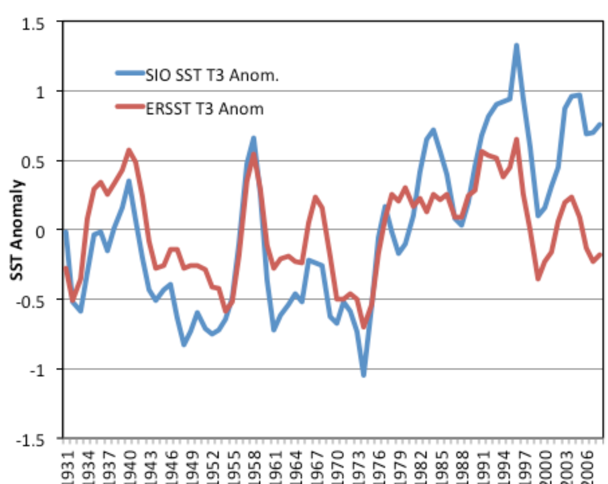

Figure 2. SST anomalies for 3 year average Scripps Pier and Extended Reconstructed sea surface temperatures (1931-2008. (Data from MacCall 2013)

> *"Obviously the claims that the original model has been 'debunked' are not valid and in fact the statistical fit with the new, and much longer time series, is considerably better than the original.*
>
> *It is also clear that the SST at Scripps Pier was considerably colder during the collapse of the sardine that occurred in the late 1940s and early 1950s than it is at present and the ERSST had a more extensive negative SST anomaly during the 1943-56 period when the stock collapsed. "*

Dr. Parrish's comments reemphasize a comment acknowledged (albeit quietly) at the sardine harvest parameters workshop – when the historical as well as recent-year sardine fishery data are considered, the long 61-year SIO time series is the better fit.

The use of a truncated time series for sardine to resolve modeling issues has created its own set of problems. The 2011 sardine STAR panel report noted, " *...dropping the early data means that it is no longer possible to assess the state of the stock prior to 1993, which adds to uncertainty about the dynamics of this population and current biomass levels.*
The scarcity of old and large sardines in the data relative to model estimates is a fundamental tension in the assessment that may be due to assumptions about, for example, growth, selectivity, natural mortality, and data weighting."
The 2011 sardine STAR panel also provided in its research recommendations: *"Explore models which consider a much longer time-period (e.g. 1931 onwards) to determine whether it is possible to model the entire period and determine whether this leads to a more informative assessment and to provide a broader context for evaluating changes in productivity."*

As I also noted in June 2013, setting the context for this discussion:
• Under the current harvest control rule (HCR), according to the 2012 stock assessment **the US sardine fishery harvested only 5 percent of a VERY conservative biomass estimate, and coast-wide exploitation was slightly over 15 percent**, while **E_{msy} for sardine is currently 18%.** Recent ecosystem modeling efforts (Horne et al 2010, Kaplan et al 2012) estimate **the entire CPS fishery harvest, sardines included, accounts for less than 4 percent of the <u>planktivorous</u> forage pool**, which is only part of the forage available overall. This harvest level is decidedly NOT overfishing, nor harming the ecosystem.

• Acoustic measurements 'drove' the 2012 stock assessment: assigned a Q of 1 meaning that acoustics 'saw' all the fish. Yet, the 2012 acoustic trawl biomass estimate for Washington-Oregon (**13,335 mt**) was far lower than actual landings made in the fishery in the same general area and time frame. OR-WA landings for the summer period totaled **48,653 mt.** Meanwhile the 2012 aerial survey estimated a biomass of **906,680 mt** for the Pacific Northwest. The 2012 assessment illuminated the **significant conflict in scale** derived from various survey methods.

• **Variability characterizes all the indices** used to measure sardine. Survey timing is crucial, and <u>each survey measures only a spot in time</u>. **It is important to maintain multiple surveys, rather than relying on only one**. Industry continues to voice concern that acoustic methods largely miss the upper 10 meters of the water column; the vessel avoidance issue has not been resolved. Nor do current acoustic surveys capture the full extent of the nearshore area, i.e., the beach, where sardines congregate in California.

We do appreciate that the SWFSC leadership acknowledges these problems and is working to resolve them. Hopefully when the new research ship RV Reuben Lasker is deployed for sardine research, with its forward and side-scanning capabilities, some of the current conflicts will be resolved.

In summary, we suggest the following:

- Although the CalCOFI temperature proxy annual series appears to be a slightly better fit to recent year data, the management team and industry recommend a 3-year average to stabilize the fishery. Considering the historical as well as recent sardine fishery, the SIO SST as environmental proxy is a better fit overall.
- In any case, we ask the Council to support the workshop recommendation to review environmental proxies frequently – and in particular, review indices using a 3-year average.
- We also ask the Council to support the 2011 sardine STAR panel research recommendation to explore models that incorporate the historical time period as well as the current period fishery.

Finally, please consider that achieving **OY requires balancing both fishery opportunity and economic stability and forage needs.** We would appreciate the Council's recognition of the continuing importance of the sardine resource to California's historic wetfish industry.

Thank you for your attention to these comments.

Best regards,

Diane Pleschner-Steele

Diane Pleschner-Steele
Executive Director

Attachment: Sardine Reanalysis
Richard Parrish
March 12, 2014

Comments on the Sardine Re-analysis.
Richard Parrish
February 12, 2014

Submitted to the Pacific Fishery Management Council for the March Briefing Book

Results from January 2014 CPSMT Meeting:

The Coastal Pelagic Species Management Team met in La Jolla in January 2014 to review the revised sardine population analysis (Hurtado-Ferro and Punt. 2013). Several different management policies, in addition to those in the above report, were examined.

