Agenda Item I.1
Situation Summary
June 2013

NATIONAL MARINE FISHERIES SERVICE REPORT

Mr. Mark Helvey (National Marine Fisheries Service, Southwest Region) will provide the Council a report on the 2012 and 2013 coastal pelagic species (CPS) fisheries and other recent activities. This will include an overview of the recent decision in the *Ocean v. Bryson* court case, and likely next steps. Dr. Russ Vetter will give a brief report on the Southwest Fisheries Science Center's research activities.

Council Task:

Discussion.

Reference Materials:

None.

Agenda Order:

a.	Agenda Item Overview	Kerry Griffin
b.	Regulatory Activities	Mark Helvey
c.	Fisheries Science Center Activities	Russ Vetter
d.	Reports and Comments of Advisory Bodies and Management Entities	
e.	Public Comment	
f.	Council Discussion	

PFMC
05/30/13

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southwest Region
501 West Ocean Boulevard, Suite 4200
Long Beach, California 90802-4213

JUN - 6 2013 150409SWR2011SF00262:JBL

Mr. Dan Wolford, Chair
Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 101
Portland, Oregon 97220-1384

Dear Chairman Wolford:

The Pacific Fishery Management Council developed Amendment 13 to the Coastal Pelagic Species Fishery Management Plan (CPS Plan) to comply with the 2007 amendments to the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson Act), using the associated advisory guidelines for National Standard One. In 2011, NOAA Fisheries reviewed and approved Amendment 13.

The central feature of Amendment 13 was to establish mechanisms to determine annual catch limits for the species managed under the CPS Plan:[1] Pacific sardine, Pacific mackerel, jack mackerel, market squid, and the central and northern subpopulation of northern anchovy. The Amendment also clarified the methods for determining the overfishing levels (OFL) and allowable biological catch (ABC) levels for managed species. Most of these revisions build on biological benchmarks already included in the Plan, including a description of maximum sustainable yield (MSY) or a reasonable proxy thereof. However, citing a lack of information, the original Plan did not specify MSY for the northern subpopulation of northern anchovy.

In an amended complaint filed with the U.S. District Court for the Northern District of California in February 2012, the environmental advocacy organization Oceana alleged that the CPS Plan, as amended by Amendment 13, violated the Magnuson Act by failing to describe optimum yield or MSY for several species, failing to appropriately account for scientific uncertainty, and failing to use the best available science; violated the National Environmental Policy Act for failure to prepare a new environmental impact statement; and violated the Endangered Species Act for failure to engage in a section 7 consultation. On April 14, 2013, the District Court issued an order granting summary judgment in favor of federal defendants on all allegations except for failure to describe MSY for the northern subpopulation of northern anchovy. This decision was remanded back to the Secretary of Commerce for action consistent with the Court's order. On April 17, the Court entered a final judgment in this case.

[1] Krill in also managed under the CPS Plan, but because the sole management measure for krill is a prohibition on targeting or retention, in developing Amendment 13 the Council did not revisit biological benchmarks for krill.

When developing the CPS Plan in 1998, the Council considered the issue of estimating MSY for the northern subpopulation of northern anchovy. However, the Council did not specify MSY at that time because of a lack of information about the stock's biomass or its variability of biomass over time. Furthermore, the population was classified as a "monitored species," not subject to active management. In developing Amendment 13, the Council considered alternatives for adding a description of MSY to the CPS Plan. The CPS Management Team took up this issue by compiling all the scientific information on the subpopulation and identified only two estimates of biomass. One was an egg and larval production estimate from the 1970s and the other was a recent acoustic survey by researchers at the Southwest Fisheries Science Center. However, at the time of Council action on Amendment 13, the Management Team was unable to determine an appropriate MSY or an MSY proxy because of this extremely limited information. Therefore the Council added language to the FMP that explicitly deferred this decision to the specification process for monitored stocks.[2] Amendment 13 was adopted by the Council in June 2010.

The information compiled by the Team was subsequently used in the formulation of the specifications for monitored CPS species, which was scheduled for November 2010. In November 2010, the Science and Statistical Committee (SSC) discussed OFLs and ABCs for CPS monitored stocks. The SSC noted in its statement that reference points for monitored CPS stocks are difficult to determine due to limited data for estimating biomass and productivity. It also acknowledged that the northern subpopulation of the northern anchovy was currently lightly fished, with inconsistent effort, making the time series of catch an unreliable_indicator of stock status. Consequently, the SSC recommended that the OFL be set by multiplying the biomass estimate of 130,000 mt (the average of the existing biomass estimates) by 0.3, the default fishing mortality rate (F_{MSY}) value used for Pacific mackerel. It determined that this approach was appropriate because northern anchovy are likely to be as productive as Pacific mackerel.

With the established uncertainty buffer of 75 percent, the SSC recommended, and the Council adopted, an OFL of 39,000 mt and an ABC of 9,750 mt for the northern subpopulation of northern anchovy in the specifications for monitored stocks.

In adopting specifications for the monitored stocks in November 2010, the Council did not take final action on setting an MSY proxy for the northern subpopulation because the reports from the Management Team and the SSC did not include an explicit recommendation to do so. However, the Council has a clear recommendation from the SSC regarding an appropriate F_{MSY}. NOAA's National Marine Fisheries Service believes that adopting the SSC's recommendation is a prudent way forward. As mentioned above, there is limited data to estimate biomass and productivity for northern anchovy. The best available information appears to indicate that an F_{MSY} of 0.3 for the northern

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[2] Section 4.6.4.2 of the CPS Plan, as amended by Amendment 13, states "**Appropriate . . . biological reference points (if determined), and harvest specifications for the northern subpopulation on northern anchovy are developed and adopted under the annual specification cycle and recorded in the CPS SAFE.**" **MSY is a biological reference point.**

subpopulation of northern anchovy when applied over the long term is a reasonably proxy for MSY. I recommend the Council take final action on this suggestion at its September meeting, and submit its recommendation to NMFS. Please note that the National Standard One guidelines give the Councils the option to adopt other measures of reproductive potential, based on the best scientific information available, that can serve as reasonable proxies for MSY, F_{MSY}, and B_{MSY}, to the extent possible when data are insufficient to estimate MSY directly (50 CFR 600.310(e)(1)(C)(iv)).

There are a couple of routes available to the Council to implement MSY for the northern population of Northern Anchovy. Probably the most expeditious path would be to process that decision with the rest of the proposed specifications for the monitored stocks. This summer NMFS will be publishing for public review the proposed specifications for the other monitored stocks per Council action on Amendment 13, and could include with those specifications a tentative MSY proxy for the northern population of northern anchovy. Because the final specifications would not be finalized until after the September meeting, the Council could confirm its recommendation at that meeting.

In closing, we agree with the SSC's recommendation that the OFL and ABC should be updated when new biomass estimates or information on productivity become available.

Sincerely,

Mark Helvey

for William W. Stelle, Jr.
Acting Regional Administrator

cc:
NWR– Barry Thom
SWR – Kevin Chu
SFD – M. Helvey
F. Lockhart
GCSW – J. Feder

Agenda Item I.1.c
Supplemental FSC PowerPoint (Vetter)
June 2013

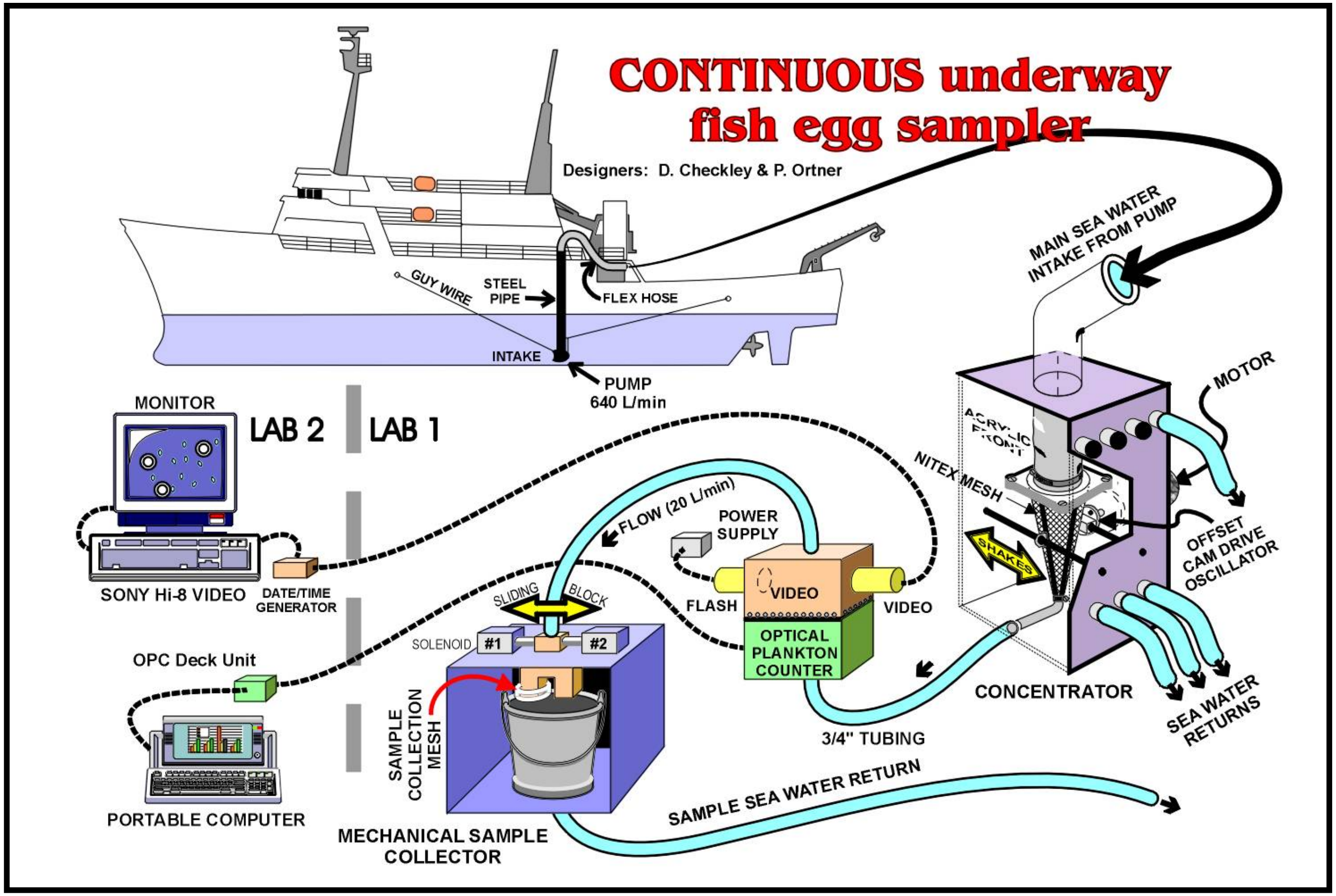
Agenda Item I. Coastal Pelagic Fisheries, I.1.c. Fisheries Science Center Activities.

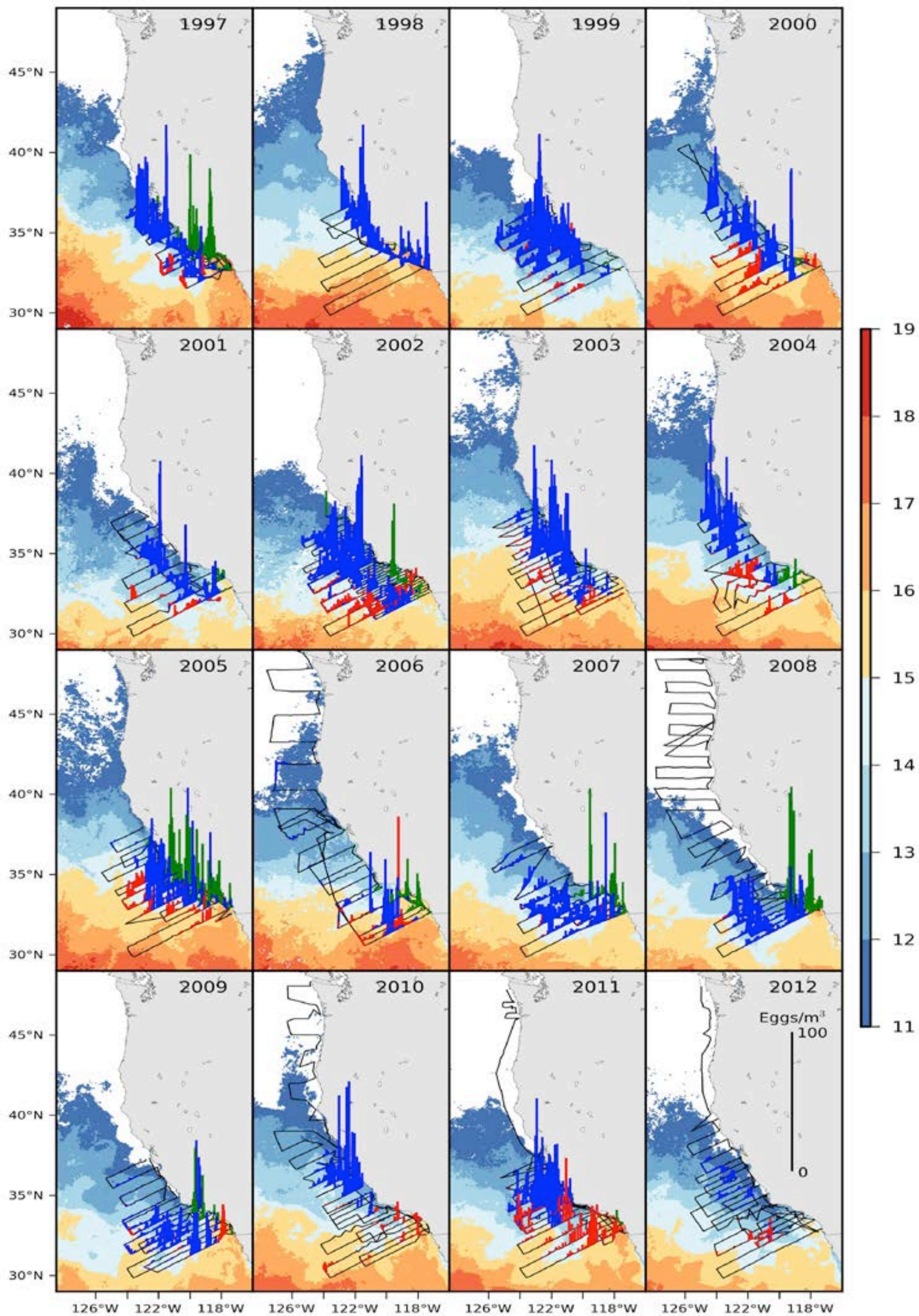
Topic 1. Update on Results from Spring 2012 Sardine DEPM/Acoustic Trawl Survey. (15 min)

Topic 2. Update on 2013 Summer Coastwide combined Sardine/Hake survey US and Canada. (10 min)

Topic 3. Update on IEA indicators and any questions from Council.

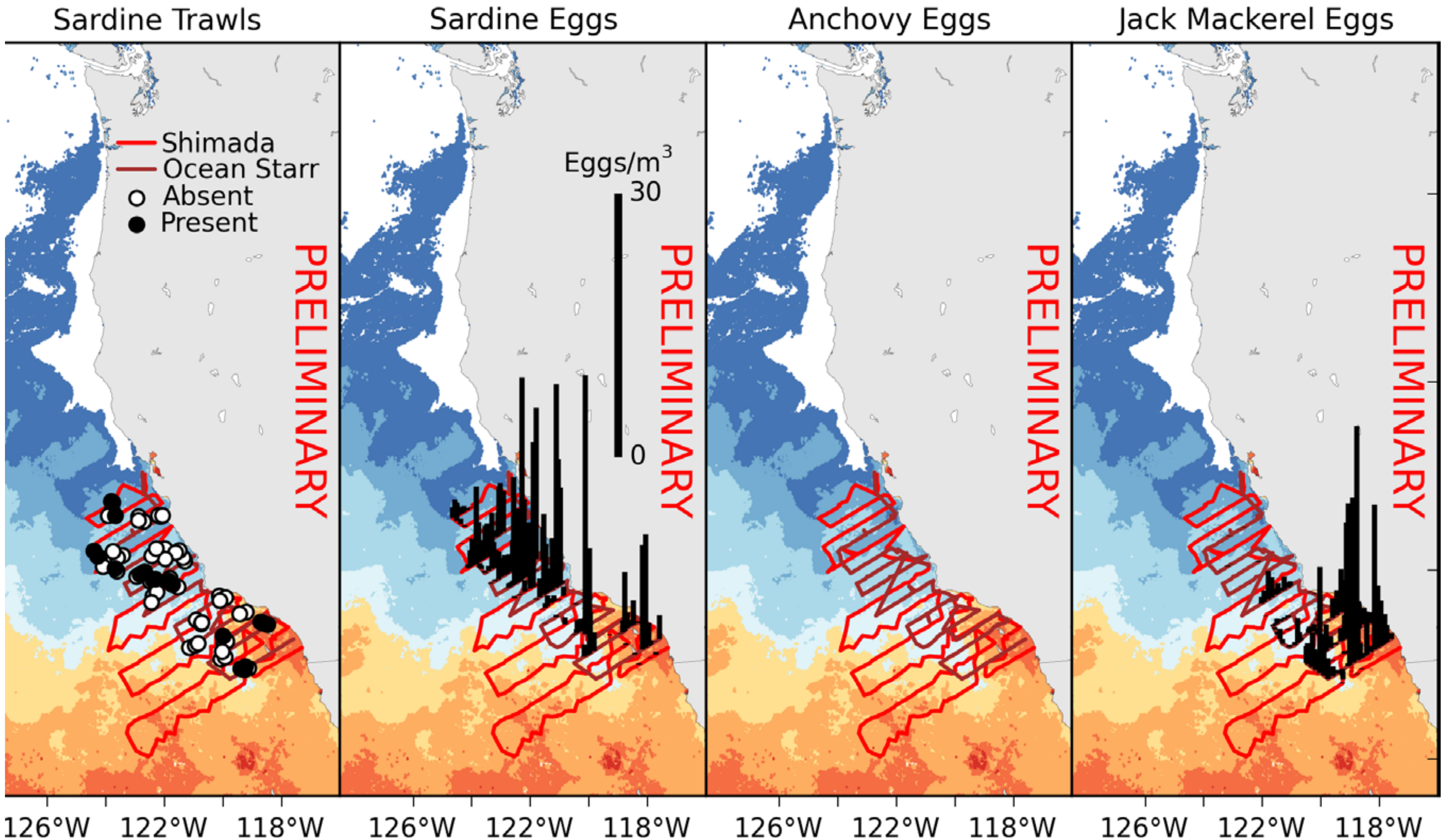
Underway Biological Sampling





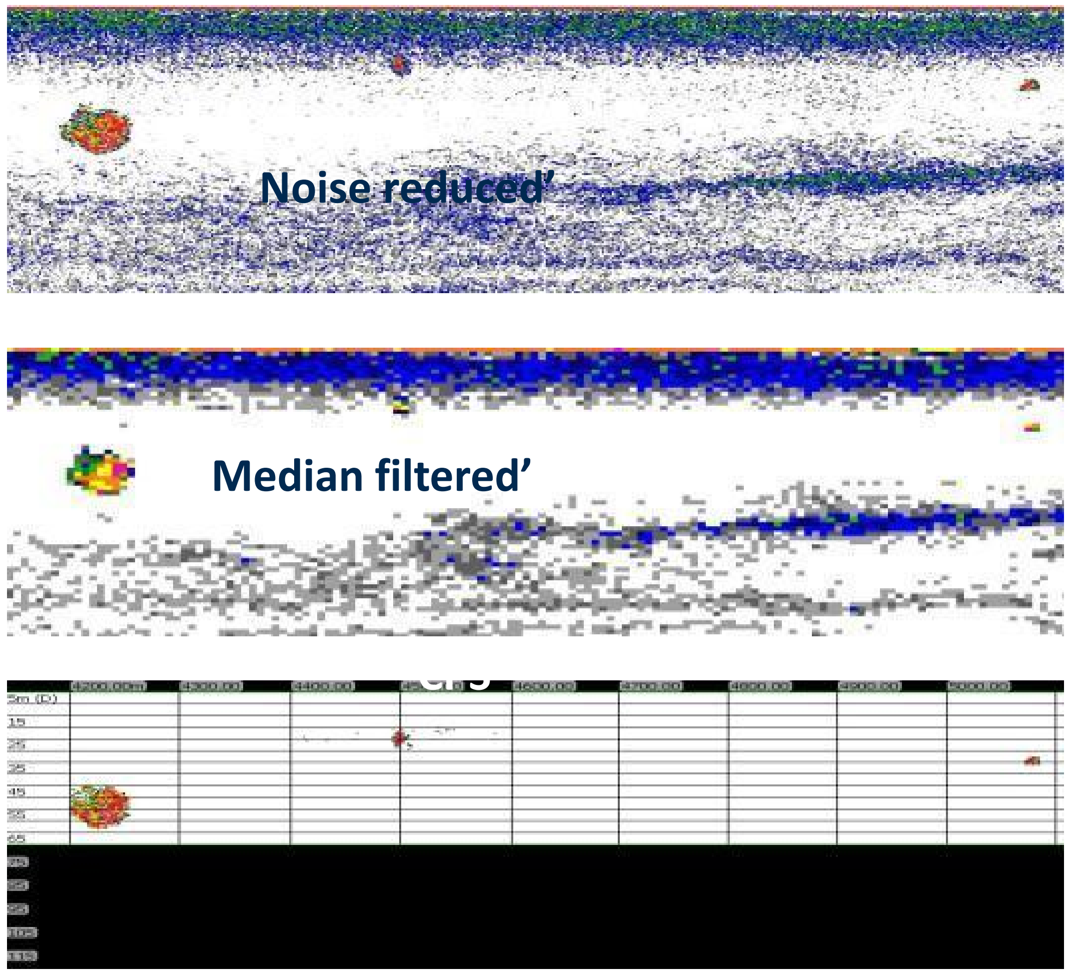
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
45°N
40°N
35°N
30°N
126°W
122°W
118°W
Eggs/m³
100
0
19
18
17
16
15
14
13
12
11

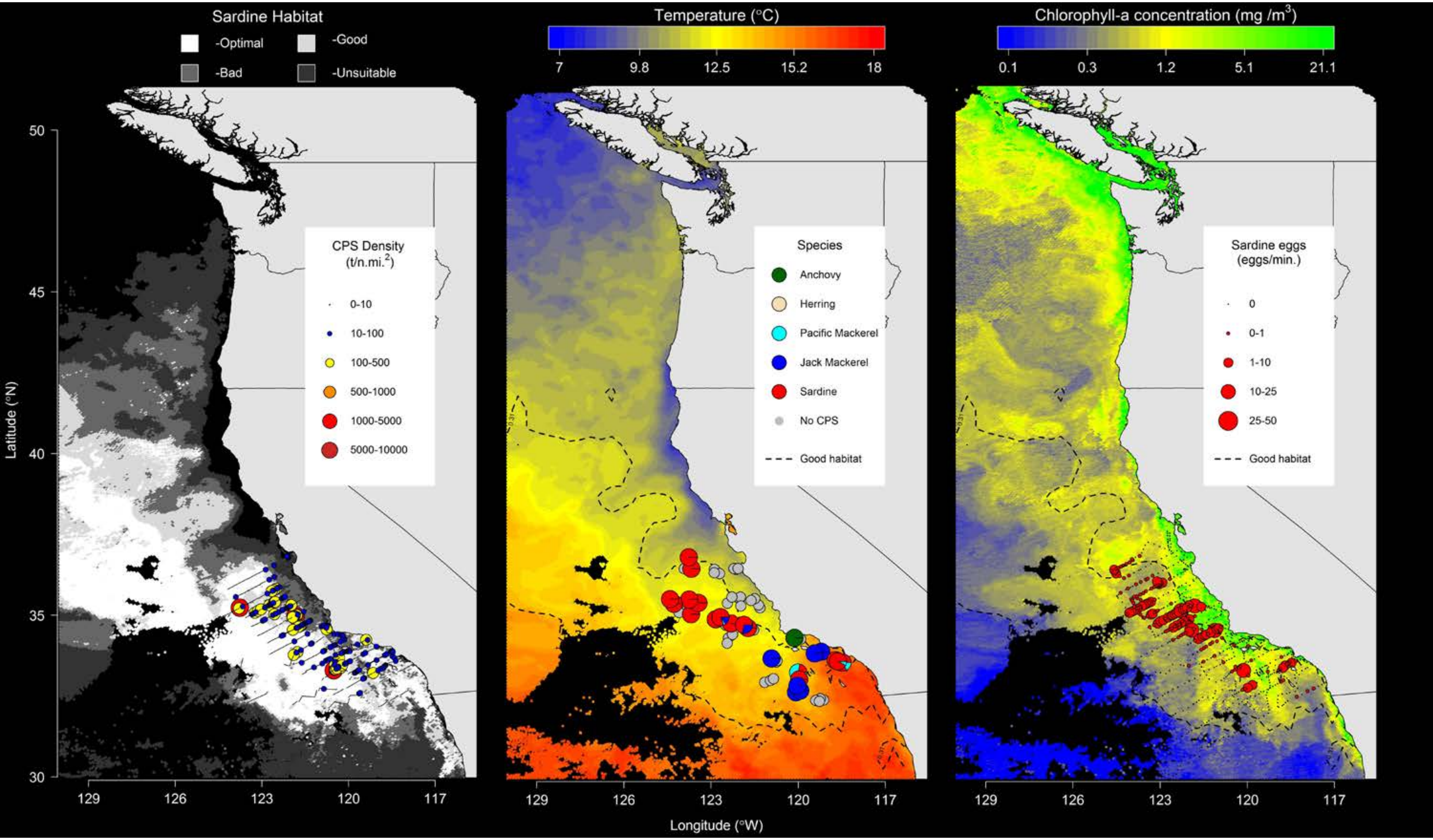
FSV Bell M. Shimada and FSV Ocean Starr
06 April to 03 May 2013



Acoustic Trawl Survey of CPS

Multi-frequency acoustic target identification





Sardine Habitat
-Optimal
-Good
-Bad
-Unsuitable
CPS Density (t/n.mi.²)
0-10
10-100
100-500
500-1000
1000-5000
5000-10000
Latitude (°N)
50
45
40
35
30
129
126
123
120
117
Temperature (°C)
7
9.8
12.5
15.2
18
Species
Anchovy
Herring
Pacific Mackerel
Jack Mackerel
Sardine
No CPS
Good habitat
Longitude (°W)
Chlorophyll-a concentration (mg /m³)
0.1
0.3
1.2
5.1
21.1
Sardine eggs (eggs/min.)
0
0-1
1-10
10-25
25-50
Good habitat

2. Figures, maps, tables, images, etc.

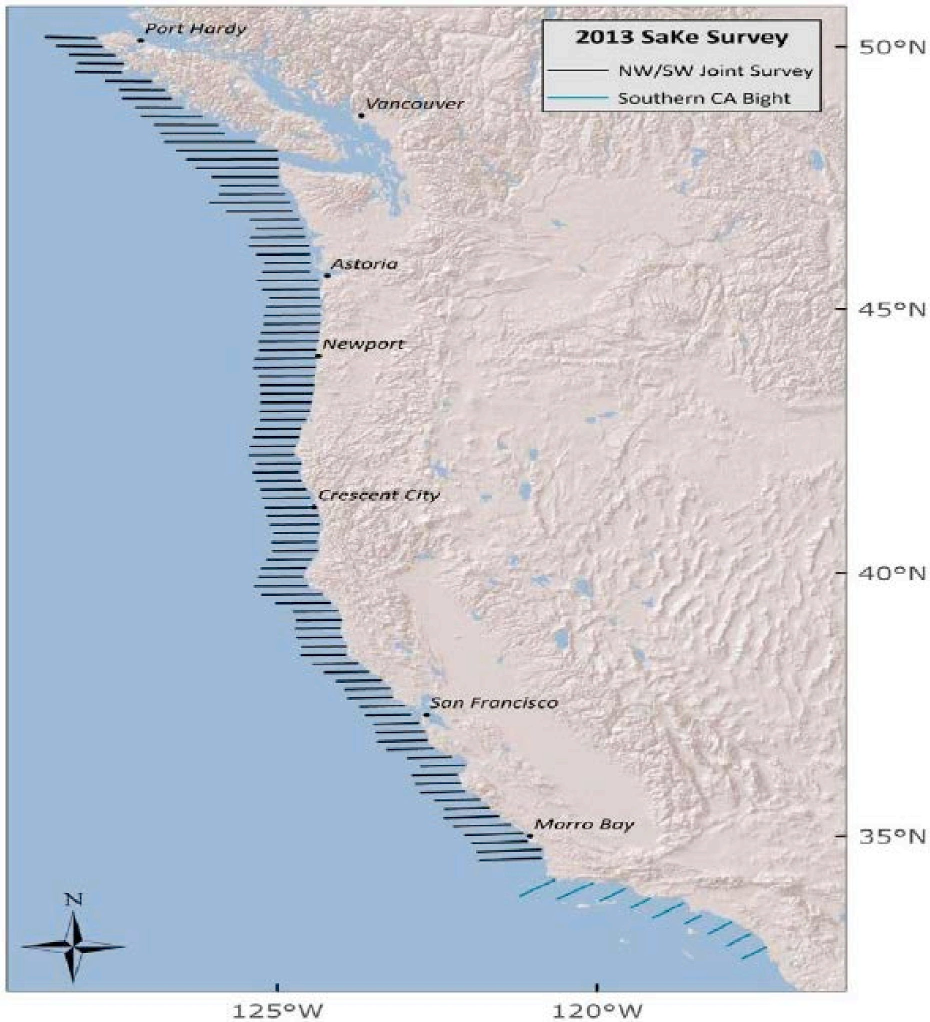
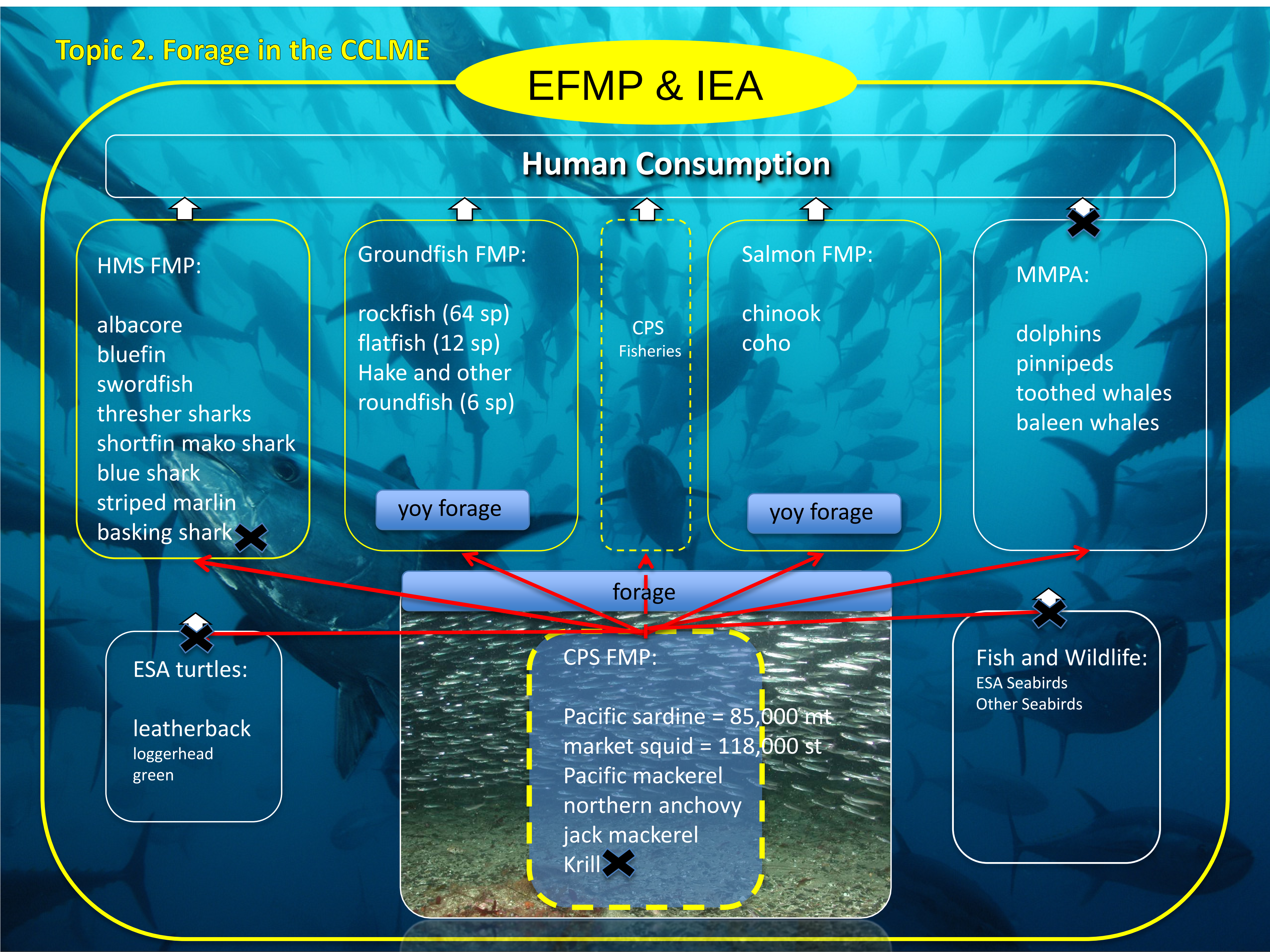
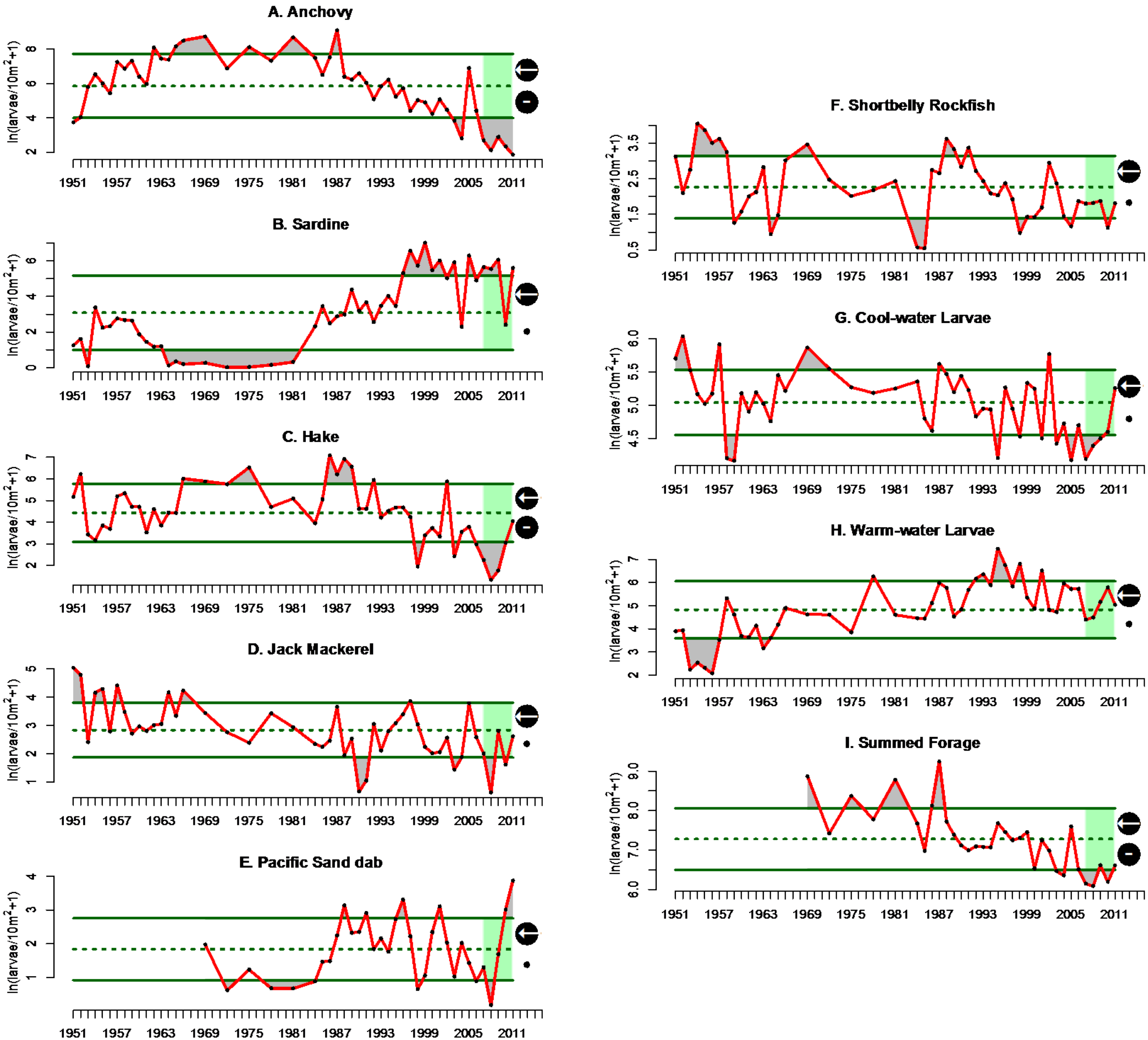
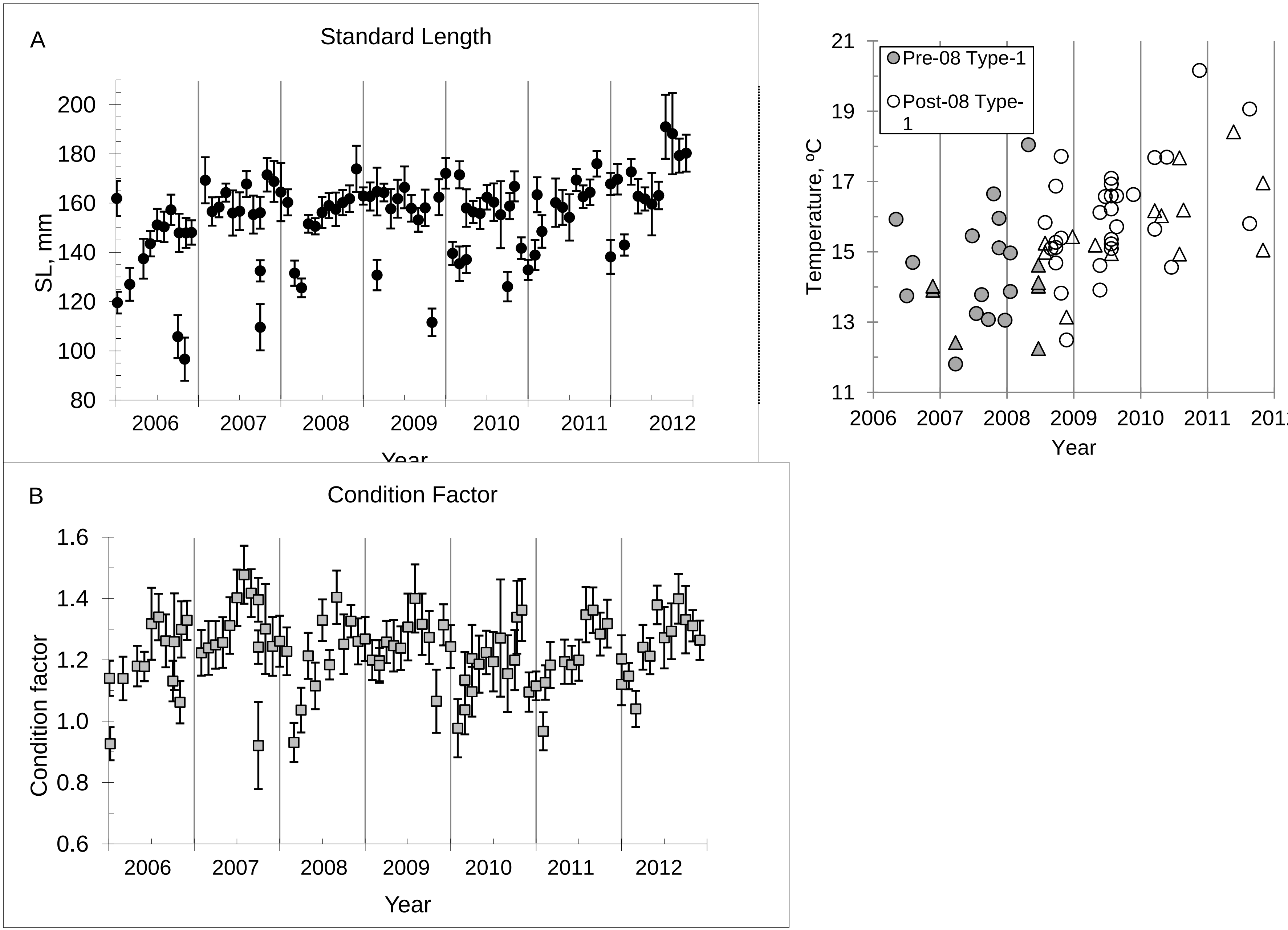


Figure 1. Proposed survey track design for the 2013 joint U.S.-Canada integrated acoustic and trawl survey of Pacific hake and Pacific sardine aboard the NOAA Ship *Bell M. Shimada*.


Topic 2. Forage in the CCLME
EFMP & IEA
Human Consumption
HMS FMP:
albacore
bluefin
swordfish
thresher sharks
shortfin mako shark
blue shark
striped marlin
basking shark
Groundfish FMP:
rockfish (64 sp)
flatfish (12 sp)
Hake and other roundfish (6 sp)
yoy forage
CPS Fisheries
Salmon FMP:
chinook
coho
yoy forage
MMPA:
dolphins
pinnipeds
toothed whales
baleen whales
forage
ESA turtles:
leatherback
loggerhead
green
CPS FMP:
Pacific sardine = 85,000 mt
market squid = 118,000 st
Pacific mackerel
northern anchovy
jack mackerel
Krill
Fish and Wildlife:
ESA Seabirds
Other Seabirds


A. Anchovy
B. Sardine
C. Hake
D. Jack Mackerel
E. Pacific Sand dab
F. Shortbelly Rockfish
G. Cool-water Larvae
H. Warm-water Larvae
I. Summed Forage
ln(larvae/10m^2+1)
1951 1957 1963 1969 1975 1981 1987 1993 1999 2005 2011



A
Standard Length
SL, mm
80
100
120
140
160
180
200
2006
2007
2008
2009
2010
2011
2012
Year
Pre-08 Type-1
Post-08 Type-1
Temperature, ºC
11
13
15
17
19
21
2006
2007
2008
2009
2010
2011
2012
Year
B
Condition Factor
Condition factor
0.6
0.8
1.0
1.2
1.4
1.6
2006
2007
2008
2009
2010
2011
2012
Year

ELSEVIER

Fisheries Research 59 (2002) 217–231

FISHERIES RESEARCH

www.elsevier.com/locate/fishres

Functionally distinct adult assemblages within a single breeding stock of the sardine, *Sardinops sagax*: management units within a management unit

Daniel J. Gaughan*, Warrick J. Fletcher, John P. McKinlay

Department of Fisheries, WA Marine Research Laboratories, P.O. Box 20, North Beach, WA 6920, Australia

Received 5 April 2000; received in revised form 30 August 2001; accepted 16 September 2001

COASTAL PELAGIC SPECIES ADVISORY SUBPANEL REPORT ON NATIONAL MARINE FISHERIES SERVICE REPORT

The Coastal Pelagic Species Advisory Subpanel (CPSAS) reviewed Agenda Item I.1.b, Supplemental National Marine Fisheries Service (NMFS) Report, regarding suggestions on how the Council may proceed to establish maximum sustainable yield (MSY) or a proxy for the northern subpopulation of northern anchovy. According to the NMFS report, both the Coastal Pelagic Species Management Team (CPSMT) and Science and Statistical Committee (SSC) previously highlighted the limited amount of data available to estimate biomass and productivity for this subpopulation of anchovy. Given this subpopulation is lightly fished and data is limited, the CPSAS supports adopting an F_{msy} of 0.30 as proposed by NMFS.

As presented, this value represents the best available science and is consistent with the F_{msy} value used by the SSC to recommend an overfishing limit (OFL) and acceptable biological catch (ABC) for the northern subpopulation of northern anchovy at the November 2010 Council meeting. The CPSAS would also like to reiterate the SSC's recommendation that the OFL and ABC for the stock be updated when new information becomes available.

Regarding the mechanism by which the Council should implement MSY for this subpopulation of northern anchovy, it is our understanding that the Council is not under a specific or court mandated timeframe to implement this change. The CPSAS would be supportive of including this action with other proposed specifications for monitored stocks during the summer of 2013, but would also support utilizing another mechanism that may better suit the current workload and agenda of the Council.

PFMC
06/24/13

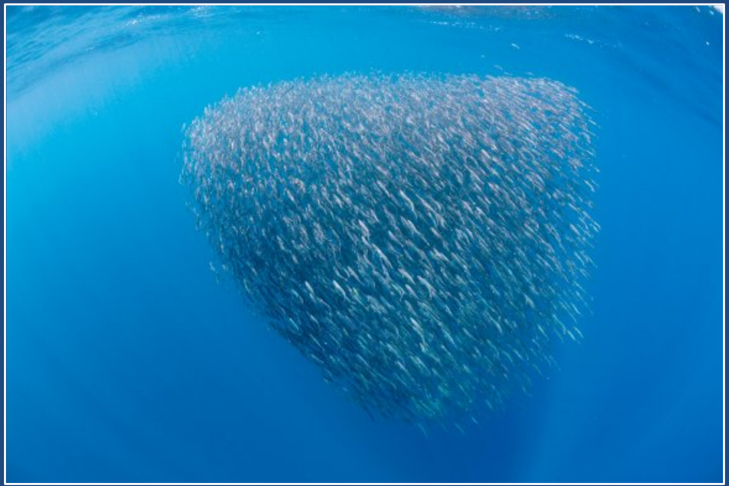
COASTAL PELAGIC SPECIES MANAGEMENT TEAM REPORT ON NATIONAL MARINE FISHERIES SERVICE REPORT

The Coastal Pelagic Species Management Team (CPSMT) reviewed the letter from the National Marine Fisheries Service (NMFS) (Agenda Item I.1.b) to the Council regarding the legal judgment necessitating action by the Council to establish maximum sustainable yield (MSY) or MSY proxy for the northern subpopulation of northern anchovy. An Fmsy of 0.3 was previously recommended by the Scientific and Statistical Committee (SSC) and approved by the Council in November 2010. The National Marine Fisheries Service (NMFS) has proposed that the Council move this forward for final action at a subsequent Council Meeting. The CPSMT supports the use of 0.3 as an Fmsy for the northern stock of northern anchovy. The CPSMT also supports the regulatory process outlined by the NMFS letter to the Council leading to its inclusion in the CPS Fishery Management Plan.

PFMC
06/24/13

Agenda Item I.1.e
Supplemental Public Comment PowerPoint (Oceana)
June 2013

Pacific Fishery Management Council
Coastal Pelagic Species Management
Northern Anchovy & Pacific Sardine



Agenda Item I.1
Ben Enticknap
June 2013

OCEANA | Protecting the World's Oceans

Magnuson-Stevens Fishery Conservation and Management Act

The MSA requires FMPs to "assess and specify the present and probable future condition of, and the *maximum sustainable yield and optimum yield* from, the fishery, and include a summary of the information utilized in making such specification."