The review focused on the shorter time series from the CalCOFI surveys (CC SST) and did not consider simulations using the Scripps Pier (SIO SST) or Extended Reconstructed (ERSST) time series. The revised analysis predicts a much smaller and more productive sardine population than the Amendment 8 analysis. Average unfished biomass is about 50% lower and average productivity is about 50% higher than the earlier analysis: (i.e. 1572 TMT vs 3050 TMT: and Emsy = 0.18 vs 0.12). The 2014 analysis predicts a population with much higher density-dependence than the earlier analysis.

A comparison of the policies from Amendment 8 and those in the CPSMT Report shows that HG J is a much more conservative a policy with the revised analysis. In the Amendment 8 analysis average depletion was 64% and the fishery was closed 1 year in 200. In the revised analysis the values are 78% and 1 year in 21. The CUTOFF was at about 5% of Bo in Amendment 8 and about 10% in the revised analysis.

The smaller biomass and higher productivity in the revised sardine analysis produces significant differences in the results predicted for the current harvest guideline (HG J) and other policies examined by the CPSMT (i.e. their Tables 1 and 2). The Amendment 8 analysis had an OFL policy (i.e. maximum long-term catch) that produced a pulse fishery closed just under 1 year in 2, an average catch of 208 TMT and an average depletion of 43%. The equivalent policy with the revised analysis (Scenario D) has the fishery shut down about 1 year in 3, an average catch of 184 TMT and an average depletion of 55%.

There has been little discussion in any of the recent sardine analyses regarding the optimum depletion level for sardine – one that balances ecosystem values with socio-economic values. The revised analysis shows that the sardine population is considerably more productive than earlier thought, as seen in the large increase in average depletion with the HG J (i.e. Scenario B; 64% to 78%.) The reference depletion level usually used in West Coast fishery management is the level that is produced by the Fmsy (or Emsy) policy. With the revised analysis this would be a depletion of 36% (Scenario F).

Scenario G with an average depletion of 66% most closely approaches the depletion level of HG J in the Amendment 8 analysis (i.e. 64%). However, it has a median catch (101 TMT) that is only 55% of the HG J Amendment 8 value of 182 TMT. The scenarios in the CPSMT's Table 2 have a very narrow range of options with no change in either CUTOFF or MAXCAT. The average depletion in these scenarios range from 73% (Scenario O) to 78% (Scenario B). The median catch for these scenarios range from 97-110 TMT; all well below the 182 TMT predicted in Amendment 8. There was no attempt to develop a policy with higher median catch; this would require reductions in MAXCAT and possibly CUTOFF. Therefor I would not personally recommend any of the proposed policies. However, I note that the CPS management team attempted to strike a balance by recommending the harvest fraction range in Scenario L (10-20%) to account for higher productivity.

The bottom line is that all of the scenarios in the CPSMT's Table 2 are much more conservative than HG J in Amendment 8; median catch levels are far lower and average depletion levels are considerably higher.

Predictions for the Future of the Sardine Fishery:

There have been numerous predictions made by several NGOs, and others, that the sardine population is going to collapse in a manner similar to the collapse that occurred in the mid-1900s. In addition, it has been suggested that the Scripps Pier sea temperatures are no longer a predictor of reproductive success in sardine. This report is an attempt to place the present situation in context with what is known about the northern population of sardine in the California

Current. Note that if the Scripps Pier sea surface temperatures are still a predictor of reproductive success in sardine the argument that we are presently going through a collapse 'like the one' in the mid-1900s is difficult to defend.

Stock Structure:

First we need to understand the stock structure of the sardine (*Sardinops sagax*). Genetic, morphometric and meristic studies show that there are five genetic stocks of sardine in the world (Parrish et al. 1989). One of these stocks occurs in the California Current and Gulf of California and it is known that this stock has extremely low genetic variation and 'almost no variation among populations in the frequencies of allozymes' (Hedgecock et al 1989). Hedgecock et al. also reported that biological data (i.e. growth rates) can safely be used for area-specific fishery models.

It has been generally accepted that the California Current sardine stock can be divided into three fishery stocks (Clark 1947, Felix-Uraga et al 2005). Recent evidence (Felix-Uraga et al. In Press) confirms that there are three fishery stocks; two in the California Current (i.e. the northern or 'cold' stock and the southern or 'temperate' stock) and one in the Gulf of California (i.e 'warm" stock).

Distribution:

The distribution of the northern sardine stock and its relationship with the stock in Baja California was described by Murphy (1966), the year I first started working on sardine.

> "Vrooman (1964) reports that the population of sardines is made up of three races. One in the Gulf of California, is apparently restricted and is not involved in the Pacific Coast fisheries. The other two are involved. The southern race has been identified from southern Baja California to San Pedro; those in the northern race, from San Quintin in northern Baja California to Monterey. The apparent wide overlap in distribution of these races is due to integration over time. Apparently their north-south movements are synchronous because they have not been found overlapping during any particular survey."

In the early California Current sardine fishery (i.e. prior to 1920) sardines were caught from British Columbia to southern California and the Canadian fishery reached 86,340 tons in the 1929-30 season (Murphy, 1966). However, the Oregon-Washington fishery did not get started until the mid-1930s. During the peak of the fishery (1926-27 to 1946-47) when the fishery was never below 200,000 tons per season, there were extensive landings from British Columbia to Southern California.

During the period of 1981-2012 sardine landings totaled 8,833,602 mt; 18.3% from the 'cold' stock, 16.0% from the 'temperate' stock and 65.7% from the 'warm' stock (Felix-Uraga et al. In Press). The dividing line between the northern and southern stocks is in the Southern California Bight and it moves seasonally in association with the 17 C isotherm. The 1981-2012 landings data in the above study suggest that 65.3% of the Ensenada, Mexico landings and 35.1% of the landings in Southern California were from the 'temperate' stock.