Coastal Pelagic Species FMP

	MSY	MFMT	MSST	ABC	OY
Northern Population Northern Anchovy	**Not specified**	Catch Exceeding ABC	**Not Specified**	25% of MSY	**Not Specified**

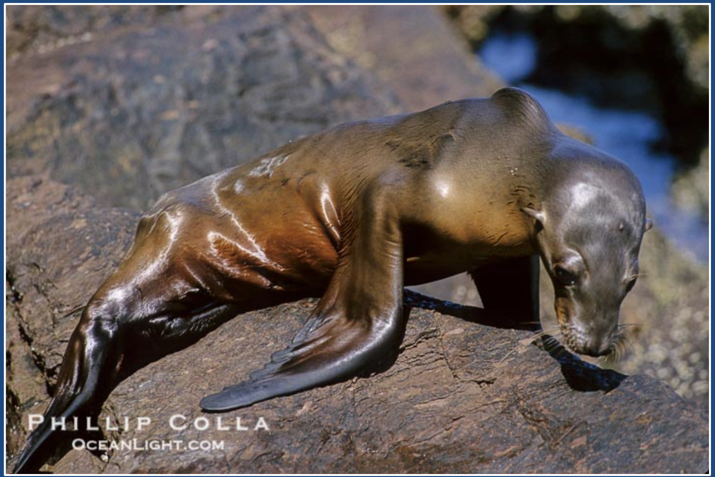
NMFS has the duty to ensure FMPs and amendments are consistent with the national standards, the MSA and other applicable laws.

The Pacific Sardine Population is in Collapse

"[a]larming is the repetition of the fishery's response to a declining sardine stock – progressively higher exploitation rates targeting the oldest, largest, and most fecund fish."

- Zwolinski and Demer 2012.

Unusual Mortality Events & Lack of Prey



		CalCOFI 3-year average				CalCOFI OFL and Actual Landings				
Mgmt year	Biomass (July)	3-y SST	HG Fraction	HG	Difference From Actual SIO HG	OFL Fraction	U.S. OFL	U.S. Landings	Coast-wide OFL	Coast-wide Landings
2000	1,581,346	16.18	0.15	186,791	0	0.24	331,561	72,496	381,104	142,063
2001	1,182,465	15.82	0.15	134,737	0	0.20	202,183	78,520	232,394	125,857
2002	1,057,599	15.47	0.14	106,625	-11,817	0.14	124,247	101,367	142,812	148,952
2003	999,871	15.38	0.12	88,639	-22,270	0.12	104,283	74,599	119,866	116,919
2004	1,090,587	15.46	0.13	109,008	-13,738	0.13	126,392	92,613	145,278	138,948
2005	1,193,515	15.56	0.15	135,381	-797	0.15	154,842	90,130	177,979	148,684
2006	1,061,391	15.71	0.15	118,937	0	0.18	162,261	90,776	186,506	149,588
2007	1,319,072	15.62	0.15	152,564	0	0.16	184,025	127,695	211,523	166,065
2008	832,706	15.38	0.12	71,394	-17,699	0.12	**87,081**	**87,175**	**100,093**	**164,466**
2009	662,886	15.30	0.11	48,181	-18,750	0.11	**62,272**	**67,083**	**71,578**	**138,328**
2010	702,024	15.11	0.08	38,243	-33,796	0.08	**48,634**	**66,891**	**55,901**	**145,935**
2011	537,173	15.26	0.10	33,950	-16,576	0.10	47,103	46,745	**54,142**	**137,801**
2012	988,385	15.15	0.09	62,453	-46,956	0.09	**73,627**	**101,547**	**84,628**	-
2013	659,539	-	-	-	-	-	-	-	-	-

Request For Emergency Action

	Age 1+ Biomass	2013 OFL	2013 HG
Mid-year biomass (2012)	659,539 mt	103,284 mt	66,495 mt
End-year biomass (2012)	**454,683 mt**	**71,203 mt**	**39,761 mt**
End-year biomass + CalCofi Temp Index and Fraction	**454,683 mt**	**35,601 mt**	**23,856 mt**

"The SSC intends to adopt the CalCOFI temperature index as the environmental covariate used to determine the sardine OFL…"

"The SSC recommends; estimated fish biomass at the start of the fishing season should be used in setting harvest quotas."

SSC June 2013 I.4.c

PACIFIC MACKEREL MANAGEMENT STATUS AND MANAGEMENT MEASURES

The Pacific Fishery Management Council (Council) is scheduled to adopt management and harvest specifications for Pacific mackerel, including Overfishing Limit (OFL), Acceptable Biological Catch (ABC), and Annual Catch Limit (ACL). The Council will also consider moving Pacific mackerel from active to monitored status. If Pacific mackerel remains in the active management category, the Council action would be to set annual harvest specifications (status quo). If mackerel is moved to monitored status, the Council would set multi-year specifications and would not have to set new specifications annually.

In 2011, the Southwest Fisheries Science Center (SWFSC) conducted a full assessment (Agenda Item I.2.b, Attachment 1, ***available on briefing book website and CD Only***) that was approved by the Scientific and Statistical Committee (SSC) and the Council. That assessment estimated the age 1+ biomass to be 211,126 mt. The Council adopted an Annual Catch Target (ACT) of 30,336 mt, and an incidental set-aside of 10,128 mt. The Council also adopted a "check in" provision to consider the possibility of re-allocating the incidental set-aside to the directed fishery. However, landings have remained well below the ACT, and therefore no action was warranted. The Council also recommended foregoing an assessment in 2012, and maintained the same management measures for the 2012-2013 fishing year, based on the 2011 assessment.

The SSC and the Coastal Pelagic Species Management Team (CPSMT) recommended (in June 2012 and November 2012, respectively) that the SWFSC develop a catch-only projection estimate of Pacific mackerel biomass (Agenda Item I.2.b, Attachment 2) to be used setting 2013-2014 harvest management specifications. Subsequently, the CPSMT recommended consideration of moving mackerel to the monitored status, based on very low catches, limited additional sample information, and indications that the population's sustainability is not presently being compromised by fishing pressure. The SSC will consider the projection estimate and method, and will recommend an OFL to the Council.

If the Council adopts a status change from active to monitored, the National Marine Fisheries Service and Council staff would develop appropriate regulatory and Council Operating Procedure changes, for adoption at a subsequent Council meeting.

<u>Council Action</u>:

1. **Adopt Change from Active to Monitored Status.**
2. **Adopt Harvest and Management Specifications.**
3. **Provide guidance on Regulatory and Council Operating Procedure Changes.**

<u>Reference Materials</u>:

1. Agenda Item I.2.b, Attachment 1: 2011 Pacific Mackerel Assessment (***Available on Briefing Book Website and CD Only***).
2. Agenda Item I.2.b, Attachment 2: Pacific Mackerel Biomass Projection Estimate.

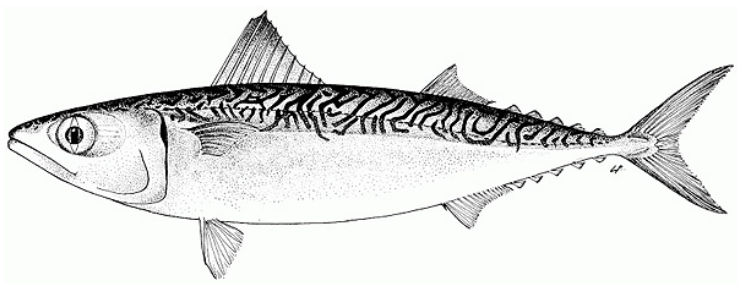
Agenda Order:

a. Agenda Item Overview — Kerry Griffin
b. Pacific Mackerel Biomass Projection — Kevin Hill
c. Reports and Comments of Advisory Bodies and Management Entities
d. Public Comment
e. **Council Action:** Consider Change in Management Status and Adopt Management Measures for Pacific Mackerel

PFMC
05/30/13

Agenda Item I.2.b
Attachment 1 (Electronic Only)
June 2013

PACIFIC MACKEREL (*Scomber japonicus*) STOCK ASSESSMENT FOR USA MANAGEMENT IN THE 2011-12 FISHING YEAR



by

P. R. Crone[1], K. T. Hill[1], J. D. McDaniel[1], and K. Lynn[2]

[1]NOAA Fisheries
Southwest Fiheries Science Center
8604 La Jolla Shores Drive
La Jolla, California, 92037

[2]California Department of Fish and Game
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla, California, 92037

Submitted to

Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 101
Portland, Oregon 97220-1384

June 2011

Crone, P. R., K. T. Hill, J. D. McDaniel, and K. Lynn. 2011. Pacific mackerel (*Scomber japonicus*) stock assessment for USA management in the 2011-12 fishing year. Pacific Fishery Management Council, Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220, USA. 100 p.

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PREFACE

Pacific mackerel stock assessment is conducted annually in support of the Pacific Fishery Management Council (PFMC) process, which ultimately establishes a harvest guideline ('HG' or quota) for the Pacific mackerel fishery that operates off the USA Pacific coast. The HG for mackerel applies to a fishing/management season that spans from July 1st and ends on June 30th of the subsequent year (henceforth, presented as a 'fishing year'). In this context, in this document, both a two-year (2010-11) and single-year (2010) reference refer to the same fishing year that spanned from July 1, 2010 to June 30, 2011. The primary purpose of the assessment is to provide an estimate of current abundance (in biomass), which is used in a harvest control rule for calculation of annual-based HGs. For details regarding this species' harvest control rule, see Amendment 8 of the Coastal Pelagic Species (CPS) Fishery Management Plan (FMP), section 4.0 (PFMC 1998). It is important to note that in 2010, federal mandates required regional fishery Councils to begin transitioning to a revised process for quota determination, which relies on additional statistics not previously included in stock assessment documents and thus, such information is presented here along with the typical HG-related parameters of interest, see Amendment 13 of the CPS FMP (PFMC 2010a) and Ralston et al. (2011) for details regarding these changes.

The last stock assessment and related reviews for this species were completed in 2009 (Crone et al. 2009), with a HG serving for two years (PFMC 2010b). That is, in the past, this species was assessed annually, but given both the population's biology and limited fishing pressure the two-year span was deemed reasonable and adopted by the PFMC in 2009. The stock assessment presented here reflects a 'full' assessment that has undergone formal review as outlined by the PFMC and Science and Statistical Committee (SSC), see PFMC (2010c). Specifically, a stock assessment review (STAR) panel was convened from May 2-5, 2011 (NOAA Fisheries, Southwest Fisheries Science Center in La Jolla, CA) to evaluate the ongoing Pacific mackerel stock assessment. Important areas of general consensus reached by the STAR panel regarding the Pacific mackerel stock assessment conducted in 2011 follow [for further details of the week-long review see STAR (2011)]:

- first and foremost, the stock assessment documentation/presentation followed stipulations set forth in the CPS stock assessment 'Terms of Reference' (PFMC 2010c) and produced a 'base case' model on which to provide formal management advice regarding exploitation of the Pacific mackerel population harvested off the Pacific coast of the United States (USA);
- a base case model (henceforth, Model *XA*) was identified as the final model configuration (hypothesized 'state of nature' or model 'scenario'), included fishery-dependent sources of data (landings, biological distributions, and catch-per-unit-effort indices of abundance), and represented a robust model that was developed via statistical (model fits and diagnostics supported 'inside the model') and pragmatic bases (sound assumptions/parameterizations supported 'outside the model');
- Model *XA* represented the culmination of substantial work over an extended timeframe, including evaluations at the data source (time series) and modeling (sensitivity analysis) levels, however, the current 'final' model is an ongoing effort that is improved upon as more pertinent time series become available and as such, still includes areas of uncertainty regarding the species' biology and influential model parameterizations, which necessarily

precludes precise estimation of absolute abundance and ultimately, may warrant consideration when setting harvest levels for this species [see Assessment uncertainty and Research and Data Needs sections, and STAR (2011)].

Given the inherent difficulties presenting the voluminous amount of results from stock assessment modeling efforts extended over a broad time period, discussion and related displays are largely presented only for the final Model *XA*, with summaries/comparisons/etc. to other models of interest where appropriate (e.g., estimated time series from previous assessments and/or the sensitivity analysis conducted in 2011).

EXECUTIVE SUMMARY

Stock

Pacific mackerel (*Scomber japonicus*) in the northeastern Pacific Ocean range from southeastern Alaska to Banderas Bay (Puerto Vallarta), Mexico, including the Gulf of California. The fish are common from Monterey Bay, California, to Cabo San Lucas, Baja California, but are most abundant south of Point Conception, California. There are possibly three spawning 'stocks' along the Pacific coasts of the USA and Mexico: one in the Gulf of California; one in the vicinity of Cabo San Lucas; and one along the Pacific coast north of Punta Abreojos, Baja California and extending north to waters off southern California and further, off the Pacific Northwest depending on oceanographic conditions (say regimes). This latter sub-stock, the 'northeastern Pacific Ocean' population, is harvested by fishers in the USA and Baja California, Mexico, and is the population considered in this assessment.

Catches

Pacific mackerel landings from both commercial and recreational fisheries in California and commercial landings in Baja California represent the catch time series used in the assessment, with landings pooled into the two broadly-defined fisheries for all modeling purposes, i.e., commercial and recreational fishing sectors, respectively. Historically, total catch time series over the last 100 years can be broadly defined by two or more 'modes,' e.g., late 1920s to mid 1960s and late 1970s to the present (Figure ES-1). Recent catches are presented in Table ES-1. Note that a historically complete catch time series is presented for illustrative purposes only, given the final Model *XA* began in 1983.

Currently, catch (including biological) data are largely collected through a California Department of Fish and Game (CDFG) port (commercial) sampling program, as well as via the Oregon Department of Fish and Wildlife (ODFW) and Washington Department of Fish and Wildlife (WDFW). That is, the CDFG has collected biological data on Pacific mackerel landed in the San Pedro (southern California) fishery since the late 1920s. Further, to some degree, port sampling data have been collected by researchers from Ensenada, Mexico (Instituto Nacional de la Pesca, INP) since 1989; however, this information is only now being distributed at a broader scale through government/academic supported programs. Recreational catches are primarily associated with southern California's marine recreational angler community, including commercial passenger fishing vessel (CPFV), as well as other modes of fishing, such as pier and private vessel. Recreational fishery-based landings are much lower than those related to commercial fisheries (i.e., sport fisheries generate less than 5% of the total catch in any given year).

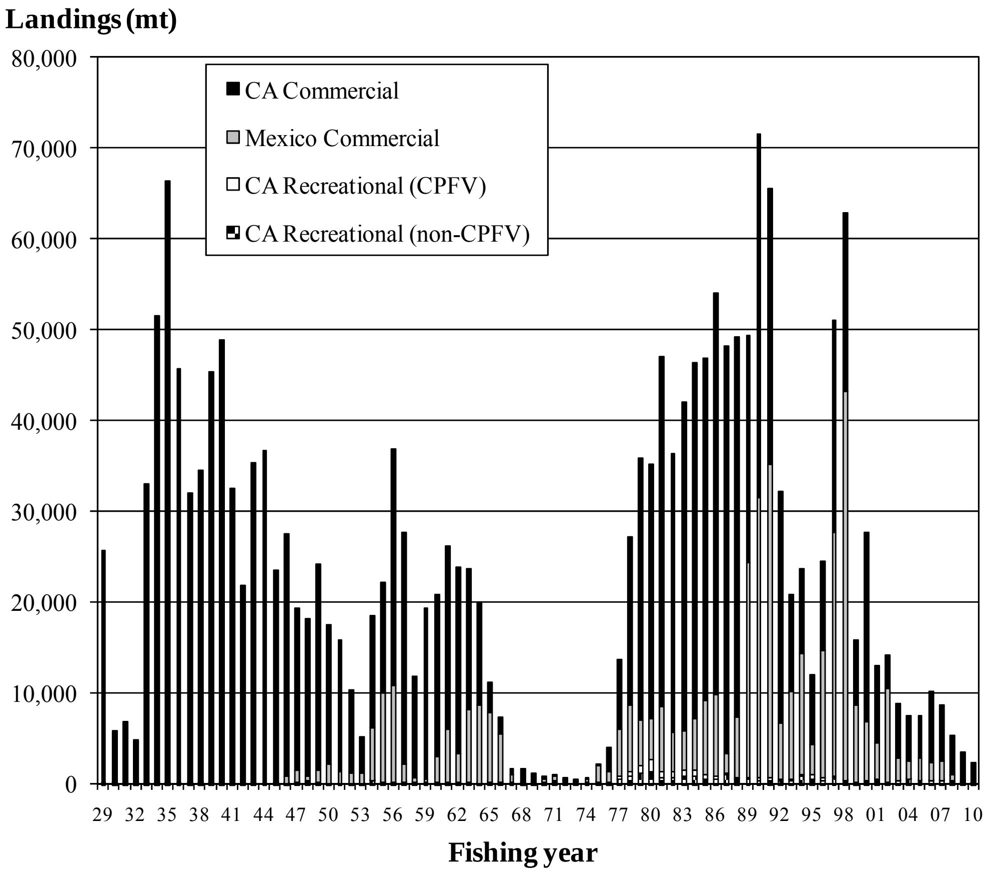

Figure ES-1. Commercial and recreational landings (mt) of Pacific mackerel in the USA (CA commercial, recreational-CPFV, and recreational-non-CPFV) and Mexico (commercial), (1929-10).

Table ES-1. Commercial and recreational landings (mt) of Pacific mackerel in the USA (CA commercial, recreational-CPFV, and recreational-non-CPFV) and Mexico (commercial), (2000-10).

Fishing year	USA Commercial (mt)	Mexico Commercial (mt)	Recreational CPFV (mt)	Recreational non-CPFV (mt)	Total (mt)
00	20,936	6,530	78	248	27,792
01	8,436	4,003	51	520	13,010
02	3,541	10,328	22	232	14,123
03	5,972	2,618	28	295	8,913
04	5,012	2,017	23	510	7,562
05	4,572	2,507	21	375	7,475
06	7,870	1,986	16	356	10,228
07	6,208	2,218	19	291	8,737
08	4,281	803	13	267	5,364
09	3,011	171	13	254	3,450
10	2,086	171	5	95	2,357

Data and assessment

Historically, various age-structured assessment models have been used to assess the status of Pacific mackerel off the west coast of North America, which were generally based on fishery landings and length/age distributions, as well as relative indices of abundance from fisheries and/or research surveys. The last assessment of Pacific mackerel was completed in 2009 for USA management in the 2009-10 fishing year. The current assessment includes the following primary sources of data: catch time series (USA/Mexico commercial and USA recreational fisheries); length (USA recreational fishery) and age (USA commercial fishery) distribution time series; and index of abundance time series from recreational fishery surveys.

Unresolved problems and uncertainties

First and foremost, given Pacific mackerel is a 'transboundary' stock, the assessment would benefit greatly from additional biological and/or 'survey' data (e.g., index of abundance time series) from Mexico. In particular, there is currently no synoptic survey (fishery-independent) index of abundance that pertains to the entire (hypothesized) range of the modeled stock. However, it is important to note that progress continues in terms of addressing these two research efforts, which are expected to gain further support in the coming years. That is, the need for formal data exchange workshops with Mexico (as well as Canada) researchers, and commitment to synoptic surveys that provide representative sample data, particularly, programs related to the CalCOFI and acoustic-trawl survey operations based at the SWFSC. Also, see Research and data needs below.

Total stock biomass

Total biomass (age-1+ biomass, *B*) has steadily declined from the mid 1980s to the early 2000s, at which time the population began to increase moderately in size, with some signs of 'rebuilding' observed over the last several years (Figure ES-2 and Table ES-2). However, in historical terms, the population remains at a relatively low abundance level, due primarily to oceanographic conditions, given limited fishing pressure over the last decade has not likely compromised this species' biology (i.e., role in the larger CPS assemblage off the Pacific coast of North America). Finally, as noted previously, recent estimates of stock size are necessarily related to assumptions regarding the dynamics of the fish (biology) and fishery (operations) over the last several years, which generally confounds long-term (abundance) forecasts for this species (also see Assessment uncertainty section).

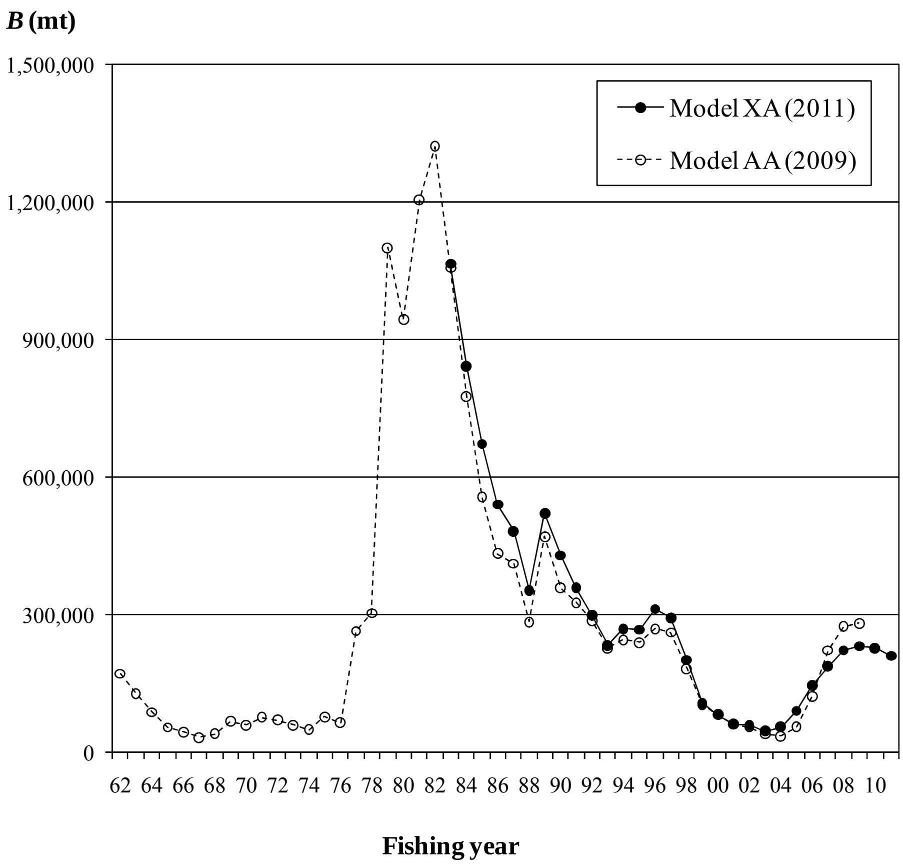

Figure ES-2. Estimated total stock biomass (age 1+ fish in mt, *B*) of Pacific mackerel based on the final Model *XA* (1983-11). Also presented is estimated *B* time series from the previous assessment conducted in 2009 (Model *AA*, 1962-09). Note Model *XA* starts in 1983 (vs. 1962).

Table ES-2. Estimated recruitment (*R*), total biomass (*B*), and spawning stock biomass (*SSB*) of Pacific mackerel based on the final Model *XA* (1983-11).

Fishing year	*R* (age-0, in 1,000s)	*B* (age-1+, mt)	*SSB* (mt)
98	91,301	202,367	116,867
99	158,241	108,333	73,713
00	206,257	83,644	56,033
01	197,479	62,130	32,964
02	90,622	60,757	25,380
03	225,580	47,902	21,127
04	435,040	56,302	20,756
05	625,105	91,182	25,241
06	585,916	146,630	37,196
07	589,941	188,743	55,562
08	427,113	222,844	77,881
09	371,214	231,853	99,082
10	280,972	228,015	112,880
11		211,126	

Spawning stock biomass

Spawning stock biomass (*SSB*) followed the general trajectory as observed in the estimated *B* time series, with magnitudes that are roughly one-half the size of total stock biomass (Figure ES-3 and Table ES-2).

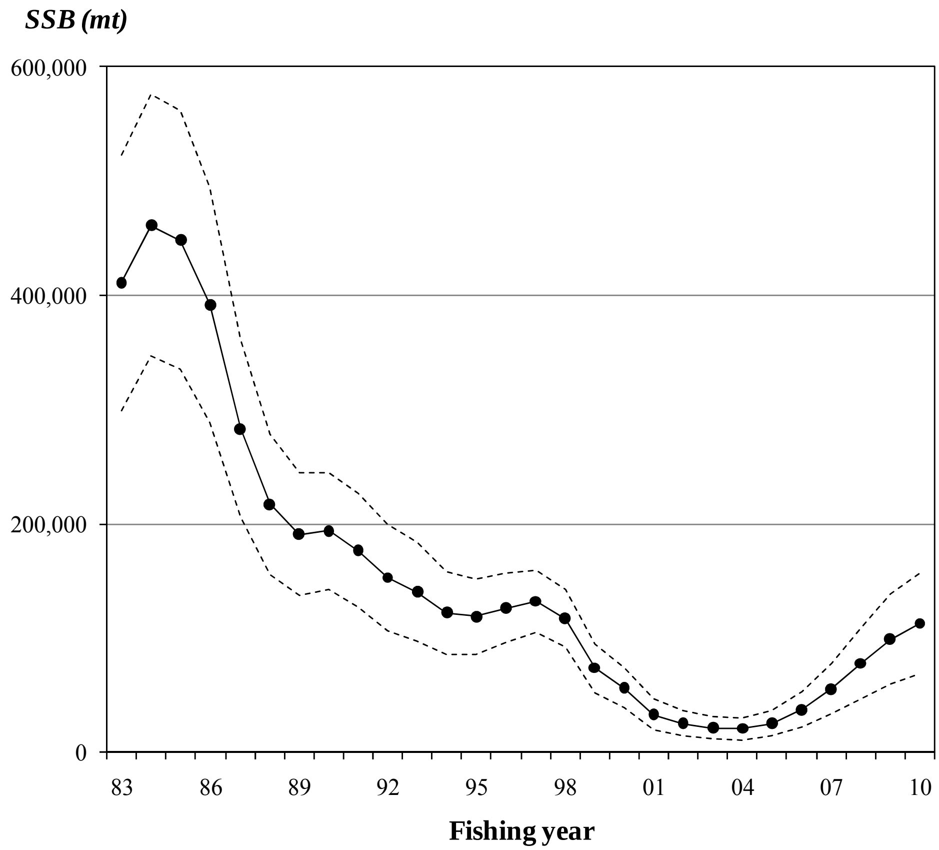

Figure ES-3. Estimated spawning stock biomass (*SSB*) of Pacific mackerel based on the final Model *XA* (1983-10). A confidence interval (95% CI) is also presented as dashed lines.

Recruitment

As expected, historically, estimated recruitment (*R*) has been highly variable, remaining relatively low since the population's last period of (high) recruitment success in the mid 1980s and moderate recruitment levels in the mid 1990s (Figure ES-4 and Table ES-2).

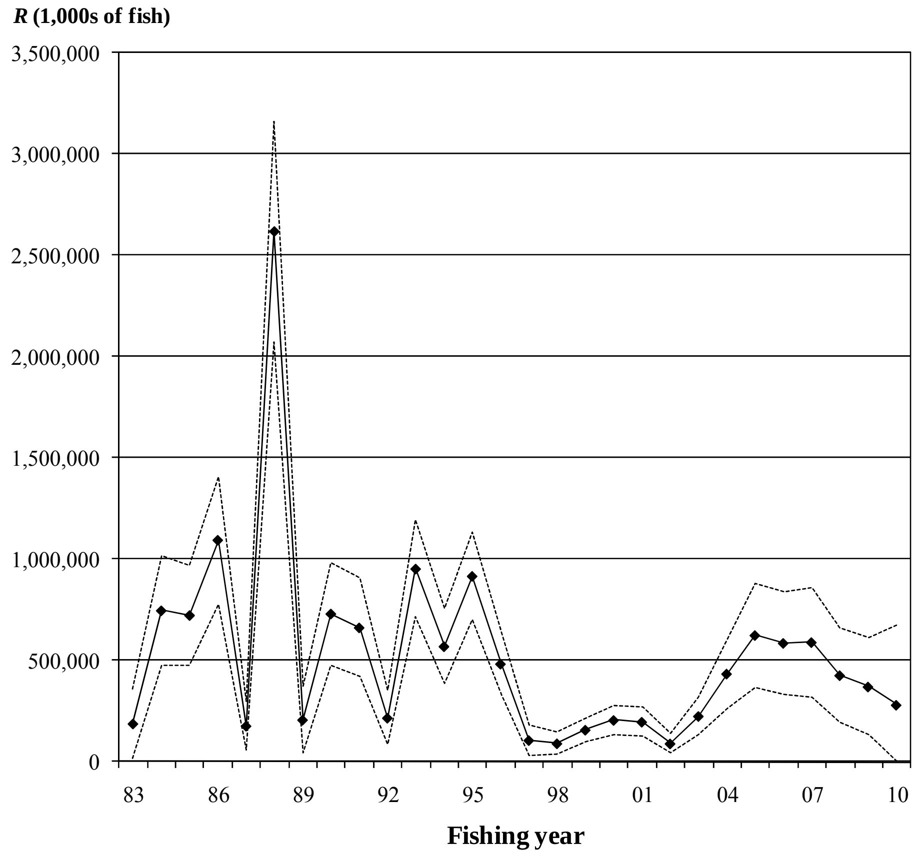

Figure ES-4. Estimated recruitment (age-0 fish in 1,000s, *R*) of Pacific mackerel based on the final Model *XA* (1983-10). A confidence interval (95% CI) is also presented as dashed lines.

Management performance

Since 2000, Pacific mackerel has been managed under a Federal Management Plan (FMP) harvest policy, stipulating that a maximum sustainable yield (MSY) for this species should be set according to the following harvest control rule:

$$\text{Harvest} = (\text{Biomass-Cutoff}) \bullet \text{Fraction} \bullet \text{Distribution},$$

where Harvest is the harvest guideline (HG), Biomass is age 1+ stock biomass (mt) in the current assessment year (211,126 mt on July 1, 2011), Cutoff (18,200 mt) is the lowest level of estimated biomass at which harvest is allowed, Fraction (30%) is the proportion of biomass above the Cutoff that can be harvested by fisheries, and Distribution (70%) is the average fraction of total Biomass (ages 1+) assumed in USA waters (PFMC 1998). The HGs under the federal FMP are applied to a July-June fishing 'year.' Landings and associated HGs since 1992 are presented in Figure ES-5. The HG for the 2011-12 fishing year based on Model *XA* is 40,514 mt (Table ES-3). Also see Harvest Control Rule for USA Management in 2011-12 section for alternative methods for quota determination that are used in concert with the current HG.

From 1985 to 1991, the biomass exceeded 136,000 mt and no state quota restrictions were in effect. State quotas for 1992-00 fishing years averaged roughly 24,000 mt. The HGs averaged roughly 15,000 mt from 2001-06. In 2007, the HG was increased substantially to over 70,000 mt based largely on assumptions regarding variability surrounding estimated recruitment and remained at an elevated level until 2009, when the calculated HG (55,408 mt) was reduced by management (PFMC) to 10,000 mt to address uncertainty related to two alternative models (see Preface and PFMC 2010b); the 10,000 mt HG was adopted in 2010 as well. Finally, note that the HG in 2011 (40,514 mt) is strictly preliminary, given formal adoption of the HG will be addressed at the next Council meeting in June 2011. It is important to note that over the last decade, from a management context, the fishery has not fully utilized HGs, with average yields since this time of roughly 5,000 mt (Figure ES-5).

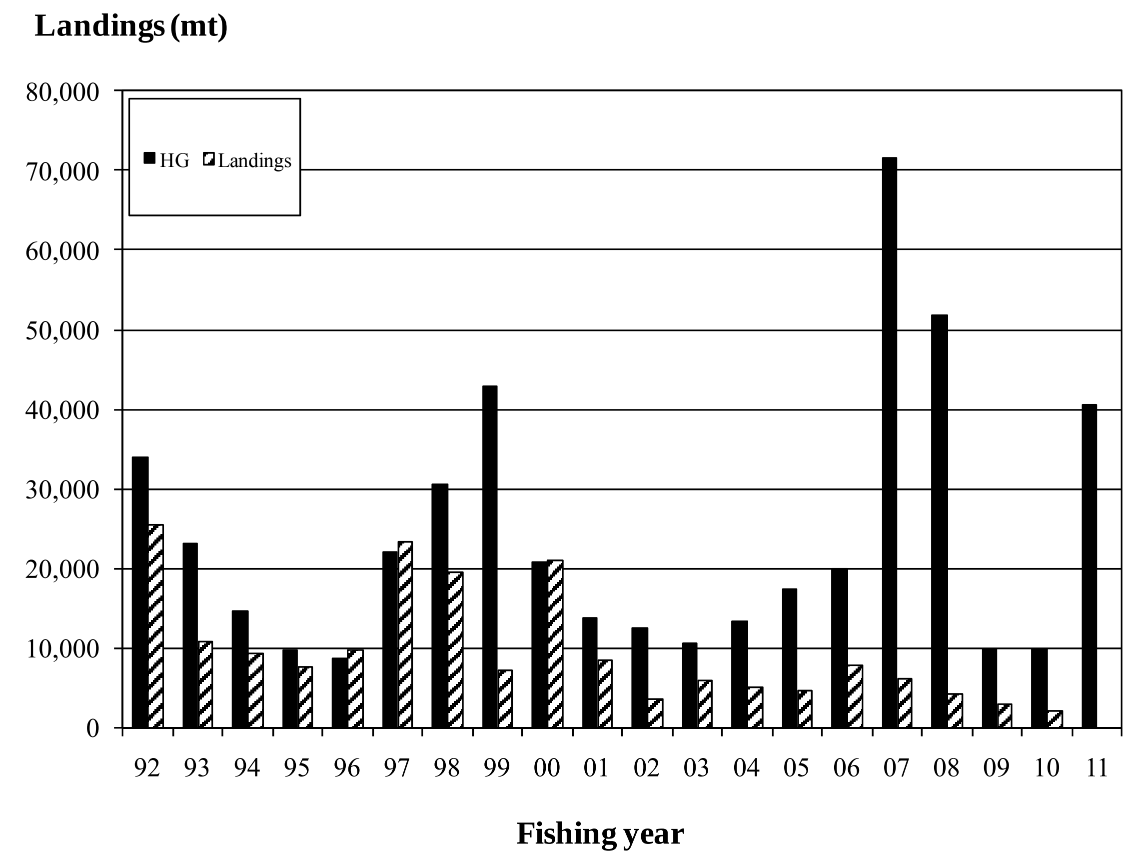

Figure ES-5. Commercial landings (USA directed fishery in mt) and quotas (HGs, mt) for Pacific mackerel (1992-11).

Table ES-3. Harvest control rule statistics for the Pacific mackerel fishery (2011-12). Also, see Harvest Control Rule for USA Management in 2011-12.

B **(Age 1+, mt)**	**Cutoff (mt)**	**Fraction**	**Distribution**	**HG (mt)**
211,126	18,200	30%	70%	**40,514**

Research and data needs

First and foremost, given the transboundary status of this fish population, it is imperative that efforts continue in terms of encouraging collaborative research and data exchange between NOAA Fisheries (Southwest Fisheries Science Center) and researchers from both Canada's and in particular, Mexico's academic and federal fishery bodies, i.e., such cooperation is critical to providing a synoptic assessment that considers available sample data across the entire range of this species in any given year.

Second, fishery-independent survey data for measuring (relative) changes in mackerel spawning (or total) biomass are currently lacking. Further, at this time, two indices of relative abundance are used in the assessment, which are developed from a marine recreational fishery (CPFV fleet and related fishing modes) that typically do not (directly) target the species. That is, the recently implemented CRFS provides useful information regarding this species' dynamics and further, represents a valuable survey for obtaining abundance trends for finfish generally targeted by marine recreational fishers in coastal waters off California. In this context, it is imperative that future research funds be focused on improvement (e.g., broadening the scope and increasing the frequency) of the current fishery-independent surveys operating out of the NOAA's SWFSC (e.g., CalCOFI and acoustic-trawl surveys), with emphasis on a long-term horizon, which will necessarily rely on cooperative efforts between the industry, research, and management, as well as cooperation from international fishery agencies.

Third, given the importance of age (and length) distribution time series to developing a sound understanding of this species' population dynamics, it is critical that data collection programs at the federal and particularly, the state level continue to be supported adequately. In particular, CDFG/NOAA funding should be bolstered to ensure ongoing ageing-related laboratory work is not interrupted, as well as providing necessary funds for related biological research that is long overdue. For example, maturity-related time series currently relied upon in the assessment model are based on data collected over twenty years ago during a period of high spawning biomass that does not reflect current levels, i.e., the SWFSC and CDFG have begun field/laboratory efforts collecting, processing, and analyzing reproductive samples from Pacific mackerel harvested in both the recreational and commercial fisheries. Also, further work is needed to obtain more timely error estimates from production ageing efforts in the laboratory, i.e., accurate interpretation of age-distribution data used in the ongoing assessment necessarily requires a reliable ageing error time series.

Finally, the MSY control rule (HG) utilized in the Pacific mackerel federal CPS-FMP was developed in the mid-1980s based on estimated abundance and stock-recruitment data at that time and thus, the control rule should be re-examined using new data and simulation methods. Given substantial amounts of additional sample data have accumulated since the initial research that was undertaken to formally establish this harvest strategy, it would be prudent to conduct further simulation modeling work to address particular parameters included in the overall control rule (including 'cutoff,' 'fraction,' and 'distribution' values). This particular research need should be considered in context with the new federal mandates regarding quota determination, i.e., in concert with reliance on current HG vs. new stipulations (PFMC 2010a).

INTRODUCTION

Distribution

Pacific mackerel (*Scomber japonicus*; a.k.a. 'chub mackerel' or 'blue mackerel') in the northeastern Pacific range from southeastern Alaska to Banderas Bay (Puerto Vallarta), Mexico, including the Gulf of California (Hart 1973). They are common from Monterey Bay, California, to Cabo San Lucas, Baja California, but are most abundant south of Point Conception, California. Pacific mackerel usually occur within 30 km of shore, but have been captured as far as 400 km offshore (Fitch 1969; Frey 1971; Allen et al. 1990; MBC 1987).

Migration

Pacific mackerel adults are found in water ranging from 10 to 22.2°C (MBC 1987) and larvae may be found in water around 14°C (Allen et al. 1990). As adults, Pacific mackerel move north in summer and south in winter between Washington and Baja California (Fry and Roedel 1949; Roedel 1949), with northerly movement in the summer accentuated during El Niño events (MBC 1987). There is an 'inshore-offshore' migration off California, with increased inshore abundance from July to November and increased offshore abundance from March to May (Cannon 1967; MBC 1987). Adult Pacific mackerel are commonly found near shallow banks. Juveniles are found off sandy beaches, around kelp beds, and in open bays. Adults are found from the surface to 300 m depth (Allen et al. 1990). Pacific mackerel often school with other coastal pelagic species (CPS), particularly jack mackerel and Pacific sardine, and likely based on age-dependent attributes as well (Parrish and MacCall 1978).

Over the last two decades, the stock has likely more fully occupied the northernmost portions of its range in response to a warm oceanographic regime in the northeastern Pacific Ocean, with further evidence, given Pacific mackerel have been found as far north as British Columbia, Canada (Ware and Hargreaves 1993; Hargreaves and Hungar 1995). During the summer months, Pacific mackerel are commonly caught incidentally in commercial whiting and salmon fisheries off the Pacific Northwest, but historically, these catches have been limited. Pacific mackerel sampled from Pacific Northwest incidental fisheries are generally older and larger than those captured in the southern California fishery (Hill 1999). In addition, this species is harvested by recreational anglers on CPFVs and private vessels, but is typically not highly prized in the fishery, with catches relatively low when compared with commercial landings.

Life history

Pacific mackerel found off the Pacific coast of North America are the same species found elsewhere in the Pacific, Atlantic, and Indian Oceans (Collette and Nauen 1983). Synopses regarding the biology of Pacific mackerel are presented in Kramer (1969) and Schaefer (1980).

Currently, the general consensus within the coastal pelagic species research forum is that there are likely three spawning stocks in the northeastern Pacific Ocean: one in the Gulf of California, one near Cabo San Lucas, and one along the Pacific coast north of Punta Abreojos, Baja California to British Columbia, Canada. Spawning occurs from Point Conception, California to Cabo San Lucas from 3 to 320 km offshore (Moser et al. 1993). Off California, spawning occurs from late April to September at depths to 100 meters. Off central Baja California, spawning occurs year round, peaking from June through October. Around Cabo San Lucas, spawning occurs primarily from late fall to early spring. Pacific mackerel seldom spawn north of Point Conception (Fritzsche 1978; MBC 1987), although young-of-year (age-0) fish have been recently reported as far north as Oregon and Washington.

Like many coastal pelagic species with similar life history strategies, Pacific mackerel have indeterminate fecundity and appear to spawn whenever sufficient food is available and appropriate oceanographic conditions prevail. Individual fish may spawn eight times or more per year and release batches of 68,000 eggs per spawning. Actively spawning fish appear capable of spawning daily or every other day (Dickerson et al. 1992).

Pacific mackerel larvae eat copepods and other zooplankton, including fish larvae (Collette and Nauen 1983; MBC 1987). Juvenile and adult mackerel feed on small fish, fish larvae, squid, and pelagic crustaceans, such as euphausids (Clemmens and Wilby 1961; Turner and Sexsmith 1967; Fitch 1969; Fitch and Lavenberg 1971; Frey 1971; Hart 1973; Collette and Nauen 1983). Pacific mackerel larvae are subject to predation from a number of invertebrate and vertebrate planktivores. Juvenile and adults are eaten by larger fishes, marine mammals, and seabirds. Principal predators include porpoises, California sea lions, pelicans, and large piscivorous fishes, such as sharks and tunas. Pacific mackerel school as a defense against predation, often with other pelagic species, including jack mackerel and Pacific sardine.

Population dynamics of the Pacific mackerel stock off southern California have been extensively studied in the past and of particular importance was pioneering research conducted during the 1970s and 1980s, e.g., Parrish (1974), Parrish and MacCall (1978), Mallicoate and Parrish 1981, and Macall et al. (1985). More recently, USA-based research efforts associated with pelagic species that inhabit coastal areas of the Pacific coast of North America have focused on the Pacific sardine population. Pacific mackerel experience cyclical periods of abundance ('boom-bust'), which is typical of other small pelagic species that are characterized by relatively short life spans and high intrinsic rates of increase. Analysis of mackerel scale-deposition data (Soutar and Issacs 1974) indicated that periods of high biomass levels, such as during the 1930s and 1980s, are relatively rare events that might be expected to occur, on average, about once every 60 years (MacCall et al. 1985). It is important to note that assessment model structure and results generally support MacCall's research, with periods of strong recruitment estimates occurring no more frequently than at least 30 years or so. Recruitment is highly variable over space and time and not likely related to spawning biomass stock size (Parrish 1974), or at least not tightly linked to parent abundance levels within the historical range of estimated spawning stock biomass levels (Parrish and MacCall 1978).

Stock structure and management units

The full range of Pacific mackerel in the northeastern Pacific Ocean is from southeastern Alaska to Banderas Bay (Puerto Vallarta), Mexico, including the Gulf of California. The majority of the fish are typically distributed from Monterey Bay, California, to Cabo San Lucas, Baja California, being most abundant south of Point Conception, California. It is likely that multiple 'spawning' stocks exist along the Pacific coasts of the USA and Mexico, although at this time, stock structure exhibited by this species is not known definitively: one in the Gulf of California; one in the vicinity of Cabo San Lucas; and one along the Pacific coast north of Punta Abreojos, Baja California and extending north to waters off southern California and further, off the Pacific

Northwest depending on oceanographic conditions (say regimes). This latter sub-stock, the 'northeastern Pacific Ocean' population, is harvested by fishers in the USA and Baja California, Mexico, and is the population considered in this assessment.

The Pacific Fishery Management Council (PFMC) manages the northeastern Pacific stock as a single unit, with no area- or sector-specific allocations. However, the formal Fishery Management Plan (FMP) harvest control rule does include a stock distribution adjustment, based on a long-term assumption that roughly 70% of this transboundary population resides in USA waters in any given year (PFMC 1998).

Fishery descriptions

Pacific mackerel are currently harvested by three 'fisheries': the USA commercial fishery that primarily operates out of southern California; a sport fishery based largely in southern California; and the Mexico commercial fishery that is based in Ensenada and Magdalena Bay, Baja California. In the commercial fisheries, Pacific mackerel are landed by the same boats that catch Pacific sardine, anchovy, jack mackerel, and market squid (generally, referred to as the west coast 'wetfish' fleet). There is no directed fishery for mackerel in Oregon or Washington; however, small amounts (100-300 mt annually) are taken (incidentally) by whiting trawlers and salmon trollers. Catches in the Pacific Northwest peaked at 1,800 mt following the major El Niño event of 1997-98.

The history of California's Pacific mackerel fishery has been reviewed by Croker (1933; 1938), Roedel (1952), and Klingbeil (1983). Pacific mackerel supported one of California's major fisheries during the 1930s and 1940s and more recently, particular years in the 1980s and 1990s. During the early years of the fishery, Pacific mackerel were taken by lampara and pole-and-line boats, which were replaced in the 1930s by the same purse seine fleet that fished for sardine. Before 1929, Pacific mackerel were taken incidentally, in relatively small volumes, with sardine and sold as fresh fish (Frey 1971). Canning of Pacific mackerel began in the late 1920s and increased as greater processing capacities and more marketable 'packs' were developed. Landings decreased in the early 1930s due to the economic depression and subsequent decline in demand, but increased significantly by the mid-1930s (66,400 mt in 1935-36). During this period, Pacific mackerel were second only to Pacific sardine in total (annual) landings. Harvests subsequently underwent a long-term decline and for many years, demand for canned mackerel remained steady and exceeded supply. Supply reached record low levels in the early 1970s, at which time the State of California implemented a 'moratorium' on the directed fishery.

Following a period of 'recovery' that spanned from the mid to late 1970s, the moratorium was lifted and subsequently, through the 1990s, the fishery ranked third in volume for finfish landed in California. During this time, the market for canned mackerel fluctuated due to availability and economic conditions. Domestic demand for canned Pacific mackerel eventually waned and the last mackerel cannery in California closed in 1992. At present, most Pacific mackerel is used for human consumption or pet food, with a small, but increasing amount sold as fresh fish.

Pacific mackerel are caught by recreational anglers in southern California, but seldom as a target species (Young 1969). During the 1980s, California's recreational catch averaged 1,500 mt per year, with Pacific mackerel being one of the most important species harvested by the California-based CPFV fleet. Pacific mackerel are also harvested in California's recreational fishery as bait for directed fishing on larger pelagic species. Additionally, Pacific mackerel are caught by anglers in central California, but typically, only in small amounts. The state-wide sport harvest constitutes a small fraction (less than 5% in weight) of the total landings.

The Mexico fishery for Pacific mackerel is primarily based in Ensenada and Magdalena Bay, Baja California. The Mexico purse seine fleet has slightly larger vessels, but is similar to southern California's fleet with respect to gear (mesh size) and fishing practices. The fleet operates in the vicinity of ports and also targets other small pelagic species. Demand for Pacific mackerel in Baja California increased after World War II. Mexico landings remained stable for several years, rose to 10,725 mt in 1956-57, then declined to a low of 100 tons in 1973-74. Catches in Mexico remained relatively low through the late 1980s. Landings of Pacific mackerel in Ensenada peaked twice, first in 1991-92 at 34,557 mt, and again in 1998-99, at 42,815 mt. The Ensenada fishery has been comparable in volume to the southern California fishery since 1990. In Baja California, Pacific mackerel are either canned for human consumption or reduced to fish meal.