History of Exploitation and Collapse of the Northern Sardine Stock:

Parrish et al (1989) reported that the major sardine stocks have extensive latitudinal changes in their distribution that is associated with population size. Sardines expand their range into higher latitudes during periods of high biomass and abandon these high latitude areas during periods of low biomass. The pattern of collapse in the northern stock of California sardine, described below, was one of the major pieces in the Parrish et al report.

The US sardine fishery first exceeded 50,000 mt in the 1917-18 season; the Canadian fishery exceeded 50,000 mt in the 1927-28 season and the northern Baja California fishery did not exceed 50,000 mt until 1997 (Murphy 1966, Hill et al. 2011). The maximum observed sardine biomass, 3.894 million tons, occurred at the start of the 1931-32 fishing season (MacCall 2013) and the peak fishery occurred in the 1936-7 season when 791,334 tons were landed in the US and Canadian fisheries (Murphy 1966).

The second peak in sardine landings occurred in the 1941-2 season with an age 2+ biomass of 2.458 million tons. Over the two decades there was no regulation of either total catch or effort and by the end of the 1962-3 season the biomass fell to 0.021 million tons (Figure 1). The exploitation rate over this period averaged 43% with a maximum of 87% in the 1961-2 season. MacCall (1979) used a simple, but logical, population analysis to show that the sardine population would not have gone below about 1 million tons if it had been fished at a constant fishing mortality rate of F=0.25 (i.e. an exploitation rate of 22.1%) or a constant annual catch of 300,000 tons.

Hill (2013) reported that the total exploitation rate of age 0+ sardines ranged from 10.43% to 24.98% during calendar years 2000-12; and the average for these years was 13.63%; the corresponding values for the US portion of the fishery was 5.57% to 14.85% and 7.84%. A moderate portion of the 200-2012 landings were southern stock sardine so the actual average coastwise exploitation rate is undoubtedly somewhere between the 7.84% and 13.63% values.

It therefore appears that the exploitation rate on the northern stock during the 2000-12 period was less than one quarter of the rate observed during the historical collapse of the sardine.

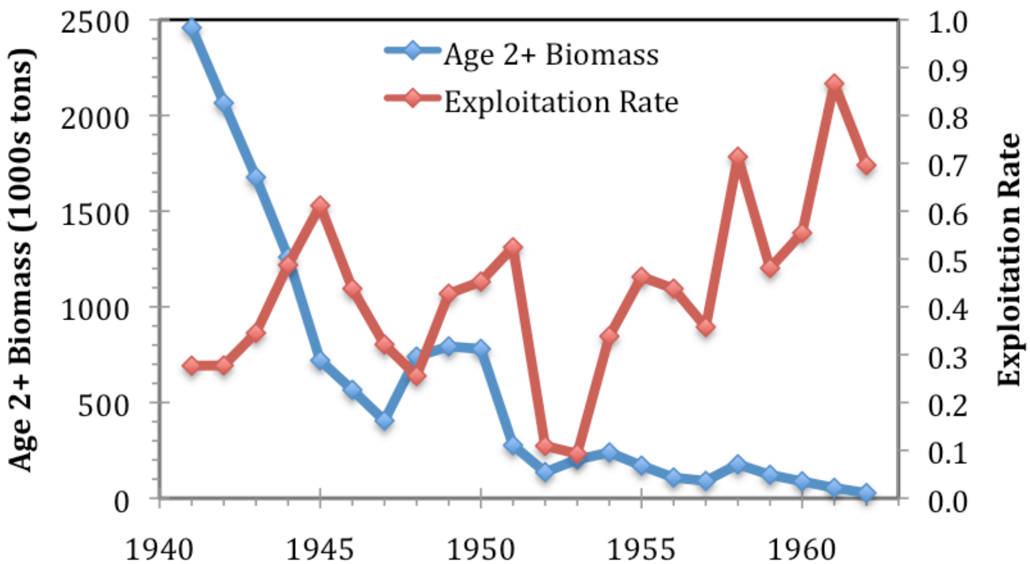

Figure 1. Sardine age 2+ biomass and exploitation rates from the second peak of the population in the 1942-3 season until the stock declined by 99% in at the end of the 1962-3 season. (Biomass in thousands of tons from MacCall 2013, landings from Murphy 1966).

Management:

The historical collapse of the Pacific sardine fishery occurred during a period when there was no regulation of annual landings or fishing effort. The present US fishery is regulated with both limited entry and an annual catch quota that automatically reduces the exploitation rate when the biomass decreases or cold environmental conditions in the southern nearshore area (i.e. Scripps Pier). The Canadian fishery is managed with an annual quota based on in-year biomass surveys and the Mexican fishery is primarily based on the southern (temperate) and Gulf of California (warm) stocks.

Environmental Conditions:

The large recent effort to re-assess sardine management was caused by the fact that environmental variable in the current harvest guideline rule (sea surface temperature at Scripps Pier) became suspect. MacCall (2013) re-analyzed the environmental-dependent spawner-recruit relationships using a number of environmental variables. The two environmental series that can be used to assess the long-term (N= 61 years) SST in the sardine's spawning grounds are the Scripps Pier SST (SIO SST) and the Extended Reconstructed SST (ERSST). The Amendment 8 sardine analyses and the current Harvest Guideline include a 3 year running mean of the SIO SST, therefore the comparisons uses the 3 year average SST for both time series (i.e SIO SST T3 and ERSST T3 in Macall 2013).

Although the correlation between the two SST time series is R=0.72, the two time series have very major differences (Figure 2). The ERSST time-series has multi-year periods above and below the mean and little long-term trend. The SIO time-series has only minor excursions above the mean in the 1931-1980 period; but it never goes under the mean after 1980. The SIO series is colder than the ERSST time series for most of the time before 1976 and warmer than the ERSST series in most of the years since 1976.