Management history

The state of California first applied management measures to Pacific mackerel in 1970, after the stock had collapsed in the mid 1960s. A moratorium was placed on the fishery at this time, with a small allowance for incidental catch in mixed-fish landings. In 1972, legislation was enacted that imposed a landing quota based on the estimate of age-1+ ($\geq$1-yr old fish) biomass generated from formal assessments. A couple of very strong year classes in the late 1970s triggered a stock recovery (increase in total abundance), which was followed by the fishery being reopened under a quota system in 1977. During the span of the recovery period from 1977 to 1985, various adjustments were made to quotas for directed take of Pacific mackerel and to incidental catch limits, i.e., even during the 'moratorium' substantial allowances were made for incidental catches associated with this species (Parrish and MacCall 1978).

State regulations enacted in 1985 imposed a moratorium on directed fishing when the total biomass was less than 18,200 mt, and limited the incidental catch of Pacific mackerel to 18% during such moratoriums. The fishing year was set to extend from July 1st to June 30th of the following year. Seasonal quotas, equal to 30% of the total biomass in excess of 18,200 mt, had been allowed when the biomass was between 18,200 and 136,000 mt, and there was no quota limitation when the total biomass was 136,000 mt or greater.

A federal fishery management plan (FMP) for coastal pelagic species, including Pacific mackerel, was implemented by the PFMC in January 2000 (PFMC 1998). The FMP's harvest policy for Pacific mackerel, originally implemented by the State of California, is based on simulation analysis conducted during the mid 1980s, with the addition of a proration to account nominally for the portion of the 'stock' assumed to inhabit USA waters, see MacCall et al. (1985) and PFMC (1998). The current maximum sustainable yield (MSY) control rule for Pacific mackerel is:

$$\text{Harvest} = (\text{Biomass-Cutoff}) \bullet \text{Fraction} \bullet \text{Distribution},$$

where Harvest is the harvest guideline (HG), Cutoff (18,200 mt) is the lowest level of estimated biomass at which harvest is allowed, Fraction (30%) is the proportion of biomass above the Cutoff that can be harvested by fisheries, and Distribution (70%) is the average fraction of total Biomass (ages 1+) assumed in USA waters. The HGs under the federal FMP are applied to a July-June 'fishing year.'

California's recreational catch of Pacific mackerel is included within the USA HG, but there are no other restrictions (e.g., size or bag limits) on this fishery. Total annual harvest of Pacific mackerel by the Mexico fishery is not regulated by quotas, but there is a minimum legal size limit of 255 mm. International management agreements between the USA and Mexico regarding transboundary stocks, such as Pacific mackerel, have not been developed to date (see Preface and Research and data needs).

Management performance

From 1985 to 1991, the biomass exceeded 136,000 mt and no state quota restrictions were in effect. State quotas for 1992-00 fishing years averaged roughly 24,000 mt. The HGs averaged roughly 15,000 mt from 2001-06. In 2007, the HG was increased substantially to over 70,000 mt based largely on assumptions regarding variability surrounding estimated recruitment and remained at an elevated level until 2009, when the calculated HG (55,408 mt) was reduced by management (PFMC) to 10,000 mt to address uncertainty related to two alternative models (see Preface and PFMC 2010b); the 10,000 mt HG was adopted in 2010 as well. It is important to note that over the last decade, from a management context, the fishery has not fully utilized HGs, with average yields since this time of roughly 5,000 mt. Finally, recent legislation concerning management of exploited fisheries in the USA now require alternative methods for quota determination that are used in concert with the HG method above [see PFMC (2010a), SSC (2010), and Ralston et al. (2011) for methods used to derive OFL, ABC, ACL, and associated buffer values]. Also, see Harvest Control Rule for USA Management in 2011-12 section below.

ASSESSMENT

Ultimately, the Pacific mackerel stock assessment final Model *XA* presented here reflects two primary changes from recently conducted assessments, including: (1) an additional index of abundance derived from recreational fishery data collected through the newly implemented California Recreational Fishery Survey (CRFS, 2004-10); and (2) additional (historical) length distribution data collected from an observer (CPFV) sampling program conducted by CDFG from 1985-89. Other changes associated with estimation methods for influential areas of parameterization were also necessary, particularly, those related to selectivity/catchability associated with biological distributions and indices of abundance. Parameterization details associated with Model *XA* are presented below (see Model description sections) and in Table 5.

A full suite of assessment-related displays for the final Model *XA* are presented in the body of this document. Additionally, SS program files associated with Model *XA* are presented in Appendix 1. Finally, Table 5 presents a broad range of important parameter-related statistics associated with Model *XA*, as well as for the final model adopted in the previous formal assessment conducted in 2009 (aka Model *AA*).

History of modeling approaches
Parrish and MacCall (1978) were the first to provide stock status determinations for Pacific mackerel using an age-structured population model (i.e., traditional virtual population analysis, VPA). The ADEPT model (the 'ADAPT' VPA modified for Pacific mackerel; Jacobson 1993 and Jacobson et al. 1994b) was used to evaluate stock status and establish management quotas for approximately 10 years. The assessment conducted in 2004 (for 2004-05 management) represented the final ADEPT-based analysis for this stock (see Hill and Crone 2004a). That is, the forward-simulation model ASAP (Legault and Restrepo 1998) was reviewed and adopted for Pacific mackerel at the 2004 STAR Panel (Hill and Crone 2004b). The ASAP model was used for assessments and management advice from 2005 through 2008. The STAR conducted in 2009 determined that the SS model provided the best (most flexible) platform for assessing the status of Pacific mackerel currently (i.e., the 2009-10 fishing year) and in the future, see STAR (2009, 2011).

Sources of data
Fishery-dependent data
<u>Overview</u>
Fishery-related data for assessing Pacific mackerel included: landings (California commercial, California recreational, and Mexico commercial); port sample (biological) data from California's commercial (purse seine) and recreational (CPFV) fisheries; biological (length) data from an observer (CPFV) sampling program coordinated through the CDFG; and logbook (CPFV) and survey (CRFS) data from marine recreational fisheries for purposes of developing catch-per-unit-effort (CPUE) indices. Since 1992, the CDFG has collected biological data on Pacific mackerel landed in the southern California fishery (primarily, San Pedro). Samples have also been collected from the Monterey fishery when available. For this assessment, raw sample data were available from 1962 through 2010. Biological samples include whole body weight, fork length, sex, maturity, and otoliths for age determination. Currently, CDFG collects 12 'random' (port) samples per month (25 fish per sample) to determine length/age distributions, catch-at-age, weight-at-age, etc. for the directed fishery. Mexico port sampling data have been collected by INP-Ensenada since 1989, but have not been available for purposes of inclusion in this ongoing assessment effort and thus, California commercial data were assumed to be representative of the combined commercial fisheries. Lack of Baja California port sampling data is not a serious problem for some years when Mexico catches were low. However, in recent years, Baja California and California catches have been roughly equal in volume, which necessarily increases the likelihood that potential biases associated with the omission of (and subsequent assumptions concerning) sample data from the Mexico fishery. Sample sizes associated with this data collection program are presented in Table 1.

Pacific mackerel were aged by CDFG biologists, based on identification of annuli in whole sagittae. Historically, a birth date of May 1st was used to assign year class (Fitch 1951). In 1976, ageing protocols changed to a July 1st birth date, which coincided with a rebounding resource, resumed fishery sampling, and a change in the management season from a May 1st opening to a July 1st start date.

Fishery inputs were compiled by 'biological year,' based on the birth dates used to assign age. Therefore, data prior to 1976-77 were aggregated in the biological year of May 1st (year$_x$)

through April 30th (year$_{x+1}$), and data from 1976-77 forward were aggregated July 1st (year$_x$) through June 30th (year$_{x+1}$). The biological year used in this assessment is synonymous with the 'fishing year' defined previously, as well as with 'fishing season' as reported in the historical literature. That is, the change in birth date assignment from May 1st to July 1st coincided with a change in the management season in the mid-1970s, with historical sources of landings and biological data reflecting this change.

Catches

The assessment includes commercial and recreational landings in California and commercial landings in Baja California (Mexico) from 1983 to 2010. Annual (fishing year) landing estimates of Pacific mackerel are presented in Table 2 and Figure 1.

The following discussion regarding harvest prior to 1983 is provided for general information only, given the current assessment model (Model *XA*) begins in 1983. California commercial landings of Pacific mackerel were obtained from a variety of sources based on dealer landing receipts (CDFG) and in some cases, augmented with port sampling for mixed load portions. Data from 1929-61 were obtained from Parrish and MacCall (1978). Monthly landings for the period May 1962 to September 1976 were obtained from CDFG fish bulletins recovered to an electronic data base format (PFEL 2005). Raw landing receipt data for Pacific mackerel from 1976 to 1991 were of marginal quality, owing to the large quantities of Pacific mackerel landed as mixed loads with jack mackerel. During this period, many processors reported either species as 'unspecified' mackerel on landing receipts. For these years, mackerel landings receipts were augmented with shoreside 'bucket' sampling of mixed loads to estimate species compositions. The CDFG reported these data in two forms: (1) annual stock status reports to the California legislature; and (2) single page 'CDFG Wetfish Tables.' Both sources are considered more accurate than PacFIN or other landing receipt-based statistics for this period. Data sources from late 1976 to the present are as follows: October-December 1976 are from Klingbeil and Wolf (1986); January-December 1977 are from Wolf and Worcester (1988); January 1978-December 1981 are from Jacobson et al. (1994a); January 1982-December 2010 are from CDFG Wetfish Tables, as well as PacFIN (for the limited landings from Oregon and Washington); and finally, landing estimates for January-June 2011 and July 2011-June 2012 were assumed to be similar to the analogous time blocks of the previous year, namely, January-June 2010 and July 2010-June 2011, respectively.

California recreational landings (mt) from 1980 to the present (2-month 'wave' resolution) were obtained directly from Pacific RecFIN data base estimates. Historical estimates (pre-1980) of total recreational catch were derived from CPFV logbook data collected since 1936 (Hill and Schneider 1999). The CPFV catch (number) was converted to metric tons using an assumed average weight of 0.453 kg (1 lb) per individual, based on RecFIN samples and consistent with Parrish and MacCall (1978). The CPFV harvest was expanded to total recreational tonnage using wave-specific ratios from RecFIN.

Baja California data include landings from commercial purse seine fisheries in Ensenada, Cedros Island, and Magdalena Bay. Ensenada landings were compiled as follows: 1946-47 through 1969-70 (May-April) data are from Parrish and MacCall (1978); 1970-71 through 1975-76 (May-April) data are from Schaefer (1980); quarterly data from July 1976 through December

1986 are from Jacobson et al. (1994b); monthly data from January 1987 through November 2003 were provided by INP-Ensenada (García and Sánchez, 2003; Celia Eva-Cotero, INP-Ensenada, personal communication, INP-Ensenada staff); monthly landings from December 2003 through December 2004 were not available and thus, were substituted with corresponding months from the previous year. Ensenada landings in 2005, available from Cota et al. (2006), were apportioned into monthly catch using ratios from the previous few years. Ensenada landings for January to June 2006 were taken from Cota et al. (2006). Monthly landing data for the Cedros Island (January 1981-December 1994) and Magdalena Bay (January 1981 – May 2003) fisheries were provided by R. Felix-Uraga (CICIMAR-IPN, La Paz, personal communication). The fishery off Cedros Island ceased in 1994. For 2003 to 2009, commercial landings for the Ensenada and Magdalena Bay fisheries were taken from CONAPESCA's web archive of Mexican fishery yearbook statistics (CONAPESCA 2010).

Finally, small volumes (100 to 300 mt per year) of Pacific mackerel are taken incidentally in other fisheries (e.g., whiting, salmon troll, and Pacific sardine) off Oregon and Washington. Biological samples collected from these fisheries (Hill 1999) indicated fish from these waters are typically larger and older than the directed fishery off California and thus, these limited samples have not been included in the current assessment model presented here.

Length distributions

All model scenarios included length distributions for the USA recreational fisheries, including CPFV (1985-89, 1992-10) and non-CPFV (2004-10) time series, i.e., utilizing age-based selectivity. Age-based selectivity was used in all model scenarios, including: age distribution time series from the fishery, as well as mean length-at-age time series (see Age distributions and Mean length-at-age distributions below); and length distribution time series (no age data available) from the recreational fisheries. Length distributions for the recreational fisheries were partitioned into CPFV (Figure 2A) and non-CPFV time series (Figure 2B): CPFV time series is developed from both a CDFG observer sampling program (1985-89) and the Marine Recreational Fishing Statistical Survey (MRFSS and related Pacific RecFIN data base) using sample examined catch data (1992-10); and non-CPFV time series developed from the California Recreational Fishery Survey (2004-10).

The CDFG conducted a CPFV onboard observer sampling program in southern California from 1975-78 and from 1985-89, and in central and northern California from 1987-98. That is, the earlier time series (1975-78) was omitted, given the model started in 1983, and the latter time series (1987-98) was omitted, given limited sample data over this time period, as well as having a representative time series for these data already in the model (i.e., 1992-10). Ultimately, selectivity parameterization for both the recreational fishery and CPFV index of abundance (i.e., mirrored the recreational fishery) was based on the length distribution developed from only the CPFV fishery. Finally, see Reilly et al. (1998) for further details of this sampling program and overall data collected.

The length distribution from CRFS represented fish caught via all recreational fishing modes, but the CPFV fleet, which allowed for the most reasonable selectivity parameterization for the CRFS index of abundance, see CRFS abundance index section below.

Length distributions were developed using 1-cm length (fork) bins, with the smallest bin equal to 1 cm and the largest equal to 60 cm. The 60-cm bin includes fish that were greater than or equal to 60 cm. The total number of lengths (say specimens measured for length) observed in each distribution (of each time step) was divided by 25 (the average number of fish collected per sample) and subsequently, used as the effective sample size in baseline model configurations. Ultimately, length distributions (in numbers of fish) were converted to proportion estimates for all modeling efforts.

Age distributions

Age distribution time series were developed from the same (CDFG) port sample data base described previously, i.e., the sampling program entails recording length, sex, age (via otolith collections), etc. from each fish in the 25-fish sample taken from a completed fishing trip. It is important to note that age (and length) distributions developed from this sampling program are considered to be representative of the landings associated with the (commercial) fishery and thus, serve as the foundation for evaluating cohort dynamics in the fully-integrated models. Ultimately, age distributions (in proportion-at-age) were based on 9 age bins that represented age-0 to age-8+, i.e., a 'plus group' that includes $\geq$8-yr old fish. The total number of ages (say specimens measured for age) observed in each distribution was divided by 25 (the average number of fish collected per sample) and subsequently, used as the effective sample size in baseline model configurations. Ultimately, age distributions (in numbers of fish) were converted to proportion estimates for all modeling efforts. Annual age distributions (1983-10) associated with all models are presented in Figure 3.

Mean length-at-age distributions

For the primary purpose of evaluating growth dynamics associated with this species, mean length-at-age time series (1983-10) were developed from the same (CDFG) port sample data base described above and used in conjunction with age distributions in SS model scenarios (Figure 4). Effective sample size estimates were obtained using the same 25-fish adjustment employed for the other biological distributions, based on typically sample sizes from a completed fishing trip.

Ageing error distribution

In efforts to provide the most realistic measure of uncertainty associated with estimated age distribution time series, an ageing error vector, based on standard 'double-read' methods, was also included in all model scenarios, i.e., a SD vector by age was used in all SS model scenarios (Figure 5). It is important to note that further ageing error analysis pertaining to this species is warranted, given the current vector is considered preliminary at this time.

Commercial passenger fishing vessel (CPFV) index of abundance

California Fish and Game legislation has required CPFV captains to provide records of catch and effort data to CDFG since 1936. In the past, Pacific mackerel have been among the top five species reported on CPFV logs, both in southern California and state-wide; however, the species is not typically targeted per say by the fishery. This information resides in a logbook data base (Hill and Barnes 1998; Hill and Schneider 1999) that summarizes CPFV catch and effort by month and Fish and Game statistical blocks (10 nm^2). A single state-wide index of relative abundance was developed, based on a delta-Generalized Linear Model (delta-GLM) approach for estimating year effects (Dick 2010), i.e., a CPUE time series of relative abundance (Figure 6A). The index is based on a fishing year basis, as is the case with other time series used in the models. Selectivity parameterization associated with this index mirrored the recreational fishery (i.e., age-based selectivity based on length distribution time series).

To account for potential changes in catchability associated with the CPFV fleet over time, a delta-GLM model was used to 'standardize' the data and separate effects from critical factors (e.g., spatial-temporal). That is, by incorporating year as a factor, the delta-GLM generates estimates of annual standardized catch rate and its variance that can be generally interpreted as a relative index of abundance of the population. Ultimately, the index of abundance is based on two GLMs: the first GLM estimates the probability of a positive observation, based on a binomial likelihood and logit link function; and the second GLM estimates the mean response for the positive observations, assuming a gamma error distribution. The final index is the product of the back-transformed year effects from the two GLMs. Technical details concerning the delta-GLM analysis follow:

(1) data were combined within year/quarter/fleet strata (i.e., the overall, statewide fishery was partitioned into a northern and southern 'fleet' based on latitude/longitude spatial fishing 'blocks');
(2) CPUE was calculated (number of fish/1,000 angler-hours fishing) for each spatial/temporal stratum;
(3) fishing years 1983 to 2010 were used in the analysis;
(4) latitude/longitude blocks were combined into broader spatial areas based on the fishing practices of the northern and southern CPFV fleets, i.e., historically, the southern fleet has exerted the vast amount of fishing pressure associated with this overall fishery (Pt. Conception was used as the 'north/south' delimiter to partition the two regional fleets);
(5) the delta-GLM method models the probability of obtaining a zero catch and the catch rate separately, given the catch rate is non-zero (Stefansson 1996; Maunder and Punt 2004). In this assessment, we estimate the probability of a positive observation using a binomial distribution and a logit link function. Then, the mean response for positive observations was estimated assuming a gamma distribution for the error term. The basic model for positive observations included the log of mean catch rate (μ) as a function of three main effects (fishing year i, quarter j, and fleet k),

$$\log_e(\mu_{ijk}) = U_R + Y_i + Q_j + F_k + \varepsilon_{ijk},$$

where μ_{ijk} is the mean catch rate (number of fish/1,000 angler-hours) in year i, quarter j, and fleet k. The fishing year effect is denoted by Y_i (i=1, 2, ..., I; I=49 fishing years). The quarter of the year effect is denoted by Q_j (j=1, 2, ..., J; J=4 quarters). The fleet effect is denoted as F_k (k=1, ..., K; K=3 fleets). The error term is denoted ε_{ijk}, where for each combination of indices, ε_{ijk} is *iid* and gamma distributed. Finally, the reference cell is denoted as *UR* (R=1 reference cell, i.e., year=2004, quarter=4, and fleet=south);
(6) no temporal/spatial interactions (e.g., year and fleet or quarter and fleet) were included in the final delta-GLM model, given such interactions had little effect on increasing the amount of variability in mean catch rate as a function of the suite of explanatory variables (i.e., minor improvement of R^2 statistic, see Hill and Crone 2005, Crone et al. 2006); and

(7) a delta-GLM function written in the statistical programming language R (Dick 2010) was used to estimate a mean catch rate from the CPFV data set. A major feature of this function is that it estimates coefficients of variation (CV) for the relative index of abundance using a jackknife (leave-one-out) method. However, because the CPFV data were very extensive (nearly 90,000 observations), estimation of both year effects for the survey simultaneously with measures of dispersion (i.e., CVs) was problematic and ultimately, unsuccessful, i.e., an average CV (0.30) was used for each annual estimate of the time series.

Finally, note that all other estimation techniques used to evaluate these data, including GLMs, GAMs, and even nominal mean time series resulted in very similar results, i.e., ultimately, trajectories used in the model to model relative population size over time.

<u>California Recreational Fisheries Survey (CRFS) index of abundance</u>

The California Recreational Fisheries Survey (CRFS) began in 2004 to provide catch and effort estimates for California marine recreational finfish fisheries in six coastal districts and four fishing modes. It represents a collaborative effort between the CDFG and the Pacific States Marine Fisheries Commission (PSMFC) and provides higher spatial and temporal resolution than the previous federal-based survey (MRFSS, 1980-03). See PSMFC (2010) for details regarding survey goals, methods, data availability/accessibility, etc.

The CRFS index of abundance was evaluated at the fishing mode level (Figure 6B), and developed in a similar manner as that above for the CPFV logbook-related index, with the final time series used in modeling efforts having the following differences:

(1) all fishing modes, with the exception of the CPFV fleet (Figure 6A-B);
(2) CPUE was calculated as the number of fish per fishing party/day, i.e., data base structure and limited (examined) sample information precluded calculations at a finer scale (e.g., angler/hour), however, the units of CPUE are likely inconsequential to the overall analysis, given 'positive catch' records composed roughly 1-4% (depending on fishing mode) of the total records (see Table 3 for summary CRFS statistics and Figure 6A-B applicable to Pacific mackerel and the overall survey); and
(3) fishing years 2004 to 2010 were used in the analysis.

Finally, this time series represents an additional index of abundance that has not been included in past assessments and was considered an alternative index in sensitivity analysis conducted in 2011, which in effect, complements the CPFV index above, given it includes data from leisure fishing modes not included in the CPFV analysis.

Biological data

Weight-length

A weight-length (W-L) relationship for Pacific mackerel was modeled using port sample data collected by CDFG from 1962 to 2010 (see Fishery-dependent data above). A straightforward power function was used to determine the relationship between weight (kg) and fork length (cm) for both sexes combined:

$$W_L = a\ (L^b),$$

where W_L is weight-at-length L, and a and b are the estimated regression coefficients. Weight-length parameters based on data from 1962-10 (a = 3.1E-06 and b = 3.4) were used (fixed) in all model scenarios (Figure 7).

Length-at-age

The von Bertalanffy growth equation was used to model the relationship between fork length (cm) and age for Pacific mackerel (1962-10):

$$L_A = L_\infty\ (1 - e^{-k(A-to)}),$$

where L_A is the length-at-age A, L_∞ ('L-infinity') is the theoretical maximum length of the fish, k is the growth coefficient, and t_o ('t-zero') is the theoretical age at which a fish would have been zero length. Length-at-age was estimated internally in all SS model scenarios, generally based on the following baseline growth equation for this population calculated from the CDFG data base (1962-10): L_∞ = 39.3 mm, k = 0.342, and t_o = -1.752 (Figure 7). Of particular note is the rapid growth exhibited by this species, i.e., past research (Parrish and MacCall 1978; Mallicoate and Parrish 1981), as well as analysis conducted here on recent biological sample data, indicates fish, on average, realize over 50% of their total growth (in length) in the first year of life and subsequently, grow a few cm per year until death at roughly 40 cm (approximately, age 7-8). Sensitivity analysis resulted in relatively robust estimates of $k \approx 0.30$.

Maximum size and age

The largest recorded Pacific mackerel was 63.0 cm in length (FL) and weighed 2.9 kg (Roedel 1938; Hart 1973), but the largest Pacific mackerel taken by commercial fishing (CA) was 47.8 cm FL and 1.72 kg. The oldest recorded age for a Pacific mackerel was 14 years, but most commercially caught Pacific mackerel are less than 4 years old, with few living beyond age 8 and larger than 45 cm.

Maturity-at-age

The estimated maturity schedule (ogive) used in the past for this stock was assumed in all model scenarios here (Table 4 and Figure 7). That is, normalized net fecundity-at-age (the product of fraction mature, spawning frequency, and batch fecundity) was used to interpret CalCOFI ichthyoplankton data and ultimately, generate estimates of *SSB*. Fraction mature was estimated by fitting a logistic regression model to age and fraction mature data from Dickerson et al. (1992). Spawning frequency was estimated by fitting a straight line to age and spawning frequency data from the same study. Following Dickerson et al. (1992), batch fecundity per gram of female body weight was assumed constant.

Natural mortality

Natural mortality rate (*M*) was assumed to be 0.5 yr^{-1} for all ages and both sexes, and used in all modeling efforts presented here (Figure 7). Parrish and MacCall (1978) estimated natural mortality for Pacific mackerel using early catch curves (M = 0.3-0.5), regression of Z on f (M = 0.5), and comparative studies of maximum age (M = 0.3-0.7; Beverton 1963) and growth rate (M = 0.4-0.6; Beverton and Holt 1959). The above authors considered the regression of Z on f to be the most reliable method, with the estimate M = 0.5 falling within the range of the plausible estimates, i.e., an instantaneous M = 0.5 can be practically interpreted as an annual rate of roughly 40% of the stock dying each year due to 'natural causes.'

Stock-recruitment

A Beverton-Holt (B-H) stock-recruitment (*S/R*) relationship was assumed for this population for all models scenarios, i.e., as observed in the historical literature, as well as from modeling efforts here, recruitment is highly variable and not likely related closely to absolute levels of *SSB* biomass (*SSB*). However, it is important to note that steepness (*h*) ranged from roughly 0.35 to 0.75, depending on the model scenario, indicating that at low *SSB* levels, recruitment is estimated to decrease slightly to moderately (Figure 8). Parrish (1974) and Parrish and MacCall (1978) discussed general life history strategies for this population that are tightly linked to oceanographic conditions and further, that periods of strong year classes (cohorts) are likely produced only when *SSB* is high (or moderately so) and more importantly, not likely to occur more than once or twice every 60 years.

Responses to past STAR/SSC recommendations

The three overriding recommendations from past reviews focused on data availability from Mexico, omission/inclusion/parameterization of available indices of relative abundance used in the ongoing assessment, and updating biological parameters considered influential in the overall modeling effort. See STAR (2009) for further discussion regarding these issues.

Regarding relations with Mexico and issues surrounding future data exchange and professional collaboration on research projects … *SWFSC staff continue to engage in such discussions, meetings, conferences, etc. with academic colleagues and federal researchers from Mexico, e.g., updated landing information and additional, albeit preliminary, larval survey data have been made available recently*.

Regarding indices of relative abundance used in the current assessment … *substantial progress was made with developing an alternative index of abundance (see CRFS index of abundance above), sensitivity analysis that addressed inclusion/omission of the suite of alternative indices, and further examinations of time-varying catchability/selectivity within an index (see Model description sections, Assessment model results, and Assessment uncertainty below).*

Regarding updating biological parameters used in the ongoing assessment ... *SWFSC and CDFG have jointly begun field/laboratory efforts collecting, processing, and analyzing reproductive samples from Pacific mackerel harvested in both the recreational and commercial fisheries. It is important to note that an 'aggressive' sampling plan over a 2 to 4 year time horizon will be required to accumulate enough samples to develop an updated maturity schedule for use in stock assessments due to limited landings of this species, coupled with few field-based surveys*.

Model description

Overview

The Stock Synthesis (SS, Methot 2005, 2011) model is founded on the AD Model Builder software environment, which essentially is a C++ library of automatic differentiation code for nonlinear statistical optimization (Otter Research 2001). The model framework allows full integration of both population size and age structure, with explicit parameterization both spatially and temporally. The model incorporates all relevant sources of variability and estimates goodness of fit in terms of the original data, allowing for final estimates of precision that accurately reflect uncertainty associated with the sources of data used as input in the overall modeling effort.

The SS model comprises three sub-models: (1) a population dynamics sub-model, where abundance, mortality, and growth patterns are incorporated to create a synthetic representation of the true population; (2) an observation sub-model that defines various processes and filters to derive expected values for different types of data; and (3) a statistical sub-model that quantifies the difference between observed data and their expected values and implements algorithms to search for the set of parameters that maximizes goodness of fit. This modeling platform is also very flexible in terms of estimation of management quantities typically involved in forecast analysis. Finally, from an international context, the SS model is rapidly gaining popularity, with SS-based stock assessments being conducted on numerous marine species throughout the world. The SS model used in this assessment was the most recently distributed version, namely, version 3.20b (January 2011).

Likelihood components and model parameters

Likelihood components and estimates for important SS model scenarios are presented in Table 5, including, fits to catch, age/length distributions, and indices, as well as parameter estimates for initial conditions (age distribution, recruitment, and fishing mortality), growth, recruitment, stock-recruitment relationship, etc.

Convergence criteria

The convergence criterion for maximum gradient determination was set to 0.0001 in the SS model. Fidelity of model convergence was explored by changing particular ‘starting’ values for multiple parameters and evaluating the converged ‘minimum’ values, i.e., evaluating ‘global’ vs. ‘local’ convergence properties of the overall, multi-dimensional numerical estimation.

Model selection and evaluation

We strongly adhered to model development (say parameterization involved in the various scenarios constructed in sensitivity analysis) that was based on the following: supports general consensus regarding this species’ life history; results in no noticeable inconsistencies (across likelihood components) within the fully-integrated model scenario; addresses uncertainty in a sound, robust, and parsimonious manner; and finally, produces realistic (meaningful) results that can be directly assimilated into ongoing management efforts.

Sensitivity analysis

Sensitivity analysis resulted in a suite of models for review at the onset of the STAR meeting in May 2011, as well as numerous model scenarios developed during the interactive meeting itself.

In keeping with final assessment documentation protocols, model presentation is largely devoted to the final base case model selected by the STAR panel and STAT (i.e., Model *XA*). Pertinent summary statistics for both Model *XA* and for comparative purposes, the previous assessment final model (Model *AA*) adopted in 2009 are presented in Table 5A-D. Additionally, final sensitivity analysis for Model *XA* is presented in Table 5D, i.e., influential parameterizations were evaluated via 16 model scenarios to ensure the final model was both robust and generally consistent across data sources. Readers interested in details regarding the plethora of model scenarios evaluated in the review meeting via sensitivity analysis should consult STAR (2011). Finally, note that other model scenarios involved in the overall sensitivity analysis were generally similar to Model *XA*, i.e., parameterization differences largely reflected a step-wise approach, whereby a single change in a parameter of interest (e.g., selectivity for a fishery, omission/addition of time series, etc.). A complete suite of displays is presented for Model *XA* within the body of the document. Key features of the final Model *XA* follow:

Model *XA*:

- *Time period*: 1983-10 (new parameterization, i.e., previously, 1962);
- *Fishery structure*: two (USA/Mexico commercial and USA recreational);
- *Surveys*: two indices of relative abundance (CPFV index and the new CRFS index);
- *Time-step*: annual;
- *Gender structure*: combined sexes;
- *Longevity*: 12 years (new parameterization, i.e., previously, 15 years);
- *Natural mortality*: 0.5 for all ages. Also, see Natural mortality above.
- *Growth*: estimated and constant over time;
  As presented in previous literature that addressed growth dynamics associated with this stock (Parrish and MacCall 1978), there is little evidence in support of noticeable growth changes over time (i.e., in terms of length-at-age). However, growth during the species last period of high recruitment success (late 1970s to late 1980s) was potentially different (say faster and realizing larger sizes) than observed over the last two decades or so, but given a start year of 1983, growth was observed to be much more consistent over the last two decades. Finally, overall sensitivity analysis resulted in robust estimates of K (Ks ≈ 0.30). Additionally, sensitivity analysis that considered time-varying changes for growth in weight (i.e., in terms of weight-length/age), which in the vast majority of animal populations is the more 'plastic' growth attribute, revealed no indication that this growth parameter has changed markedly over the last 20 years;
- *Selectivity (biological distributions)*: age-based, a single time block, and asymptotic for the commercial fishery and dome-shaped for the recreational fishery. Selectivity issues regarding age- or size-based approaches were given much attention, based on relations to the actual operation of the fisheries and dynamics of the stock. That is, we feel that the distribution exhibited by this species on any given year and subsequently, its probability of capture (selectivity) is more influenced by 'time' (say age) than by size (say length), i.e., this is true for all age groups, from the high variability observed in the presence/absence of 0-1 yr-old fish to the adults in the estimated age distributions modeled here. Recognizing that in reality, both attributes are likely influential to some degree, it is more likely that movement (and capture) are driven by age, i.e., versus gear (mesh) constraints that also generally influence vulnerability. Given the biological sampling design in place provides 'random' samples of fish (for purposes of length, age, etc.) from completed boat trips,

selectivity parameterization based on representative age distributions of the catch becomes the logical approach. Although the biological distributions from the recreational fishery were in terms of size (length, given no age data available), age-based selectivity was estimated from CPFV length distribution for this fishery as well. Finally, preliminary modeling efforts indicated age- or size-based selectivity resulted in similar conclusions of stock status;

- *Selectivity (indices)*: age-based, a single time block, and dome-shaped (i.e., mirrors recreational fishery) for the CPFV index of abundance and age-based, a single time block, and dome-shaped (estimated from non-CPFV length distribution);
- *Catchability*: constant over time, with CVs = 0.30 for year effects;
- *Stock-recruitment*: Beverton-Holt stock-recruitment model. An asymptotic relationship between parents and offspring was assumed in all model scenarios. Also, see Stock-recruitment above. Variance associated with log recruitment estimation was fixed, i.e., σ_R = 1.0 (in most model scenarios, generated root MSEs were roughly = 1.0 (0.8-1.25); and
- *Variance adjustments to time series*: None. Note that in the final model in 2009, a variance adjustment was implemented for the recreational fishery length distribution parameterization, i.e., this re-weighting was not deemed necessary for the final model in 2011.

Assessment model results (Model *XA*)

Results are summarized below, with discussion regarding important topics related to the overall population analysis presented in the Assessment uncertainty section below. Trends of estimated trajectories of management-related time series (e.g., biomass, spawning stock biomass, and recruitment) from updated model scenarios in 2011 were very similar to those generated from the previous assessment in 2009, with strictly magnitude differences observed for the most dynamic period of the historical time series, i.e., higher estimates of stock size and recruitment in the late 1970s to late 1980s in the updated 2011 models, which were expected, given: (1) the additional length time series included in the updated models, i.e., 1975-78 and 1985-89 distributions, which were composed of large and old fish (also, see Length distributions section above); (2) related changes to estimated selectivity and time blocks associated with this roughly 10-yr period; (3) the inclusion of the mean length-at-age time series, coupled with a maturity schedule that is based on larger/older individuals being more fecund than smaller/younger fish; (4) catches and catch rates increasing markedly; which ultimately, (5) represented the high recruitment success for that narrow timeframe. It is important to note that the points above are essentially moot, given the final Model *XA* has a start year of 1983, which essentially resulted in a period of consistent growth over the modeled timeframe (1983-10).

Model fits to biological distributions are presented in the following displays: Figure 9A is observed vs. predicted estimates for the age distribution time series for the commercial fishery; Figure 9B is the associated Pearson residual plot for the age distribution fits; Figure 9C is the associated input vs. effective sample size plot for the age distribution fits; Figures 10A and 10D are observed vs. predicted estimates for the length distribution time series from the recreational fishery, CPFV and CRFS (non-CPFV fishing modes), respectively; Figures 10B and 10E are the associated Pearson residual plot for the length distribution fits, CPFV and CRFS (non-CPFV fishing modes), respectively; Figures 10C and 10F are the associated input vs. effective sample size plots for the length distribution fits, CPFV and CRFS (non-CPFV fishing modes), respectively; Figure 4 is the observed vs. predicted estimates for the mean length-at-age distribution time series for the commercial fishery; and Figure 11 is the associated Pearson residual plot for the mean length-at-age distribution fits. Estimated selectivity for the fishery catches is presented in Figure 12A (commercial fishery) and Figure 12B [recreational fishery, CPFV and CRFS (non-CPFV fishing modes)]. In general, fits to biological distributions were relatively good; however, in some years, large 'pulses' of younger fish were not fit with high precision, e.g., 0-1 yr-old fish in the commercial fishery age distributions.

Fits (normal and log space) to the indices of abundance are presented in Figures 13 and 14, for CPFV and CRFS, respectively. In general, model fits to the indices were relatively good; however, as previously noted above, no iterative reweighting of variance was conducted and thus, fits could be improved for the indices, noting that fits to the biological distributions would be compromised to some degree.

Estimated Beverton-Holt stock-recruitment relationship is presented in Figure 8 (see Stock-recruitment section above). Estimates of recruitment deviations and associated asymptotic standard errors are presented in Figure 15.

The estimated *F*-based spawning potential ratio (SPR) time series is presented in Figure 16. As expected, SPR estimates have varied over time, with exploitation declining markedly since roughly 2000 to historically low levels (see Assessment uncertainty below).

Estimated time series for management-related derived quantities of interest for Model *XA* are presented in the following displays: Figure 17 is total stock biomass (age 1+ fish in mt, *B*); Figure 18 is spawning stock biomass (*SSB* in mt); and Figure 19 is recruitment (age-0 fish in numbers). Both *B* and *SSB* as steadily declined from the mid 1980s to the early 2000s, at which time the population began to increase moderately in size, with some signs of 'rebuilding' observed over the last several years. However, as noted previously, recent estimates of stock size are necessarily related to assumptions regarding the dynamics of the fish (biology) and fishery (operations) over the last few, which generally confounds long-term (abundance) forecasts for this species. Again, estimated *B* time series from the overall sensitivity analysis were very similar in trend and as noted above, differed in magnitude only for a short period of time historically, when additional length data/selectivity from particularly the 1970s are included in the model scenario. Results from retrospective and prospective analyses for Model *XA* are presented in Figure 20A-B, i.e., for the retrospective analysis, data associated with terminal years 2010 to 2005 were omitted (sequentially) from the model and for the prospective analysis, the model was begun one year later than 1983 in a sequential manner. As observed in all past assessments, a retrospective pattern was evident in the current assessment as well, i.e., a tendency to overestimate stock abundance (*B*) in any current year, with future assessments based on additional data producing estimates lower in magnitude. The prospective analysis indicated moderate variability in model results based on later start years, but the pattern was not consistent from a chronological context as was the case with the retrospective. For comparative purposes, final estimated *B* time series for the historical assessment period (2004-11) are presented in Figure 21. It is important to note that in 2007, estimated *B* scaled upwards substantially, based largely on assumptions regarding variability surrounding estimated recruitment, i.e., since 2005, σ_R has increased from 0.25 to 0.7 to the current level of assumed variability of 1.0, which is more in line with internal estimation of recruitment uncertainty associated with assessment models developed recently for this (and other) species.

Assessment uncertainty

Assessment uncertainty can be partitioned into essentially two inter-related areas.

First and foremost, the collective information, i.e., all sample data (time series used in the stock assessment presented here) and modeling results (via sensitivity analysis), as well as time series from available survey data, laboratory research, and related stock status studies conducted in the past, indicate the following:

- in terms of life history strategy, the Pacific mackerel population off the Pacific coast of North America is in many (most really …) ways a typical coastal pelagic species, but in a (key) few, unique as well, including;
    - exhibiting high recruitment success not on a decadal basis, say like many small, large-schooling pelagic species, but rather, on a multi-decadal cycle spanning 30 to 50 or more years;
    - growing rapidly from a prey existence to a predator role, with nearly 70% of growth in size (length) realized by age 1;
    - upon reaching adult status, it maintains a relatively low profile at the CPS assemblage level for extended periods of time, until oceanographic conditions are favorable and SSB is at least average in size, which produces a brief period of population expansion;
- it is important to note that although the stock is currently at a low level (i.e., not experiencing the 50-yr or so boom in recruitment), it is not very likely due to fishing pressure, but rather a less than ideal oceanographic regime (say for this species);
    - harvest rates have been very low over the last decade (see Harvest Control Rule for USA Management in 2011-12 below), e.g., recent F_{SPR} estimates are 90%-95%, which is a very small removal of reproductive potential for such a species with a moderately high intrinsic rate of increase (r);
    - further, the species' has a relatively short life span, with longevity of roughly 8-10 years likely, which provides additional resiliency to ongoing artificial perturbations, such as fishing operations managed under conservative exploitation schemes; and
    - the bottom-line is this is a classical recruitment fishery situation, whereby the stock provides relatively little benefit to fishing interests (commercial or leisure) for protracted periods, with narrow windows of opportunity (very high abundance) every 30-60 years.

In terms of this stock assessment modeling effort, the following areas contribute the most variation in the overall model and in this context, would benefit from further evaluation, i.e., model robustness could be improved by further addressing the following:

- which data source(s) are emphasized in the model scenario, e.g., decisions regarding 'weighting' biological distributions vs. indices of abundance, the inclusion/omission of length and/or mean length-at-age distributions, etc.;
- selectivity and catchability parameterization;

- selectivity estimation associated with age (commercial fishery) and length (recreational fisheries) distributions were sensitive in particular model scenarios of interest and related to other influential parameterizations, such as growth;
- catchability estimation associated with the CPFV and CRFS indices of abundance is necessarily an ongoing parameterization effort, given re-weighting and model emphasis considerations regarding the sources of data included in the model scenario of interest;

- the need for two fisheries, given both the commercial and recreational fisheries harvest very similar fish and at low levels, particularly, the leisure fishery;
  - a model with fisheries combined was evaluated, but differences in some years concerning the size (and age) of fish harvested in each of the fisheries precluded further development of this model scenario at this time, i.e., further examinations of differences/similarities between the two fisheries is warranted, given such a parameterization would substantially simplify the current assessment; and finally,
- stock-recruitment parameterization related to sensitivity analysis should include evaluating the influence of steepness (*h*) set at different (hypothetical) values, particularly, *h* = 1.0, given suppositions regarding this species' reproductive compensation at low SSB levels.

Generally speaking, uncertainty in the overall assessment was evaluated using some combination of the following: the confidence intervals associated with estimated parameters of interest (e.g., time series of *SSB* and recruitment); sensitivity analysis (i.e., developing alternative model scenarios); and examinations (qualitative and quantitative) of important residual plots from critical model fits (e.g., fits to biological distributions and indices of abundance). All of the above were addressed in the assessment conducted here. Finally, it is important to note that model estimates of absolute stock size are likely more uncertain than presented here, given the final estimates are necessarily based on the following: strict probability samples in the field cannot be obtained; subjective assumptions used to develop model scenarios; potential weighting issues with particular data sources; and unaccounted for variability associated with related sources of data and parameters within the fully-integrated, multiple likelihood modeling platform.

HARVEST CONTROL RULE FOR USA MANAGEMENT IN 2011-12

As stipulated in Amendment 8 to the CPS FMP (PFMC 1998), the recommended maximum sustainable yield (MSY) control rule for Pacific mackerel is (Table 6A):

Harvest = (Biomass-Cutoff) • Fraction • Distribution,

Since 2000, Pacific mackerel has been managed under a Federal Management Plan (FMP) harvest policy, stipulating that a maximum sustainable yield (MSY) for this species should be set according to the following harvest control rule:

Harvest = (Biomass-Cutoff) • Fraction • Distribution,

where Harvest is the harvest guideline (HG), Biomass is age 1+ stock biomass (mt) in the current assessment year (211,126 mt on July 1, 2011), Cutoff (18,200 mt) is the lowest level of estimated biomass at which harvest is allowed, Fraction (30%) is the proportion of biomass above the Cutoff that can be harvested by fisheries, and Distribution (70%) is the average fraction of total Biomass (ages 1+) assumed in USA waters (PFMC 1998). The HGs under the federal FMP are applied to a July-June fishing year. Landings and associated HGs since 1992 are presented in Figure 22A.

From 1985 to 1991, the biomass exceeded 136,000 mt and no state quota restrictions were in effect. State quotas for 1992-00 fishing years averaged roughly 24,000 mt. The HGs averaged roughly 15,000 mt from 2001-06. In 2007, the HG was increased substantially to over 70,000 mt based largely on assumptions regarding variability surrounding estimated recruitment and remained at an elevated level until 2009, when the calculated HG (55,408 mt) was reduced by management (PFMC) to 10,000 mt to address uncertainty related to two alternative models (see Preface and PFMC 2010b); the 10,000 mt HG was adopted in 2010 as well. Note that the HG in 2011 (40,514 mt) is strictly preliminary, given formal adoption of the HG will be addressed at the next Council meeting in June 2011. It is important to note that over the last decade, from a management context, the fishery has not fully utilized HGs, with average yields since this time of roughly 5,000 mt (Figure 22A). 'Hypothetical' quotas and total landings, based on omission of the USA 'Distribution' parameter in the harvest control rule are presented in Figure 22B. Finally, recent legislation concerning management of exploited fisheries in the USA now require alternative methods for quota determination that are used in concert with the HG method above, see PFMC (2010a) and SSC (2010), and Ralston et al. (2011) for methods used to derive OFL, ABC, ACL, and associated buffer values (Table 6B).

RESEARCH AND DATA NEEDS

First and foremost, given the transboundary status of this fish population, it is imperative that efforts continue in terms of encouraging collaborative research and data exchange between NOAA Fisheries (Southwest Fisheries Science Center) and researchers from both Canada's and in particular, Mexico's academic and federal fishery bodies, i.e., such cooperation is critical to providing a synoptic assessment that considers available sample data across the entire range of this species in any given year.

Second, fishery-independent survey data for measuring (relative) changes in mackerel spawning (or total) biomass are currently lacking. Further, at this time, two indices of relative abundance are used in the assessment, which are developed from a marine recreational fishery (CPFV fleet and related fishing modes) that typically do not (directly) target the species. That is, the recently implemented CRFS provides useful information regarding this species' dynamics and further, represents a valuable survey for obtaining abundance trends for finfish generally targeted by marine recreational fishers in coastal waters off California. In this context, it is imperative that future research funds be focused on improvement (e.g., broadening the scope and increasing the frequency) of the current fishery-independent surveys operating out of the NOAA's SWFSC (e.g., CalCOFI and acoustic-trawl surveys), with emphasis on a long-term horizon, which will necessarily rely on cooperative efforts between the industry, research, and management, as well as cooperation from international fishery agencies.

Third, given the importance of age (and length) distribution time series to developing a sound understanding of this species' population dynamics, it is critical that data collection programs at the federal and particularly, the state level continue to be supported adequately. In particular, CDFG/NOAA funding should be bolstered to ensure ongoing ageing-related laboratory work is not interrupted, as well as providing necessary funds for related biological research that is long overdue. For example, maturity-related time series currently relied upon in the assessment model are based on data collected over twenty years ago during a period of high spawning biomass that does not reflect current levels, i.e., the SWFSC and CDFG have begun field/laboratory efforts collecting, processing, and analyzing reproductive samples from Pacific mackerel harvested in both the recreational and commercial fisheries. Also, further work is needed to obtain more timely error estimates from production ageing efforts in the laboratory, i.e., accurate interpretation of age-distribution data used in the ongoing assessment necessarily requires a reliable ageing error time series.

Finally, the MSY control rule utilized in the Pacific mackerel federal CPS-FMP was developed in the mid-1980s based on estimated abundance and stock-recruitment data at that time and thus, the control rule should be re-examined using new data and simulation methods. Given substantial amounts of additional sample data have accumulated since the initial research that was undertaken to formally establish this harvest strategy, it would be prudent to conduct further simulation modeling work to address particular parameters included in the overall control rule (including 'cutoff,' 'fraction,' and 'distribution' values).

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Table 1. Sample sizes associated with CDFG data collection program for Pacific mackerel (1983-10).