The two time-series represent different geographical areas and the 1931-2008 average Scripps Pier SST (17.15 C) shows that is 1.62 degrees C colder than the ERSST average (18.77).

Has time invalidated the original (Jacobson and MacCall 1995) temperature-dependent spawner-recruit model? MacCalls (2013) R- non-linear and linear fits to the ln(R/S) model with SIO SST T3 both have an R-squared of 0.39 with 61 years of data. The same model with the ERSST time series has an R-squared of 0.27. The original linear fit to the ln(R/S) model had an R-squared of 0.27 with 34 years of data (Jacobson and MacCall 1995). Clearly the new Scripps Pier time series is a better descriptor of sardine recruitment than either the original, shorter time series, or ERSST the other long-term SST time series examined.

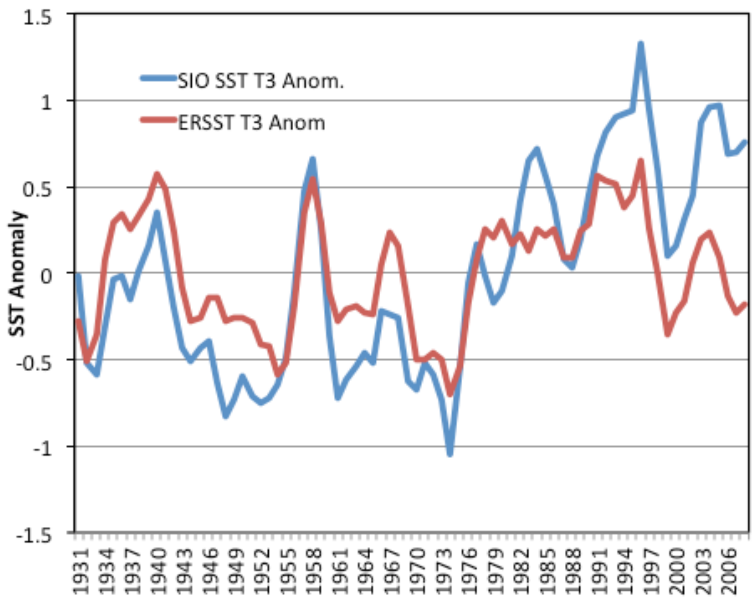

Figure 2. SST anomalies for 3 year average Scripps Pier and Extended Reconstructed sea surface temperatures (1931-2008. (Data from MacCall 2013)

Obviously the claims that the original model has been 'debunked' are not valid and in fact the statistical fit with the new, and much longer time series, are considerably better than the original.

It is also clear that the SST at Scripps Pier was considerably colder during the collapse of the sardine that occurred in the late 1940s and early 1950s than it is at present and the ERSST had a more extensive negative SST anomaly during the 1943-56 period when the stock collapsed.

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February 28, 2014

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Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 101
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Mr. William Stelle, Regional Administrator
NOAA Fisheries, West Coast Region
7600 Sand Point Way NE
Seattle, WA 98115

RE: Agenda Item I.1: Coastal Pelagic Species: Pacific Sardine Temperature Parameter Review

Dear Chair Lowman, Mr. Stelle, and Members of the Council:

Oceana remains deeply concerned about the current collapse of Pacific sardines in the California Current as confirmed in most recent 2013 stock assessment, particularly about the serious ecological consequences of the reduced availability of this critically important forage species to its predators. We commend the Council's necessary triage in response to this information in November 2013 to reduce the 2014 Pacific sardine Annual Catch Target below that specified in the Harvest Guideline. However, the current sardine harvest parameters that provide the default basis for calculating catch levels and other management measures are seriously flawed. These parameters are failing to prevent overfishing, failing to provide sufficient forage to dependent species, and failing to achieve Optimum Yield. To address the current deficiencies and relevant ecological factors, we request that the Council adopt the suite of Harvest Control Rule parameters Oceana proposed in our May 2013 letter, which is analyzed in the CPSMT Report (March 2014 Agenda Item I.1.c, Appendix Table 1, p. 14, Scenario "Request 6". March 2014 Briefing Book (Agenda Item I.1.b). Specifically, we propose a CUTOFF of at least 640,000 metric tons to provide sufficient forage for predators and an alternative for calculating DISTRIBUTION to prevent overfishing. Our full suite of proposed harvest control rule parameters are summarized below in Table 1.

Table 1: Oceana's proposed Pacific sardine harvest control in comparison to the current parameters in the CPS FMP as amended by Amendment 13.

Parameters	Current HG	Oceana Proposed Harvest Control Rule
CUTOFF (B1+, mt)	150,000	640,000
FRACTION	5-15% (based on SIO index)	5-15% (based on CalCOFI index)
MAXCAT (mt)	200,000	300,000
DISTRIBUTION (U.S.)	87% of TOTAL HG	TOTAL HG - Lmexico - Lcanada
MSST (1+, mt)	50,000	640,000
OFL (TOTAL)	18% of Biomass (1+)	Emsy (0-25%) based on CalCOFI
OFL (US)	87% of TOTAL OFL	TOTAL OFL - Lmexico - Lcanada

Sardine management by the PFMC is currently failing meet the goals and objectives of the CPS FMP (in *italics* below) and violating key provisions of the Magnuson-Stevens Act (*e.g.,* 16 U.S.C. §§ 1851(a)(1) and 1853(a)(3)(requiring management measures to prevent overfishing and achieve Optimum Yield, and assessment and specification of OY in FMP); § 1851(a)(3) (requiring a stock to be managed as a unit throughout its range)). Specifically, the fishery fails to:

- *"achieve Optimum Yield"* as required under the MSA, as Optimum Yield is not assessed or specified in the CPS FMP, relevant ecological factors are not identified in the CPS FMP or accounted for in the sardine harvest control rule, and actual exploitation rates exceed the harvest guideline;
- *"provide adequate forage for dependent species"* which is an essential part of achieving OY, as evidenced by the unusual mortality events of California sea lions, nesting failures brown pelicans, in which the lack of sardines and anchovies have been implicated as the primary cause;
- *"prevent overfishing"* as evidenced by the October 2013 stock assessment showing that the exploitation rate on Pacific sardines in 2012 was 25%, exceeding the Maximum Sustainable Yield exploitation rate of 18%; and
- *"encourage cooperative international and interstate management"* as there is no international agreement and U.S. sardine management does not account for actual sardine catch in Mexico or Canada. The MSA requires NMFS, in cooperation with the Secretary of State, to "immediately take appropriate action at the international level to end overfishing." 16 U.S.C. § 1854(i)(*sic*)(1). Yet NMFS has not taken any such action; nor has the Council taken sufficient action to account for U.S. fleet's part in depleting the overall sardine stock, as it must do in order to manage the stock as a unit throughout its range.

The failure to responsibly manage the sardine fishery is causing ecological reverberations in the California current ecosystem. In 2013, over a thousand California sea lion pups were stranded on Southern California beaches because of the lack of forage species, specifically sardines and anchovies.[1] In addition, California brown pelicans breeding in the Channel Islands have undergone a decline in reproductive success since 2010 culminating in major nesting failures in 2012 and 2013,[i] while unusual adult Brown Pelican stranding events during the non-breeding season on the California and Oregon coasts were observed in 2009-2010. These unusual events were attributed to the lack of prey availability during the breeding season and attributed primarily to starvation[ii]. Sardines are an essential prey item for numerous piscivorous seabirds including Brown Pelicans, Elegant Terns, Heerman's Gulls and the federally threatened Marbled Murrelet[iii]. Sardines comprised 25%-67% of the diets of breeding pelicans in six years of surveys that took place at the Channel Islands between 1991-2005, however have been absent from the diets of breeding pelicans in recent years.[iv] On February 12, 2014, NRDC submitted a petition to the Secretary of the Interior to list the contiguous U.S. distinct population segment of tufted puffins under the endangered species act, citing the current low abundance of Pacific sardines and other prey as a threat to this distinct population segment. These examples illustrate that serious ecological impacts of inadequate forage are occurring at sardine abundances much greater than the current CUTOFF in the Pacific sardine harvest control rule. The fact that the stock biomass from 2007 to 2013 declined by approximately the same amount as was landed by the sardine fishery during this period clearly implicates fishing as a primary driver of the extent of the current collapse. The low current abundance is now causing mortality events and reproductive failure in multiple dependent sardine predators.

While Pacific sardine population dynamics are complex, it has become apparent that while the Pacific sardine population undergoes wide swings in abundance even in the absence of fishing due to prolonged periods of low and high productivity, fishing pressure has a major effect on the population dynamics during periods of low productivity and/or low abundance. In other words, fishing during a natural population decline has three fundamental effects on the sardine stock:

1. Increases the severity or steepness of the decline, causing the population to "bottom out" at a lower level than would have naturally occurred;
2. The population takes longer to recover or rebuild when ocean conditions become more favorable because the population is starting at a lower level than would have naturally occurred;
3. The population peaks at lower levels than would have naturally occurred because the period of higher productivity is finite.

These conclusions are supported not only by the current sardine simulation model, but also by what has been observed over the last century. Specifically, the population in the 1930s and 1940s peaked several times greater than the most recent peak of approximately 1.5 million metric tons, likely because it took so long to recover from the heavy fishing rates in the 1950s and 1960s.

CUTOFF

1 NOAA Office of Protected Resources presented at the December 2013 CalCOFI meeting in La Jolla that the cause of the 2013 California sea lion Unusual Mortality Event was likely a lack of forage

The CUTOFF is the most critical parameter of the harvest control rule for lowering the risk of stock collapse and preventing the fishery from becoming overfished.[2] CUTOFF could – and should – also be used to ensure the provision of adequate forage for dependent predators. At the current level of at 150,000 metric tons, however, the CUTOFF neither prevents the fishery from becoming overfished nor provides forage for dependent predators.

The Lenfest forage fish task force[v] recommended that CUTOFFs for forage species be set at approximately 40% of mean unfished biomass. Based on this recommendation, we propose a CUTOFF of 640,000 metric tons (~40% of mean unfished biomass as estimated in the most recent simulation models). To ensure adequate forage, the CUTOFF should be set higher than the biomass at which predators are impacted by lack of forage (such as nesting failures, starvation, unusual mortality events). This is especially crucial when the predators' alternative preferred prey populations are also suppressed, as they are in the CA Current Large Marine Ecosystem. For example, many of the same predators that rely on sardine also rely on anchovy, which is also at low abundance. As we have indicated, we are now seeing negative effects on sardine predators now that the population is below 640,000 mt. Additionally, if critical biomass thresholds are identified below which the stock becomes at serious risk of collapse (e.g., as identified for Pacific sardines by Zwolinski & Demer 2012)[vi], CUTOFFs should be set to minimize the time at which the population is below these thresholds.

Lastly, the proposed CUTOFF may address practical, economic interests of the fishing industry. Once Pacific sardine biomass drops below 640,000 metric tons, for example, it may take more time and effort to locate sardines (as was seen in Southern California in early 2013), and thus it may not be as profitable to fish sardines at these low relative levels. In summary, our proposed CUTOFF is based on sound science and economic reason, and should be fully considered and analyzed.