	Commercial	Recreational
Fishing Year	**Age**	**Length**
83	2,668	
84	2,291	
85	2,606	2,038
86	3,000	5,953
87	4,129	4,354
88	4,477	3,904
89	3,583	3,678
90	2,114	
91	1,655	
92	1,994	710
93	2,688	1,736
94	3,114	885
95	2,706	739
96	2,189	1,899
97	2,714	2,278
98	2,255	1,524
99	1,666	1,253
00	1,910	1,084
01	2,111	1,051
02	2,145	1,145
03	1,570	1,037
04	2,529	1,693
05	2,299	2,109
06	2,393	2,363
07	1,609	2,439
08	723	1,998
09	422	1,783
10	298	350

Table 2. Landings (mt) of Pacific mackerel by fishery (1983-2010).

Fishing year	USA Commercial (mt)	Mexico Commercial (mt)	Recreational CPFV (mt)	Recreational non-CPFV (mt)	Total (mt)
83	36,309	4,264	700	844	42,118
84	39,240	5,761	612	855	46,468
85	37,615	8,197	524	492	46,828
86	44,298	8,965	386	474	54,123
87	44,838	2,120	245	1020	48,223
88	41,968	6,608	181	507	49,265
89	25,063	23,724	167	451	49,406
90	39,974	30,961	230	386	71,551
91	30,268	34,557	252	429	65,505
92	25,584	6,170	135	329	32,217
93	10,787	9,524	196	413	20,920
94	9,372	13,302	226	837	23,737
95	7,615	3,368	439	574	11,996
96	9,788	14,089	320	366	24,563
97	23,413	26,860	104	700	51,076
98	19,578	42,815	108	322	62,823
99	7,170	8,587	55	97	15,910
00	20,936	6,530	78	248	27,792
01	8,436	4,003	51	520	13,010
02	3,541	10,328	22	232	14,123
03	5,972	2,618	28	295	8,913
04	5,012	2,017	23	510	7,562
05	4,572	2,507	21	375	7,475
06	7,870	1,986	16	356	10,228
07	6,208	2,218	19	291	8,737
08	4,281	803	13	267	5,364
09	3,011	171	13	254	3,450
10	2,086	171	5	95	2,357

Table 3. California Recreational Fisheries Survey (CRFS) summary statistics relevant to the CRFS index of abundance derived for Pacific mackerel (2004-10): Region is number of samples (i.e., interviewed party=sample) and NC=northern CA and SC=southern CA; Modes are number of samples, with All=zero catch and positive catch samples and Positive Creel=positive catch samples; Party Size is number of samples; Catch Size is number of samples (by number of fish in creel); Avg. No. Anglers in Party is average number of anglers; and Avg. Trip Length is average trip length in hours.

REGION		
Fishing Year	**NC**	**SC**
04	33,491	36,069
05	31,882	35,330
06	32,632	36,407
07	27,052	36,124
08	26,579	40,329
09	27,453	35,974
10	12,384	13,519
Total	191,473	233,752
Grand total	**425,225**	

PARTY SIZE				
Fishing Year	**0**	**1**	**2-4**	**≥5**
04	12,585	40,359	28,113	1,088
05	3,283	38,988	27,168	1,056
06	7,741	41,908	26,046	1,085
07	15,845	40,633	21,563	980
08	16,269	44,720	21,115	1,073
09	14,500	42,706	19,740	981
10	6,257	17,014	8,514	375
Total	76,480	266,328	152,259	6,638
Grand total		**501,705**		

CATCH SIZE (ALL)				
Fishing Year	**0**	**1**	**2-4**	**≥5**
04	68,030	492	503	535
05	65,842	423	409	538
06	67,692	406	440	501
07	61,556	439	552	629
08	65,265	437	581	625
09	61,916	467	473	571
10	25,504	125	128	146
Total	415,805	2,789	3,086	3,545
Grand total		**425,225**		

MODE (ALL)				
Fishing Year	**Man-made**	**Beach-Bank**	**Party-Charter**	**Private-Rental**
04	17,231	2,144	12,287	37,898
05	15,657	1,947	12,712	36,896
06	18,585	2,371	12,326	35,757
07	18,311	2,092	13,674	29,099
08	20,587	2,567	14,669	29,085
09	20,045	2,079	13,751	27,552
10	7,342	30	6,433	12,098
Total	117,758	13,230	85,852	208,385
Grand total		**425,225**		

MODE (POSITIVE CREEL)				
Fishing Year	**Man-made**	**Beach-Bank**	**Party-Charter**	**Private-Rental**
04	523	9	389	609
05	558	2	309	501
06	443	3	318	583
07	457	0	486	677
08	556	0	553	534
09	531	1	507	472
10	138	0	158	103
Total	3,206	15	2,720	3,479
Grand total		**9,420**		

AVG. NO. ANGLERS IN PARTY (INTERVIEW)				
Fishing Year	**Man-made**	**Beach-Bank**	**Party-Charter**	**Private-Rental**
04	1.09	1.07	1.11	2.20
05	1.07	1.03	1.13	2.20
06	1.05	1.04	1.14	2.20
07	1.04	1.04	1.16	2.21
08	1.04	1.03	1.16	2.20
09	1.05	1.03	1.17	2.17
10	1.04	1.00	1.21	2.10
Total	1.06	1.04	1.15	2.18
Grand total		**1.36**		

AVG. TRIP LENGTH (INTERVIEW)				
Fishing Year	**Man-made**	**Beach-Bank**	**Party-Charter**	**Private-Rental**
04	3.02	2.63	3.48	4.52
05	2.97	2.64	3.34	4.37
06	3.00	2.77	3.13	4.51
07	2.92	2.85	3.20	4.55
08	2.95	2.84	3.12	4.63
09	3.05	2.91	3.30	4.84
10	3.09	2.94	3.26	4.69
Total	3.00	2.80	3.26	4.59
Grand total		**3.41**		

Table 4. Normalized net fecundity calculations for Pacific mackerel, which in effect, represented the maturity schedule (ogive) used in all model scenarios[a].

Age (yrs)	**Observed Fraction Mature**	**Predicted Fraction Mature**	**Observed Spawning Frequency (% spawning day^{-1})**	**Predicted Spawning Frequency (% spawning day^{-1})**	**Net Fecundity (eggs g^{-1})**	**Normalized Net Fecundity (eggs g^{-1})**
0	0.000	0.000	0.000	0.000	0.000	**0.000**
1	0.214	0.487	0.000	1.380	0.672	**0.074**
2	0.867	0.636	3.900	3.520	2.240	**0.246**
3	0.815	0.763	6.800	5.660	4.320	**0.474**
4	0.851	0.855	9.900	7.800	6.670	**0.733**
5	0.882	0.916	7.700	9.940	9.110	**1.000**
6+	0.882	0.916	7.700	9.940	9.110	**1.000**

[a] Observed fraction mature and observed spawning frequency from Dickerson et al. (1992). Predicted fraction mature from logistic regression. Predicted spawning frequency from linear regression. Net fecundity is adjusted (normalized) to a maximum value of 1.0. Batch fecundity is assumed constant.

Table 5. Model scenario summaries for the final model (Model *XA*) selected for management purposes of the Pacific mackerel stock in the current year 2011 and for the previous assessment conducted in 2009 (Model *AA*), including: (A) new data sources and critical parameterizations; (B) likelihood component estimates and derived quantities of importance; (C) model parameters included in Model *XA*; and D) final sensitivity analysis for Model *XA*.

(A)

	Model scenario	
Time series	***AA* (2009)**	***XA* (2011)**
Landings - Commercial (USA/Mexico fisheries)	■	■
Landings - Recreational (USA fishery)	■	■
Age distributions - Commercial fishery	■	■
Length distributions - Recreational fishery (1992-10) - All fishing modes	■	
*Length distributions - Recreational fishery (1985-89) - CPFV (**new time series (2011)**)*		■
Length distributions - Recreational fishery (1992-10) - CPFV		■
Length distributions - Recreational fishery (2004-10)- non-CPFV		■
Mean length-at-age distributions - Commercial fishery	■	■
CPFV index	■	■
*CRFS index (2004-10) - **new time series (2011)***		■

Parameterization	***AA (2009)***	***XA (2011)***
Model structure		
Time period	1962-08	1983-10
Number of fisheries	2	2
Number of surveys	1	2
Genders	Combined	Combined
Time-step	Annual	Annual
Biology		
Maturity-at-age	Fixed	Fixed
Length-at-age (k)	Estimated	Estimated
Weight-length	Fixed	Fixed
Weight-at-age	Estimated	Estimated
Natural mortality (M)	Fixed - all ages (M=0.5)	Fixed - all ages (M=0.5)
Stock-recruitment		
$\ln(R_0)$	Estimated	Estimated
Offset for initial equilibrium R_1	Estimated	Estimated
Steepness (h)	Estimated	Estimated
σ-R	Fixed (σ-R=1.0)	Fixed (σ-R=1.0)
Initial conditions for population dynamics		
Age distribution	Non-equilibrium	Non-equilibrium
Fishing mortality (F) - Commercial fishery	Estimated	Estimated
Fishing mortality (F) - Recreational fishery	Fixed	Fixed
Selectivity		
Fisheries		
Parameterization	Estimated	Estimated
Time block	Commercial fishery=3 blocks / Recreational fishery=single	Single
Shape	Dome-shaped	Commercial fishery=asymptotic / Recreational fishery=dome-shaped
Surveys		
Parameterization	CPFV=mirrors recreational fishery	CPFV=mirrors recreational fishery / CRFS=dome-shaped
Time block	Single	Single
Shape	Dome-shaped	Dome-shaped
Catchability		
q - Surveys	Estimated (median unbiased)	Estimated (median unbiased)
Variance adjustment factors		
Biological distributions and indices	No additional weighting	No additional weighting

Table 5. Continued.

(B)

Likelihood component	*AA (2009)*	*XA (2011)*
Biological distributions		
Age distributions		
Commercial fishery	700.4	368.0
Length distributions		
Recreational fishery (All fishing mode: 1992-10)	201.4	Na
Recreational fishery (CPFV: 1985-10)	Na	184.9
Recreational fishery (non-CPFV: 2004-10))	Na	57.3
Sub-total		242.2
Length-at-age distributions		
Commercial fishery	540.4	232.4
Surveys		
CPFV	-18.3	-6.4
CRFS	Na	-5.3
Sub-total	-18.3	-11.7
Recruitment		
Model time period	34.7 (1958-08)	11.34 (1978-10)
Forecast	0.016 (2009)	0.245 (2011)
Global		
Likelihood (*L*)	1,458.6	842.5
Number of estimated parameters	84	57
Softbounds	0.0036	0.0028
Key estimated parameters and derived quantities		
Biology		
Length-at-age (k)	0.22	0.33
$\ln(R_0)$	13.5	13.6
Offset for initial equilibrium R_1	0.2473	0.4731
Steepness (h)	0.47	0.70
Initial conditions for population dynamics		
Fishing mortality (F) - Commercial fishery[a]	0.654	0.014
Fishing mortality (F) - Recreational fishery	0.001	0.001
Population time series		
SSB (peak year)	598,046 (1983)	461,354 (1984)
SSB (end year)	76,441 (2008)	112,880 (2010)
B (peak year)	1,321,550 (1982)	1,065,990 (1983)
B (end year)	282,849 (2009)	211,126 (2011)
HG (current year)	55,408	40,514

[a]Estimated initial fishing mortality was not fit to 'equilibrium' catch, but rather, implemented for purposes of providing a more robust initial non-equilibrium age composition.

Table 5. Continued.

(C)

Parameter	Min_Value	Max_Value	Init_Value	Fin_Value	SD
NatM_p_1_Fem_GP_1	0.3	0.7	0.5	0.5	_
L_at_Amin_Fem_GP_1	4	35	15	21.116	0.205664
L_at_Amax_Fem_GP_1	30	70	45	40.0231	0.197782
VonBert_K_Fem_GP_1	0.1	0.7	0.35	0.325098	0.0128458
CV_young_Fem_GP_1	0.01	0.5	0.1	0.279009	0.010219
CV_old_Fem_GP_1	0.0001	0.5	0.01	0.01	_
Wtlen_1_Fem	-1	5	0.00000312	3.12E-06	_
Wtlen_2_Fem	1	5	3.40352	3.40352	_
Mat50%_Fem	-3	3	3	3	_
Mat_slope_Fem	-3	3	3	3	_
Eggs/kg_inter_Fem	-3	3	1	1	_
Eggs/kg_slope_wt_Fem	-3	3	0	0	_
RecrDist_GP_1	-4	4	0	0	_
RecrDist_Area_1	-4	4	1	1	_
RecrDist_Seas_1	-4	4	0	0	_
CohortGrowDev	1	5	1	1	_
SR_R0	1	30	10	13.6014	0.217755
SR_steep	0.1	1	0.9	0.699827	0.211953
SR_sigmaR	0	2	1	1	_
SR_envlink	-5	5	0	0	_
SR_R1_offset	-15	15	0	0.47311	0.527798
SR_autocorr	0	2	0	0	_
Main_InitAge_5	_	_	_	-0.472933	0.843491
Main_InitAge_4	_	_	_	0.268622	0.759753
Main_InitAge_3	_	_	_	0.150757	0.772089
Main_InitAge_2	_	_	_	2.08434	0.398218
Main_InitAge_1	_	_	_	-0.506919	0.596872
Main_RecrDev_1983	_	_	_	-1.00104	0.489547
Main_RecrDev_1984	_	_	_	0.366911	0.296722
Main_RecrDev_1985	_	_	_	0.337156	0.279371
Main_RecrDev_1986	_	_	_	0.759464	0.264261
Main_RecrDev_1987	_	_	_	-1.03251	0.37629
Main_RecrDev_1988	_	_	_	1.68254	0.195281
Main_RecrDev_1989	_	_	_	-0.836794	0.413652
Main_RecrDev_1990	_	_	_	0.420333	0.233331
Main_RecrDev_1991	_	_	_	0.334561	0.228476
Main_RecrDev_1992	_	_	_	-0.759672	0.321362
Main_RecrDev_1993	_	_	_	0.731879	0.164942
Main_RecrDev_1994	_	_	_	0.242322	0.186322

Table 5. Continued.

(C)

Parameter	Min_Value	Max_Value	Init_Value	Fin_Value	SD
Main_RecrDev_1995	_	_	_	0.723032	0.151321
Main_RecrDev_1996	_	_	_	0.0728743	0.19468
Main_RecrDev_1997	_	_	_	-1.44384	0.362163
Main_RecrDev_1998	_	_	_	-1.5808	0.306414
Main_RecrDev_1999	_	_	_	-0.924772	0.200919
Main_RecrDev_2000	_	_	_	-0.577272	0.211409
Main_RecrDev_2001	_	_	_	-0.412906	0.338449
Main_RecrDev_2002	_	_	_	-1.06413	0.443654
Main_RecrDev_2003	_	_	_	-0.0524016	0.458841
Main_RecrDev_2004	_	_	_	0.614432	0.457423
Main_RecrDev_2005	_	_	_	0.869945	0.397333
Main_RecrDev_2006	_	_	_	0.621383	0.293877
Main_RecrDev_2007	_	_	_	0.476419	0.219778
Main_RecrDev_2008	_	_	_	0.0534656	0.236146
Main_RecrDev_2009	_	_	_	-0.144445	0.289408
Late_RecrDev_2010	_	_	_	-0.699974	0.699216
ForeRecr_2011	_	_	_	0	1
Impl_err_2011	_	_	_	0	_
InitF_1COM	0.0001	5	0.1	0.0144242	0.0897996
InitF_2REC	0.00001	5	0.001	0.001	_
AgeSel_1P_1_COM	-20	15	1	0.0576732	2.81372
AgeSel_1P_2_COM	-20	15	-5	-5	_
AgeSel_1P_3_COM	-20	15	4	-7.37128	121.562
AgeSel_1P_4_COM	-20	15	1.5	1.5	_
AgeSel_1P_5_COM	-20	20	-1	0.104554	24.0497
AgeSel_1P_6_COM	-20	20	15	15	_
AgeSel_2P_1_REC	-10	15	2	2.00031	0.320612
AgeSel_2P_2_REC	-10	15	-4	-2.3412	3.39767
AgeSel_2P_3_REC	-15	15	-1	-0.940619	0.654569
AgeSel_2P_4_REC	-20	15	-4	-2.09116	22.7202
AgeSel_2P_5_REC	-25	15	-5	-15.9471	104.601
AgeSel_2P_6_REC	-20	15	-2	-0.426842	0.341071
AgeSel_4P_1_CRFS	-10	15	2	0.505643	0.404807
AgeSel_4P_2_CRFS	-10	15	-4	-8.49388	30.5612
AgeSel_4P_3_CRFS	-15	15	-1	3.69201	128.658
AgeSel_4P_4_CRFS	-20	15	-4	-4.27335	70.9969
AgeSel_4P_5_CRFS	-25	15	-5	-13.2365	131.22
AgeSel_4P_6_CRFS	-20	15	-2	-12.6752	91.1591

Table 5. Continued.

(D)

Sensitivity run	Model	*B* (2011)	*B* (2011) - Peak	*-ln L* (Total)	*-ln L* (CPFV)	*-ln L* (CRFS)
Base case	XA	211,126	1,065,990	842.5	-6.4	-5.3
2x λ (CPFV index)	XA1	219,896	1,123,910	830.4	-16.3	-6.2
2x λ (CRFS index)	XA2	200,383	1,073,720	836.4	-7.6	-6.6
2x λ (Recreational length distribution)	XA3	287,442	1,025,710	1,029.7	-5.8	-3.9
2x λ (Commercial age distribution)	XA4	178,682	981,870	1,188.6	10.8	-1.5
2x λ (Length-at-age distribution)	XA5	210,748	1,103,060	864.1	-5.9	-5.6
Omit CRFS data (inclusive)	XA6	251,550	1,047,730	785.2	-0.5	na
M = 0.3 yr^{-1}	XA7	95,667	323,656	853.9	4.4	-4.8
M = 0.4 yr^{-1}	XA8	130,857	444,452	860.2	-1.8	-3.4
M = 0.6 yr^{-1}	XA9	606,752	3,676,670	840.3	-8.6	-5.9
M = 0.7 yr^{-1} [a]	XA10	**	**	839.3	-6.7	-5.9
Start in 1978	XA11	171,415	1,080,300	1,231.6	-1.1	-5.2
Start in 1981	XA12	190,897	1,096,960	1,007.1	-4.3	-5.0
Start in 1990	XA13	217,789	556,043	455.0	-9.9	-4.9
Length-at-age max - estimate CV	XA14	226,929	1,082,290	851.5	-8.4	-4.3
Sigma r = 0.8	XA15	210,172	1,053,200	841.4	-6.9	-5.4
Sigma r = 1.2	XA16	211,258	1,071,720	845.0	-6.2	-5.3

**Biomass estimate from sensitivity run was essentially infinite and hessian may not be positive definite.

Table 6. Harvest control rule information for the Pacific mackerel fishery (2011-12) based on Model *XA*, including: (A) 'harvest guideline' statistics (see Harvest Control Rule and USA Management in 2011-12) ; and (B) harvest formulas associated with recent regulations associated with reauthorization of National Standards 1 of the MSFCMA, see PFMC (2010a) for parameter definitions (σ=0.36).

(A)

B **(Age 1+, mt)**	**Cutoff (mt)**	**Fraction**	**Distribution**	**HG (mt)**
211,126	18,200	30%	70%	**40,514**

(B)

Harvest Formula Parameters	**Value**			
BIOMASS (ages 1+, mt)	211,126			
Pstar (probability of overfishing)	0.45	0.4	0.3	0.2
$BUFFER_{Pstar}$	0.95577	0.91283	0.82797	0.73861
F_{MSY}	0.3			
FRACTION	0.3			
CUTOFF (mt)	18,200			
DISTRIBUTION (U.S.)	0.7			

Amendment 13 Harvest Formulas	**MT**
OFL = BIOMASS * F_{MSY} * DISTRIBUTION	44,336
$ABC_{0.45}$ = BIOMASS * BUFFER0.45 * F_{MSY} * DISTRIBUTION	42,375
$ABC_{0.40}$ = BIOMASS * BUFFER0.40 * F_{MSY} * DISTRIBUTION	40,472
$ABC_{0.30}$ = BIOMASS * BUFFER0.30 * F_{MSY} * DISTRIBUTION	36,709
$ABC_{0.20}$ = BIOMASS * BUFFER0.20 * F_{MSY} * DISTRIBUTION	32,747
ACL=LESS THAN OR EQUAL TO ABC	TBD
HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION	40,514
ACT=EQUAL TO HG OR ACL, WHICHEVER VALUE IS LESS	TBD

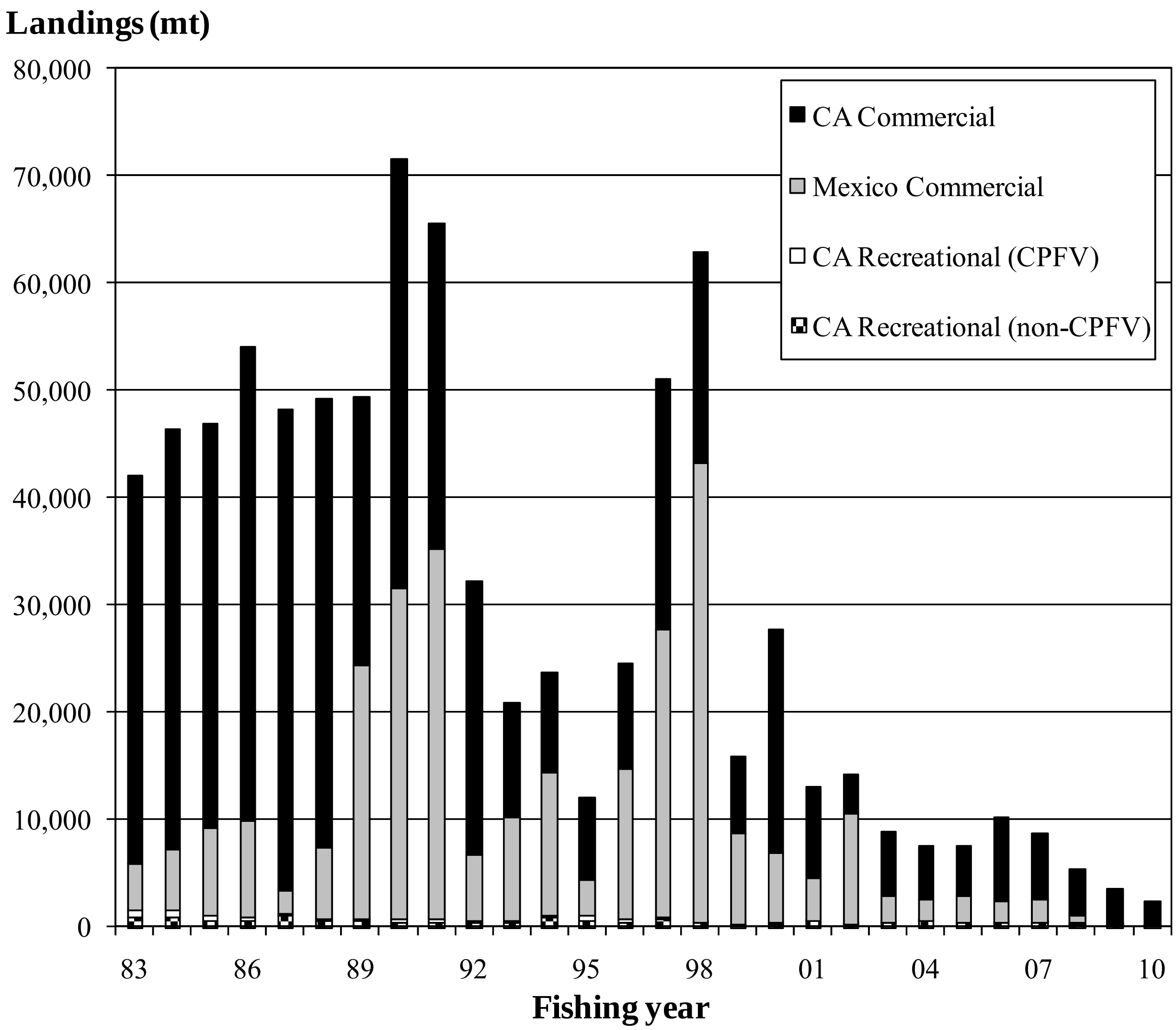
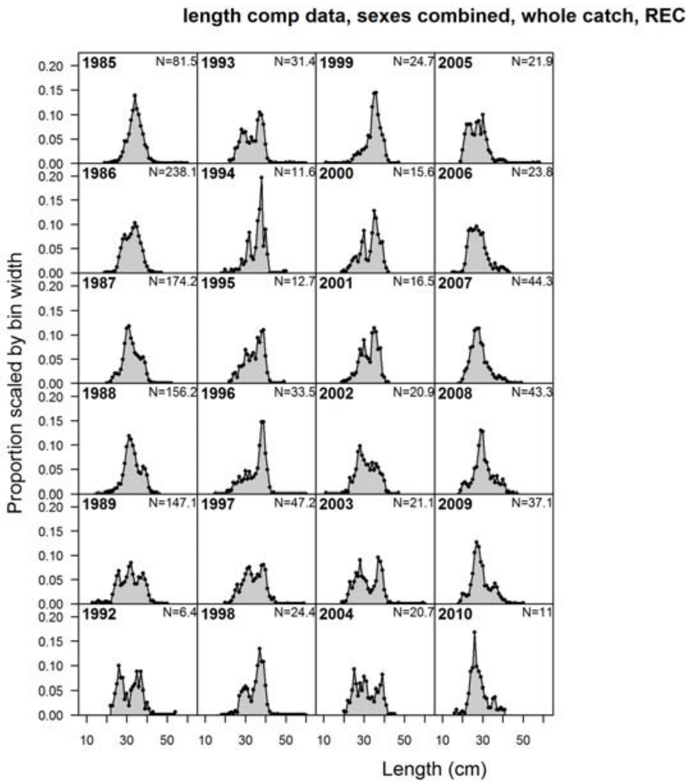


Figure 1. Commercial and recreational landings (mt) of Pacific mackerel in the USA (CA commercial, recreational-CPFV, and recreational-non-CPFV) and Mexico (commercial), (1983-10).

(A)



(B)

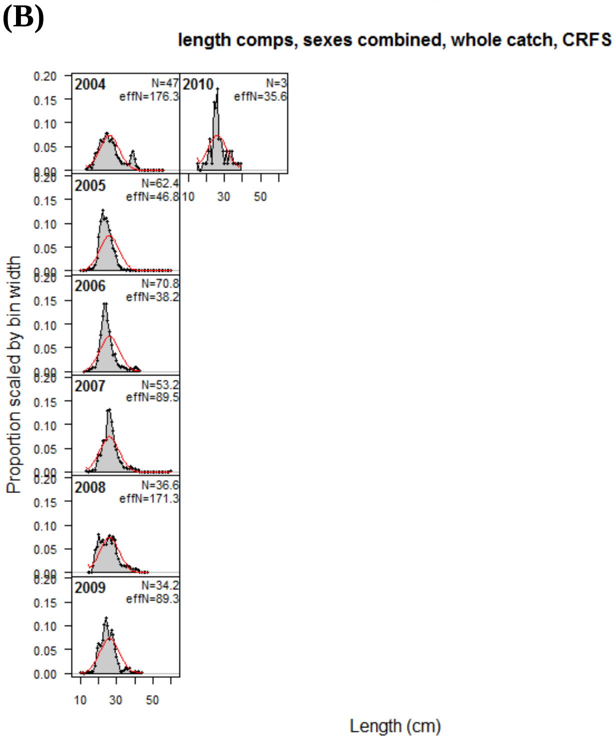


Figure 2. Length distributions of Pacific mackerel from: (A) the CDFG observer sampling program (1985-89) and RecFIN (CPFV) data base (1992-10) associated with the CPFV fishery; and (B) the CRFS sampling program (2004-10) associated with the non-CPFV fisheries.

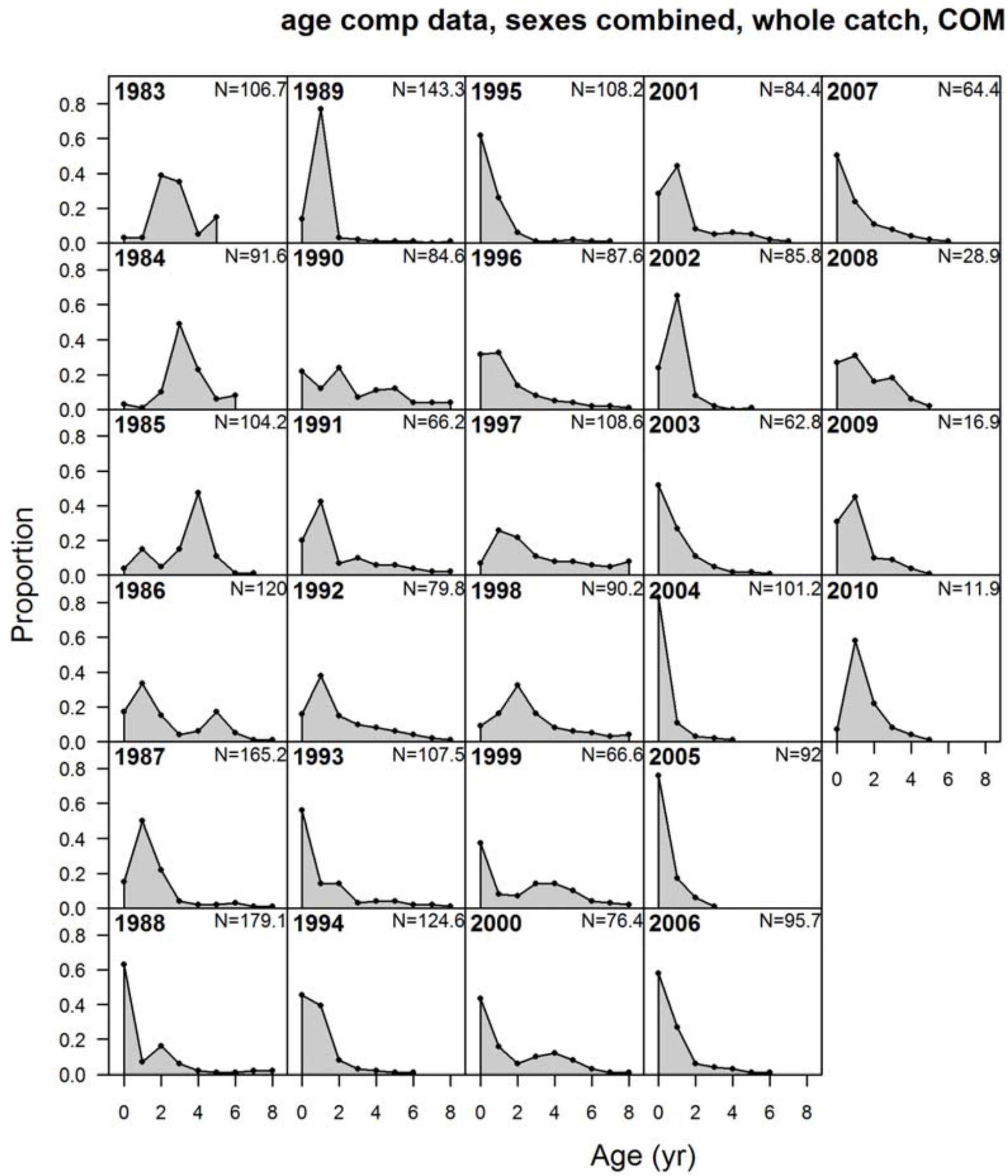


Figure 3. Age distributions of Pacific mackerel from the CDFG (commercial fishery) port sampling program (1983-10).

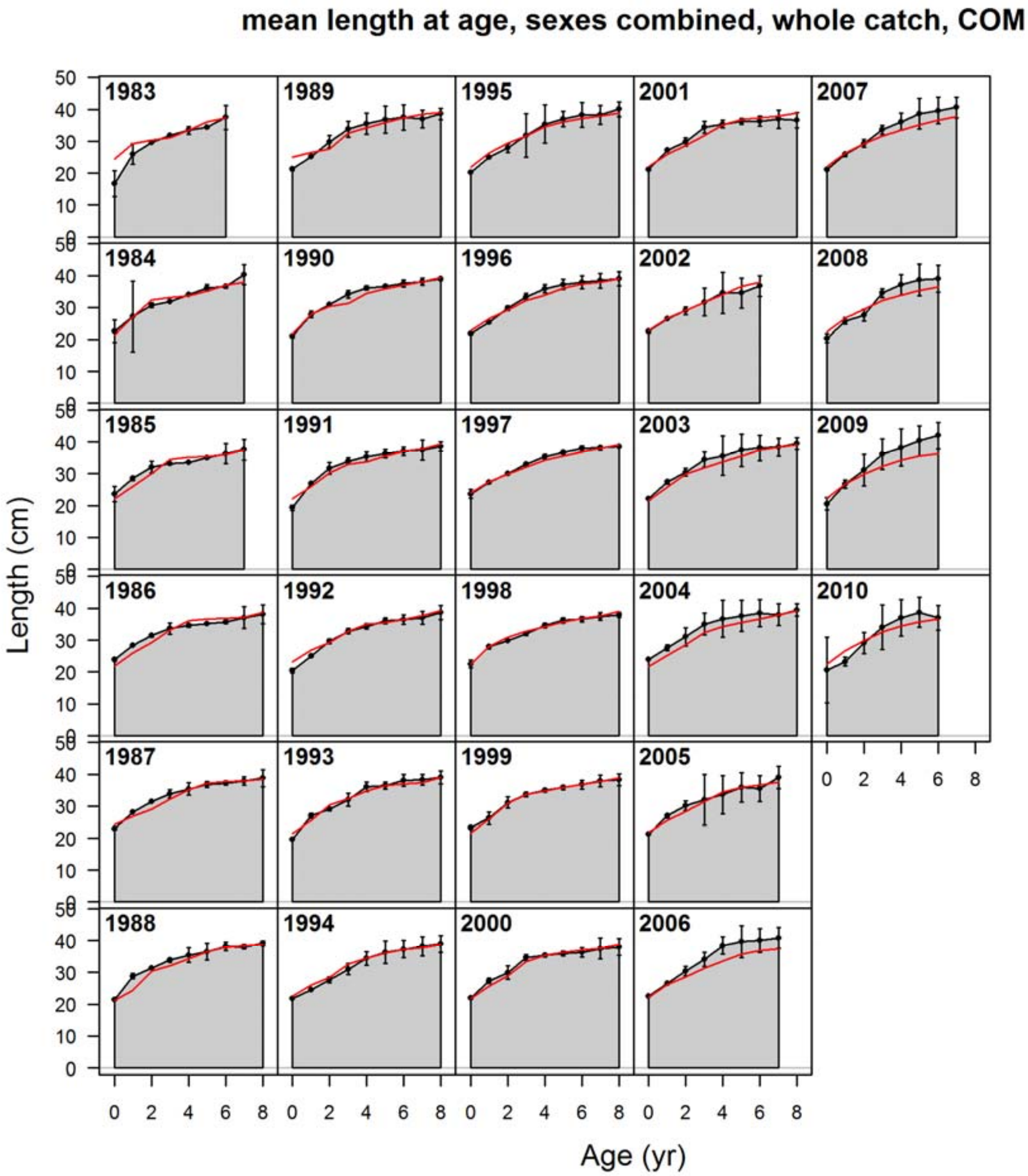


Figure 4. Estimated mean length-at-age (cm/yr, open circles) time series of Pacific mackerel from CDFG (commercial fishery) port sampling program (1983-10). Also, model fits to this time series are presented (curved line in each display).

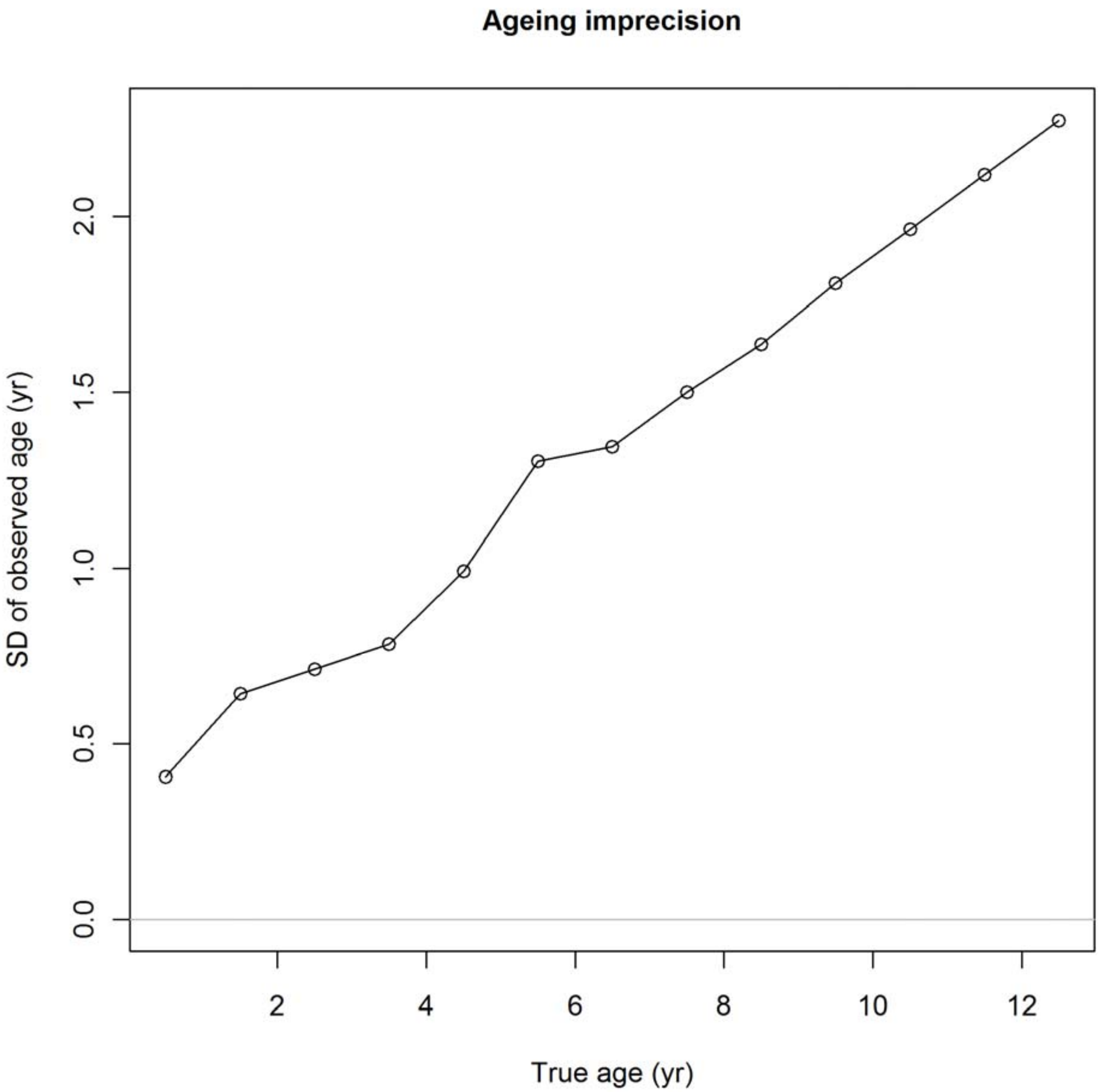


Figure 5. Pacific mackerel ageing error vector (SD by age) from CDFG age production laboratory based on double-read analysis.

(A)

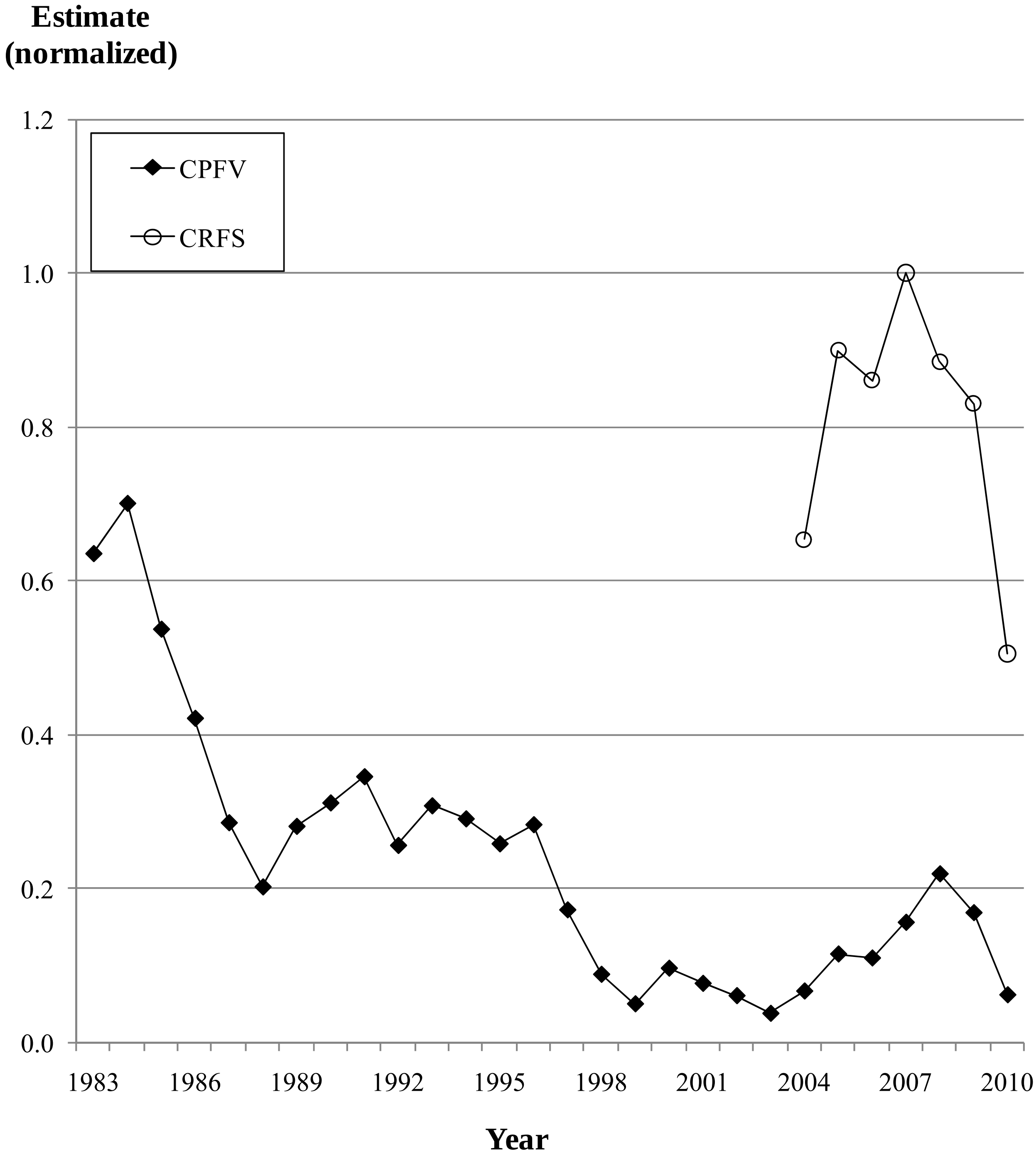
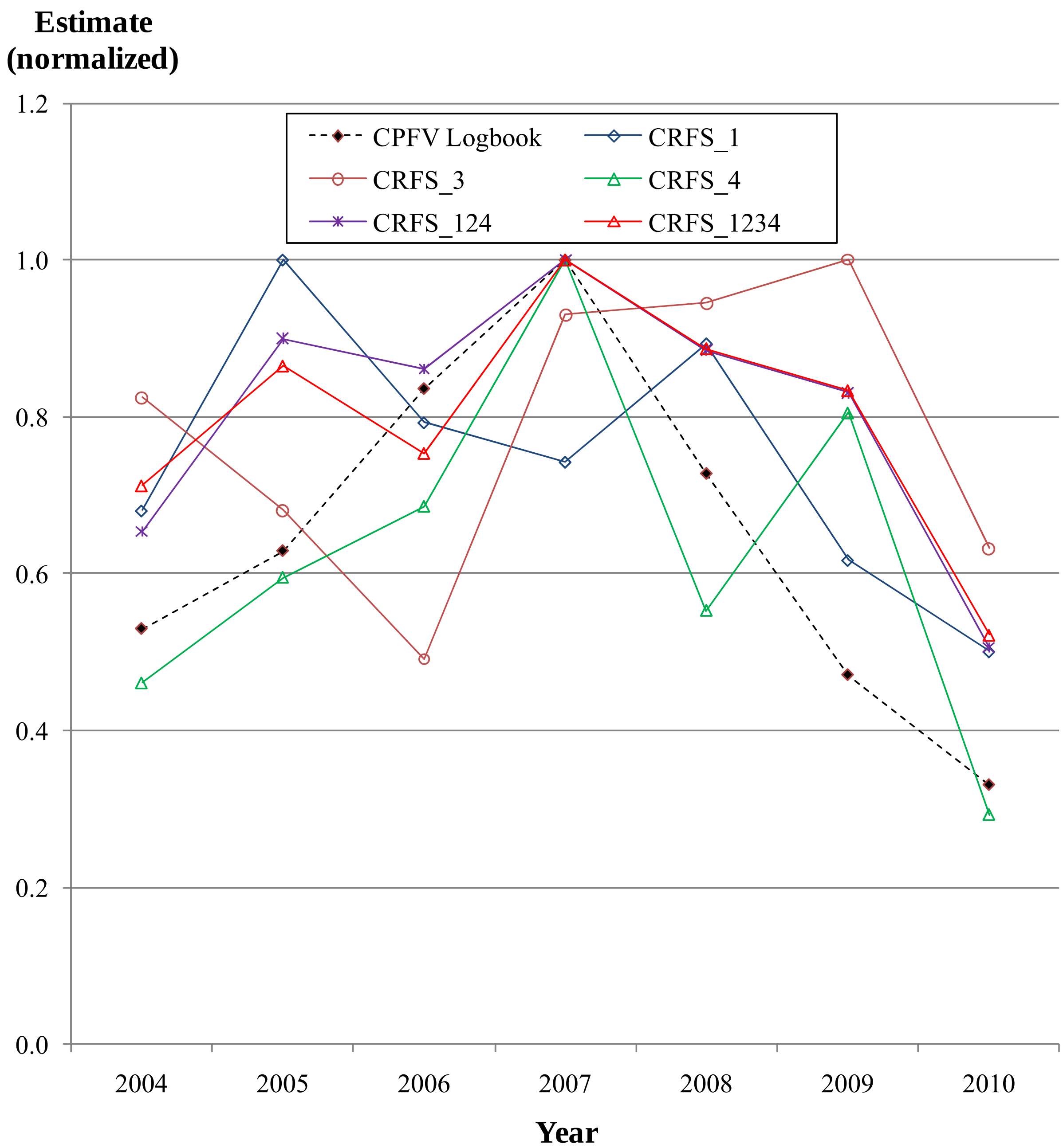
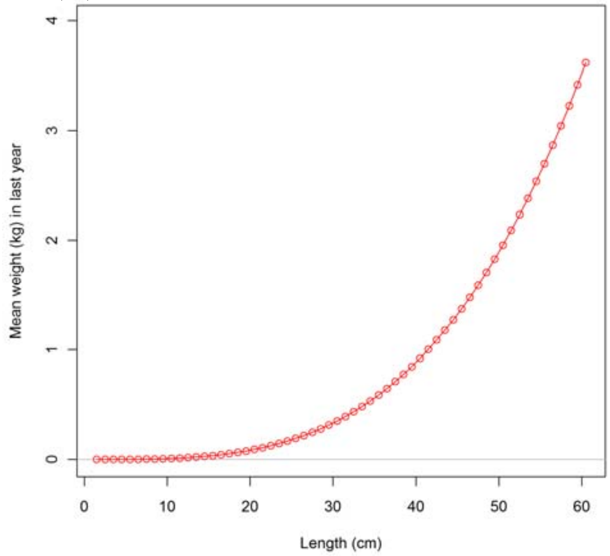


Figure 6. Indices of abundance: (A) CPFV (CPFV logbook sampling program) and CRFS (non-CPFV fisheries); and (B) the CRFS survey time series evaluated at the fishing mode level (CPFV Logbook=abbreviated CPFV in 6A, CRFS_1 = man-made, CRFS_2=beach/bank, CRFS_3=charter/party, CRFS_4=private/rental, CRFS_124=omits charter/party, and CRFS_1234=all modes). Note that only the CPFV and CRFS_124 indices were used in Model *XA*. Also, missing lines between data points reflects years with no sampling.