TEMPERATURE-BASED FRACTION

We understand that the SSC has previously identified the CalCOFI 3-year average temperature index as the best available predictor of Pacific sardine productivity, and that the revised analyses have reconfirmed that conclusion. Therefore, we support the proposed HCR change to the CalCOFI index for use in the Harvest Guideline and ABC control rule.

We strongly oppose the CPSMT's proposed change in FRACTION range of 10-20 (Scenario K). This is a significantly more aggressive harvest policy than the current harvest control rule, in which FRACTION ranges from 5-15%, which we have previously argued is already insufficient to protect the stock. Table 3 of the CPSMT March 2014 report demonstrates that increase the FRACTION range from 5-15% to 10-20% would result in lower mean sardine biomass (hence less forage production) and higher catch levels. Absent any other changes in harvest parameters,

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If the CUTOFF is sufficiently high, it may be possible to increase FRACTION and/or MAXCAT parameters while still minimizing risk to the sardine stock and its ability to provide forage. The CUTOFF only applies to the Harvest Guideline, not the OFL or ABC control rule; therefore it only operates when the HG is below the ABC control rule.

increasing the FRACTION would allow higher catches – moving sardine management in the opposite direction of where it must go given the current dire situation of the sardine stock, the identified failures of the current harvest control rule, and the best available science. The CPSMT's rationale that new median CalCOFI temperatures and a new understanding of sardine productivity justify a FRACTION increase directly conflicts with the reality of severely depleted sardine numbers and steep declines in predator health that are now playing out in the water.

In addition, the proposed increase in the lower bound of the FRACTION range conflicts with one of the primary objectives of the current harvest control, which is to add additional precaution during periods of low sardine productivity. In the current structure of the HG formula, the CUTOFF reduces harvest rates when the stock is low, while the FRACTION range reduces harvest rates when productivity is predicted by temperature to be low. Setting the lower bound at 10% rather than 5% diminishes this effect.

Moreover, the ABC control rule does not account for these concerns, as it only creates a scientific uncertainty buffer from the OFL. As indicated in Fig. 1 of the CPSMT report, the Emsy for sardines drops below 10% with CalCOFI temperatures below 15.2 degrees C. Raising the lower bound of the range up to 10% would essentially eliminate the role of CUTOFF when the temperature-based Emsy is less than 10% and sardine productivity is low, as the ABC becomes lower than the HG at low temperatures. This is a more risk-prone approach than the current Harvest control rule. . Allowing the FRACTION range to reach zero would ensure sufficient precaution when sardine productivity is low, so that the HG is always below the ABC control rule regardless of temperature.

We do not think there is a need or rationale to change the FRACTION range. However, if the Council substantially increased the CUTOFF as we have proposed, we could potentially support a change in the FRACTION range to 0-20% to allow for increased fishing opportunities during periods of high abundance and productivity, while adding more precaution during periods of low abundance and/or productivity.

DISTRIBUTION

Most of the analyses by Hurtado-Ferro and Punt and the CPSMT are predicated on the assumption that Mexico and Canada always catch 13% of the coastwide harvest, as the analyses use a DISTRIBUTION of 1.0 as was done originally in Amendment 8 (CPSMT report, March 2014 Agenda Item I.1.c, p. 5). Based on their sensitivity analysis of this assumption, Hurtado-Ferro and Punt (p. 5) acknowledge: "The results are sensitive to Mexico and Canada not following the US control rule". In their model scenario where Mexico and Canada do not follow the US control rule, mean B1+ biomass is 42% lower than under the current option J, and this scenario is the only one that results in full stock collapse (see Table 6, Scenarios "HG J" and "MF"). The fact that the actual 2012 coastwide exploitation rate on the Pacific sardine population was 25% (greater than the coastwide Emsy of 18% used by the SSC to set the OFL) is definitive evidence that Mexico and Canada are not following the U.S. control rule, resulting in overfishing (October 2013 Pacific Sardine Stock Assessment). This existence of this problem also supports a higher CUTOFF. Specifically, the CPS FMP currently states "If the portion of the stock in U.S. waters cannot be estimated or is highly variable, then other approaches may be used. It may be more practical, for example, to use a high CUTOFF in the harvest control rule to compensate for stock biomass off Mexico or Canada."

Correcting the U.S. DISTRIBUTION value so that the annual total tri-national landings more consistently match the target fishing fraction is essential for managing this stock. Therefore, we propose the PFMC adopt the landings-based formula for calculating U.S. distribution where the US harvest guideline and US OFL are calculated by reducing the coastwide HG and OFL by the most recent year's actual landings (L) in Mexico and Canada (as proposed and analyzed in Demer & Zwolinski 2013)[vii]:

HG (US) = HG (TOTAL) – L (MEXICO) – L(CANADA)
OFL(US) = OFL(TOTAL) – L(MEXICO) – L(CANADA)

Alternatively, as is suggested in the CPS FMP (4.6.1), if the stock assessment provides estimates of only the portion of the Pacific sardine stock biomass currently within U.S. waters, this value can be used as BIOMASS without any need to pro-rate harvest with a DISTRIBUTION parameter. Therefore, the Council may also consider requesting changes to the terms of reference for future sardine stock assessments to provide estimates of only the biomass within US waters to help simply and resolve the current problems with the DISTRIBUTION parameter.

Minimum Stock Size Threshold

The minimum stock size threshold (MSST) is intended to indicate when a stock is considered "overfished", prompting rebuilding. 16 U.S.C. § 1853(a)(10); 50 C.F.R. § 600.310(e)(2). While we recognize the difficulty in applying this concept for a stock that may vary widely even in the absence of fishing, the practical application is generally that fishing effort be reduced or ceased when the stock is below MSST. *See, e.g.,* 50 C.F.R. § 600.310(e)(2)(ii)(B)-iii. However, current MSST of 50,000 metric tons violates both the letter of the NS1 guidance and the overall purpose of the guidance and statute. Therefore, we propose the Council and NMFS set MSST equal to Oceana's proposed CUTOFF, as fishing for sardine would close whenever the biomass drops below this threshold value anyway.