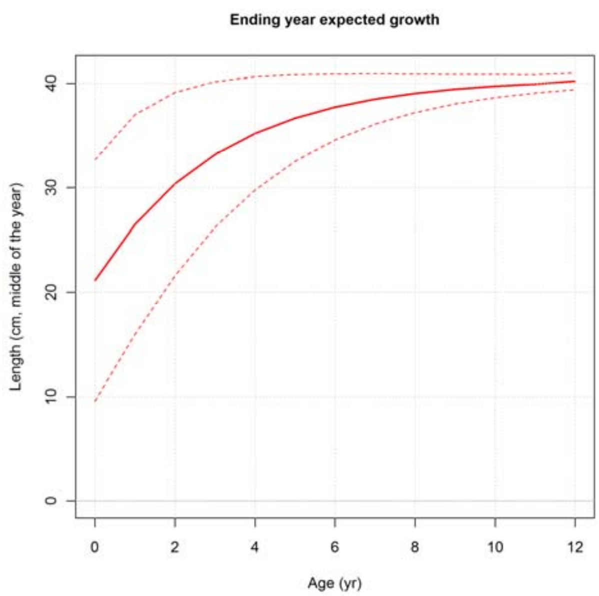
(B)


Estimate (normalized)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
CPFV Logbook
CRFS_1
CRFS_3
CRFS_4
CRFS_124
CRFS_1234
2004
2005
2006
2007
2008
2009
2010
Year

(A) **(B)**



Mean weight (kg) in last year
0
1
2
3
4
0
10
20
30
40
50
60
Length (cm)



Ending year expected growth
Length (cm, middle of the year)
0
10
20
30
40
0
2
4
6
8
10
12
Age (yr)

(C)

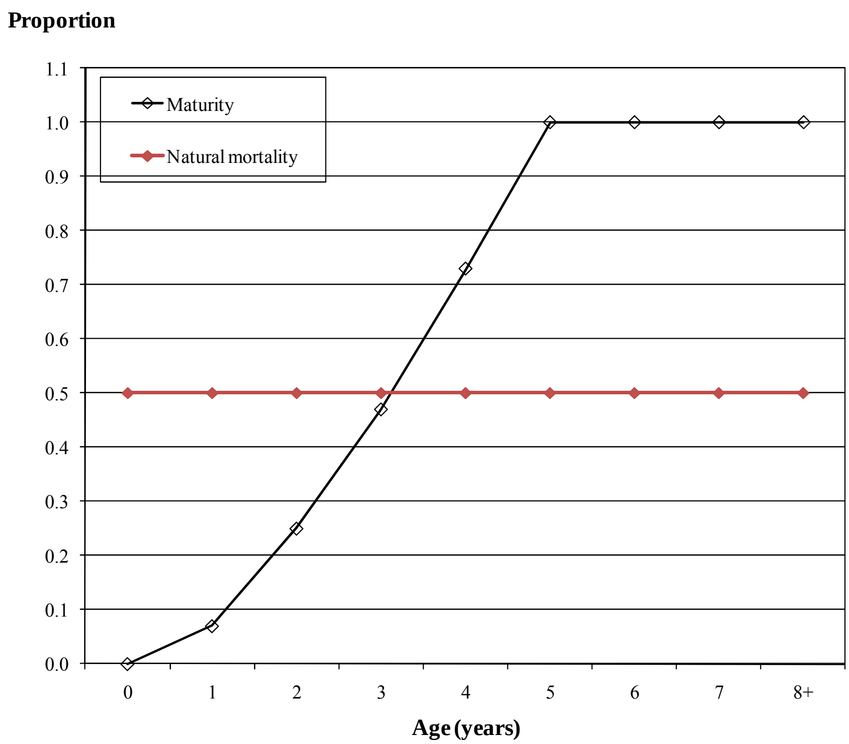


Figure 7. Biological parameters for Pacific mackerel either assumed or estimated in the assessment models: (A) weight-length relationship; (B) length (cm)-at-age (yr); and (C) maturity (also, see Table 4) and natural mortality (*M*).

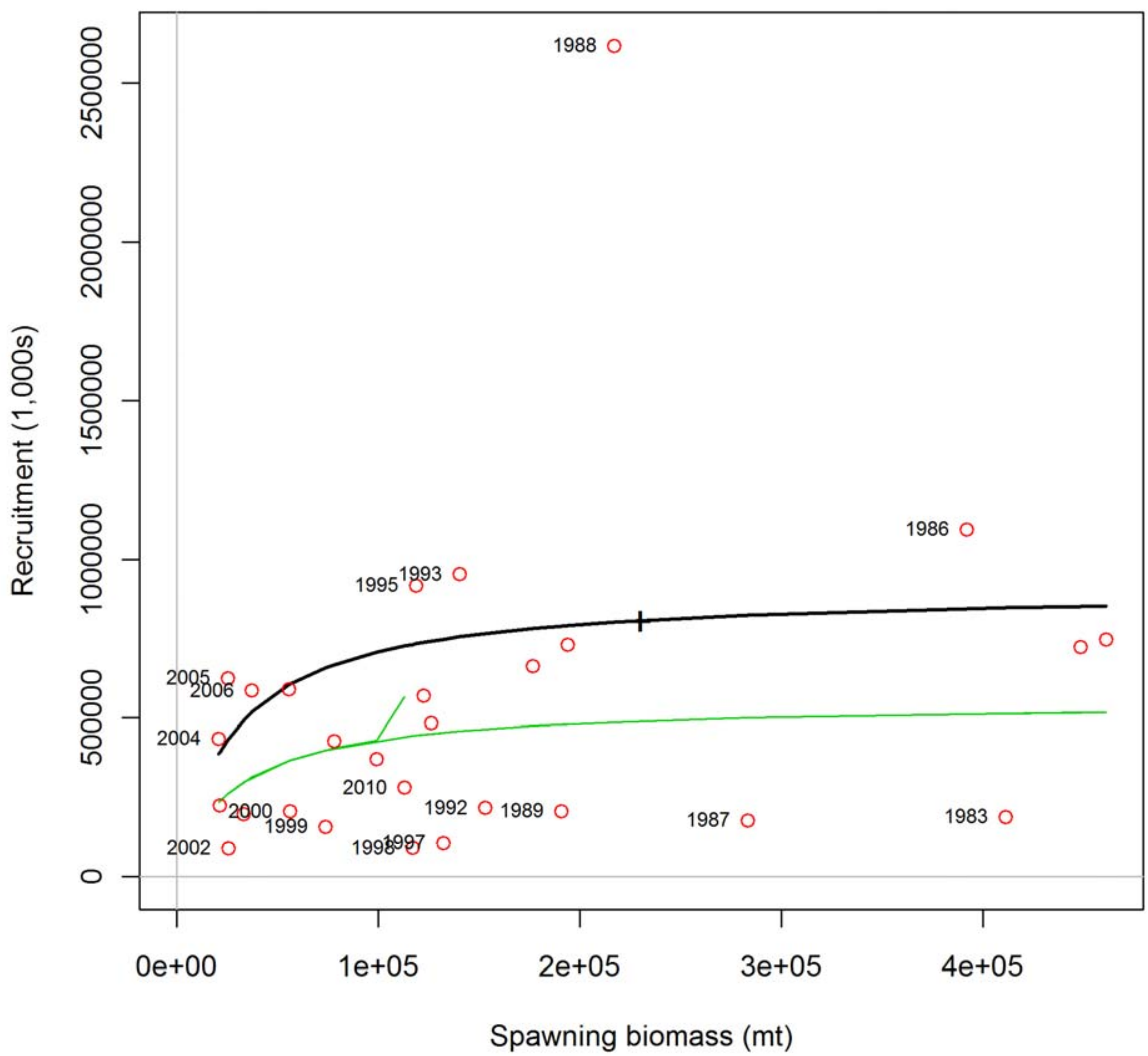


Figure 8. Beverton-Holt stock (*SSB* in 1000s mt)-recruitment (*R* in millions of fish) relationship for Pacific mackerel estimated in the final Model *XA*. Recruitment estimates are presented as (year+1) values. Strong year classes are highlighted and steepness (*h*) = 0.70.

(A)

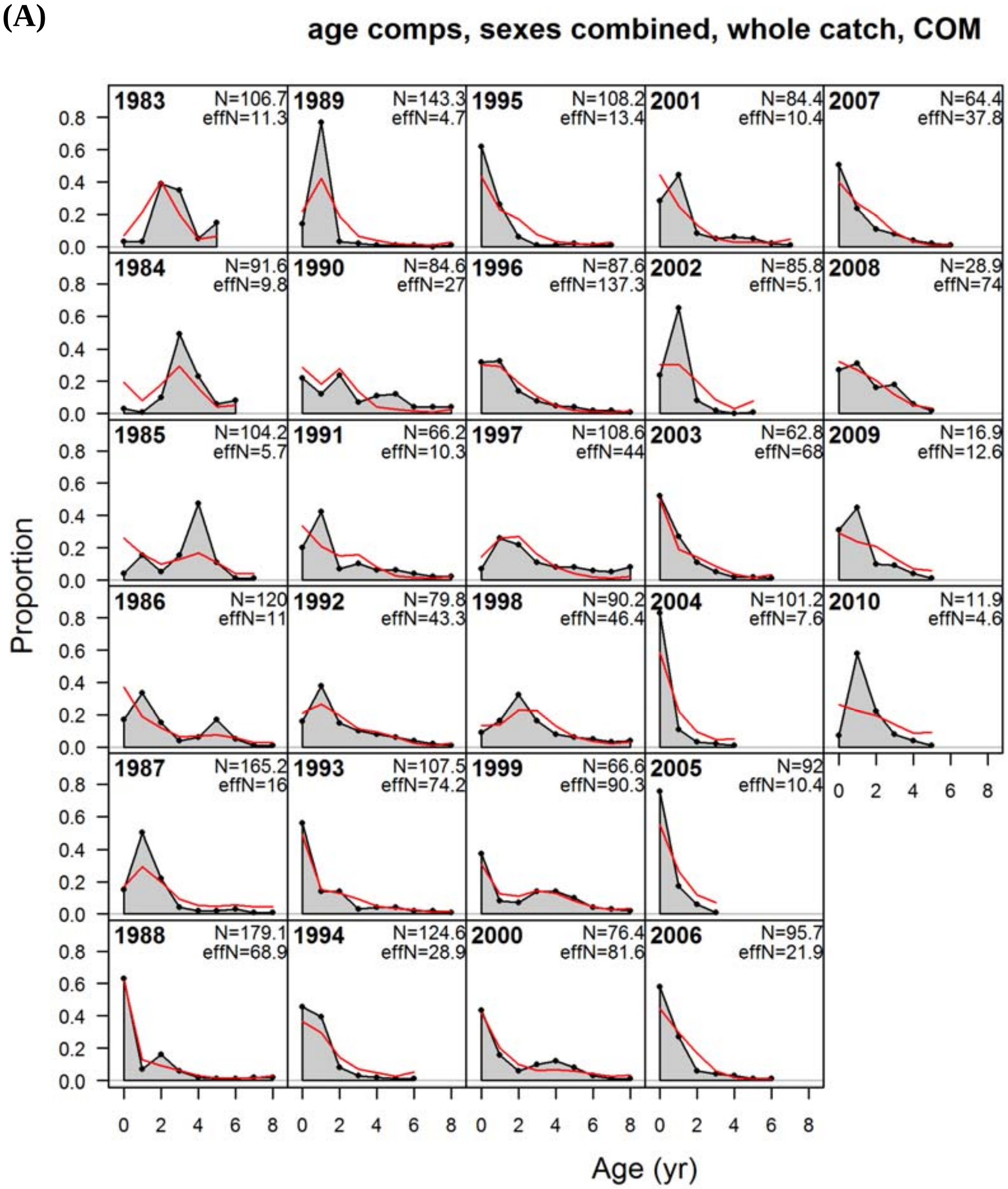
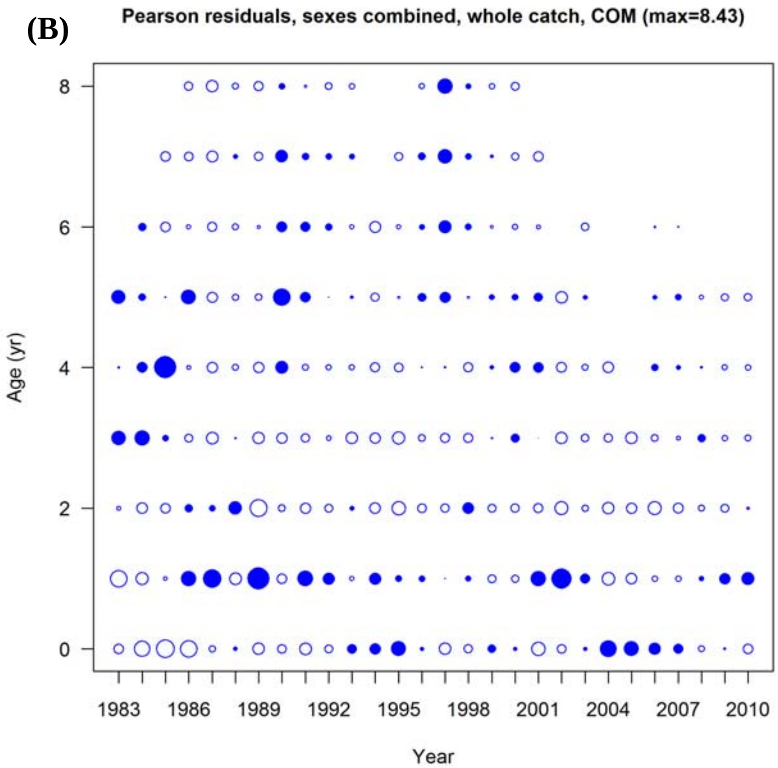


Figure 9. Model *XA* fit diagnostics associated with the commercial fishery age distribution time series (1983-10): (A) observed (open circles) vs. predicted (line) estimates; (B) Pearson standardized residuals (observed – predicted; maximum bubble size = 8.43; dark circles represent positive values); and (C) effective vs. observed (input) sample sizes for the commercial fishery age distribution time series (solid line represents a 1:1 relationship and the dashed line reflects a loess smoother).

(B)



(C)

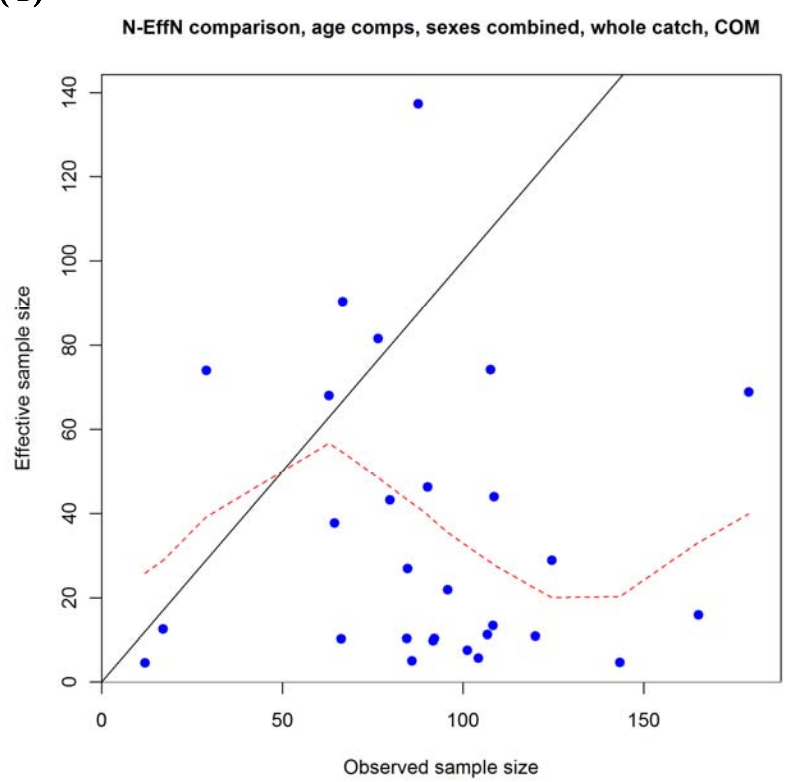


Figure 9. Continued.

(A)

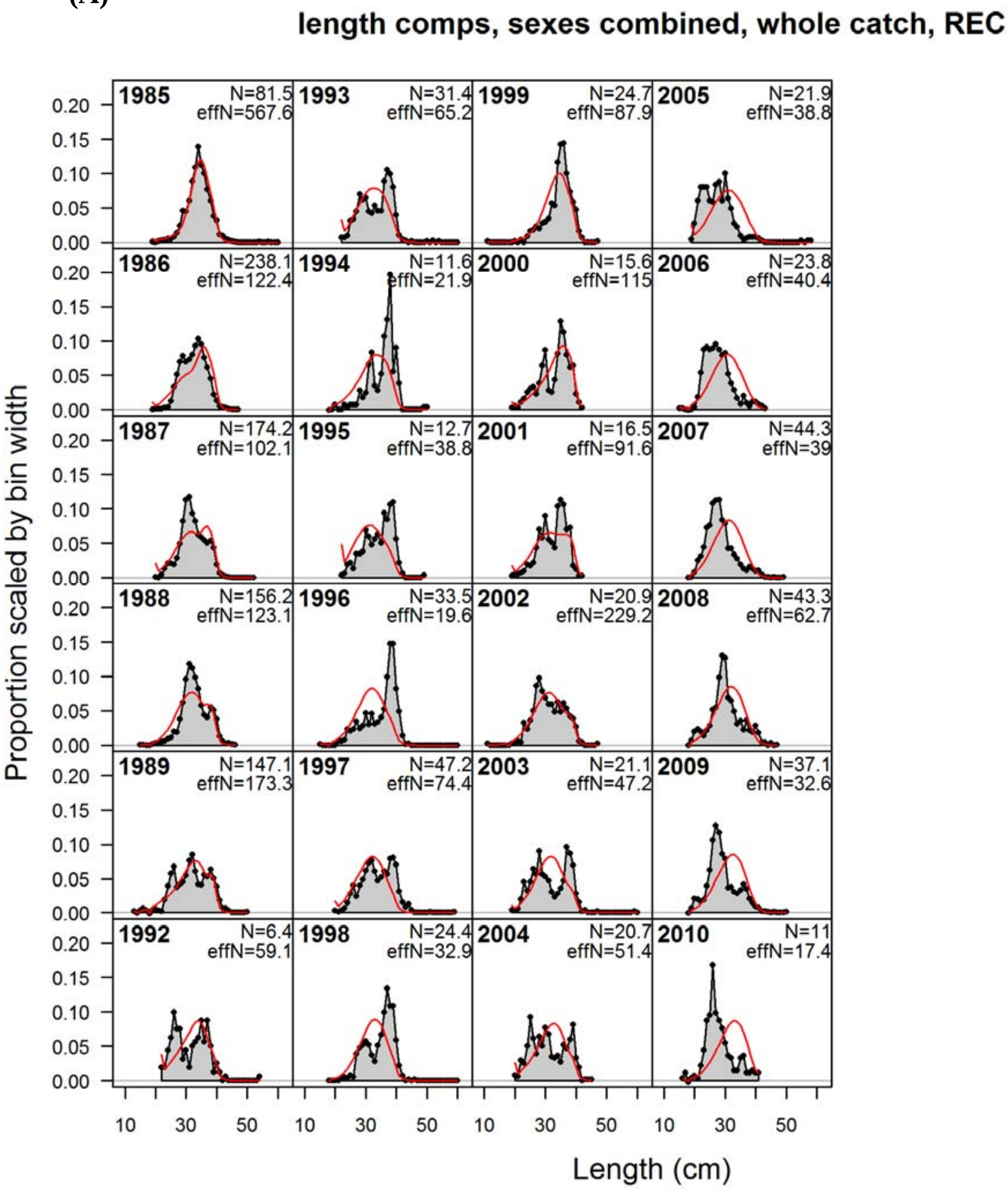
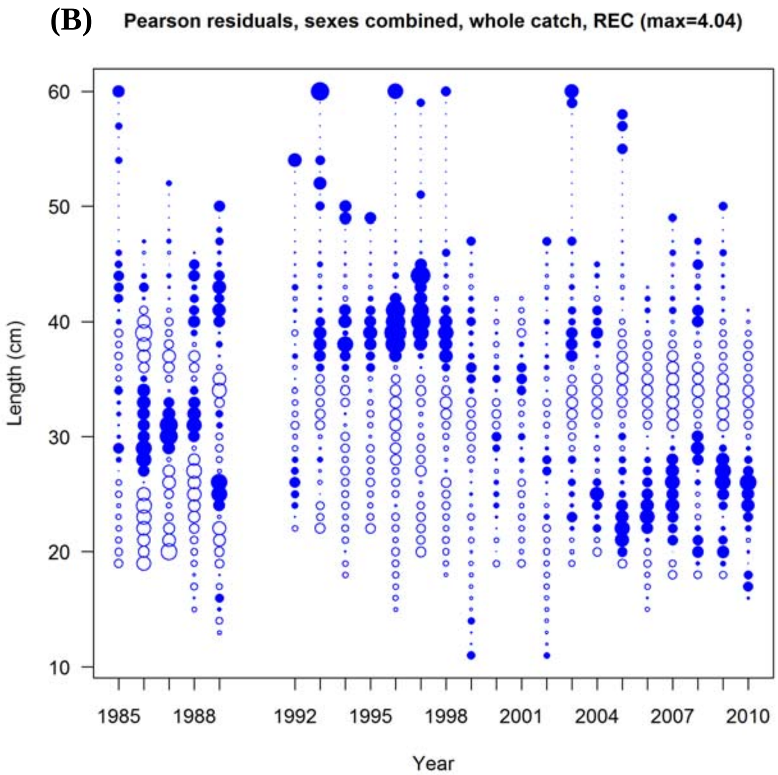


Figure 10. Model *XA* fit diagnostics associated with the recreational fisheries length distribution time series (displays A-C=CPFV fishery via CPFV logbook sampling program and displays D-F=non-CPFV fisheries via CRFS): (A and D) observed (open circles) vs. predicted (line) estimates; (B and E) Pearson standardized residuals (observed – predicted; maximum bubble size = 4.04 and 3.88, dark circles represent positive values); and (C and F) effective vs. observed (input) sample sizes for the commercial fishery age distribution time series (solid line represents a 1:1 relationship and the dashed line reflects a loess smoother).

(B)



(C)

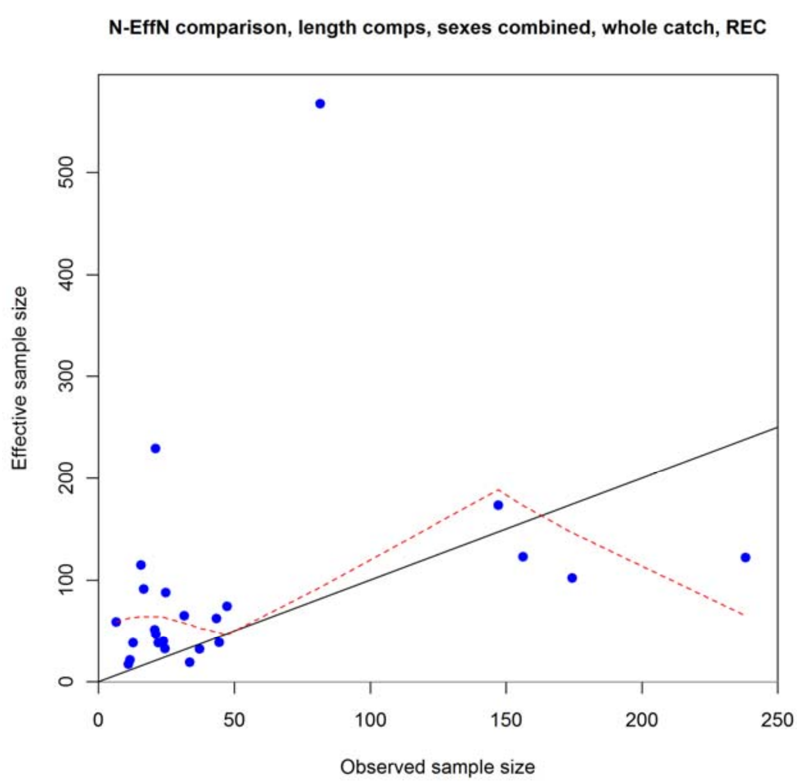


Figure 10. Continued.

(D)

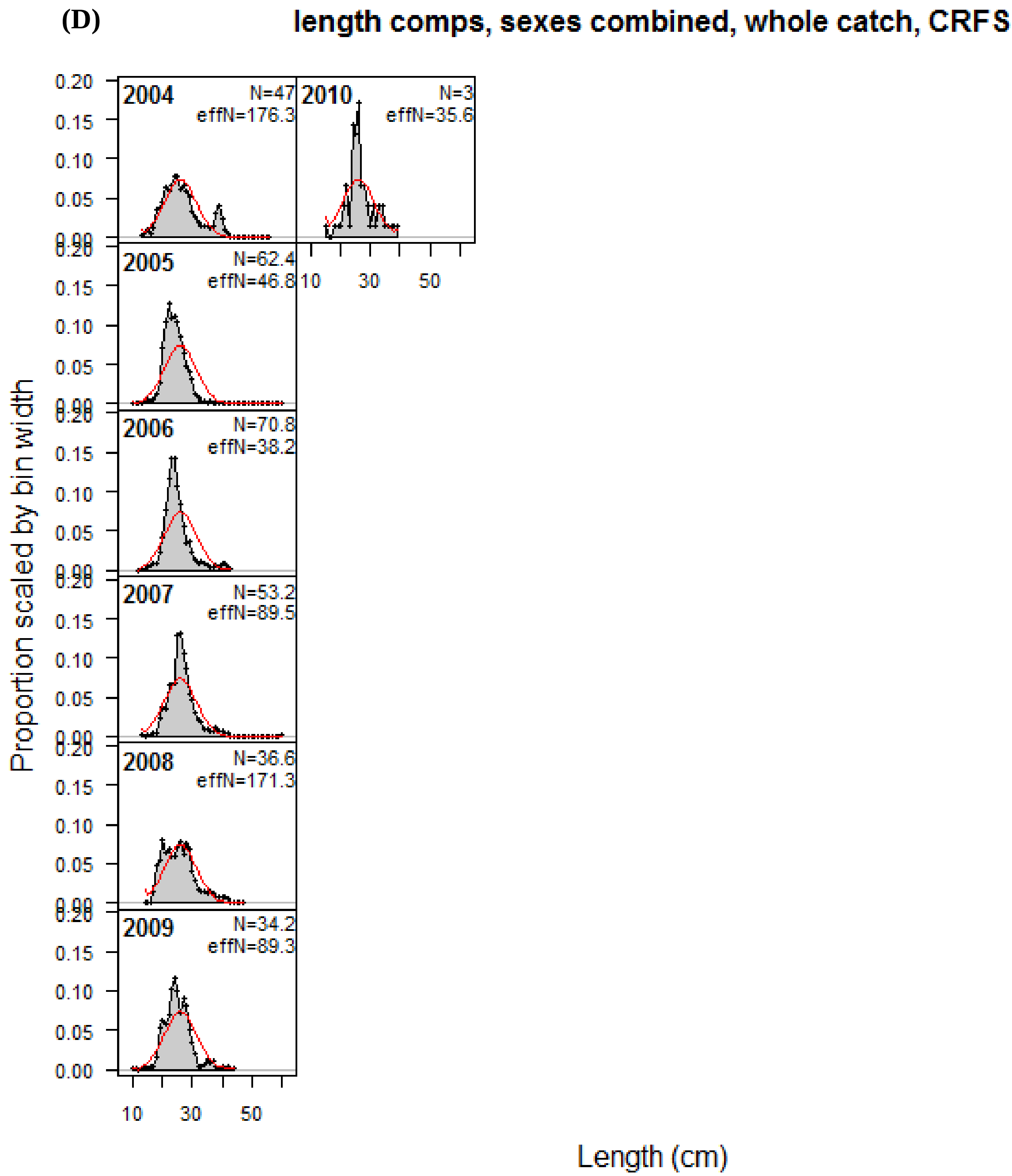
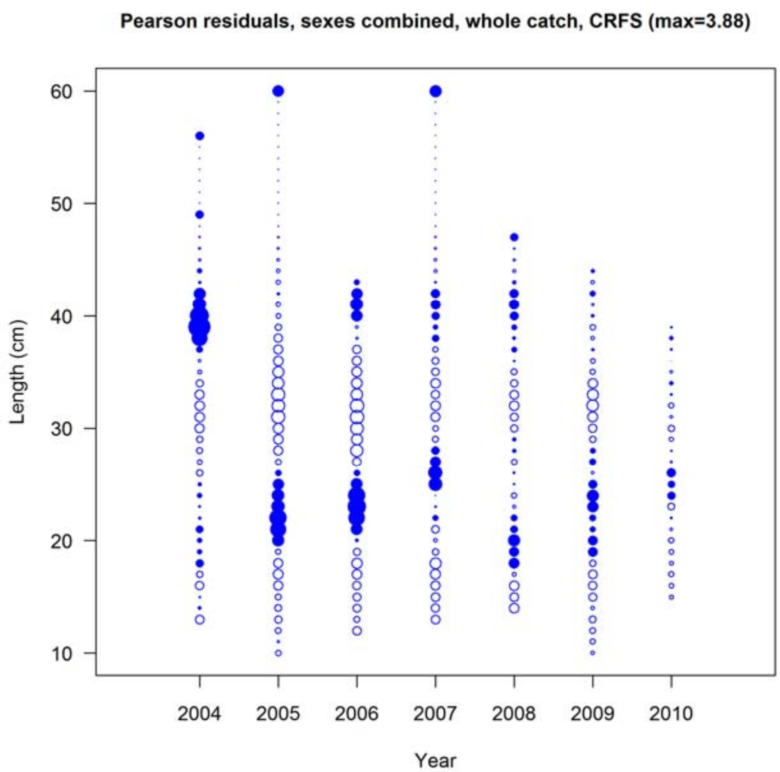


Figure 10. Continued.

(E)



(F)

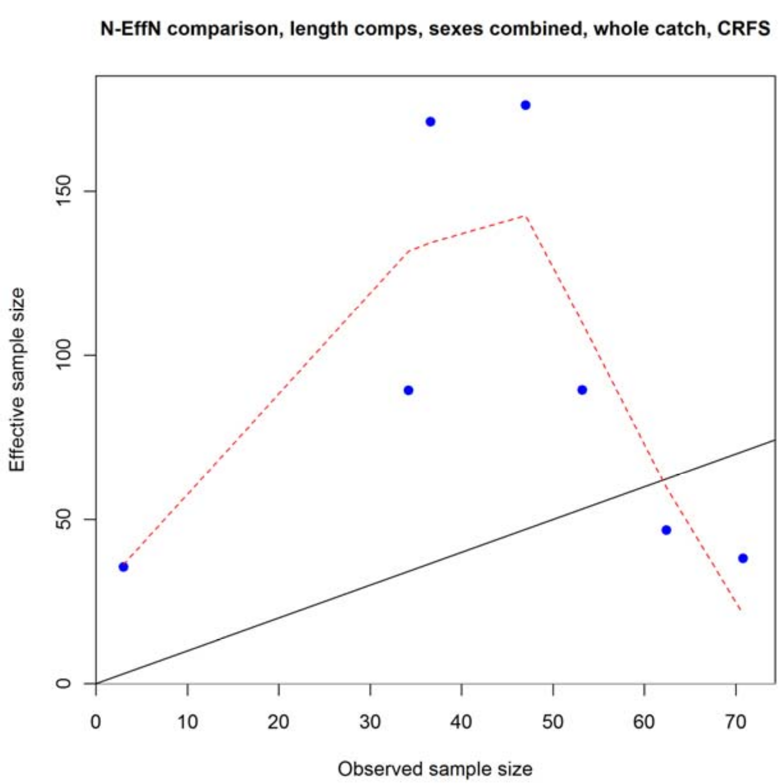


Figure 10. Continued.

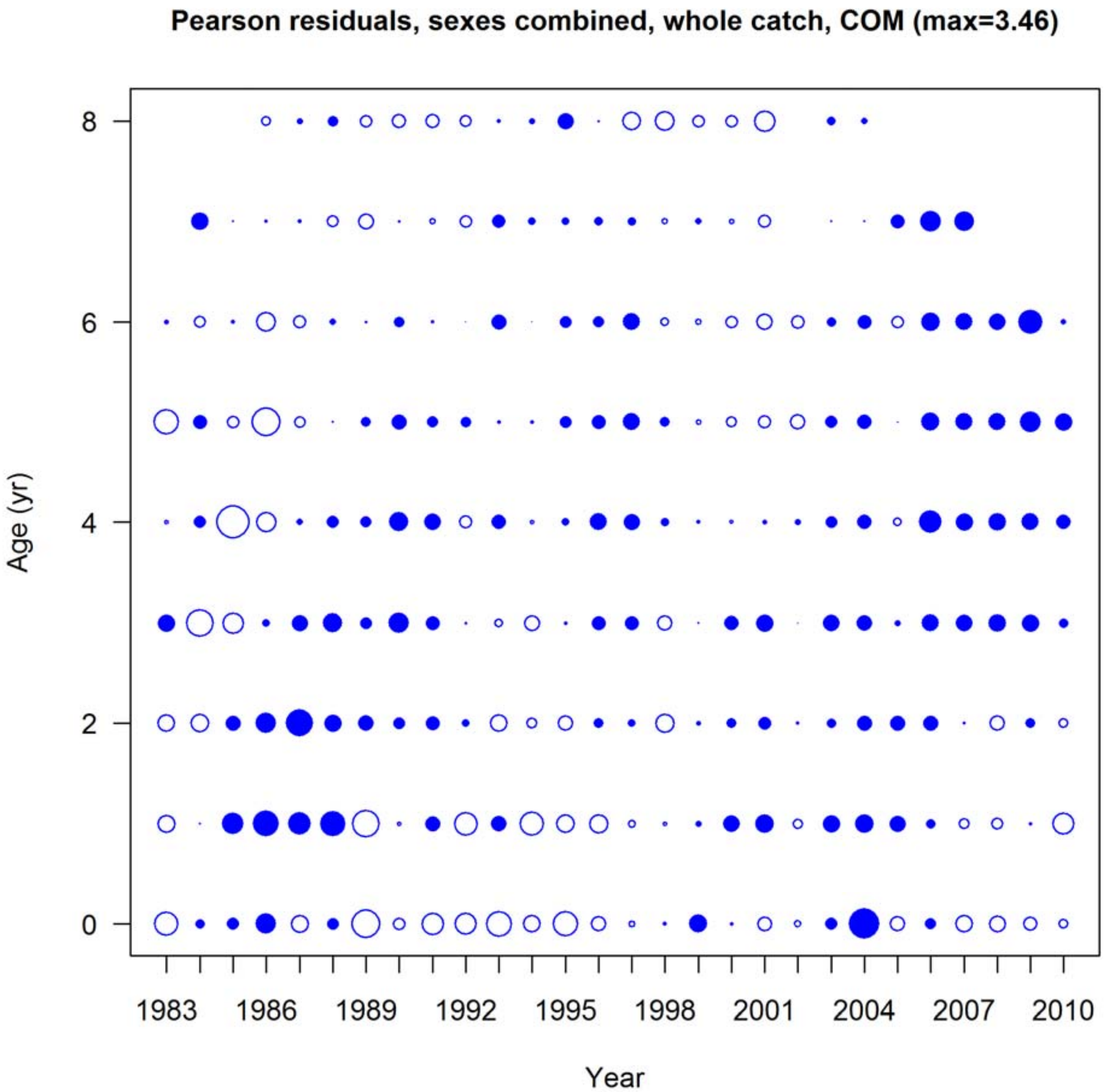
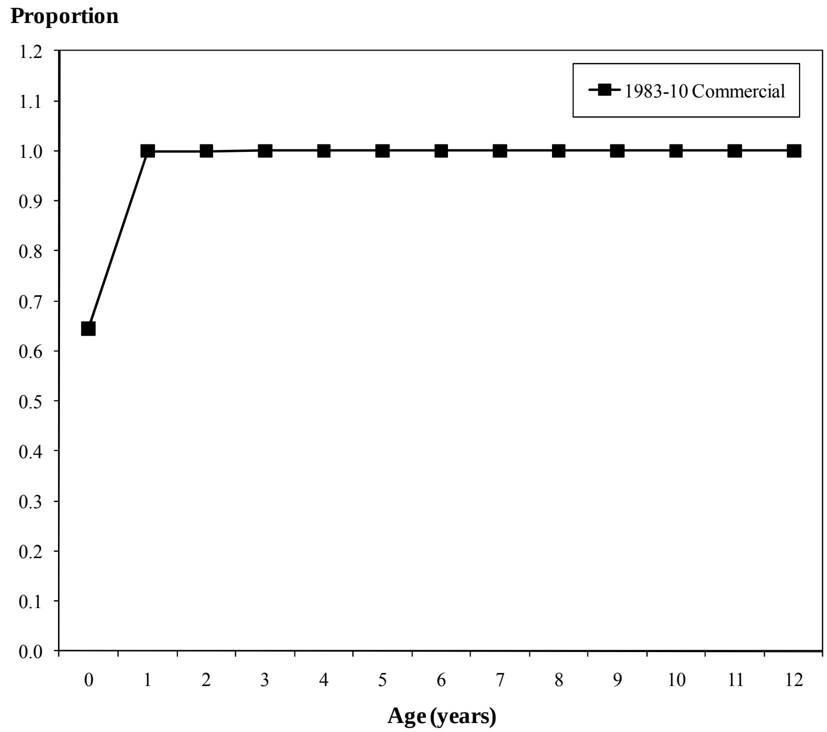


Figure 11. Model *XA* fit diagnostics associated with the commercial fishery mean length-at-age time series (1983-10), i.e., the associated Pearson standardized residuals plot (observed – predicted; maximum bubble size = 3.46; dark circles represent positive values). Also, see Figure 4 related diagnostics.

(A)



(B)

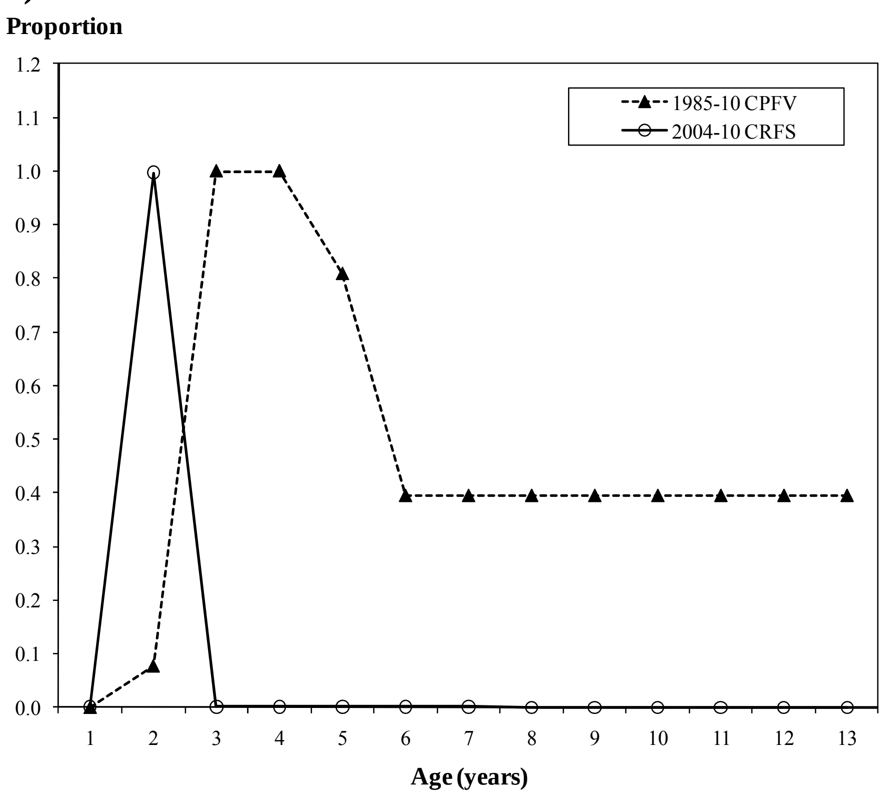
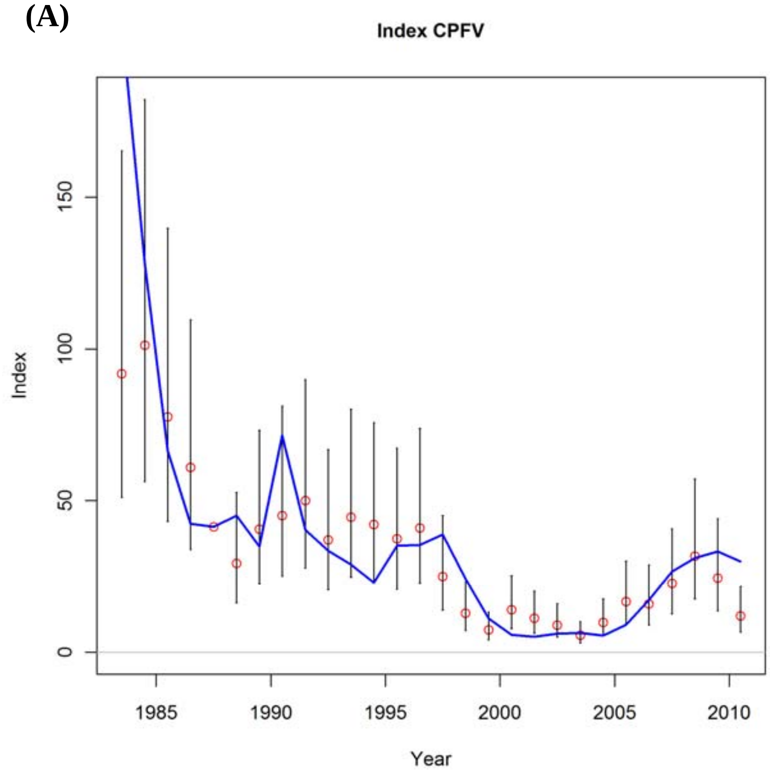


Figure 12. Estimated time-varying age-based selectivity distributions associated with model *XA*: (A) commercial fishery (1983-10); and (B) recreational fishery (1985-10 CPFV) and (2004-10 CRFS).

(A)



(B)

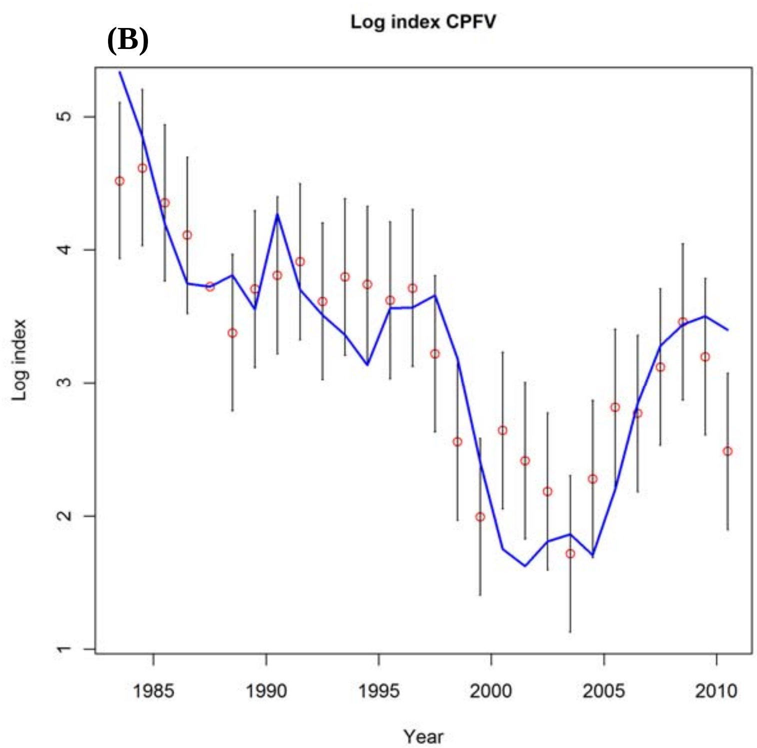


Figure 13. Model *XA* fits to the CPFV index of relative abundance (one time block, 1983-10): (A) normal space; and (B) log space.

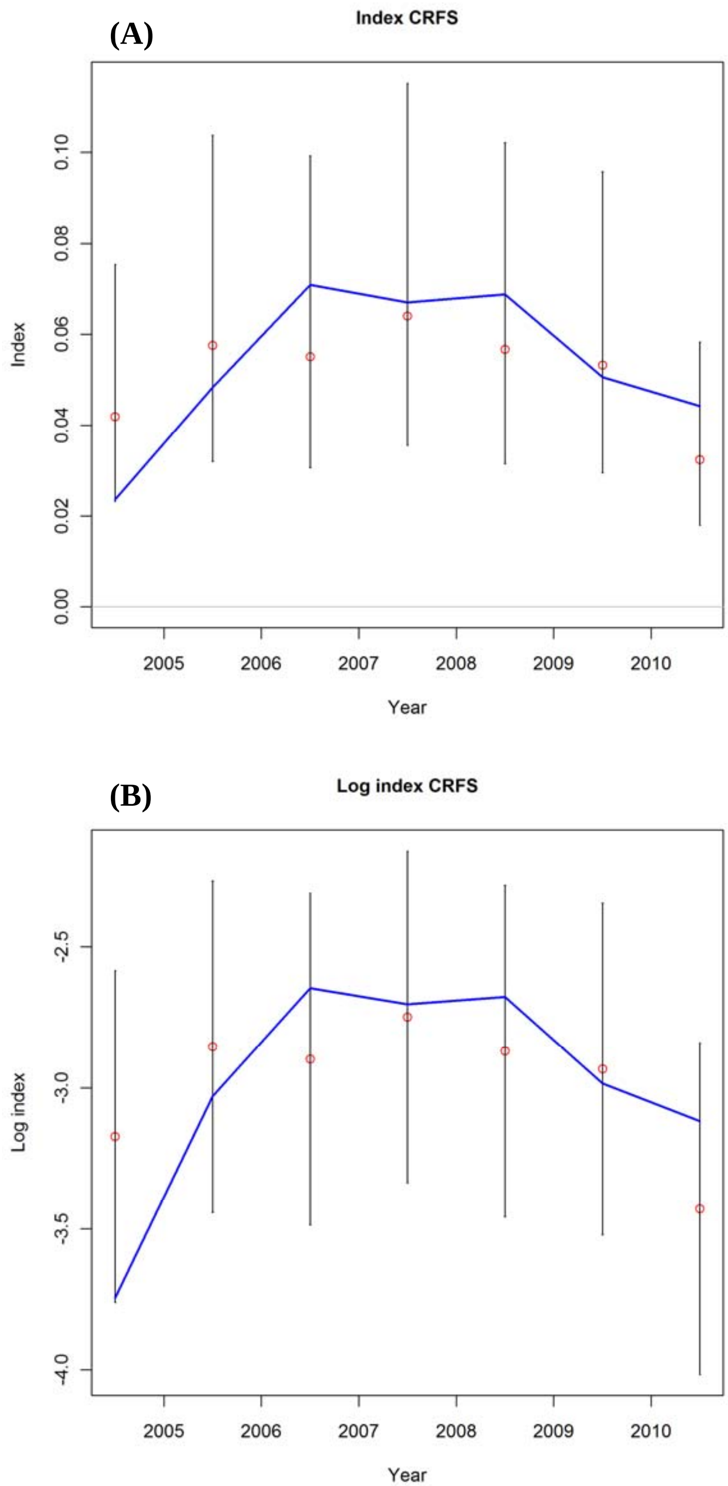
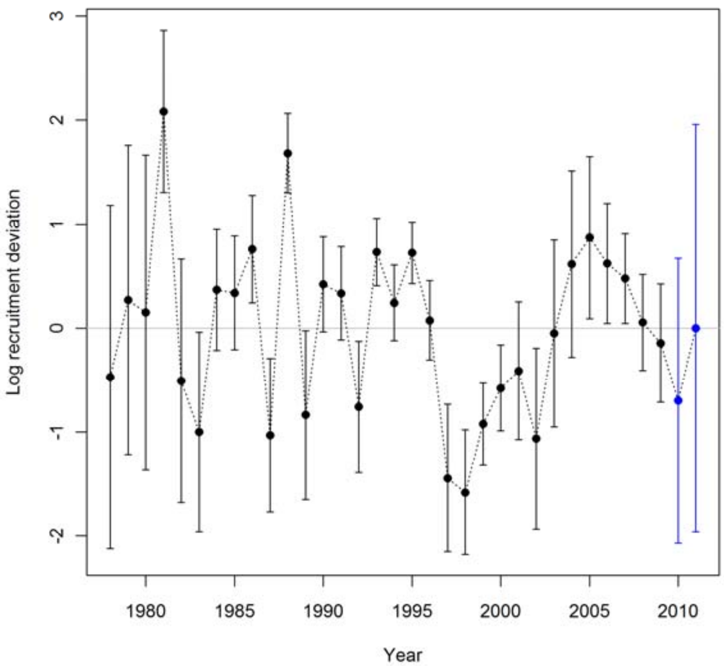


Figure 14. Model *XA* fits to the CRFS index of relative abundance (one time block, 2004-10): (A) normal space; and (B) log space.

(A)



(B)

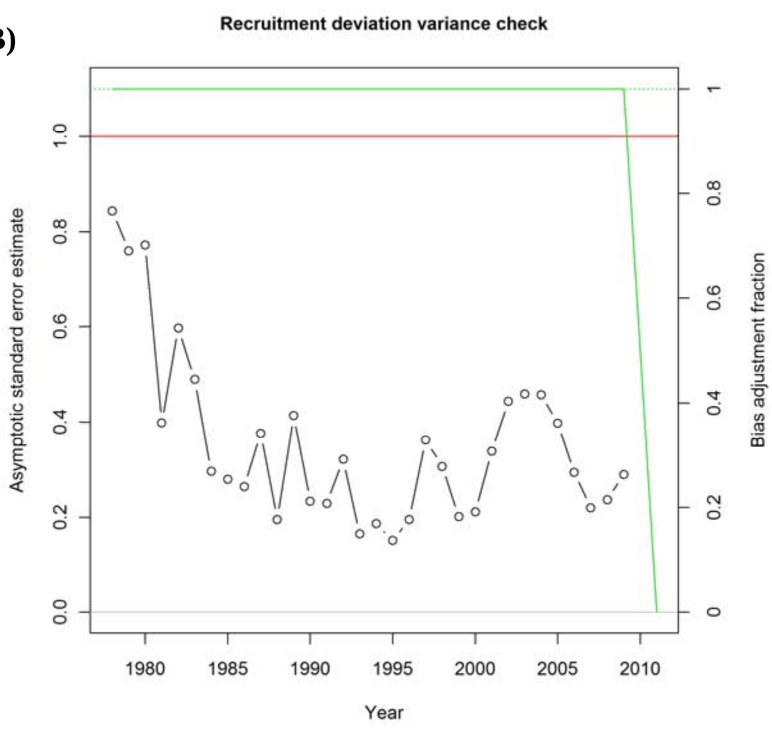


Figure 15. Recruitment-related estimates from model *XA*: (A) recruitment deviations; and (B) SEs associated with the deviations (horizontal line indicates the estimate of the standard deviation of log recruitment deviations, i.e., fixed σ_R =1.0).

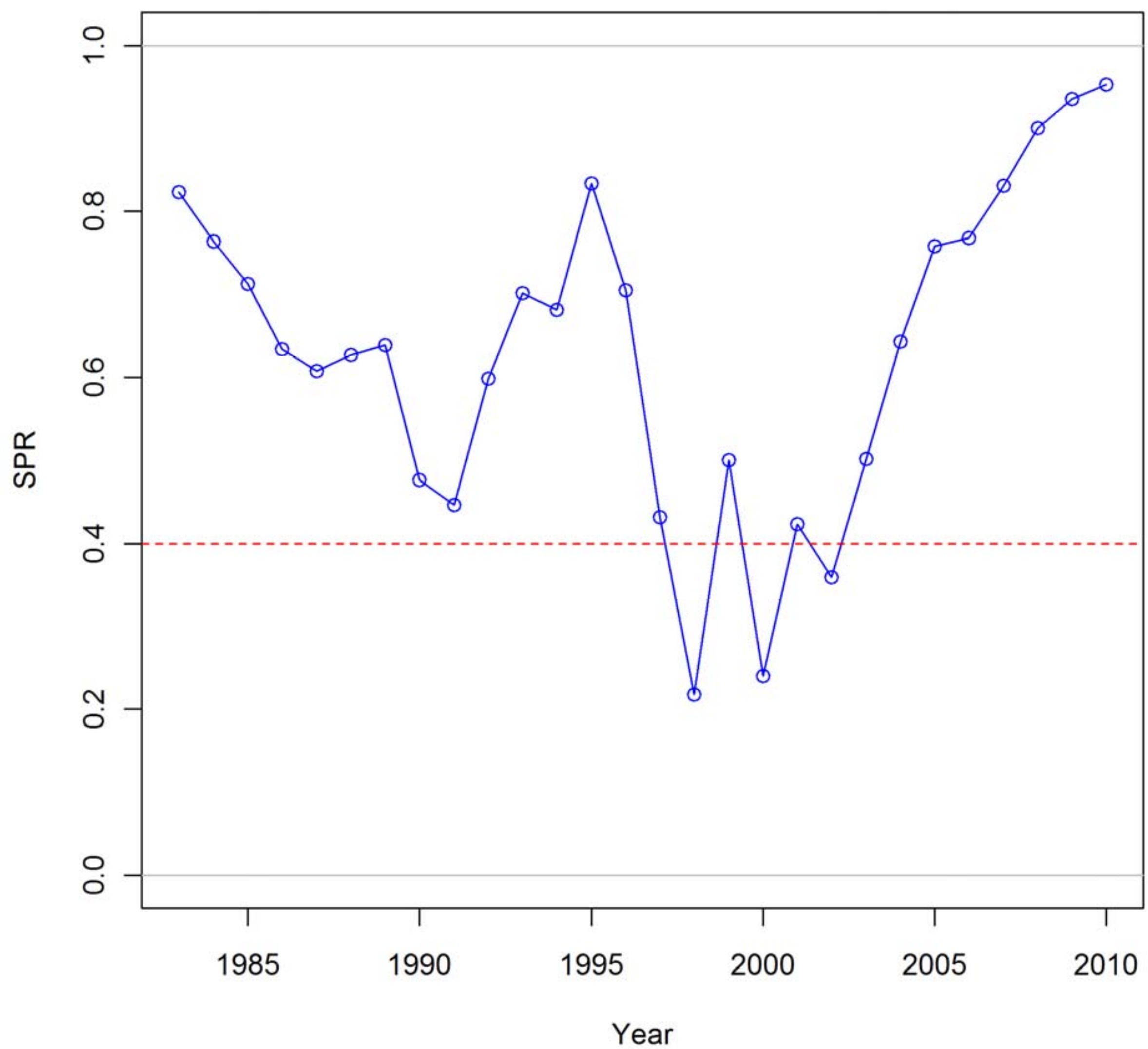


Figure 16. Estimated *F*-based spawning potential ratio time series for model *XA* (1983-10).

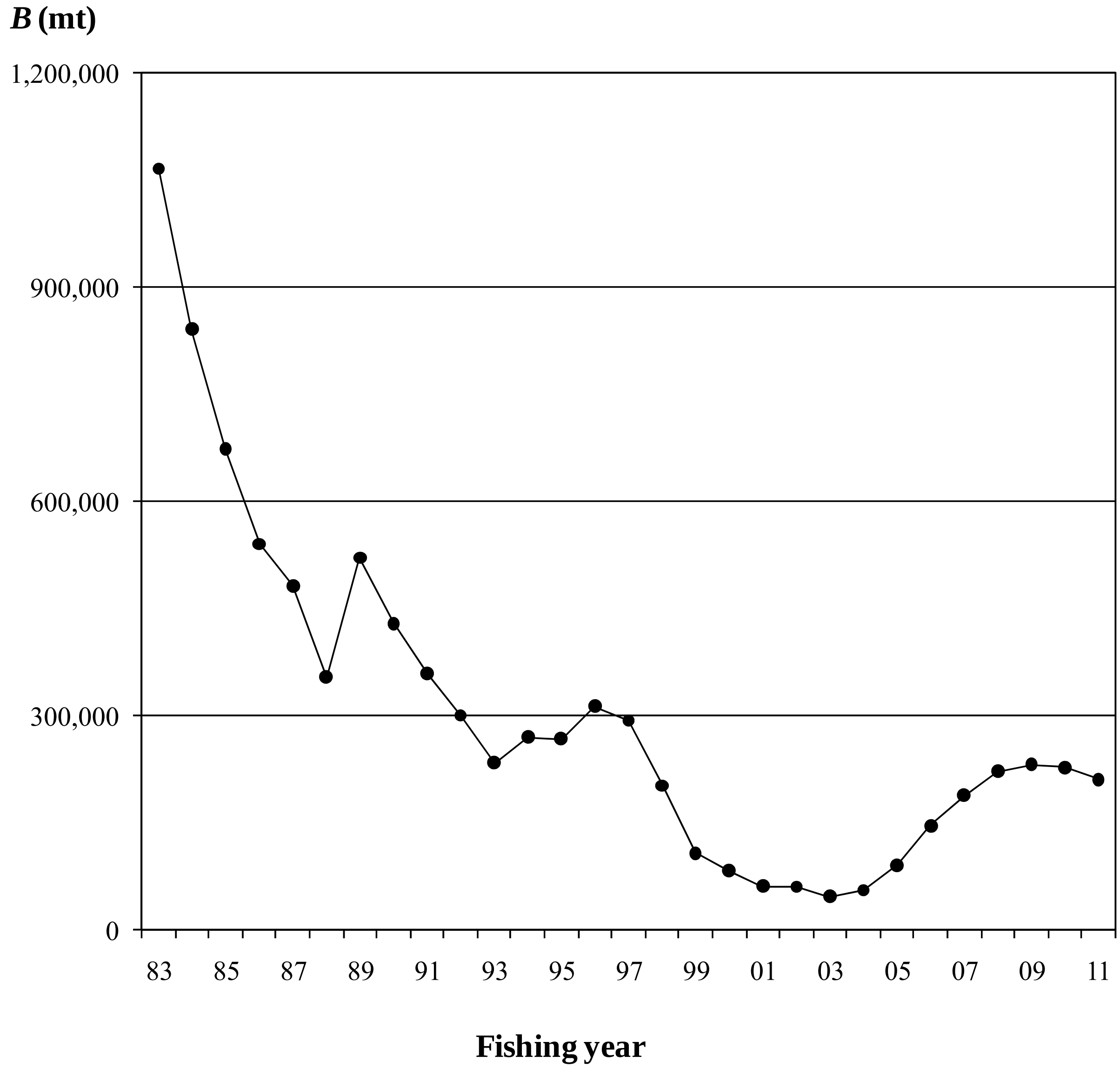


Figure 17. Estimated total stock biomass (age 1+ fish in mt, *B*) of Pacific mackerel based on Model *XA* (1983-11).

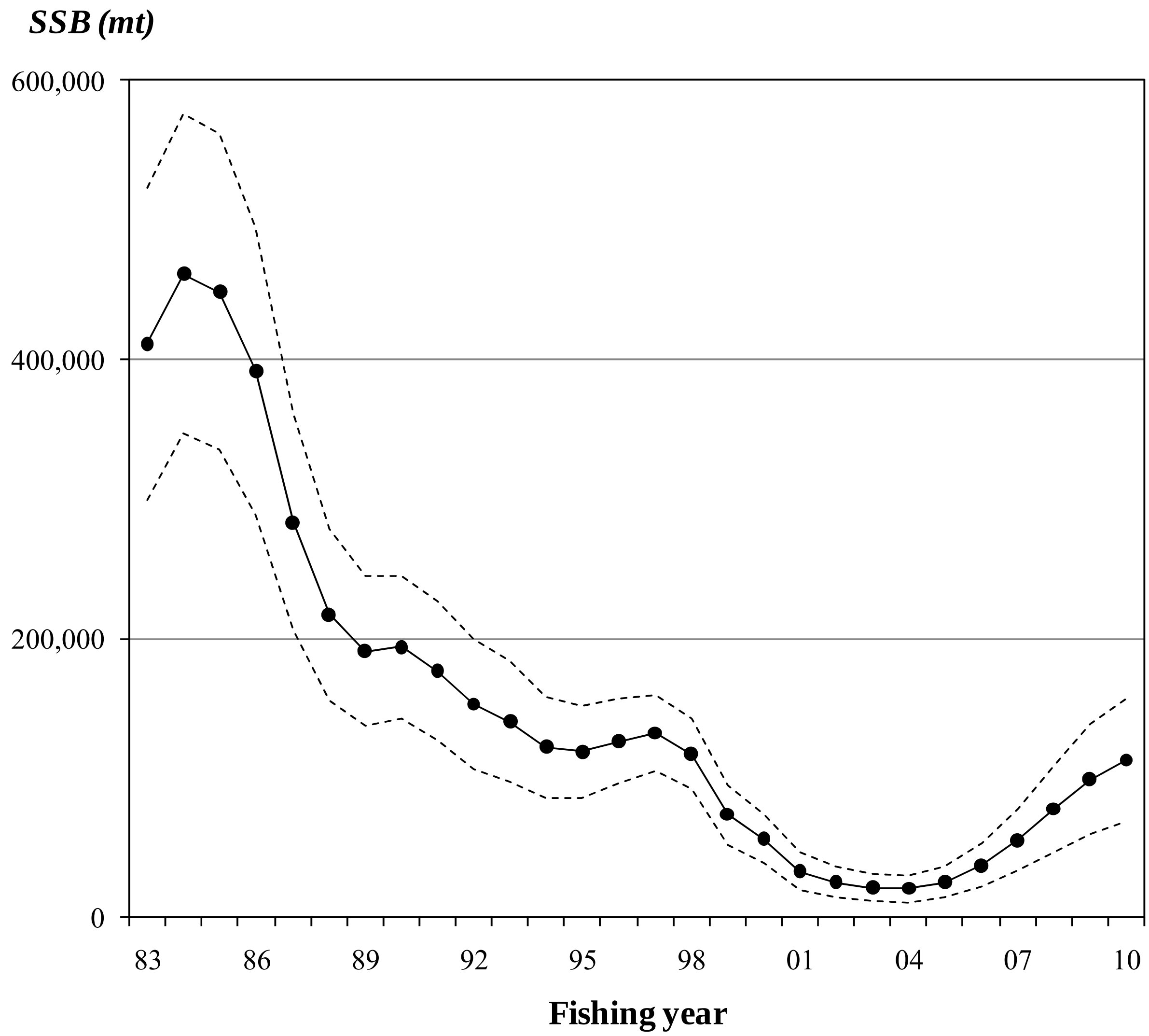


Figure 18. Estimated spawning stock biomass (*SSB*) of Pacific mackerel based on Model *XA* (1983-10). A confidence interval (95% CI) is also presented as dashed lines.

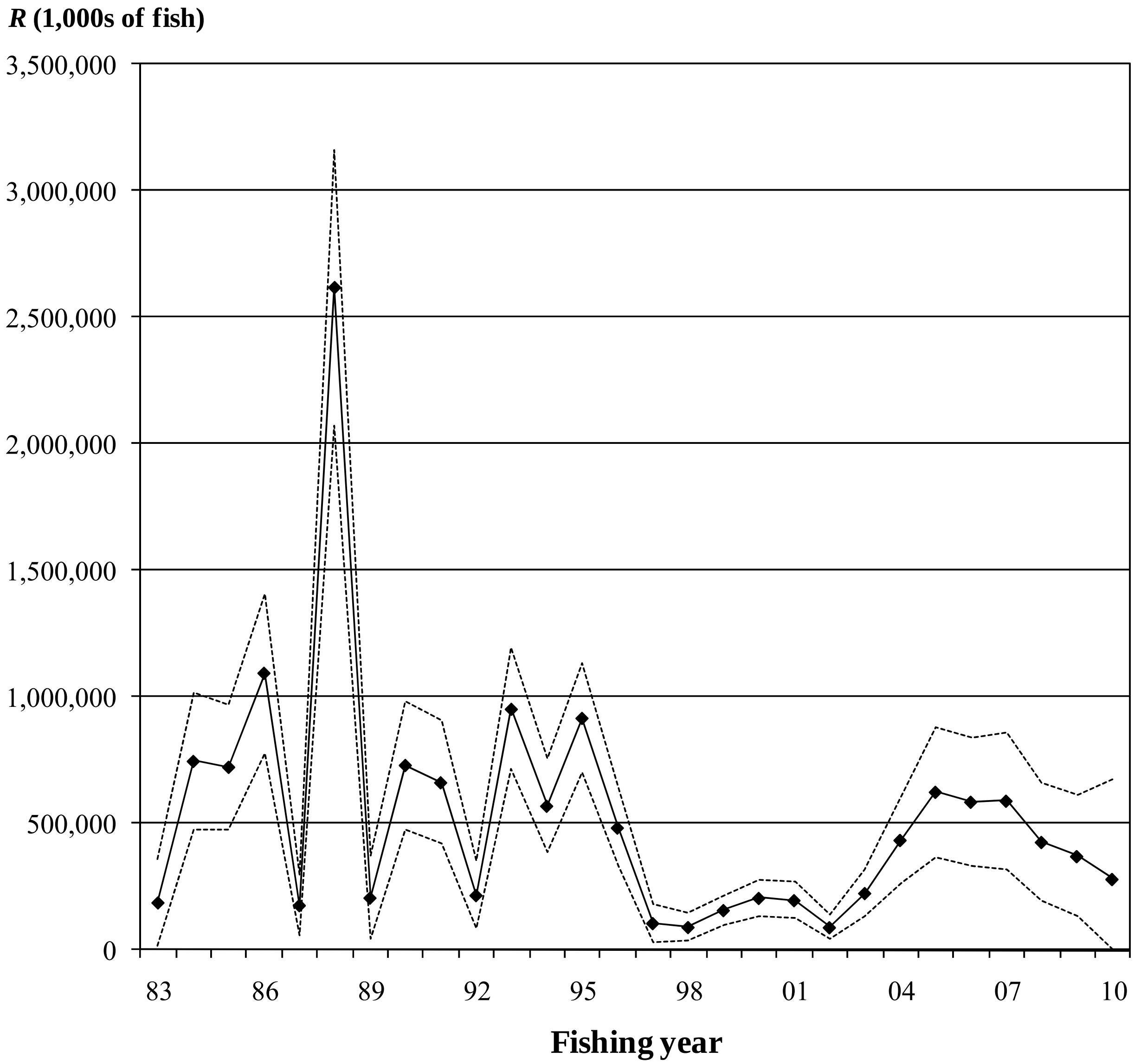
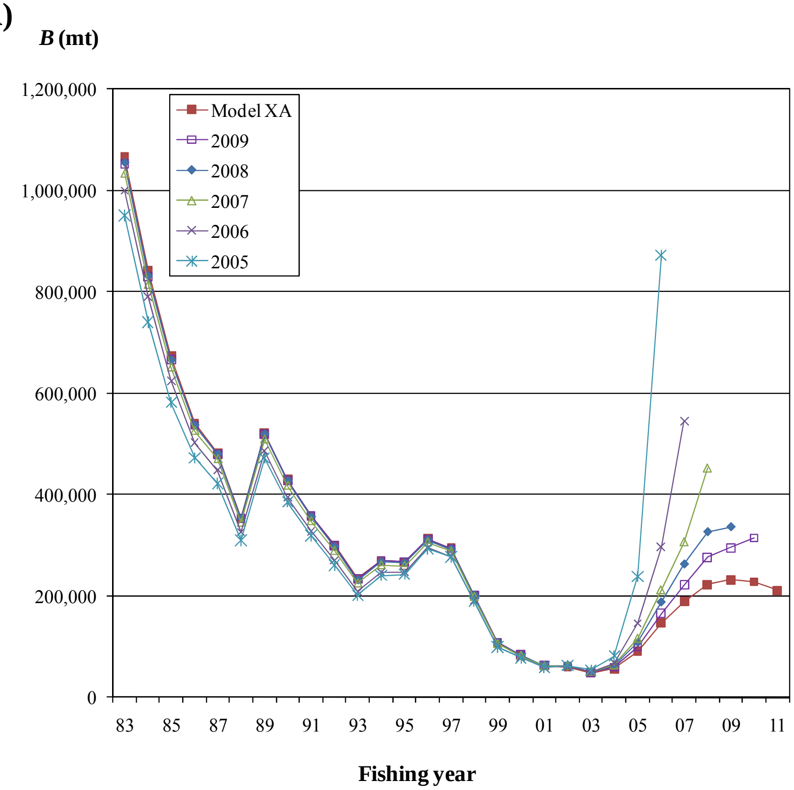


Figure 19. Estimated recruitment (age-0 fish in 1,000s, *R)* of Pacific mackerel based on Model *XA* (1983-10). A confidence interval (95% CI) is also presented as dashed lines.

(A)



(B)

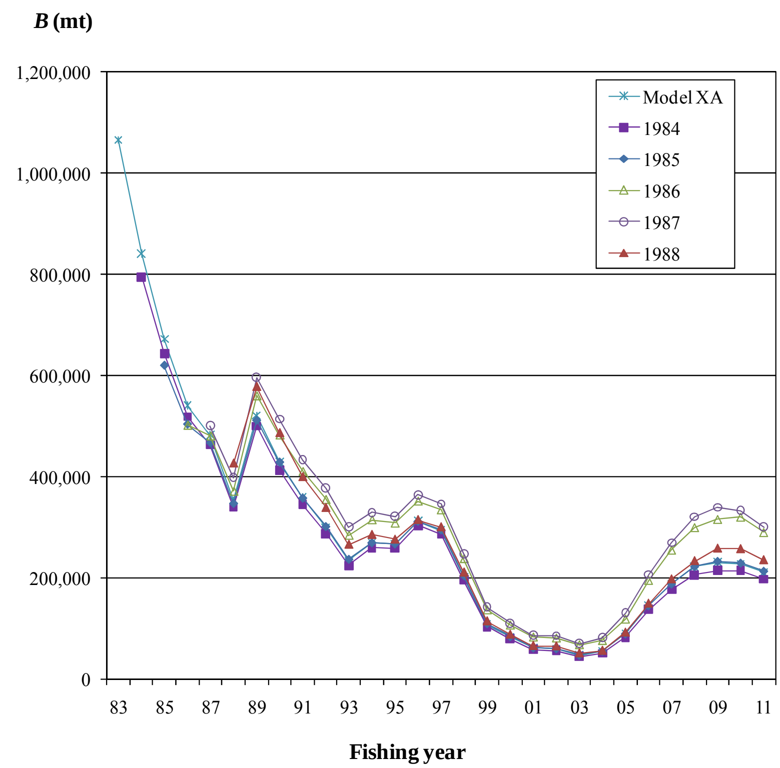


Figure 20. Estimated total stock biomass (age 1+ fish in mt, *B*) of Pacific mackerel based on a: (A) retrospective analysis that omitted one year of data in chronological order (2006-10), i.e., Model *XA*=2010; and (B) prospective analysis that started the model one year later in chronological order, i.e., Model *XA*=1983.

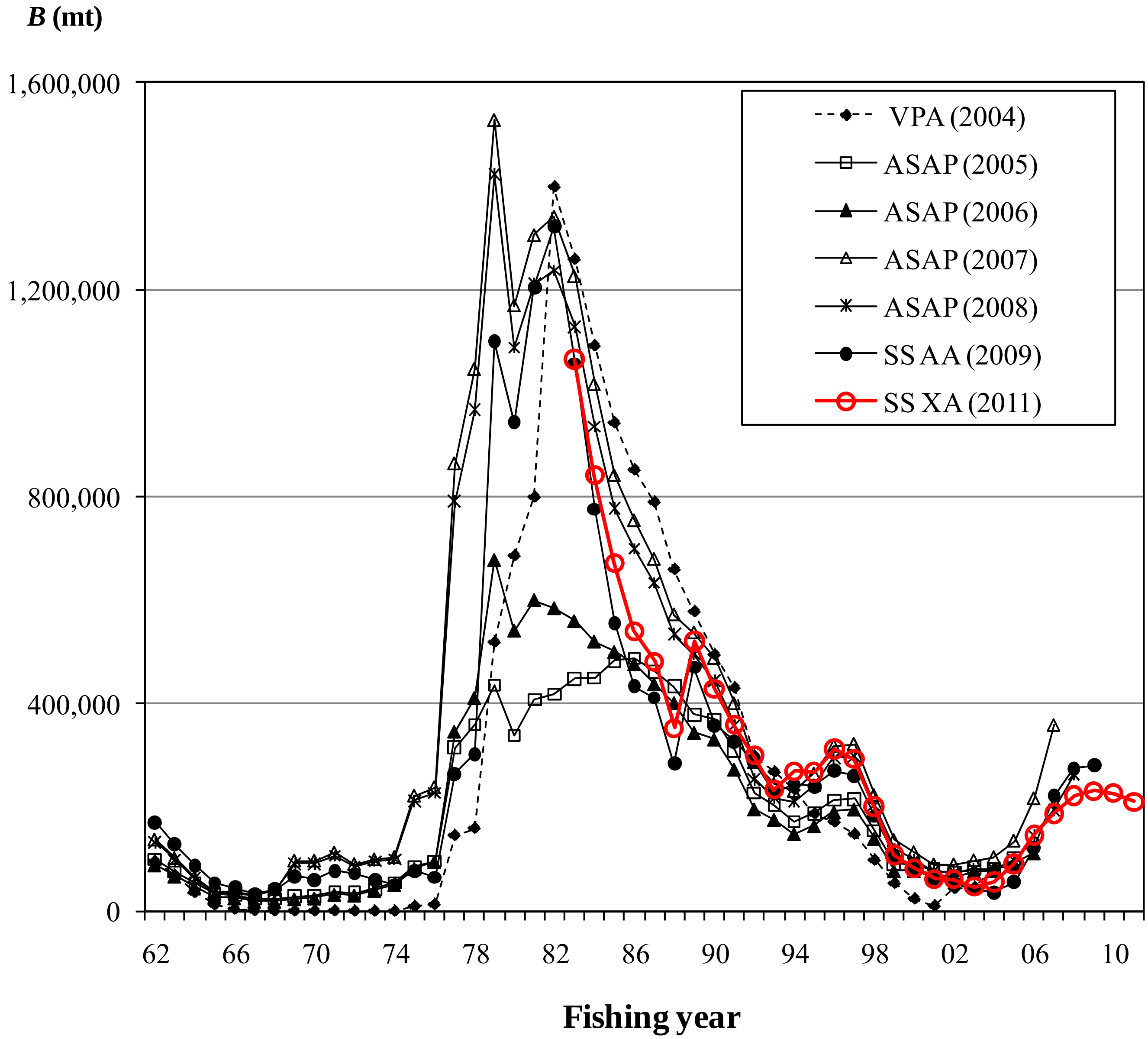


Figure 21. Estimated total stock biomass (*B* age 1+ fish in mt) of Pacific mackerel for the historical assessment period (2004-11): VPA model-based assessments from 1994-04; ASAP model-based (2005-08); and SS model-based (2009-11).

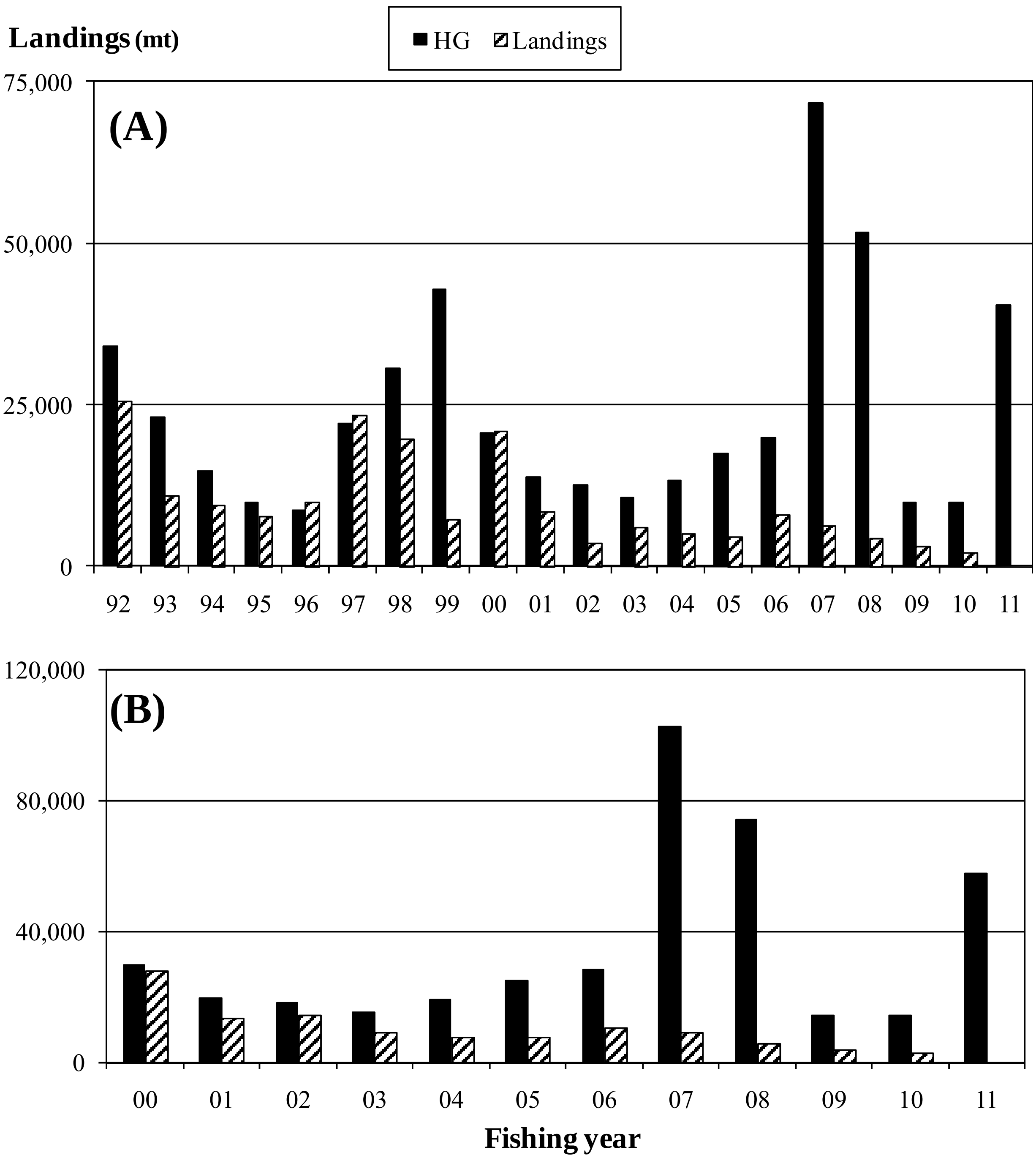


Figure 22. Harvest guideline statistics for Pacific mackerel: (A) commercial landings (USA directed fishery in mt) and quotas (HGs in mt), (1992-11); and (B) total landings (mt) and hypothetical quotas based on no USA 'Distribution' parameter in the harvest control rule. Incidental landings from Pacific Northwest fisheries are not included, but typically are limited, ranging 100 to 300 mt per year. Also, see Harvest Control Rule for USA Management in 2011-12 section.

Appendix 1

SS Model *XA (2011)* files

```
##############################################################################
# P. mackerel stock assessment (1983-10)
# P. R. Crone (June 2011)
# Stock Synthesis 3 (v. 3.20b) - R. Methot
# Model XA: number of fisheries = 2 / surveys = 2 / time-step = annual /
  biological distributions = age, length, and mean length-at-age /
  selectivity = age-based
#
# NOTES: ** ... ** = Pending questions and/or comments
#
```

 # STARTER FILE

```
#
XA.dat # Data file
XA.ctl # Control file
0 #   Read initial values from 'par' file: 0 = no, 1 = yes
1 #   DOS display detail: 0, 1, 2
1 #   Report file detail: 0, 1, 2
0 #   Detailed checkup.sso file: 0 = no, 1 = yes
0 #   Write parameter iteration trace file during minimization
1 #   Write cumulative report: 0 = skip, 1 = short, 2 = full
0 #   Include prior likelihood for non-estimated parameters
1 #   Use soft boundaries to aid convergence: 0 = no, 1 = yes (recommended)
1 #   Number of bootstrap data files to produce    ** New parameterization **
20 #  Last phase for estimation
10 #  MCMC burn-in interval
2 #   MCMC thinning interval
0 #   Jitter initial parameter values by this fraction
-1 #  Minimum year for SSB sd_report: (-1 = styr-2, i.e., virgin population)
-2 #  Maximum year for SSB sd_report: (-1 = endyr, -2 = endyr+N_forecastyrs
0 #   N individual SD years
0.0001 # final convergence criteria (e.g., 1.0e-04)
0 #   Retrospective year relative to end year (e.g., -4)
1 #   Minimum age for 'summary' biomass
1 #   Depletion basis (denominator is: 0 = skip, 1 = relative X*B0, 2 =
      relative X*Bmsy, 3 = relative X*B_styr
0.6 # Fraction for depletion denominator (e.g., 0.4)
1 #   (1-SPR) report basis: 0 = skip, 1 = (1-SPR)/(1-SPR_tgt), 2 = (1-
      SPR)/(1-SPR_MSY), 3 = (1-SPR)/(1-SPR_Btarget), 4 = raw_SPR ** If no
      Forecast, then option = 4 **
1 #   F SD report basis: 0 = skip, 1 = exploitation(Bio), 2 =
      exploitation(Num), 3 = sum(F_rates) ** If no Forecast, then option = 0
      **
1 #   F report basis: 0 = raw, 1 = F/Fspr, 2 = F/Fmsy, 3 = F/Fbtgt  ** New
      parameterization **
999 # End of file
```

```
##############################################################################
# P. mackerel stock assessment (1983-10)
# P. R. Crone (June 2011)
# Stock Synthesis 3 (v. 3.20b) - R. Methot
# Model XA: number of fisheries = 2 / surveys = 2 / time-step = annual /
  biological distributions = age, length, and mean length-at-age / selectivity
  = age-based
#
# NOTES: ** ... ** = Pending questions and/or comments
#
```

FORECAST FILE

```
1 #   Benchmarks: 0 = skip, 1 = calculate (F_SPR, F_btgt, F_MSY) ** Related
      to Benchmark relative_F basis, Forecast, and F and SPR report basis (in
      ctl file) options **
2 #   MSY: 0 = none, 1 = set to F_SPR, 2 = calculate F_MSY, 3 = set to
      F_Btgt, 4 = set to F(endyr)
      0.3 # SPR target - relative to B0 (e.g., 0.3)
      0.5 # Biomass target - relative to B0 (e.g., 0.5)
#     Benchmark years: begin_bio, end_bio, begin_selex, end_selex,
      begin_relative F, end_relative F (enter actual year, -999 = start_yr, 0
      = end_yr, <0 = relative end_yr)
0 0 0 0 0 0
1 #   Benchmark relative_F basis: 1 = use year range, 2 = set relative_F same
      as Forecast below
#
1 #   Forecast: 0 = none, 1 = F_SPR, 2 = F_MSY, 3 = F_Btgt, 4 = Avg_F (uses
      first-last relative_F years), 5 = input annual F scalar
1 #   Number of forecast years
1.0 # F scalar (only used for Forecast = 5)
#     Forecast years: begin_selex, end_selex, begin_relative F, end_relative
      F (enter actual year, -999 = start_yr, 0 = end_yr, <0 = relative
      end_yr)
0 0 0 0
#
1 #   Control rule method: 1 = catch = f(SSB) West Coast, 2 = F = f(SSB)
      0.5 # Control rule Biomass level (as fraction of B0, e.g. 0.40) above
      which F is constant
0.1 # Control rule Biomass level (as fraction of B0, e.g. 0.10) below which F
     is set to 0
0.75# Control rule target as fraction of F_limit (e.g., 0.75)
3 #   Number of forecast loops (1-3: fixed at 3 for now)
3 #   First forecast loop with stochastic recruitment
0 #   Forecast loop control #3 (reserved for future bells&whistles)
0 #   Forecast loop control #4 (reserved for future bells&whistles)
0 #   Forecast loop control #5 (reserved for future bells&whistles)
2015 # First year for caps and allocations (should be after years with fixed
inputs)
0 #   SD of log(realized F/target F) in forecast (set value >0.0 to cause
      active implementation error)
0 #   Do West Coast groundfish rebuilder output (0 = no, 1 = 0)
2007 #Rebuilder: first year catch could have been set to zero (Ydecl)(-1 to
      set to 1999)
2010 #Rebuilder: year for current age structure (Yinit) (-1 to set to
     endyear+1)
```

```
1 #  fleet relative F: 1 = use first-last allocation year, 2 = read
     season(row) x fleet(column) below
#    Note: that fleet allocation is used directly as average F if Forecast =
     4
2 #  Basis for forecast catch tuning and for forecast catch caps and
     allocation: 2 = dead_bio, 3 = retain_bio, 5 = dead_num, 6 = retain_num
#     Conditional input if relative F = 2 (total of 4 lines)
#     Fishery relative F: rows = seasons and columns = Fishery
#     Fishery: F1 F2 F3
# 0.1 0.1
#     Maximum total catch by fishery (-1 to have no max)
-1 -1
#     Maximum total catch by area (-1 to have no max)
-1
#     Fleet assignment to allocation group (enter group ID# for each Fishery,
0     for not included in an allocation group)
0 0
#     Conditional on >1 allocation groups (total of 3 lines)
#     Allocation fraction for each of: 0 allocation groups
#     No allocation groups
2 #   Number of forecast catch levels to input (otherwise calculate catch
      from forecast F)
2 #   Basis for input forecast catch: 2 = dead catch, 3 = retained catch, 99
      = input Hrate(F) with units that are from fishery units (note new codes
      in SSv3.20b)
#     Input fixed catch values: year, season, Fishery, catch (or F)
2011 1 1 2257
2011 1 2 100
999 # End of file
```

```
##############################################################################
# Pacific mackerel stock assessment (1983-10)
# P. R. Crone (June 2011)
# Stock Synthesis 3 (v. 3.20b) - R. Methot
# Model XA: number of fisheries = 2 / surveys = 2 / time-step = annual /
  biological distributions = age, length, and mean length-at-age / selectivity
  = age-based
#
```