Summary and Discussion of CPSMT Analysis of Oceana's Proposed Harvest Control Rule

Given the new analysis and information on stock dynamics and the ecosystem impacts of the current harvest control rule now available since the adoption of Amendment 8, we believe a management change is warranted. To achieve Optimum Yield and provide adequate forage for dependent predators, it is necessary to further reduce catches at times of low stock abundance and/or productivity when the stock is most at risk.

According to the analyses in the CPSMT analysis, Oceana's proposed HCR outperforms the current status quo HCR (Option J) in terms of biomass (hence provision of harvest) and risk to the stock regardless of what is assumed about foreign catch. In terms of mean sardine catch and number of years with low catch (<50,000mt), it initially appears that Option J is preferable to Oceana's proposed HCR. However, given that available evidence clearly documents that Mexico and Canada are not following the US control rule, it is likely that the full adoption of Oceana's HCR would outperform the status quo HCR on catch, stability, biomass, forage provision, and precaution (Table 2).

Table 2: Summary of key performance measures of three HCR scenarios from CPSMT March 2014 Report and Hurtado-Ferro and Punt (2014).

Performance Measure	Oceana proposed ("Request 6")	Option J assuming Mex/Can follow US (Option J)	Option J with only US following US control rule (MF)
Mean B1+	1346	1220	716
% of unfished B1+	0.86	0.78	0.46
%B1+>400	97.75	92.4	58.9
Mean catch (all years)	89.4	105.8	57.2
% catch<50	49.2	31.2	58.8

Due to the natural fluctuations in productivity, sardine catch is inherently unstable. While efforts can be made to make catch more stable, it is inevitable that the fleet will undergo prolonged periods of low or zero harvest of certain individual species. However, because catch stability requires continued harvest during periods of low abundance and productivity, more stable catch results in lower long-term catch, greater risk of stock collapse, lower stock biomass, and diminished provision of forage to dependent predators. The ability to cope with these events by targeting other species in the CPS assemblage (e.g., market squid, Northern anchovy, and Pacific mackerel) while setting up markets and infrastructure that can respond to such changes is critical to the socioeconomic success of CPS fisheries, regardless of the HCRs used for each species. We urge the Council to further explore how to address these inherent socioeconomic challenges through a more holistic approach to the CPS assemblage whereby the harvest of each individual species depends not only on its biomass, but also the biomass and catch rates of other species in the assemblage, as well as the status of dependent predators.

In conclusion, the current sardine crisis and its ramifications for key California current predators is clear evidence that the existing harvest parameters are not working. We support updating the temperature index to CalCOFI based on the best available science. However, it would be irresponsible to maintain the other aspects of the status quo harvest parameters given this information, much less make it more aggressive as suggested by the CPSMT. We ask that the Council adopt Oceana's full proposed suite of harvest parameters as presented in this letter as soon as feasible, for the sake of U.S. west coast communities, fisheries, wildlife, and ecosystem.

Sincerely,

Geoffrey Shester, Ph.D.
California Program Director

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THE PEW CHARITABLE TRUSTS

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March 2, 2014

Dorothy Lowman, Chair
Pacific Fishery Management Council
1100 NE Ambassador Place, #101
Portland, OR 97220

RE: Agenda Item I.1 – Sardine Temperature Parameter Review

Dear Chair Lowman and Council Members,

We write in regards to the Pacific Fishery Management Council's (Council) consideration of changes to the harvest control rule for the Pacific sardine fishery. We support the proposed Council action to adopt the California Cooperative Fisheries Investigation (CalCOFI) temperature index for use in management of the Pacific sardine fishery. This change is consistent with the best available science on sardine population dynamics.

Specifically, we request that the Council take the following action at this meeting:

- Adopt the CalCOFI temperature index for use in the calculation of the annual harvest guideline (HG). Taking this action will help ensure that catch limits correspond accurately to sardine productivity and the overall status of the stock.
- Establish a range of FRACTION (fishing mortality rate) of 5 - 20 percent. Taking this action will help ensure that fishing pressure is sufficiently reduced in times of low sardine productivity.
- Continue to pursue development of ecosystem-based improvements to the management of coastal pelagic species in order to maintain adequate forage for dependent predators and the long-term health of the sardine stock.

Below we discuss each of these requests in greater detail.

Adopt CalCOFI Temperature Index

The current harvest control rule for sardine includes a parameter that is dependent upon sea-surface temperature (SST), which has been measured at the Scripps Institution of Oceanography pier. In the control rule, SST is considered a proxy for sardine productivity and is used to determine the allowable fishing mortality rate, referred to in the rule as FRACTION. In 2010, scientists at the National Oceanic and Atmospheric Administration's Fisheries Service (NOAA Fisheries) found that the SST at Scripps pier no longer accurately reflected ocean SST off the southern California coast and therefore was no longer a reliable proxy for productivity.[1] During a sardine workshop held in February of 2013, scientists determined that the CalCOFI mean

[1] McClatchie, S., R. Goericke, G. Auad, and K. Hill. 2010. Re-assessment of the stock–recruit and temperature–recruit relationships for Pacific sardine (*Sardinops sagax*). Can. J. Fish. Aquat. Sci. 67: 1782–1790.

temperature index more accurately reflected the SST off of California and better explained sardine recruitment variability.[2]

Based on this new information, the Coastal Pelagic Species Management Team (CPSMT) recommended that the CalCOFI temperature index should be used in the harvest control rule for sardine. We support the Council taking action to make this change to the control rule so that fishing mortality rates are better linked to sardine productivity. This change will help ensure the long-term sustainability of the sardine fishery by reducing fishing mortality rates when sardine productivity is low or declining, and raising rates when productivity is increasing.

Establish a Precautionary Range for FRACTION

An updated sardine population model was developed to perform the current analysis of the harvest control rule.[3] This updated model is age-structured, whereas the previous model used to develop the original suite of control rules was production-structured. Additionally, the newer model incorporates more recent data from a number of years when the sardine population was expanding rapidly. This results in a higher estimate of stochastic Emsy[4] than the previous model; 18 percent of the biomass available to the fishery as opposed to 12 percent.

In the original control rule, when stochastic Emsy was set at 12 percent, fishing rates (FRACTION) were allowed to rise as high as 15 percent, or drop to as low as 5 percent depending on SST at Scripps pier. Now that stochastic Emsy has been updated to 18 percent, we understand that the Council will also be considering a corresponding increase in the range of potential fishing rates to 10 – 20 or perhaps 15 – 25 percent. Regarding this issue, we request that the Council adopt a range of fishing rates that is at least as precautionary as the current range. Capping rates at 20 percent appears to maintain the Council's previous level of precaution by only exceeding stochastic Emsy by 2 percent. (In the original control rule, rates were capped at 15 percent, which exceeded stochastic Emsy by 3 percent) Considering the current state of the sardine stock, it is essential that fishing rates decrease sufficiently in times of low SST and low productivity. Correspondingly, we recommend a lower bound for FRACTION at 5 percent rather than the 10 percent suggested by the CPSMT. In summary, we urge the Council to adopt a range of FRACTION from 5 – 20 percent.

Pursue Ecosystem-Based Improvements

As part of the analysis of the FRACTION parameter and SST indices, the CPSMT was also provided with simulated long-term results from potential changes to other parameters in the harvest control rule, including CUTOFF (The biomass level below which fishing is not allowed) and MAXCAT (The maximum catch allowed for any year). The results of this analysis help to

[2] PFMC. March 2014. Coastal Pelagic Species Management Team Report on Sardine Harvest Parameter Changes. Agenda Item I.1.c.
[3] Hurtado-Ferro, F., and A. E. Punt. 2013. Revised analyses related to Pacific sardine harvest parameters. School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195-5020
[4] Emsy is an annual exploitation rate used as a proxy for Fmsy, and is the established fishing mortality rate for a given year, dependent upon sea-surface temperature.

illustrate the economic, social and ecological tradeoffs resulting from different fishery management strategies. This type of evaluation can and should be a key tool in determining how best to achieve optimum yield from our nation's fisheries. For example, increasing CUTOFF along with MAXCAT creates more of a pulse fishery where revenue is maximized, yet the number of years with low or no fishing is increased.[5] This management strategy (higher CUTOFF) provides more forage for the ecosystem relative to other strategies, but results in a short-lived fishery. Ostensibly such an approach would not be attractive to the CPS fleet unless there were science and management in place and ready to respond to changes in the relative abundance of CPS species. This is exactly why a forward thinking, ecosystem-based assemblage approach is need for the management of the Coastal Pelagic Species Fishery Management Plan (CPS FMP). Rather than fighting over the last sardine, we should be looking ahead to make sure that we are prepared to correctly manage the next iteration of the CPS fishery. For instance, ecosystem-based control rules for anchovy and mackerel, with CUTOFF, MAXCAT, and other precautionary reference points, as well as environmental parameters, will be needed to support responsible shifts in fleet effort.

Moving forward as the Council considers such an approach to the CPS FMP we would like to see this management strategy evaluation tool utilized within a multi-species context to ensure that catches are set at ecologically sustainable levels and that fishing opportunity is adaptive to species abundance. We fully understand and acknowledge that there are data gaps that will need to be filled and multi-species population models to be developed to truly usher in an ecosystem-based approach to CPS management. However, such an approach is needed if management is to be responsive to the highly variable, dynamic, and environmentally-dependent species that comprise the CPS FMP.

In addition to the multi-species evaluation described above the Council should continue to explore new methodologies and sources of data to better inform the DISTRIBUTION parameter that sets the percentage of the sardine stock in U.S. waters and therefore available to the U.S. fishery. We know that this percentage changes with the status of the sardine stock, yet it currently is set at a fixed value. This issue was discussed at length during the February 2013 workshop and should be a research priority for the CPS FMP moving forward.

Conclusion

In many regards, the management of the Pacific sardine fishery can serve as a model for ecosystem-based management of forage fisheries. The control rule used to establish the annual catch limit includes a biomass reserve below which fishing is not allowed (CUTOFF), sets the fishing rate according to ocean temperatures (used as a proxy for sardine productivity) and buffers against international catch. The changes under consideration today will bring management up-to-date with the best available science regarding sardine population dynamics.

However, more can and should be done to ensure that management of sardine and other CPS provides adequate forage for the ecosystem and avoids negative impacts to marine wildlife. As

[5] Hurtado-Ferro, F., and A. E. Punt. 2013. Revised analyses related to Pacific sardine harvest parameters. School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195-5020

our knowledge of ecosystem dynamics expand, fishery managers should establish CUTOFF at a level that is informed by predator dependencies, and set fishing rates that respond quickly and accurately to stock productivity. Ultimately, we look forward to a management regime that is adaptive to the relative abundance of CPS so that as the ocean changes, management responds accordingly and appropriately.

We appreciate the Council undertaking this endeavor and look forward to working with all stakeholders to maintain healthy oceans and sustainable fisheries.

Thank you in advance for your time and consideration.

Sincerely,

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