CONTROL FILE

```
#
# MODEL DIMENSION PARAMETERS
==============================================================================
#
#      Morph parameterization
#
1 #    Number of growth patterns (morphs)
1 #    Number of sub-morhps within morphs
#
#      Note: 'conditional' (8) lines follow, based on above morp/season/area
       parameterization
#
#      Time block parameterization (time-varying parameterization)
1 #    Number of block designs: Selectivity/Catchability
2 #    Blocks in design 1
#
1983 1989 1990 2011 # Blocks - design 1
#
# BIOLOGICAL PARAMETERS
==============================================================================
#
0.5 # Fraction = female (at birth)
#      Natural mortality (M)
0 #    Natural mortality type: 0 = 1 parameter, 1 = N_breakpoints, 2 =
       Lorenzen, 3 = age-specific, 4 = age-specific with season interpolation
#      Placeholder for number of M breakpoints (if M type option >0)
#      Placeholder for Age (real) at M breakpoints
#      Growth
1 #    Growth model: 1 = VB with L1 and L2, 2 = VB with A0 and Linf, 3 =
       Richards, 4 = readvector
0.5 # Growth_age at L1 (L_min): Age_min for growth
12 #   Growth_age at L2 (L_max) - (to use L_inf = 999): Age_max for growth
0 #    SD constant added to length-at-age (LAA)
0 #    Variability of growth: 0 = CV_f(LAA), 1 = CV_f(A), 2 = SD_f(LAA), 3 =
       SD_f(A)
#      Maturity
3 #    Maturity option: 1 = logistic (length), 2 = logistic (age), 3 = fixed
       (vector of proportion-at-age), 4 = read age fecundity
#      Maturity-at-age (if maturity option = 3)
0 0.07 0.25 0.47 0.73 1 1 1 1 1 1 1 1 # Maturity-at-age (proportion) for
       option = 3, i.e., 'Accumulator age' + 1 **;
1 #    First mature age (no read if maturity option = 3)
1 #    Fecundity option: 1 is eggs=Wt*(a+b*Wt), 2 is eggs=(a*L^b), 3 is
       eggs=(a*Wt^b)
0 #    Hermaphroditism option: 0 = none, 1 = invoke female to male transition
1 #    MG parameter offset option: 1 = none, 2 = M,G,CV_G as offset from GP1,
       3 = like SS2
```

```
1 #   MG parameter adjust method: 1 = do SS2 approach, 2 = use logistic
      transformation to keep between bounds of base parameter approach
#
#     M, maturity, and growth parameterization
#     Low High Initial Prior_mean Prior_type SD Phase Env_var Use_dev
      Dev_minyr Dev_maxyr Dev_stddev Block_def Block_type
#     M parameterization
0.3 0.7 0.5 0 -1 0 -3 0 0 0 0 0 0 0 0 # M_p1 (M = 0.5, all ages)
#     Growth parameterization
#     Length-at-age
4 35 15 0 -1 0 3 0 0 0 0 0 0 0 0 # VB_L_Amin (Length-at-age = 0.5)
30 70 45 0 -1 0 3 0 0 0 0 0 0 0 0 # VB_L_Amax  (Length-at-age = 12)
0.1 0.7 0.35 0 -1 0 3 0 0 0 0 0 0 0 0 # VB_K
0.01 0.5 0.1 0 -1 0 3 0 0 0 0 0 0 0 0 # CV_young
0.0001 0.5 0.01 0 -1 0 -3 0 0 0 0 0 0 0 0 # CV_old
#     Weight-length
-1 5 3.12e-006 0 -1 0 -3 0 0 0 0 0 0 0 0 # W-L_a
1 5 3.40352 0 -1 0 -3 0 0 0 0 0 0 0 0 # W-L_b
#     Maturity parameterization ** fixed vector for maturity-at-age **
-3 3 3 0 -1 0 -3 0 0 0 0 0 0 0 0 # Maturity (inflection)
-3 3 3 0 -1 0 -3 0 0 0 0 0 0 0 0 # Maturity (slope)
-3 3 1 0 -1 0 -3 0 0 0 0 0 0 0 0 # Eggs/gm (intercept)
-3 3 0 0 -1 0 -3 0 0 0 0 0 0 0 0 # Eggs/gm (slope)
#     Population recruitment apportionment (distribution) ** Placeholders **
-4 4 0 0 -1 0 -4 0 0 0 0 0 0 0 0 # Recruitment distribution (growth pattern)
-4 4 1 0 -1 0 -4 0 0 0 0 0 0 0 0 # Recruitment distribution (area)
-4 4 0 0 -1 0 -4 0 0 0 0 0 0 0 0 # Recruitment distribution (season)
#     Cohort growth deviation
1 5 1 0 -1 0 -4 0 0 0 0 0 0 0 # Cohort growth deviation
#
# 1 # Custom environment (MG) parameterization
#
# 1 # Custom block (MG) parameterization ** No time block for growth
      parameterization **
#     Low High Initial Prior_mean Prior_type SD Phase
# -5 5 0 0 -1 0 3 # VB_L_Amin: (1962-89)
# -5 5 0 0 -1 0 3 # VB_L_Amin: (1990-10)
# -5 5 0 0 -1 0 3 # VB_L_Amax: (1962-89)
# -5 5 0 0 -1 0 3 # VB_L_Amax: (1990-10)
# -5 5 0 0 -1 0 3 # VB_K: (1962-89)
# -5 5 0 0 -1 0 3 # VB_K: (1990-10)
#
#     Seasonal effects on biology parameters
0 0 0 0 0 0 0 0 0 0 # ** Placeholder **
#
#     Stock-recruit (S-R)
3 #   S-R function: 1 = B-H w/flat top, 2 = Ricker, 3 = standard B-H, 4 = no
      steepness or bias adjustment
#     Low High Initial Prior_mean Prior_type SD Phase
1 30 10 0 -1 0 1 # ln(R0)
0.1 1 0.9 0 1 0 5 # Steepness
0 2 1.0 0 -1 0 -3 # Sigma_R
-5 5 0 0 -1 0 -3 # Env link coefficient
-15 15 0 0 -1 0 1 # Initial eqilibrium recruitment offset
0 2 0 0 -1 0 -3 # Autocorrelation in recruitment devs
0 #   Index for environment variable to be used
0 #   Environment target
```

```
#
#     Recruitment residual (recruitment devs) parameterization
1 #   Recruitment dev type: 0 = none, 1 = dev_vector, 2 = simple
1978 # Start year for recruitment devs
2009 # Last year for recruitment devs
1 #   Phase for recruitment devs
0 #   Read 11 advanced recruitment options: 0 = off, 1 = on - ** Placeholders
**
#     Start year for (early) recruitment devs
#     Phase for (early) recruitment devs
#     Phase for forecast recruitment devs
#     Lambda for forecast recruitment devs (before endyr+1)
#     Last recruitment dev with no bias adjustment
#     First year of full bias correction adjustment
#     Last year for full bias correction adjustment in MPD
#     First recent year no bias adjustment in MPD
#     Lower bound for recruitment devs
#     Upper bound for recruitment devs
#     Read initial values for recruitment devs
#
# FISHING MORTALITY PARAMETERS
=============================================================================
#
#     Fishing mortality (F) parameterization
0.1 # F ballpark for tuning early phases
-2000 # F ballpark year (negative value = off)
1 #   F method: 1 = Pope, 2 = instantaneous F, 3 = hybrid
0.9 # F or Harvest rate (depends on F method)
#     No additional F input needed for F method = 1 - ** Placeholders **
#     Read overall start F value, overall phase, N detailed inputs to read
      for F method = 2
#     Read N iterations for tuning for F method = 3 (recommend 3 to 7)
#
#     Initial F parameters ** non-equilibrium initial age distribution
      implemented **
#     Low High Initial Prior_mean Prior_type SD Phase
0.0001 5 0.1 0 -1 0 1 # Initial F (F1)
0.00001 5 0.001 0 -1 0 -1 # Initial F (F2)
#
# CATCHABILITY (q) PARAMETERS
=============================================================================
#
#     Catchability (q) parameterization
#     Columns: Do den_dep power (0 = off and survey is proportional to
      abundance, 1 = add parameter for non-linearity); Do env_link (0 = off,
      1 = add parameter for env effect on q);
#     Do extra SD (0 = off, 1 = add parameter for additive constant to input
      SE in ln space); q_type (<0 = mirror other fishery/survey, 0 = no
      parameter q - median unbiased,
#     1 = no parameter q - mean unbiased, 2 = estimate parameter for ln(q), 3
      = ln(q)+set of devs about ln(q) for all years - parm_rand_dev,
#     4 = ln(q)+set of devs about q for index_yr-1 - parm_rand_walk)
0 0 0 0 # F1 = COM (USA commercial and Mexico commercial)
0 0 0 0 # F2 = REC (USA recreational)
0 0 0 0 # S1 = CPFV
0 0 0 0 # S2 = CRFS
#     q parameters (if any)
```

```
#     Low High Initial Prior_mean Prior_type SD Phase
# -1 1 0.0001 0 -1 99 3 # ln(q) - S1
#
# SELECTIVITY (S) PARAMETERS
=============================================================================
#
#     Selectivity/retention parameterization
#     Size (length) parameterization
#     A = selectivity option: 1 - 24
#     B = do retention: 0 = no, 1 = yes
#     C = male offset to female: 0 = no, 1 = yes
#     D = mirror selectivity (fishery/survey)
#     A B C D
#     Size selectivity (S) - ** No size-based S **
0 0 0 0 # F1
0 0 0 0 # F2
0 0 0 0 # S1
0 0 0 0 # S2
#
#     Age selectivity (S) - ** Age-based S is implemented **
20 0 0 0 # F1 (double-normal distribution)
20 0 0 0 # F2 (double-normal distribution)
15 0 0 2 # S1 (mirror F2)
20 0 0 0 # S2 (double-normal distribution)
#
#     S (age) parameters
#     Low High Initial Prior_mean Prior_type SD Phase Env_var Use_dev
      Dev_minyr Dev_maxyr Dev_stddev Block_def Block_type
#     F1 (double-normal)
-20 15 1 0 -1 0 4 0 0 0 0 0 0 0 0 # P_1 (1983-10, peak size)
-20 15 -5 0 -1 0 -4 0 0 0 0 0 0 0 0 # P_2 (1983-10, top logistic)
-20 15 4 0 -1 0 4 0 0 0 0 0 0 0 0 # P_3 (1983-10, ascending limb width - exp)
-20 15 1.5 0 -1 0 -4 0 0 0 0 0 0 0 0 # P_4 (1983-10, descending limb width -
     exp)
-20 20 -1 0 -1 0 4 0 0 0 0 0 0 0 0 # P_5 (1983-10, initial S - at first age
     bin)
-20 20 15 0 -1 0 -4 0 0 0 0 0 0 0 0 # P_6 (1983-10, final S - at last age bin)
#
#     F2 (double-normal)
-10 15 2 0 -1 0 4 0 0 0 0 0 0 0 0 # P_1 (1983-10, peak size)
-10 15 -4 0 -1 0 4 0 0 0 0 0 0 0 0 # P_2 (1983-10, top logistic)
-15 15 -1 0 -1 0 4 0 0 0 0 0 0 0 0 # P_3 (1983-10, ascending limb width - exp)
-20 15 -4 0 -1 0 4 0 0 0 0 0 0 0 0 # P_4 (1983-10, descending limb width - exp)
-25 15 -5 0 -1 0 4 0 0 0 0 0 0 0 0 # P_5 (1983-10, initial S - at first age
    bin)
-20 15 -2 0 -1 0 4 0 0 0 0 0 0 0 0 # P_6 (1983-10, final S - at last age bin)
#
#     S1 (mirror F2) ** no additional parameter lines needed **
#
#     S2 (double-normal)
-10 15 2 0 -1 0 4 0 0 0 0 0 0 0 0 # P_1 (1983-10, peak size)
-10 15 -4 0 -1 0 4 0 0 0 0 0 0 0 0 # P_2 (1983-10, top logistic)
-15 15 -1 0 -1 0 4 0 0 0 0 0 0 0 0 # P_3 (1983-10, ascending limb width - exp)
-20 15 -4 0 -1 0 4 0 0 0 0 0 0 0 0 # P_4 (1983-10, descending limb width - exp)
-25 15 -5 0 -1 0 4 0 0 0 0 0 0 0 0 # P_5 (1983-10, initial S - at first age
      bin)
-20 15 -2 0 -1 0 4 0 0 0 0 0 0 0 0 # P_6 (1983-10, final S - at last age bin)
```

```
#
# 1 # Conditional: custom Sel_env parameterization ** No time block for
      selectivity parameterization **
#     Low High Initial Prior_mean Prior_type SD Phase
# -2 2 0 0 -1 99 -2
#
# 1 # Conditional: custom Sel-block parameterization
#     F1 S time blocks (block design 1) ** For age-based S **
#     Low High Initial Prior_mean Prior_type SD Phase
#
# 1 # Conditional: selparm trends
# 1 # Conditional: for selparm_dev_Phase
# 1 # Conditional: env/block/dev adjust method (1 = standard, 2 = logistic
      transition to keep in base parm bounds, 3 = standard with no bound
      check)
#
#     Tag loss and reporting parameterization
0 #   TG_custom: 0 = no read, 1 = read if tags exist
#     Conditional if no tag parameters
#     Low High Initial Prior_mean Prior_type SD Phase Env_var Use_dev
      Dev_minyr Dev_maxyr Dev_stddev Block_def Block_type
# -6 6 1 1 2 0.01 -4 0 0 0 0 0 0 0
#
# LIKELIHOOD COMPONENT PARAMETERS
=============================================================================
#
1 #   Variance and sample size/effective sample size adjustments (by
      fleet/survey): (0/1)
#     F1 F2 S1 S2
0 0 0 0 # constant (added) to survey CV
0 0 0 0 # constant (added) to discard CV
0 0 0 0 # constant (added) to body weight CV
1 1 1 1 # scalar (multiplied) to length distribution sample size (effective
     ss)
1 1 1 1 # scalar (multipled) to age distribution sample size (effective ss)
1 1 1 1 # scalar (multiplied) to size-at-age distribution sample size
     (effective ss)
#
1 #   Maximum lambda phase: 1 = none
1 #   SD offset: 1 = include
#
#     Likelihood component (lambda) parameterization
#     Likelihood component codes:
# 1 = survey, 2 = discard, 3 = mean body weight, 4 = length distribution, 5 =
      age distribution, 6 = weight distribution, 7 = size-at-age
      distribution,
# 8 = catch, 9 = initial equilibrium catch, 10 = recruitment devs, 11 =
      parameter priors, 12 = parameter devs, 13 = crash penalty, 14 = morph
      composition
# 15 = tag composition, 16 = tag neg_bin
#
4 #   Number of changes to likelihood components
#     Columns: Likelihood_comp Fishery/Survey Phase Lambda_value
      Size_distribtuion_method
#
#     Surveys
# 1 3 1 0 1 # Survey off = S1
```

```
# 1 4 1 0 1 # Survey off = S2
#
#     Length distributions
4 1 1 0 1 # Length distribution off = F1
#
#     Age distributions
# 5 1 1 0 1 # Length distribution off = F1
#
#     Mean size-at-age distributions
# 7 1 1 0 1 # Size-at-age distribution off = F1
#
#     Equilibrium catch
9 1 1 0 1 # Equilibrium catch off = F1
9 2 1 0 1 # Equilibrium catch off = F2
#
#     Priors
11 1 1 0 1 # Priors = off
#
0 #   SD reporting option: (0/1)
999 # End of file
```

```
################################################################################
# Pacific mackerel stock assessment (1983-10)
# P. R. Crone (June 2011)
# Stock Synthesis 3 (v. 3.20b) - R. Methot
# Model XA: number of fisheries = 2 / surveys = 2 / time-step = annual /
  biological distributions = age, length, and mean length-at-age /
  selectivity = age-based
#
```

 # INPUT DATA FILE

```
#
1983 # Start year
2010 # End year
1 #   Number of 'seasons' (quarters)
12 #  Number of months per season
1 #   Spawning season
2 #   Number of fishing 'fleets' (fisheries)
#     F1 = COM (USA commercial and Mexico commercial)
#     F2 = REC (USA recreational)
2 #   Number of 'surveys' (CPUE Indices: annual-based)
#     S1 = CPFV
#     S2 = CRFS
#
1 #   Number of areas (populations)
      COM%REC%CPFV%CRFS
0.5 0.5 0.5 0.5 # Fishery/survey timing within time block
1 1 1 1 # Area assignment for each fishery/survey
#
1 1 #       Catch units: 1=biomass, 2=numbers
0.01 0.01 # SE of ln(catch), i.e., equals CV in ln space
#
1 #   Number of genders
12 #  Number of ages (accumulator age)
#     Catch: initial (annual) 'equilibrium' catch (mt)
100 100
#     Number of catch records (lines)
28
#     Catch time series (biomass in mt): Columns=fisheries, year, season
40573.39    1544.12     1983  1
45001.01    1467.32     1984  1
45811.90    1015.90     1985  1
53263.39    859.20      1986  1
46958.31    1264.46     1987  1
48576.06    688.56      1988  1
48787.53    618.27      1989  1
70934.59    616.06      1990  1
64824.75    680.14      1991  1
31753.59    463.87      1992  1
20311.09    608.80      1993  1
22674.40    1062.65     1994  1
10982.43    1013.40     1995  1
23877.14    685.54      1996  1
50272.33    803.99      1997  1
62393.05    429.61      1998  1
15757.21    152.65      1999  1
27466.58    325.32      2000  1
12439.36    571.05      2001  1
```

```
13868.67    254.10      2002  1
8589.59     323.26      2003  1
7028.76     533.46      2004  1
7079.24     395.84      2005  1
9856.14     372.11      2006  1
8426.80     310.00      2007  1
5084.47     280.00      2008  1
3182.60     267.00      2009  1
2256.99     100.00      2010  1
#
#     Number of observations (lines) for all surveys (indices)
35
#     Columns: Fishery/Survey, Units (0=numbers, 1=biomass, 2=F), Error type
      (-1=normal, 0=lognormal), >0=t-dist. (df = input value)
1 1 0 # F1 = COM (USA commercial and Mexico commercial)
2 1 0 # F2 = REC (USA recreational)
3 0 0 # S1 = CPFV
4 0 0 # S2 = CRFS
#
#     Columns: Year, Season, Survey, Observation, Error
1983  1     3     91.82 0.30
1984  1     3     101.23      0.30
1985  1     3     77.63 0.30
1986  1     3     60.91 0.30
1987  1     3     41.32 0.00
1988  1     3     29.28 0.30
1989  1     3     40.64 0.30
1990  1     3     45.04 0.30
1991  1     3     49.95 0.30
1992  1     3     37.06 0.30
1993  1     3     44.49 0.30
1994  1     3     42.05 0.30
1995  1     3     37.36 0.30
1996  1     3     40.95 0.30
1997  1     3     24.98 0.30
1998  1     3     12.89 0.30
1999  1     3     7.34  0.30
2000  1     3     14.03 0.30
2001  1     3     11.19 0.30
2002  1     3     8.88  0.30
2003  1     3     5.56  0.30
2004  1     3     9.75  0.30
2005  1     3     16.70 0.30
2006  1     3     15.95 0.30
2007  1     3     22.64 0.30
2008  1     3     31.73 0.30
2009  1     3     24.45 0.30
2010  1     3     12.00 0.30
2004  1     4     0.0419      0.30
2005  1     4     0.0576      0.30
2006  1     4     0.0551      0.30
2007  1     4     0.0640      0.30
2008  1     4     0.0567      0.30
2009  1     4     0.0532      0.30
2010  1     4     0.0324      0.30
#
#     Discard parameterization
```

```
0 #   Number of Fisheries with discard
#     Placeholder for discard units (1 = same as catch units, 2 = fraction, 3
      = number)
#     Placeholder for Fishery discard error type (>0 = df of t-dist - read CV
      below, 0 = normal with CV, -1 = normal with se, -2 = lognormal)
#     Columns: Fishery, Units, Error type
0 #   Number of discard observations (lines)
#     Placeholder for discard lines
#     Columns: Year, Season, Fishery, Observation, Error
#
#     Mean body weight parameterization
0 #   Number of mean body weight observations (lines)
100 # df for t-dist - not conditional, i.e., needs number even if no mean
      body weight observations
#
#     Population size distributions
1 #   Length bin method: 1 = use fishery length bins below, 2 = generate from
      min/max/width below, 3 = read count and vector below
#     Placeholder for number of population length bins
#     Placeholder for vector of population length bins
#
0 #   Compression of length/age distribution 'tails'
0.0001 # Constant added to length/age data (constant added to expected
      frequencies)
#
0 #   Combine males and females at or below this bin number
#
#     Fishery/Survey size distributions
60 #  Number of length bins
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55
56 57 58 59 60
#
59 #  Number of fishery length distribution observations (lines) ** Length
      distributions for Fishery 1 are not used (included for
      provisional/comparative purposes only **
#     Length distributions (1983-10) - annual (percent)

#     Length distributions: Columns=year, season, fishery/survey, gender,
      partition, sample size, length bin observations (in numbers)
1983  1     1     0     0     106.7 0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00037     0.00225     0.00075     0.00300     0.00300
      0.00150     0.00450     0.00300     0.00150     0.00262     0.00300
      0.00000     0.00112     0.00525     0.00937     0.02211     0.03636
      0.06297     0.09370     0.12969     0.14355     0.14318     0.13718
      0.08883     0.05022     0.02849     0.01237     0.00600     0.00187
      0.00187     0.00037     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
1984  1     1     0     0     91.6  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00044     0.00306     0.00480
      0.01135     0.00436     0.00567     0.00262     0.00262     0.00000
      0.01528     0.04845     0.10170     0.16194     0.16019     0.12353
```

```
     0.10214     0.08904     0.07071     0.04801     0.02750     0.01091
     0.00393     0.00175     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1985 1     1     0     0     104.2 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00038     0.00230
     0.00652     0.01266     0.00959     0.00767     0.01880     0.02916
     0.02533     0.04490     0.04029     0.07252     0.13315     0.17920
     0.16500     0.10860     0.07905     0.04068     0.01765     0.00422
     0.00153     0.00077     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1986 1     1     0     0     120.0 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00100     0.00967     0.01633     0.00400     0.00933
     0.00800     0.01133     0.01767     0.04000     0.06067     0.07867
     0.09633     0.09800     0.06600     0.05633     0.05700     0.06567
     0.09267     0.07833     0.06000     0.03867     0.01767     0.01000
     0.00433     0.00133     0.00067     0.00033     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1987 1     1     0     0     165.2 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00194     0.00509     0.01332     0.01502
     0.02349     0.03391     0.04384     0.06491     0.08695     0.08937
     0.07798     0.07145     0.09106     0.11940     0.08646     0.04626
     0.03197     0.02228     0.02180     0.02083     0.01502     0.01380
     0.00315     0.00048     0.00024     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1988 1     1     0     0     179.1 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00022     0.00156     0.01474     0.11660     0.20415
     0.16038     0.08979     0.02859     0.00960     0.00692     0.00893
     0.01631     0.02993     0.04333     0.04981     0.04646     0.03931
     0.03239     0.02792     0.01720     0.01273     0.01631     0.01407
     0.00871     0.00290     0.00089     0.00022     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1989 1     1     0     0     143.3 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00056     0.00112     0.02428     0.05833
     0.04996     0.09433     0.21100     0.19620     0.13536     0.07089
     0.03684     0.02623     0.01423     0.01144     0.00726     0.00977
     0.00893     0.00893     0.01144     0.00921     0.00670     0.00558
     0.00084     0.00056     0.00000     0.00000     0.00000     0.00000
```

```
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1990 1     1     0     0     84.6  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00095     0.01183     0.02933     0.03926     0.04494
     0.05771     0.02365     0.00473     0.00757     0.01892     0.02838
     0.04588     0.04730     0.07569     0.06575     0.04730     0.03453
     0.03974     0.06433     0.09413     0.10218     0.06575     0.02980
     0.01372     0.00520     0.00142     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1991 1     1     0     0     66.2  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00121     0.02236     0.05619     0.04592     0.02961     0.02840
     0.01873     0.01390     0.01873     0.04773     0.08520     0.09184
     0.08761     0.06767     0.03625     0.01269     0.02477     0.04230
     0.05438     0.04955     0.05015     0.04773     0.03565     0.01873
     0.00846     0.00363     0.00060     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1992 1     1     0     0     79.8  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00100     0.00150     0.01153     0.02758     0.05065     0.03862
     0.02909     0.06620     0.09478     0.10782     0.08024     0.04965
     0.03009     0.02407     0.03410     0.03059     0.03661     0.03410
     0.05817     0.05918     0.05316     0.03912     0.02758     0.00903
     0.00401     0.00150     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1993 1     1     0     0     107.5 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00446     0.04576     0.11942     0.12649     0.09710     0.08966
     0.04018     0.02493     0.01414     0.03460     0.03832     0.04167
     0.04799     0.05952     0.03720     0.02344     0.01079     0.00632
     0.00967     0.02121     0.02269     0.02902     0.02641     0.01860
     0.00670     0.00335     0.00000     0.00037     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1994 1     1     0     0     124.6 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00032     0.00000     0.00417     0.01638     0.05845     0.12139
     0.13712     0.15125     0.16506     0.11689     0.05652     0.03565
     0.02408     0.01574     0.01991     0.01413     0.01060     0.00578
     0.00385     0.00417     0.00803     0.01509     0.00867     0.00450
     0.00161     0.00064     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
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     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1995 1    1     0    0     108.2 0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00333    0.04361    0.14412    0.19586    0.13673
     0.09054    0.04435    0.05839    0.07095    0.06689    0.04028
     0.02772    0.00776    0.00665    0.00517    0.00665    0.00333
     0.00333    0.00296    0.00407    0.01109    0.01220    0.00739
     0.00333    0.00296    0.00037    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1996 1    1     0    0     87.6  0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00091    0.00183    0.00594    0.04523    0.09228
     0.10233    0.09274    0.09045    0.07766    0.06578    0.04888
     0.04797    0.03609    0.03518    0.02421    0.02101    0.02878
     0.02787    0.02969    0.02330    0.03563    0.02787    0.02604
     0.01005    0.00137    0.00046    0.00000    0.00046    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1997 1    1     0    0     108.6 0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00074    0.00074    0.00221    0.00626    0.00774
     0.00516    0.01363    0.02174    0.05232    0.06890    0.08364
     0.07148    0.06043    0.05453    0.05269    0.05748    0.03758
     0.04422    0.04937    0.05453    0.07443    0.08438    0.06190
     0.02763    0.00590    0.00037    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1998 1    1     0    0     90.2  0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00044    0.00089    0.00576    0.00710    0.01330
     0.02217    0.02483    0.01729    0.01729    0.02483    0.03991
     0.07894    0.12772    0.11264    0.09534    0.06962    0.05366
     0.03503    0.05144    0.07317    0.06208    0.03503    0.01951
     0.01020    0.00177    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1999 1    1     0    0     66.6  0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00060    0.00900    0.02821
     0.09364    0.09844    0.08884    0.06002    0.03241    0.02281
     0.01681    0.01801    0.02161    0.02641    0.03541    0.06002
     0.08643    0.08944    0.07263    0.06843    0.03902    0.01981
     0.00780    0.00180    0.00180    0.00060    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
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2000  1     1     0     0     76.4  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00209     0.00524     0.00681     0.01728     0.05079     0.10419
      0.12094     0.09110     0.04764     0.02513     0.01675     0.01623
      0.03874     0.04607     0.03665     0.02094     0.01047     0.01990
      0.05445     0.09319     0.06702     0.05288     0.03665     0.00995
      0.00471     0.00366     0.00052     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
2001  1     1     0     0     84.4  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00284     0.01137     0.04121     0.06821     0.05590
      0.03932     0.03648     0.04074     0.05921     0.08764     0.09664
      0.10137     0.06490     0.03932     0.02795     0.02226     0.01611
      0.03316     0.04074     0.04500     0.03221     0.02416     0.00758
      0.00521     0.00047     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
2002  1     1     0     0     85.8  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00140     0.01119     0.02797     0.05035
      0.05221     0.06900     0.08159     0.11608     0.14592     0.15758
      0.14079     0.06247     0.03683     0.01772     0.00839     0.00420
      0.00373     0.00373     0.00186     0.00326     0.00233     0.00140
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
2003  1     1     0     0     62.8  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00255     0.01338     0.04777     0.11911
      0.13567     0.13376     0.04841     0.03822     0.05796     0.06943
      0.08025     0.06369     0.04013     0.02229     0.02102     0.01656
      0.01911     0.01529     0.01847     0.01656     0.01083     0.00573
      0.00191     0.00127     0.00064     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
2004  1     1     0     0     101.2 0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00119     0.00356     0.00514     0.01463     0.02847     0.05299
      0.11111     0.13642     0.14591     0.14037     0.11190     0.07078
      0.07038     0.03361     0.01423     0.01305     0.00989     0.00830
      0.00395     0.00751     0.00633     0.00237     0.00435     0.00237
      0.00079     0.00040     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
2005  1     1     0     0     92.0  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
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     0.00000     0.00000     0.00000     0.00000     0.00000     0.00043
     0.00304     0.01914     0.02305     0.06916     0.15485     0.17529
     0.13658     0.08830     0.04959     0.04045     0.04393     0.03045
     0.03871     0.03958     0.04002     0.02044     0.01305     0.00783
     0.00261     0.00000     0.00043     0.00130     0.00087     0.00087
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
2006 1     1     0     0     95.7  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00084     0.00084     0.00919     0.01713     0.03886     0.09193
     0.13623     0.12996     0.11032     0.10155     0.06979     0.06728
     0.04931     0.03636     0.02591     0.01546     0.01379     0.01212
     0.01588     0.00501     0.00125     0.00669     0.01087     0.01421
     0.01045     0.00627     0.00125     0.00042     0.00042     0.00042
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
2007 1     1     0     0     64.4  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00062
     0.00808     0.03791     0.01740     0.02051     0.06464     0.13735
     0.11933     0.09136     0.07769     0.06588     0.05221     0.03294
     0.02548     0.03543     0.02735     0.02921     0.01927     0.02113
     0.01989     0.02610     0.02300     0.01429     0.01305     0.00622
     0.00808     0.00373     0.00186     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
2008 1     1     0     0     28.9  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00138     0.00000     0.01107     0.04841     0.09544     0.09820
     0.05394     0.04149     0.03873     0.04149     0.07746     0.07884
     0.08990     0.03320     0.00830     0.00968     0.00968     0.03596
     0.04149     0.05256     0.04426     0.03596     0.02213     0.01660
     0.00553     0.00553     0.00138     0.00138     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
2009 1     1     0     0     16.9  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00474     0.05924     0.12085     0.06872
     0.02370     0.01422     0.03318     0.07583     0.10664     0.11137
     0.10664     0.06635     0.01896     0.00237     0.02133     0.01185
     0.02133     0.01422     0.01659     0.04739     0.01185     0.01659
     0.00948     0.01185     0.00474     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
2010 1     1     0     0     11.9  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.01342     0.08725     0.14094
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     0.10738     0.06040     0.05369     0.08389     0.06376     0.04698
     0.05034     0.03356     0.06711     0.02685     0.02013     0.03691
     0.03356     0.00671     0.01678     0.01342     0.02349     0.00671
     0.00671     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1985 1     2     0     0     81.5  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00049     0.00000     0.00098
     0.00196     0.00294     0.00491     0.00442     0.00736     0.01374
     0.02355     0.04563     0.04514     0.06035     0.08881     0.10893
     0.13935     0.11237     0.10059     0.07704     0.06035     0.03778
     0.03189     0.01079     0.00883     0.00491     0.00294     0.00098
     0.00049     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00049     0.00000     0.00000     0.00049
     0.00000     0.00000     0.00147
1986 1     2     0     0     238.1 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00034     0.00118     0.00101
     0.00084     0.00252     0.00403     0.01209     0.03292     0.05107
     0.06971     0.07845     0.06971     0.07324     0.07979     0.09306
     0.10297     0.09525     0.07593     0.06165     0.04569     0.02217
     0.01361     0.00521     0.00353     0.00286     0.00084     0.00017
     0.00000     0.00017     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1987 1     2     0     0     174.2 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00046     0.00023
     0.00436     0.01263     0.02067     0.02067     0.01883     0.02825
     0.04892     0.08222     0.11346     0.11805     0.09348     0.08199
     0.06270     0.05926     0.05489     0.04984     0.05397     0.04318
     0.01929     0.00666     0.00299     0.00138     0.00092     0.00023
     0.00000     0.00023     0.00000     0.00000     0.00000     0.00000
     0.00023     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1988 1     2     0     0     156.2 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00026
     0.00051     0.00000     0.00154     0.00179     0.00307     0.00435
     0.00512     0.00564     0.00948     0.01101     0.01998     0.01895
     0.03817     0.06199     0.09606     0.11885     0.11194     0.09887
     0.08171     0.05815     0.04406     0.04073     0.05507     0.05072
     0.03765     0.01230     0.00538     0.00205     0.00282     0.00154
     0.00026     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1989 1     2     0     0     147.1 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00190     0.00027     0.00299
     0.00653     0.00299     0.00625     0.00381     0.00489     0.00299
     0.00218     0.01876     0.03915     0.05791     0.06770     0.03752
     0.04160     0.04568     0.05492     0.07667     0.08510     0.06090
```

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        0.04160     0.04133     0.05546     0.05356     0.06362     0.05057
        0.03834     0.01767     0.00625     0.00598     0.00245     0.00054
        0.00027     0.00054     0.00027     0.00000     0.00082     0.00000
        0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
        0.00000     0.00000     0.00000
1992    1     2     0     0     6.4   0     0     0     0     0     0     0
        0     0     0     0     0     0     0     0     0     0     0     0
        0     0     0.01875     0.01875     0.04375     0.0625      0.1   0.075
        0.075 0.03125     0.04375     0.01875     0.05  0.05625     0.0625
        0.0875      0.05625     0.0875      0.05  0.0125      0.025 0.0125
        0     0.00625     0     0     0     0     0     0     0     0     0
        0     0.00625     0     0     0     0     0     0
1993    1     2     0     0     31.44 0     0     0     0     0     0     0
        0     0     0     0     0     0     0     0     0     0     0     0
        0     0     0.00636     0.00636     0.00891     0.03053     0.03308
        0.04453     0.06997     0.06234     0.06489     0.04453     0.04198
        0.05344     0.0458      0.0458      0.08906     0.1056      0.09924
        0.08015     0.03944     0.01018     0.00382     0.00254     0
        0.00127     0     0     0     0     0.00127     0     0.00254     0
        0.00127     0     0     0     0     0     0.00509
1994    1     2     0     0     11.56 0     0     0     0     0     0     0
        0     0     0     0     0     0     0     0     0     0     0.00346
        0     0.00692     0     0     0.00692     0.00346     0.00692
        0.00692     0.00692     0.02768     0.0173      0.02422     0.06574
        0.08304     0.0346      0.02768     0.0519      0.10727     0.13149
        0.19723     0.05536     0.08997     0.03806     0     0     0     0
        0     0     0     0.00346     0.00346     0     0     0     0     0
        0     0     0     0     0
1995    1     2     0     0     12.72 0     0     0     0     0     0     0
        0     0     0     0     0     0     0     0     0     0     0     0
        0     0     0.00314     0.00629     0.01887     0.02201     0.01258
        0.03459     0.03459     0.03774     0.06918     0.05975     0.04717
        0.0566      0.06289     0.05031     0.09434     0.08491     0.10692
        0.11006     0.0566      0.02201     0.00629     0     0     0     0
        0     0     0.00314     0     0     0     0     0     0     0     0
        0     0     0
1996    1     2     0     0     33.48 0     0     0     0     0     0     0
        0     0     0     0     0     0     0     0.00119     0     0     0
        0     0     0.00597     0.00597     0.00717     0.0227      0.02031
        0.0227      0.03465     0.02389     0.02867     0.04659     0.02987
        0.0454      0.03106     0.03345     0.04062     0.05257     0.09916
        0.14815     0.14815     0.08244     0.04898     0.01314     0.00119
        0.00239     0     0     0     0     0     0     0     0     0     0
        0     0     0     0     0     0.00358
1997    1     2     0     0     47.24 0     0     0     0     0     0     0
        0     0     0     0     0     0     0     0     0     0     0     0
        0.00254     0.00085     0.00254     0.00593     0.01439     0.02794
        0.0398      0.02371     0.0398      0.04911     0.06181     0.07282
        0.07621     0.06097     0.04742     0.0525      0.06097     0.05673
        0.07959     0.08129     0.07028     0.03133     0.01524     0.00847
        0.0127      0.00339     0     0     0     0     0     0.00085     0
        0     0     0     0     0     0     0.00085     0
1998    1     2     0     0     24.44 0     0     0     0     0     0     0
        0     0     0     0     0     0     0     0     0     0     0.00164
        0     0     0     0.00327     0.00491     0.00327     0.00818
        0.00491     0.03928     0.04746     0.05237     0.05728     0.05237
        0.03764     0.02782     0.05074     0.0671      0.09984     0.13421
```

```
	0.10802	0.10802	0.05892	0.02128	0.00655	0
	0.00164	0	0.00164	0	0	0	0	0	0	0
	0	0	0	0	0	0	0.00164
1999	1	2	0	0	24.68	0	0	0	0	0	0	0
	0	0	0	0.00162	0	0	0.00162	0	0	0
	0	0	0.00162	0	0.00324	0	0.0081	0.01621
	0.01783	0.02269	0.01945	0.02755	0.02917	0.03404
	0.05673	0.05348	0.11669	0.14263	0.14425	0.10049
	0.07293	0.05835	0.047	0.01621	0.00648	0	0	0
	0	0.00162	0	0	0	0	0	0	0	0	0
	0	0	0	0
2000	1	2	0	0	15.6	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0.00256	0.00513	0.00256	0.01026	0.01538	0.02564
	0.03077	0.03333	0.02308	0.03846	0.0641	0.08718
	0.02821	0.02564	0.04359	0.08205	0.12821	0.11282
	0.07949	0.06154	0.0641	0.02308	0.01026	0.00256
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0
2001	1	2	0	0	16.52	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0.00242	0.00484	0.00484	0.00726	0.00969	0.01937
	0.01695	0.02179	0.04358	0.07022	0.05811	0.08959
	0.05569	0.05085	0.04358	0.10412	0.1138	0.10654
	0.07022	0.07264	0.01695	0.01211	0.00242	0.00242
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0
2002	1	2	0	0	20.88	0	0	0	0	0	0	0
	0	0	0	0.00192	0	0	0	0	0	0	0
	0.00192	0.00192	0.00575	0.00383	0.03257	0.02299
	0.0364	0.04981	0.08621	0.0977	0.07854	0.06897
	0.05939	0.05939	0.04789	0.06322	0.04789	0.0613
	0.05364	0.04215	0.03831	0.02682	0.00575	0.00383
	0	0	0	0	0.00192	0	0	0	0	0	0
	0	0	0	0	0	0	0
2003	1	2	0	0	21.12	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0.00379	0.00379	0.00568	0.01894	0.04545	0.0322
	0.04545	0.06439	0.05682	0.09091	0.05682	0.05303
	0.04735	0.0303	0.02273	0.02841	0.03598	0.04735
	0.09659	0.08712	0.07008	0.02841	0.01515	0.00189
	0.00379	0	0	0	0.00189	0	0	0	0	0
	0	0	0	0	0	0	0.00189	0.00379
2004	1	2	0	0	20.68	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	0.00774	0.0058	0.02901	0.02515	0.05029	0.09284
	0.0619	0.03868	0.06383	0.05029	0.07737	0.0677
	0.03482	0.03288	0.03675	0.02708	0.05222	0.04642
	0.05996	0.08124	0.03288	0.01934	0	0.00193
	0.00193	0.00193	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0
2005	1	2	0	0	21.88	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0.00366	0.02742	0.06033	0.08044	0.08044	0.08044
	0.06033	0.0585	0.0841	0.08775	0.06033	0.10055
	0.06399	0.04936	0.02742	0.02194	0.00914	0.00366
	0.00548	0.00731	0.00731	0.00731	0.00548	0.00183
```

```
     0     0     0     0     0     0     0     0     0     0     0     0
     0.00183     0     0.00183     0.00183     0     0
2006 1     2     0     0     23.76 0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0.00168     0.00168     0
     0.00168     0     0.00337     0.01852     0.05387     0.08754
     0.09091     0.08754     0.08923     0.09596     0.08754     0.07912
     0.08249     0.05219     0.03872     0.02862     0.01684     0.00842
     0.0202      0.0101      0.00505     0.01178     0.01178     0.00842
     0.00505     0.00168     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0
2007 1     2     0     0     44.28 0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0.0009
     0.0009      0.00813     0.02529     0.03071     0.04426     0.07317
     0.07588     0.1084      0.11292     0.11382     0.08401     0.07859
     0.04246     0.04246     0.03342     0.028 0.01897     0.01265
     0.00994     0.01536     0.01265     0.00903     0.00994     0.00452
     0.0009      0.0009      0     0.0009      0     0     0.0009      0
     0     0     0     0     0     0     0     0     0     0
2008 1     2     0     0     43.32 0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0.00185
     0.00646     0.01939     0.02308     0.01939     0.01385     0.02124
     0.02862     0.05171     0.05448     0.0988      0.13019     0.12742
     0.06925     0.06464     0.04894     0.03047     0.03509     0.02216
     0.03601     0.02124     0.01847     0.02862     0.01754     0.00369
     0.00369     0     0.00277     0     0.00092     0     0     0     0
     0     0     0     0     0     0     0     0     0
2009 1     2     0     0     37.08 0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0.00108
     0.00647     0.0205      0.01942     0.01618     0.01834     0.03883
     0.06257     0.10572     0.12729     0.11758     0.0863      0.07875
     0.03668     0.03776     0.0302      0.02805     0.03344     0.04207
     0.03452     0.0205      0.01402     0.00863     0.00755     0.00216
     0.00216     0.00108     0     0.00108     0     0     0     0.00108
     0     0     0     0     0     0     0     0     0     0
2010 1     2     0     0     10.96 0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0.00365     0.01095
     0.01095     0.00365     0.0073      0.00365     0.0219      0.0438
     0.08759     0.09489     0.16788     0.09854     0.08759     0.07664
     0.05474     0.0365      0.03285     0.0146      0.0146      0.03285
     0.0365      0.01095     0.01095     0.0146      0.01095     0.01095
     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
2004 1     4     0     0     47.0  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00170     0.00765     0.01020
     0.00425     0.01190     0.03571     0.03741     0.04592     0.06293
     0.05952     0.06633     0.07738     0.07823     0.06207     0.06548
     0.05867     0.05187     0.03316     0.02551     0.01871     0.01531
     0.01531     0.01531     0.01190     0.01446     0.02976     0.03997
     0.02381     0.01020     0.00595     0.00085     0.00085     0.00000
     0.00000     0.00000     0.00000     0.00085     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00085     0.00000
     0.00000     0.00000     0.00000
2005 1     4     0     0     62.4  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00064     0.00128     0.00064     0.00064     0.00256     0.00577
     0.00384     0.00512     0.01217     0.02691     0.07047     0.10570
```

```
     0.12748    0.10955    0.11211    0.10506    0.08520    0.06470
     0.04741    0.04100    0.03139    0.01217    0.00897    0.00320
     0.00384    0.00192    0.00256    0.00128    0.00064    0.00128
     0.00128    0.00064    0.00128    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00128
2006 1    4     0    0     70.8  0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00057    0.00170    0.00170    0.00339
     0.00565    0.00735    0.00904    0.02374    0.04240    0.07801
     0.11702    0.14302    0.14245    0.10797    0.08423    0.05596
     0.03392    0.03561    0.02148    0.01357    0.00791    0.01018
     0.00848    0.00565    0.00396    0.00283    0.00565    0.00339
     0.00848    0.00791    0.00452    0.00226    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
2007 1    4     0    0     53.2  0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00150    0.00000    0.00150
     0.00301    0.00451    0.00376    0.02404    0.03681    0.03456
     0.06612    0.06536    0.06912    0.12923    0.13223    0.10518
     0.08790    0.05334    0.04808    0.02930    0.02029    0.01803
     0.00902    0.00977    0.00751    0.00601    0.01052    0.00601
     0.00601    0.00526    0.00376    0.00075    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00150
2008 1    4     0    0     36.6  0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00109    0.00000
     0.00000    0.01530    0.04809    0.05355    0.08087    0.06448
     0.06995    0.06011    0.06011    0.07213    0.07760    0.06230
     0.07541    0.06885    0.04044    0.02951    0.01749    0.01421
     0.01421    0.01202    0.01421    0.01311    0.00765    0.00656
     0.00765    0.00656    0.00437    0.00109    0.00000    0.00000
     0.00000    0.00109    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
2009 1    4     0    0     34.2  0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00117    0.00000    0.00000    0.00000    0.00467    0.00117
     0.00234    0.00467    0.01636    0.05257    0.06308    0.05841
     0.07009    0.10280    0.11682    0.10047    0.07126    0.08995
     0.08061    0.05023    0.03388    0.01986    0.00467    0.00234
     0.00584    0.01285    0.00935    0.01051    0.00467    0.00117
     0.00350    0.00117    0.00234    0.00000    0.00117    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
2010 1    4     0    0     3.0   0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.01316
     0.00000    0.00000    0.01316    0.01316    0.01316    0.03947
     0.06579    0.01316    0.14474    0.13158    0.17105    0.06579
     0.06579    0.03947    0.01316    0.03947    0.01316    0.03947
```

```
      0.03947     0.01316     0.01316     0.01316     0.01316     0.01316
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
#
#     Fishery age distributions
9 #   Number of age_bins
0 1 2 3 4 5 6 7 8
#
1 #   Number of ageing error matrices ('Accumulator age' (12) + 1 vectors)
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 # Age bin mid-points
      0.406 0.642 0.712 0.784 0.992 1.304 1.345 1.5 1.637 1.809 1.964 2.119
      2.273 # Age bin SD
#
28 #  Number of age distributions observations (lines)
2 #   Length bin method for Lbin_lo and Lbin_hi: 1 = use population length
      bin index, 2 = use length data bin index, 3 = actual lengths (must use
      population length index option)
-1 #  Combine males and females at or below this bin number
#
#     Fishery age distributions (1983-10) - annual (percent)

#     Age distributions: Columns=year, season, fishery/survey, gender,
      partition, ageing error (age bin SD), Lbin_lo, Lbin_hi, sample size,
      age bin observations (in percent)
1983  1     1     0     0     1     -1    -1    106.72      0.03  0.03  0.39
      0.35  0.05  0.15  0.00  0.00  0.00
1984  1     1     0     0     1     -1    -1    91.64 0.03  0.01  0.10  0.49
      0.23  0.06  0.08  0.00  0.00
1985  1     1     0     0     1     -1    -1    104.24      0.04  0.15  0.05
      0.15  0.47  0.11  0.01  0.01  0.00
1986  1     1     0     0     1     -1    -1    120         0.17  0.33  0.15
      0.04  0.06  0.17  0.05  0.01  0.01
1987  1     1     0     0     1     -1    -1    165.16      0.15  0.50  0.22
      0.04  0.02  0.02  0.03  0.01  0.01
1988  1     1     0     0     1     -1    -1    179.08      0.63  0.07  0.16
      0.06  0.02  0.01  0.01  0.02  0.02
1989  1     1     0     0     1     -1    -1    143.32      0.14  0.77  0.03
      0.02  0.01  0.01  0.01  0.00  0.01
1990  1     1     0     0     1     -1    -1    84.56 0.22  0.12  0.24  0.07
      0.11  0.12  0.04  0.04  0.04
1991  1     1     0     0     1     -1    -1    66.2  0.20  0.42  0.07  0.10
      0.06  0.06  0.04  0.02  0.02
1992  1     1     0     0     1     -1    -1    79.76 0.16  0.38  0.15  0.10
      0.08  0.06  0.04  0.02  0.01
1993  1     1     0     0     1     -1    -1    107.52      0.56  0.14  0.14
      0.03  0.04  0.04  0.02  0.02  0.01
1994  1     1     0     0     1     -1    -1    124.56      0.45  0.39  0.08
      0.03  0.02  0.01  0.01  0.00  0.00
1995  1     1     0     0     1     -1    -1    108.24      0.62  0.26  0.06
      0.01  0.01  0.02  0.01  0.01  0.00
1996  1     1     0     0     1     -1    -1    87.56 0.32  0.33  0.14  0.08
      0.05  0.04  0.02  0.02  0.01
1997  1     1     0     0     1     -1    -1    108.56      0.07  0.26  0.22
      0.11  0.08  0.08  0.06  0.05  0.08
```

```
1998  1     1     0     0     1     -1    -1    90.2  0.09  0.16  0.32  0.16
      0.08  0.06  0.05  0.03  0.04
1999  1     1     0     0     1     -1    -1    66.64 0.37  0.08  0.07  0.14
      0.14  0.10  0.04  0.03  0.02
2000  1     1     0     0     1     -1    -1    76.4  0.44  0.16  0.06  0.10
      0.12  0.08  0.03  0.01  0.01
2001  1     1     0     0     1     -1    -1    84.44 0.28  0.44  0.08  0.05
      0.06  0.05  0.02  0.01  0.00
2002  1     1     0     0     1     -1    -1    85.8  0.24  0.65  0.08  0.02
      0.00  0.01  0.00  0.00  0.00
2003  1     1     0     0     1     -1    -1    62.8  0.52  0.27  0.11  0.05
      0.02  0.02  0.01  0.00  0.00
2004  1     1     0     0     1     -1    -1    101.16      0.83  0.11  0.03
      0.02  0.01  0.00  0.00  0.00  0.00
2005  1     1     0     0     1     -1    -1    91.96 0.75  0.17  0.06  0.01
      0.00  0.00  0.00  0.00  0.00
2006  1     1     0     0     1     -1    -1    95.72 0.58  0.27  0.06  0.04
      0.03  0.01  0.01  0.00  0.00
2007  1     1     0     0     1     -1    -1    64.36 0.51  0.24  0.11  0.08
      0.04  0.02  0.01  0.00  0.00
2008  1     1     0     0     1     -1    -1    28.92 0.27  0.31  0.16  0.18
      0.06  0.02  0.00  0.00  0.00
2009  1     1     0     0     1     -1    -1    16.88 0.31  0.45  0.10  0.09
      0.04  0.01  0.00  0.00  0.00
2010  1     1     0     0     1     -1    -1    11.92 0.07  0.58  0.22  0.08
      0.04  0.01  0.00  0.00  0.00
#
#     Fishery mean length-at-age distributions
28 #  Number of mean length-at-age observations (lines)
#      Mean length-at-age distributions (1983-10) - annual (cm)
#     Mean length-at-age distributions: Columns=year, season, fishery/survey,
      gender, partition, ageing error, sample size (nominal only), mean
      length-at-age observations (in cm), mean length-at-age sample sizes
1983  1     1     0     0     1     1     16.69 26.03 29.62 31.87 33.46 34.46
      37.50 -1.00 -1.00 2.68000     2.68000     41.96000    37.04000
      5.84000     16.28000    0.24000     0.00000     0.00000
1984  1     1     0     0     1     1     22.59 27.14 30.71 31.76 34.03 36.10
      36.64 40.25 -1.00 2.84000     0.56000     9.48000     45.04000
      21.20000    5.32000     7.04000     0.16000     0.00000
1985  1     1     0     0     1     1     23.66 28.55 32.11 33.15 33.61 35.06
      36.34 37.57 -1.00 4.24000     15.76000    5.28000     16.12000
      49.36000    10.96000    1.40000     1.12000     0.00000
1986  1     1     0     0     1     1     23.94 28.44 31.43 33.63 34.66 35.27
      35.76 37.13 38.17 20.96000    39.88000    17.88000    4.56000
      7.68000     20.96000    6.20000     0.96000     0.92000
1987  1     1     0     0     1     1     22.98 28.03 31.41 33.85 35.41 36.77
      37.24 37.92 38.77 25.04000    82.48000    36.76000    6.08000
      3.16000     3.88000     4.76000     2.12000     0.88000
1988  1     1     0     0     1     1     21.51 28.83 31.43 33.94 35.50 36.54
      38.16 38.08 39.10 112.00000   13.20000    28.44000    11.52000
      2.72000     1.84000     2.44000     3.80000     3.12000
1989  1     1     0     0     1     1     21.35 25.20 29.88 33.87 35.53 36.86
      37.50 37.08 38.61 19.36000    111.00000   4.76000     3.00000
      1.72000     1.16000     0.88000     0.52000     0.92000
1990  1     1     0     0     1     1     21.02 27.82 30.80 34.15 36.07 36.62
      37.47 38.08 38.93 18.20000    9.92000     20.48000    6.24000
      9.56000     9.84000     3.64000     3.20000     3.48000
```

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1991  1     1     0     0     1     1     19.30 26.99 31.83 34.03 35.47 36.34
      37.12 37.54 38.61 13.56000    28.00000    4.88000     6.60000
      4.00000     4.00000     2.68000     1.04000     1.44000
1992  1     1     0     0     1     1     20.44 25.01 29.66 32.87 34.36 36.08
      36.49 37.00 38.63 12.80000    30.32000    11.68000    8.20000
      6.76000     4.80000     2.96000     1.60000     0.64000
1993  1     1     0     0     1     1     19.68 27.00 29.05 31.97 36.08 36.48
      38.08 38.24 39.06 60.44000    15.32000    14.84000    3.60000
      4.08000     3.80000     2.04000     2.04000     1.36000
1994  1     1     0     0     1     1     21.76 24.51 27.75 31.04 34.44 36.38
      37.36 38.21 39.00 55.60000    48.60000    10.08000    4.04000
      2.64000     1.36000     1.32000     0.56000     0.36000
1995  1     1     0     0     1     1     20.24 25.00 27.92 31.82 35.45 37.08
      38.32 38.38 40.10 67.16000    28.64000    6.36000     1.12000
      0.80000     1.92000     1.00000     0.84000     0.40000
1996  1     1     0     0     1     1     21.90 25.28 29.72 33.37 35.87 37.18
      37.96 38.41 38.96 27.64000    29.16000    11.88000    6.96000
      4.60000     3.16000     1.80000     1.36000     1.00000
1997  1     1     0     0     1     1     23.69 27.33 30.10 33.00 35.44 36.77
      38.01 38.16 38.56 7.28000     28.20000    23.92000    12.48000
      8.92000     8.52000     6.08000     5.00000     8.16000
1998  1     1     0     0     1     1     22.55 27.94 29.90 32.01 34.62 36.26
      36.59 37.45 37.98 8.52000     14.20000    28.84000    14.40000
      7.52000     5.76000     4.60000     2.92000     3.44000
1999  1     1     0     0     1     1     23.24 26.21 31.15 33.65 34.92 35.81
      36.71 37.87 38.24 24.80000    5.44000     4.68000     9.56000
      9.32000     6.88000     2.80000     1.80000     1.36000
2000  1     1     0     0     1     1     21.89 27.38 29.95 34.71 35.47 35.98
      36.37 37.50 38.00 33.28000    12.48000    4.32000     7.28000
      9.08000     5.80000     2.60000     0.96000     0.60000
2001  1     1     0     0     1     1     21.15 27.26 29.92 34.37 35.42 36.30
      36.31 36.95 36.60 23.68000    36.88000    6.88000     4.28000
      5.04000     4.32000     2.08000     0.88000     0.40000
2002  1     1     0     0     1     1     22.58 26.38 28.95 31.67 34.56 34.55
      36.71 -1.00 -1.00 20.52000    55.44000    7.04000     1.72000
      0.36000     0.44000     0.28000     0.00000     0.00000
2003  1     1     0     0     1     1     22.11 27.41 30.49 34.46 35.67 37.38
      38.13 38.40 39.50 32.60000    17.24000    7.12000     3.04000
      0.96000     0.96000     0.60000     0.20000     0.08000
2004  1     1     0     0     1     1     23.94 27.68 31.05 35.08 36.72 37.67
      38.50 38.00 39.50 84.00000    10.76000    3.28000     2.08000
      0.72000     0.12000     0.08000     0.04000     0.08000
2005  1     1     0     0     1     1     21.31 27.00 30.13 32.04 33.64 35.83
      35.50 39.00 -1.00 68.96000    15.36000    5.84000     1.00000
      0.44000     0.24000     0.08000     0.04000     0.00000
2006  1     1     0     0     1     1     22.55 26.51 30.47 34.16 38.46 39.68
      40.05 40.83 -1.00 55.60000    26.28000    5.88000     3.48000
      2.44000     1.00000     0.80000     0.24000     0.00000
2007  1     1     0     0     1     1     21.11 25.87 29.37 33.63 36.16 38.70
      39.64 40.67 -1.00 32.68000    15.52000    7.00000     5.20000
      2.32000     1.08000     0.44000     0.12000     0.00000
2008  1     1     0     0     1     1     20.44 25.77 27.59 34.54 37.11 38.64
      39.00 -1.00 -1.00 7.84000     9.04000     4.56000     5.12000
      1.84000     0.44000     0.08000     0.00000     0.00000
2009  1     1     0     0     1     1     20.57 26.73 31.19 36.14 38.29 40.33
      42.00 -1.00 -1.00 5.16000     7.68000     1.68000     1.48000
      0.68000     0.12000     0.08000     0.00000     0.00000
```

```
2010  1     1     0     0     1     1     20.60 23.26 29.03 34.04 37.00 38.75
      37.00 -1.00 -1.00 0.80000     6.88000     2.60000     0.96000
      0.48000     0.16000     0.04000     0.00000     0.00000
#
0 #   Number of 'environmental' variables
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0 #   Weight distributions
0 #   Tag data
0 #   Morph data
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```

PACIFIC MACKEREL (*Scomber japonicus*) BIOMASS PROJECTION ESTIMATE FOR USA MANAGEMENT

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May 2013

Introduction

Pacific mackerel stock assessments are typically conducted annually, in accordance with Pacific Fishery Management Council (Council) operating procedures. Full assessments are conducted every three years, with update assessments conducted in the intervening years. In June 2011, the Council recommended foregoing an updated assessment in 2012, acknowledging 1) very low catches relative to biomass and allowable harvest, 2) absence of a conservation concern resulting from fishing pressure or other reasons, and 3) limited amount of data available on which to base an assessment. In June 2012, the Council based annual management specifications on the prior year's assessment. This change to a multiple-year assessment approach is consistent with the Southwest Fisheries Science Center's (SWFSC) suggestion as an efficient way to approach stock assessments for the CPS species.

Based on recommendations from the Scientific and Statistical Committee (June 2012 Briefing Book Item F.2.b, Supplemental SSC Report) and from the Coastal Pelagic Species Management Team (November 2012 Briefing Book Item F.4.b, Supplemental CPSMT Report 2), we present here a catch-only projection estimate, based on the 2011 full stock assessment.

Methods

Detailed methods for the base case model *XA* are described in the 2011 stock assessment (Agenda Item I.2.b, Electronic Attachment 1). The projection model scenario was parameterized as forecasted catch for the two fisheries included in the model (commercial and recreational) in future years of interest, i.e., beyond the terminal year of the 2011 assessment. Other details about the projection estimate are as follows:

- Forecasted catch for 2013-14 fishing year was 3,000 mt and 500 mt for the commercial and recreational fisheries, respectively, i.e., amounts slightly higher than landed catch observed over the last few years.
- No other parameterization changes were made to the assessment model.
- The 3-year forecasted estimate of stock biomass is higher than the terminal year estimate of the assessment model, i.e., in the absence of any measurable fishing pressure, the stock is hypothesized to have increased in size over this timeframe. Although forecasted recruitment estimates are acknowledged to be uncertain in model projections, there is general recognition that Pacific mackerel abundance appears to be increasing.

Management Specification Outputs
Pacific mackerel Harvest Control Rule (HCR) formulas are shown here:

B (age 1+, mt)	Cutoff (mt)	Fraction	Distribution	HG (mt)
	18,200	0.3	0.7	

Harvest Formula Parameters	Value			
Biomass (1+, mt)				
P* (probability of overfishing)	0.45	0.40	0.30	0.20
$Buffer_{Pstar}$	0.95577	0.91283	0.82797	0.73861
F_{MSY}	0.3			
Fraction	0.3			
Cutoff (mt)	18,200			
Distribution (U.S.)	0.7			

Harvest specifications from June 2011 and June 2012 are shown below, and are based on the Pacific mackerel stock biomass (age 1+) estimate of 211,126 mt. These HCR outputs were used as the basis for management decisions guiding the 2011-12 as well as the 2012-13 fishing years.

	MT
Biomass	211,126
OFL=Biomass*Fmsy*Distribution	44,336
$ABC_{0.45}$ = Biomass*$buffer_{0.45}$*Fmsy*Distribution	42,375
$ABC_{0.40}$ = Biomass*$buffer_{0.40}$*Fmsy*Distribution	40,472
$ABC_{0.30}$ = Biomass*$buffer_{0.30}$*Fmsy*Distribution	36,709
$ABC_{0.20}$ = Biomass*$buffer_{0.20}$*Fmsy*Distribution	32,747
HG = (Biomass - Cutoff) * Fraction * Distribution	40,514

Harvest specifications associated with the 2013-14 projection estimate are shown below, and are based on a Pacific mackerel stock biomass (age 1+) estimate of 272,932 mt .

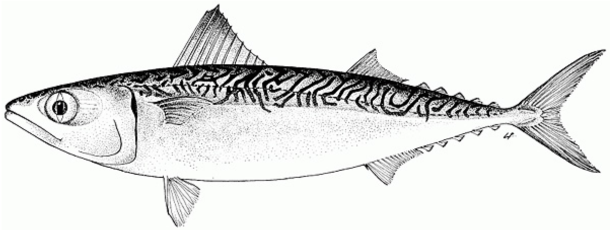
	MT
Biomass	272,932
OFL=Biomass*Fmsy*Distribution	57,316
$ABC_{0.45}$ = Biomass*$buffer_{0.45}$*Fmsy*Distribution	54,781
$ABC_{0.40}$ = Biomass*$buffer_{0.40}$*Fmsy*Distribution	52,320
$ABC_{0.30}$ = Biomass*$buffer_{0.30}$*Fmsy*Distribution	47,456
$ABC_{0.20}$ = Biomass*$buffer_{0.20}$*Fmsy*Distribution	42,334
HG = (Biomass - Cutoff) * Fraction * Distribution	53,494

Research Recommendations

1. Pacific mackerel maturity study.
   a. Maturity schedule used in stock assessments is being re-evaluated (last research effort was conducted over 20 years ago).
   b. Timeline: overall study began in summer 2009; data collection phase ended in fall 2012 (700 specimens); laboratory analysis phase will end in spring/summer 2013; preliminary results available in fall 2013.
2. Pacific mackerel age and growth study.
   a. 1^{st}-year growth will be evaluated experimentally using laboratory setting (critical information for age determination efforts and ultimately, age composition development in stock assessments).
   b. Timeline: overall study to begin summer 2013; data collection phase will end in summer/fall 2014; laboratory analysis phase will end in fall 2014; preliminary results available in winter 2014.

Agenda Item I.2.b
Supplemental SWFSC PowerPoint
June 2013

Pacific Mackerel Biomass Projection Estimate for the 2013-14 Fishing Year



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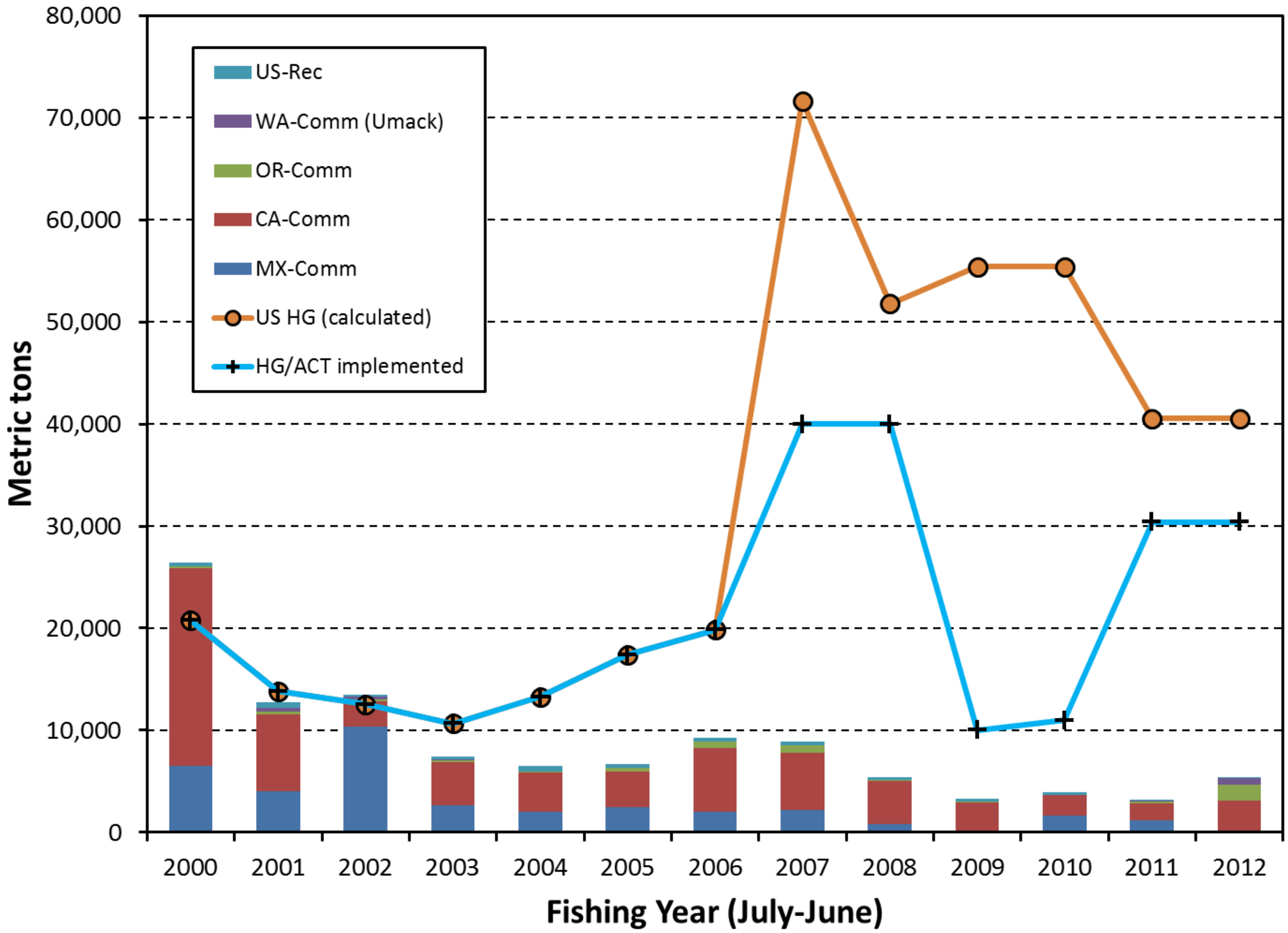
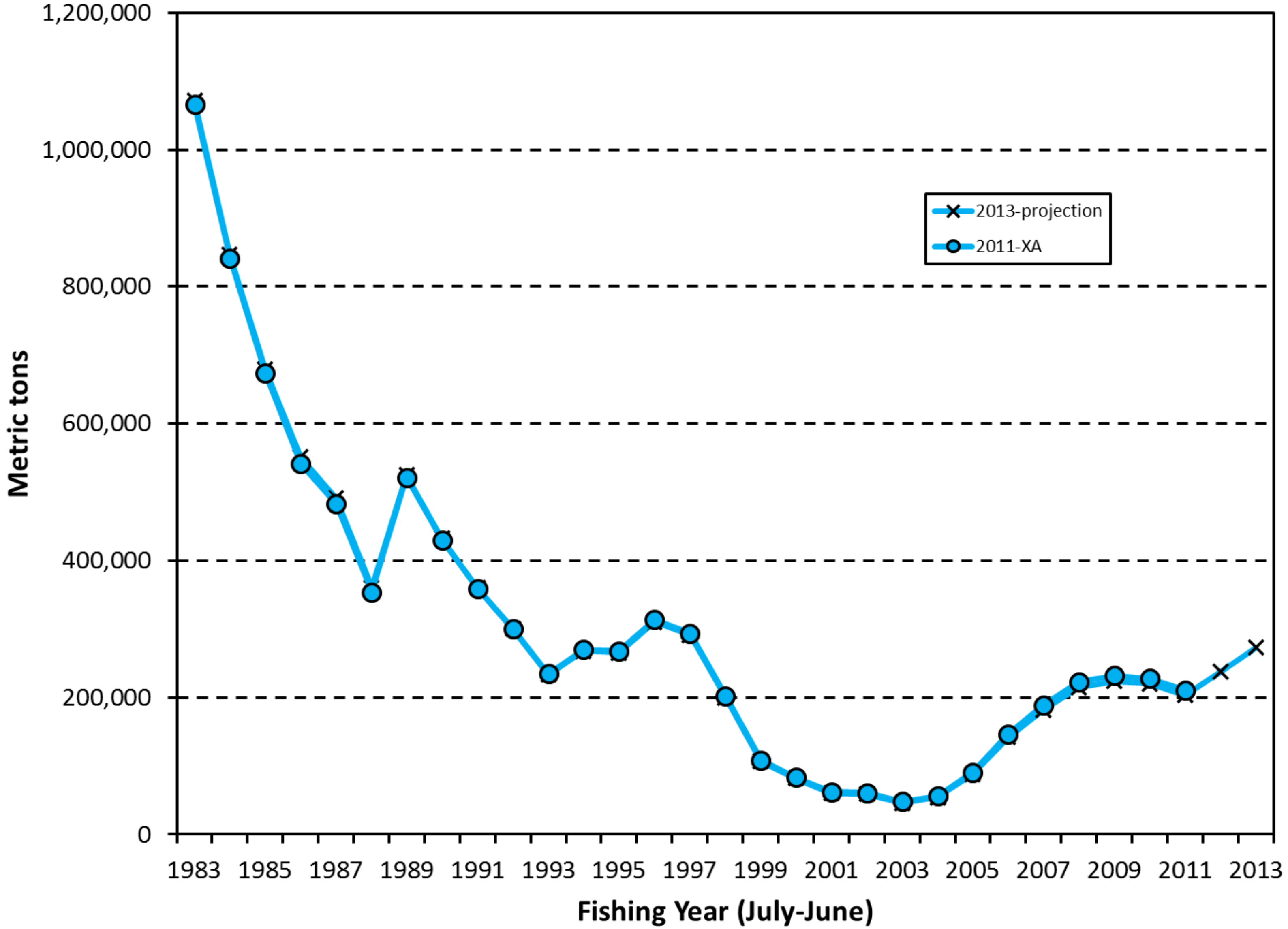
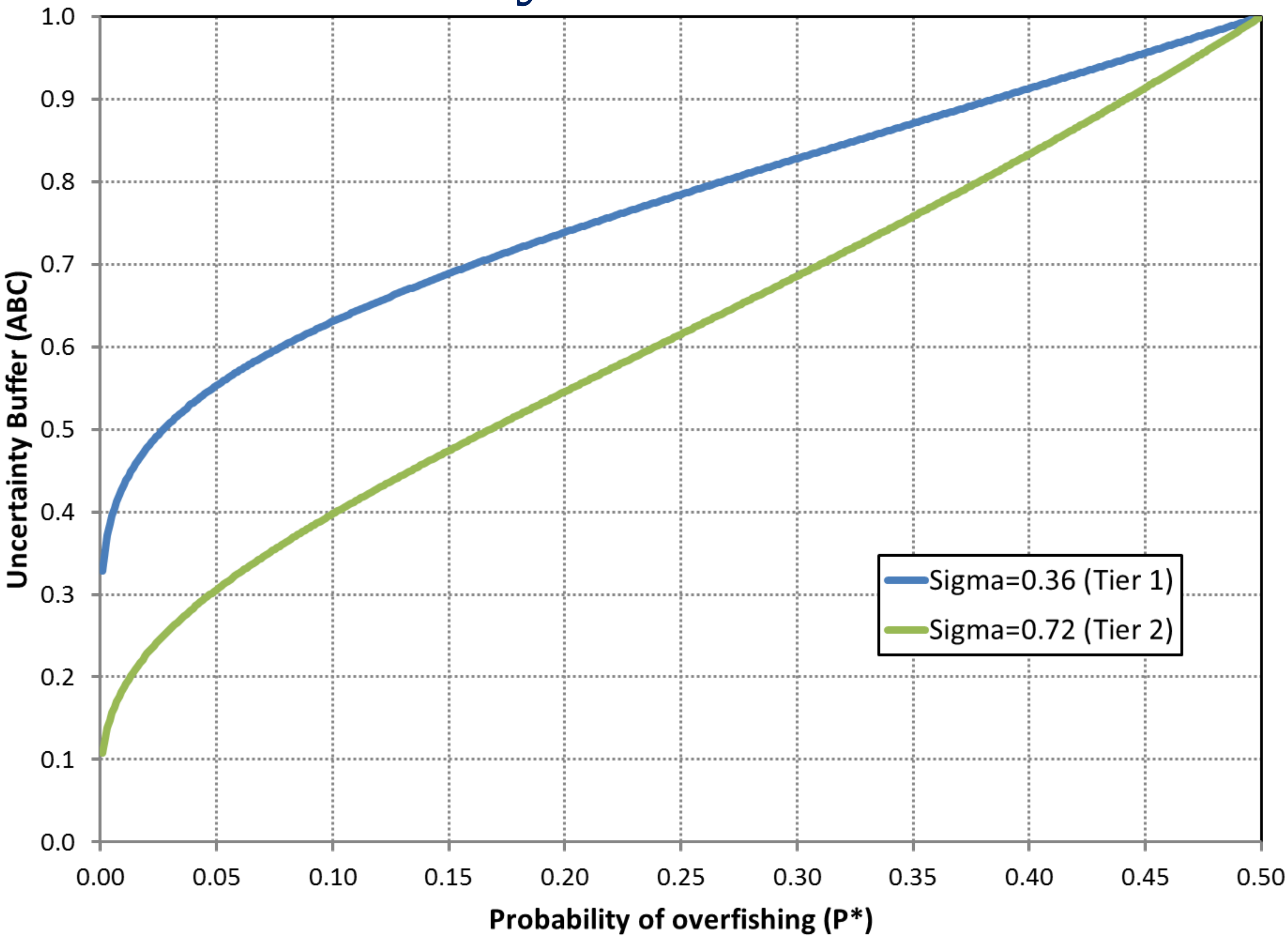
Pacific Mackerel Management & Landings



Estimated Biomass Time Series – 2011 & 2013



Uncertainty Buffers for ABC



Harvest Control Rules

2011 Assessment Model

Harvest Formula Parameters	Value			
BIOMASS (ages 1+, mt)	211,126			
Pstar (probability of overfishing)	0.45	0.4	0.3	0.2
$BUFFER_{Pstar}$ for Sigma=0.36	0.95577	0.91283	0.82797	0.73861
F_{MSY}	0.3			
FRACTION	0.3			
CUTOFF (mt)	18,200			
DISTRIBUTION (U.S.)	0.7			

Amendment 13 Harvest Formulas	MT
OFL = BIOMASS * F_{MSY} * DISTRIBUTION	**44,336**
$ABC_{0.45}$ = BIOMASS * BUFFER0.45 * F_{MSY} * DISTRIBUTION	**42,375**
$ABC_{0.40}$ = BIOMASS * BUFFER0.40 * F_{MSY} * DISTRIBUTION	40,472
$ABC_{0.30}$ = BIOMASS * BUFFER0.30 * F_{MSY} * DISTRIBUTION	36,709
$ABC_{0.20}$ = BIOMASS * BUFFER0.20 * F_{MSY} * DISTRIBUTION	32,747
ACL/HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION	**40,514**
ACT=EQUAL TO HG OR ACL, WHICHEVER VALUE IS LESS	**30,386**

2013 Projection Model

Harvest Formula Parameters	Value			
BIOMASS (ages 1+, mt)	272,932			
Pstar (probability of overfishing)	0.45	0.4	0.3	0.2
$BUFFER_{Pstar}$ for Sigma=0.72	0.9135	0.83326	0.68553	0.54555
F_{MSY}	0.3			
FRACTION	0.3			
CUTOFF (mt)	18,200			
DISTRIBUTION (U.S.)	0.7			

Amendment 13 Harvest Formulas	MT
OFL = BIOMASS * F_{MSY} * DISTRIBUTION	**57,316**
$ABC_{0.45}$ = BIOMASS * BUFFER0.45 * F_{MSY} * DISTRIBUTION	**52,358**
$ABC_{0.40}$ = BIOMASS * BUFFER0.40 * F_{MSY} * DISTRIBUTION	47,759
$ABC_{0.30}$ = BIOMASS * BUFFER0.30 * F_{MSY} * DISTRIBUTION	39,292
$ABC_{0.20}$ = BIOMASS * BUFFER0.20 * F_{MSY} * DISTRIBUTION	31,269
ACL=LESS THAN OR EQUAL TO ABC	**TBD**
HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION	53,494
ACT=EQUAL TO HG OR ACL, WHICHEVER VALUE IS LESS	**TBD**

COASTAL PELAGIC SPECIES ADVISORY SUBPANEL REPORT ON PACIFIC MACKEREL MANAGEMENT STATUS AND MANAGEMENT MEASURES

The Coastal Pelagic Species Advisory Subpanel (CPSAS) met June 23, 2013 to review management and research recommendations for Pacific mackerel for the 2013-2014 fishing year, and to discuss the management status of Pacific mackerel. Discussion included the Southwest Fisheries Science Center (SWFSC) catch-only projection estimate of the Pacific mackerel biomass (Agenda Item I.2.b, Attachment 2) for setting 2013-2014 harvest management specifications.

Harvest and Management Specifications

The CPSAS concurs with Coastal Pelagic Species Management Team (CPSMT) recommendations (1), (2) and (3) in Agenda Item I.2.c, Supplemental CPSMT Report, for the 2013-14 fishery with the following observations.

The Pacific mackerel resource is subject to periodic outbreaks in biomass and landings, as occurred in the 2000-2001 season. Recent surveys have indicated increasing Pacific mackerel abundance, and catches have also increased. The 2013 assessment and biomass projection also increased, suggesting that another 'boom' may be forthcoming. The CPSAS believes it is important to maintain the opportunity to harvest Pacific mackerel at the level recommended by the CPSMT for the 2013-14 fishery, in light of the apparent increase in biomass and potential decrease in harvest opportunity for other CPS, i.e. sardine.

In addition, the CPSAS recommends an in-season review of the 2013-2014 Pacific mackerel fishery at the April 2014 Council meeting, if needed, to consider releasing a portion of the incidental set-aside to the directed fishery.

Moving Pacific Mackerel from Active to Monitored Status

The CPSAS is concerned with the real-world ramifications of such a move, proposed for the 2014-15 season, particularly regarding the opportunity to maintain harvest opportunity in a stock that is characterized by rapid increases in abundance and that appears to be exhibiting an increase in biomass. The CPSAS supports the idea to manage CPS from an assemblage perspective, and understands the need to prioritize time and resources to provide the most efficient and effective management outcomes for all CPS, both active and monitored. If Pacific mackerel is moved to monitored status, the in-season review described above should be included as a management measure.

The CPSAS notes that the CPS Fishery Management Plan describes flexibility to move a stock quickly from monitored to active status, should catches or other information warrant a move in status. This may be an important issue, if the biomass and/or catch increases rapidly.

The CPSAS supports the CPSMT's intent to consider multiple options for setting harvest control rule (HCR) levels for the monitored stock and making a recommendation to the Council at a future meeting, and notes that in setting HCR levels, there is much more information known about Pacific mackerel than known about other monitored stocks. This should be taken into consideration.

Finally, the CPSAS also encourages the Council to look forward, not backward, when considering Pacific mackerel catches as the sole or primary rationale to change management status.

PFMC
06/24/13

COASTAL PELAGIC SPECIES MANAGEMENT TEAM REPORT ON PACIFIC MACKEREL MANAGEMENT STATUS AND MANAGEMENT MEASURES

The Coastal Pelagic Species Management Team (CPSMT) met to review management and research recommendations for Pacific mackerel for the 2013-2014 fishing year, and considered the management status of Pacific mackerel. In May 2011, a full stock assessment for Pacific mackerel was reviewed by a Stock Assessment Review (STAR) Panel in La Jolla, California and subsequently approved by the Pacific Fishery Management Council (Council) in June 2011 in Spokane, Washington. The 2011 assessment was used for two consecutive management cycles. The Scientific and Statistical Committee (SSC) and the CPSMT recommended (in June 2012 and November 2012, respectively) the Southwest Fisheries Science Center (SWFSC) develop a catch-only projection estimate of the Pacific mackerel biomass (Agenda Item I.2.b, Attachment 2) to be used for setting the 2013-2014 harvest management specifications.

Harvest and Management Specifications

For the 2013-2014 fishing year, the CPSMT supports the SSC's recommendation of setting a sigma value for computing the buffer between the overfishing limit (OFL) and acceptable biological catch (ABC) to 0.72 to address uncertainty in the stock assessment projection model. The CPSMT recommends the following:

(1) establish an OFL of 57,316 mt, an ABC and annual catch limit (ACL) of 52,358 mt (based on a P* of 0.45), and an annual catch target (ACT) of 39,269 mt (Table 1). The ACT is 75 percent of the ACL per the Council's actions in 2011 and 2012. The difference between the ACL and ACT is effectively an incidental set-aside of 13,090 mt for catch in non-directed fisheries. Of note, the 2013-2014 ACL and ACT are based on the ABC due to the Harvest Guideline (HG) being larger than the ABC;

(2) should the directed fishery realize the ACT (39,268 mt), the Council recommends that National Marine Fisheries Service (NMFS) close the directed fishery and shift to an incidental catch-only fishery, with a 45 percent incidental landing allowance when Pacific mackerel are landed with other coastal pelagic species (CPS), with the exception that up to 1 mt of Pacific mackerel could be landed without landing any other CPS; and,

(3) to provide time to address the broader CPS assemblage assessment efforts, and due to low catches, limited additional sample information, and indications that the population's sustainability is not presently being compromised by fishing pressure, no stock assessment be completed for Pacific mackerel in 2014 due to a possible management status change in the following season.

Table 1. Pacific Mackerel Harvest Formulas	MT
Biomass	272,932
OFL=Biomass*Fmsy*Distribution	**57,316**
$ABC_{0.45}$ = Biomass*$buffer_{0.45}$*Fmsy*Distribution	**52,358**
$ABC_{0.40}$ = Biomass*$buffer_{0.40}$*Fmsy*Distribution	47,759
$ABC_{0.30}$ = Biomass*$buffer_{0.30}$*Fmsy*Distribution	39,292
$ABC_{0.20}$ = Biomass*$buffer_{0.20}$*Fmsy*Distribution	31,269
HG = (Biomass - Cutoff) * Fraction * Distribution	53,494
ACL=LESS THAN OR EQUAL TO ABC	**52,358**
ACT=0.75* ACL	**39,269**

Change from Active to Monitored Status

The CPSMT recommends moving Pacific mackerel from actively managed to monitored status starting in the 2014-2015 season, based on very low catches, limited additional sample information, and indications that the population's sustainability is not presently being compromised by fishing pressure. The CPSMT will consider multiple options for setting HCR levels for the monitored stock and make a recommendation to the Council at a future meeting.

PFMC
06/24/13

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON PACIFIC MACKEREL MANAGEMENT STATUS AND MANAGEMENT MEASURES

The Scientific and Statistical Committee (SSC) discussed the recent analysis of Pacific mackerel status with Mr. Kerry Griffin. The projection provides the best estimate of current biomass and hence the overfishing limit (OFL). However, it is based on an assessment conducted two years ago. Consequently, the recruitments are not individually estimated for several recent years but are instead taken directly from the estimated stock-recruitment relationship. This, along with the concerns raised about the stock assessment during the most recent Stock Assessment Review (STAR) Panel, suggests that scientific uncertainty is greater than the default sigma of 0.36 would suggest. The SSC consequently recommends setting the sigma for computing the buffer between the OFL and acceptable biological catch (ABC) to 0.72 which is the sigma value for category 2 groundfish stocks. These are groundfish stocks for which recruitments are not estimated or the assessment is not considered as reliable as category 1 stock assessments. This change in sigma is included in Table 1 below.

Table 1. OFL ABC range, and harvest guideline (HG)

Biomass	272,932
OFL=Biomass*Fmsy*Distribution	57,316
$ABC_{0.45}$ = Biomass*$buffer_{0.45}$*Fmsy*Distribution	52,358
$ABC_{0.40}$ = Biomass*$buffer_{0.40}$*Fmsy*Distribution	47,759
$ABC_{0.30}$ = Biomass*$buffer_{0.30}$*Fmsy*Distribution	39,292
$ABC_{0.20}$ = Biomass*$buffer_{0.20}$*Fmsy*Distribution	31,269
HG = (Biomass - Cutoff) * Fraction * Distribution	53,494

The SSC recommends that the Terms of Reference for stock assessments be updated to include stock assessment categories for Coastal Pelagic Species (CPS) stocks, and that CPS stock assessments are formally assigned to a category in the future.

PFMC
06/23/13

COASTAL PELAGIC SPECIES: SARDINE FISHERY START DATE AND MANAGEMENT SCHEDULE

The Pacific sardine fishery currently follows the calendar year, starting January 1 and ending December 31. The fishing year is broken into three periods: January 1-June 30, July 1-September 15, and September 16-December 31. Each fishing period is allocated 35 percent, 40 percent, and 25 percent, respectively, of the total allowable harvest for that fishing year.

An issue that has become more apparent in recent years is the fact that two summer surveys (the Northwest Aerial Sardine Survey and the National Oceanic and Atmospheric Administration's acoustic-trawl summer survey) face a very compressed time frame if they are to deliver their products to the Stock Assessment Team (STAT) sufficiently in advance of the stock assessment review meeting (typically in late September or early October). This in turn makes it challenging for the STAT to deliver the final stock assessment documents to the Council on time for the November briefing book deadline.

At its April 2013 meeting, the Council considered a white paper that analyzed a start date change (http://www.pcouncil.org/wp-content/uploads/I2b_CPSMTandCPSAS_APR2013BB.pdf) and tasked the Coastal Pelagic Species Management Team (CPSMT) with developing an implementation plan that would enable final approval consideration. The CPSMT met with the Scientific and Statistical Committee's Coastal Pelagic Species Subcommittee (SSC CPSS) and representatives of the Coastal Pelagic Species Advisory Subpanel in May 2013 to further consider the process. The SSC CPSS was asked to specifically consider the scientific validity of generating a biomass estimate and management specifications for the six-month transition period of January 1 through June 30, 2013. The CPSMT implementation plan is provided as (Agenda Item I.3.b, CPSMT Report).

In the event the Council adopts a change to the fishery start date, the National Marine Fisheries Service (NMFS) will need to develop new regulations, and a change to Council Operating Procedure 9 will be required to implement a start date change. The Council would have to approve COP changes.

Council Action:

1. **Decide on a Change to the Sardine Fishery Start Date.**
2. **Approve Process for Management Specifications for Transition Year.**
3. **Approve Annual Management Schedule.**

Reference Materials:

1. Agenda Item I.3.b, CPSMT Report.

Agenda Order:

a. Agenda Item Overview Kerry Griffin
b. Reports and Comments of Advisory Bodies and Management Entities
c. Public Comment
d. **Council Action**: Adopt Changes to Sardine Fishery Start Date for 2014 and the Annual Management Schedule

PFMC
05/31/13

COASTAL PELAGIC SPECIES MANAGEMENT: SARDINE FISHERY START DATE AND MANAGEMENT SCHEDULE

At the April 2013 Pacific Fishery Management Council (Council) meeting, the Coastal Pelagic Species Management Team (CPSMT) and Coastal Pelagic Species Advisory Subpanel (CPSAS) presented a joint report to the Council that proposed July 1 as an alternative Pacific sardine fishery start date, to address resource assessment scheduling constraints that exist as a result of the current fishery year start of January 1. Following discussion at the April meeting, the CPSMT, CPSAS, and Scientific and Statistical Committee (SSC) recommended the change. The Council supported the concept and tasked the CPSMT with presenting an implementation plan for a possible final decision in June. The start date proposal and implementation plan was further reviewed and developed at a May 20-23, 2013 joint meeting of the CPSMT and the SSC Coastal Pelagic Species Subcommittee (SSC-CPSS) meeting, which included representatives from the CPSAS.

The current Pacific sardine fishing year begins January 1 with the annual harvest guideline divided by fixed percentages to three periods: January 1 – June 30, July – September 15 and September 16 –December 31. This regime was adopted under Amendment 11 to address long-term allocation of Pacific sardine in 2006. Amendment 11 changed the prevailing allocation scheme from a geographical construct to a three-period fishing year, open coastwide but with three different fishing openers. The CPSMT has evaluated the proposed start date change and found it consistent with objectives and analyses conducted in Amendment 11 to the CPS Fishery Management Plan (FMP). Among its objectives, Amendment 11 intended to allow for un-harvested quota to be transferred to the subsequent fishing period. Transfer of un-harvested allocation allows fish allocated but not harvested in the first and second periods to be added to the subsequent period's allocation. The CPSMT notes that the dynamics relative to allocation period rollovers may change with a July 1 start date. Under the proposed start date of July 1, rollovers may occur between Periods 1 and 2 (September 14 to September 15) and between Periods 2 to 3 (December 31 to January 1), but after the third period, any unharvested allocation as of June 30 would not be rolled into the subsequent fishing year. Since implementation of Amendment 11 in 2006, allocation rollovers occurred four times from the first to the second period. The CPSMT recognizes that there may be modest changes in fishing patterns in order to fully utilize the harvest guideline rather than let it expire. However, market and weather conditions, which are not predictable, will also play a significant factor in fishing behavior. CPSAS representatives at the May 2013 meeting acknowledged this possibility and noted that this had been discussed and was supported among industry members.

Should the Council adopt the date change in start date, technical and regulatory changes will be necessary to accomplish full implementation by July 1, 2014. This includes a regulatory amendment (regulations issued by NMFS) and approval of a revised Council Operating Procedure (COP) 9, which guides annual management cycles for CPS and other Council-managed species. The CPSMT reiterates from the April supplemental team report (Agenda I.2.b) the following steps to address interim management for January through June 2014 and to develop management measures for July 1, 2014 through June 30, 2015:

- Forego a full-scale update review by the SSC-CPSS this fall.
- Use the current assessment model to produce a simple catch-only projection update that would provide the basis for the first allocation period of 2014 (January 1 to June 30). The STAT would provide the update in an executive summary format.
- At the November 2013 Council meeting, the SSC reviews the abbreviated update, the Council adopts a revised COP 9, and adopts management measures for January - June of 2014.
- In February 2014, conduct a full stock assessment review for the following July 1 start date. SSC reviews in April.
- In April 2014, Council adopts the full stock assessment and management measures for July 1, 2014 - June 30, 2015.

At their joint meeting in May 2013, the CPSMT again reviewed these steps and discussed the approach with the SSC CPS subcommittee and the subcommittee concurred.

Under the CPS FMP, the Point of Concern Framework provides the mechanism to make modifications to management procedures without the need to amend the FMP. Accordingly, the fishery start date can be accomplished through regulatory action. Implementation of a July 1 start date will require a two meeting process and a regulation amendment via federal rule-making action. Under this scenario, the April 2013 meeting could constitute the first of the two meetings, and June 2013 the second.

In conclusion, the CPSMT recommends the Council adopt a fishing year start date of July 1 for the Pacific sardine fishery.

PFMC
05/31/13

COASTAL PELAGIC SPECIES ADVISORY SUBPANEL REPORT ON SARDINE FISHERY START DATE AND MANAGEMENT SCHEDULE

The Coastal Pelagic Species Advisory Subpanel (CPSAS) engaged in further discussion on shifting the sardine fishery start date (Agenda Item I.3.b.), to address concerns voiced by a representative of the Northwest sardine fishery about the potential for foregone catches if the season start date is changed to July 1.

After further reviewing the potential benefits of changing the start date to July 1 to provide more time for surveys to be conducted and for data to be analyzed, versus the potential harvest opportunity foregone, consensus was reached amongst industry representatives and CPSAS members to reaffirm the CPSAS's April Council statement unanimously supporting the season start date change (Agenda Item I.2.b, Supplemental CPSAS Report, April 2013).

PFMC
06/25/13

Agenda Item I.3.b
Supplemental CPSMT Report 2
June 2013

COASTAL PELAGIC SPECIES MANAGEMENT TEAM REPORT ON SARDINE FISHERY START DATE AND MANAGEMENT SCHEDULE

The Coastal Pelagic Species Management Team (CPSMT) supports methodology reviews of the Southwest Fisheries Science Center (SWFSC) Acoustic-Trawl (A-T) survey and the Northwest Sardine Survey (NWSS). Other surveys approved by the Council for review could potentially be reviewed concurrently.

The CPSMT also supports the Scientific and Statistical Committee's (SSC) request to the survey principals for a formal, point-by-point response the list of potential items that were requested of the lead scientists of the A-T and NWSS surveys. This will give an indication of whether and when sufficient information would be available in order to conduct the reviews.

Finally, the CPSMT understands that the National Oceanic and Atmospheric Administration-sponsored joint sardine-hake survey will undergo a review in early 2014, and suggests that a detailed review of A-T methodology could be reviewed at the same time.

PFMC
06/25/13

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON SARDINE FISHERY START DATE AND MANAGEMENT SCHEDULE

Sardine Fishery Start Date

The Scientific and Statistical Committee (SSC) continues to support a shift in the sardine fishery start date from January 1 to July 1 to allow more time for modeling and sensitivity analyses to estimate the stock size of Pacific sardine.

In transitioning to a new start date, the SSC supports the process (illustration provided below) to set catch specifications for the 2014 season that were outlined in the Coastal Pelagic Species Management Team (CPSMT) April 2013 statement as follows:

- Forego a full-scale update review by the SSC-Coastal Pelagic Species (CPS) Subcommittee in fall, 2013.
- Use the current assessment model to produce a simple catch-only projection update that would provide the basis for the first allocation period of 2014 (January 1 to June 30). The Stock Assessment Team (STAT) provides the update in an executive summary format.
- At the November 2013 Council meeting, the SSC reviews the abbreviated update, and the Council adopts management measures for January - June of 2014.
- In February 2014, conduct a full stock assessment review for the following July 1 start date. SSC reviews in April.
- In April 2014, Council adopts the full stock assessment and management measures for July 1, 2014 - June 30, 2015.

The recommendation to the STAT was to update the current assessment model with recent catches and forecast the biomass for 2014, using the biomass estimate at the beginning of the fishing season to set the overfishing limit (OFL) for the January through June, 2014 time period. Forecasting should account for the uncertainty in recruitment rather than assuming that recruitment comes off the stock recruitment relationship.

Jan 2013	*FALL update*	Nov 2013	Jan 2014	*SPRING full*	April 2014	July 2014	June 2015
OFLs are already set							
		SSC review ------>	use update results to set OFLs for Jan-June 2014				
					SSC review ---->	use full assessment results to set OFLs July 2014 –June 2015	

Proposed Methodology Reviews

The SSC discussed the status of planning a proposed methodology review meeting to cover: 1) the Southwest Fisheries Science Center (SWFSC) Acoustic-Trawl (ATM) survey, and 2) the northwest sardine survey (NWSS). At the Council's request, other surveys targeting sardine could be reviewed at the proposed survey joint methodology review meeting.

The chair of the SSC-CPS Subcommittee has sent each of the lead scientists of the ATM and NWSS surveys a list of potential items to be discussed in a methodology review. In order to facilitate planning of the proposed methodology review, the SSC requests a formal, point by point response to these, in time for review at the September SSC meeting.

PFMC
06/23/13

COASTAL PELAGIC SPECIES MANAGEMENT: ADJUSTMENTS TO PACIFIC SARDINE HARVEST PARAMETERS

In February, 2013, the Council and the Southwest Fisheries Science Center (SWFSC) convened a workshop to address four objectives related to current Pacific sardine management: developing a risk assessment framework to evaluate the performance of alternative harvest control rules; reviewing the temperature-recruit relationship used to inform each year's harvest fraction; reviewing the portion of the stock residing in US waters; and planning for a full management strategy evaluation (MSE). The workshop produced a draft risk assessment framework, and a recommendation that there was sufficient new information to move forward with a revised temperature-recruit relationship. The workshop participants also agreed that there was not sufficient new information to warrant further consideration of a revised geographic distribution term and that existing ecosystem and economic model support was insufficient at this time to warrant specific planning for a comprehensive MSE. At the April, 2013 meeting, the Council considered the workshop results and scheduled for the June 2013 Council meeting (1) a possible final decision on the use of a new temperature-recruitment index, and (2) consideration of a supplemental report from the risk assessment analysts evaluating the effect on long term stock productivity and associated fishery performance measures of alternative overfishing limit (OFL) and harvest guideline (HG) control rules suggested by the Council and its advisory bodies.

<u>Temperature-recruit index</u>: Currently, the Scripps Institution of Oceanography (SIO) temperature is used as an indicator of sardine recruitment. The temperature is used to generate a fishing rate (harvest fraction) which in turn is used to calculate OFL and HG. When the temperature drops below a certain threshold, the OFL and fishing rate are both reduced accordingly, but the fishing rate will never go above 15 percent or fall below 5 percent, based on the Council's precautionary policy approach described in the fishery management plan (FMP).

The February workshop found that although a temperature-recruitment correlation is still valid, the California Cooperative Oceanic Fisheries Investigations (CalCOFI) temperature index showed better alignment with sardine recruitment than the SIO temperature series. Further, it was shown that the SIO temperature series has diverged from other temperature indices in the Southern California Bight since its initial adoption for use in 1998. Initial analysis of changing to the CalCOFI temperature index, and making no other changes in harvest control rules, shows that in some recent years, the fishing rate would have been lower than it was using the current SIO temperature index. In other words, instead of the harvest fraction being set at 15% (the highest allowed under the CPS FMP) using the SIO index in some recent years, it would have been in the 8 percent-14 percent range, resulting in lower OFLs and HGs. The Coastal Pelagic Species Management Team and Advisory Panel, and the Scientific and Statistical Committee, are expected to have additional analysis relative to the Council consideration to change this harvest parameter.

<u>Risk assessment framework</u>: The report from Felipe Hurtado-Ferro and Andre Punt, the primary analysts for this matter, is presented as Agenda Item I.4.b, Attachment 1 and includes stock and fishery performance measures of alternative OFL and HG control rules, sensitivity tests, and an

assessment of changing to a new temperature recruit index. The report was considered at a May 21-23 joint meeting of the CPSMT and the SSC CPS Subcommittee.

After taking advisory body statements and considering public testimony, the Council should consider incorporating the CalCOFI temperature series and the associated fishing rate relationship into the harvest control rules that generate OFL, acceptable biological catch (ABC), and HG. The Council should also consider whether the set of simulations and fishery performance measures in the risk assessment analysis warrants further changes in the Council's current fishery management policy approach for Pacific sardines.

Council Action:

1. **Consider adopting a new temperature-recruit relationship as a harvest parameter change for Pacific Sardine.**
2. **Consider other fishery management policy changes as a result of the harvest parameters risk assessment analysis.**

Reference Materials:

1. Agenda Item I.4.b, Attachment 1: Revised Analyses Related to Pacific Sardine Harvest Parameters.
2. Agenda Item I.4.c, Supplemental CPSMT Report.
3. Agenda Item I.4.d, Public Comment.

Agenda Order:

a. Agenda Item Overview — Kerry Griffin
b. Report overview and description — Felipe Hurtado-Ferro
c. Reports and Comments of Advisory Bodies and Management Entities
d. Public Comment
e. **Council Action**: Adopt Harvest Parameter Changes for Pacific Sardine

PFMC
06/03/13

Agenda Item I.4.b
Attachment 1
June 2013

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

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

MANAGEMENT STRATEGY EVALUATION (MSE) FRAMEWORK

The MSE framework on which the analyses of this document are based is shown 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 year (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 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.

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[2] The value of E_{MSY} is 0.17 if expected yield is taken to be median rather than the mean of the distribution.
[3] With variation in the environment, and recruitment given the environment.

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 E_{MSY} corresponding to the upper quartile of observed temperature. ABC is defined as 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 $HG_y = \text{DISTRIBUTION} \times \text{HG FRACTION}_y (B_y^{1+} - \text{CUTOFF})$, 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 an E_{MIN} 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 0-26%; 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 a 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 V instead of a 3-year average.
- Variant 20: HG FRACTION depends on the most recent year of V instead of a 3-year average.
- Variant 21: No fishing
- Variant 22: HG FRACTION is 15%.

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 difference between the various time series (Figure 6), where the CalCOFI and SIO series have 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, first calculate the reference points using SIO. From the relationship shown in the right panel of Figure 4, the E_{MSY} for an SIO SST of 18.08^0C is 66%, and the HG FRACTION is consequently 15% (HG FRACTION = max(E_{MSY}, HG

[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 and is related to the environment. Thus, the definition of B_0 being used here is not appropriate for defining an overfished threshold.

$FRACTION_{max}$)). The OFL for 2000 using SIO temperature is equal to the biomass (1’581,346t) times OFL FRACTION (44%, not shown in table; OFL FRACTION = max(E_{MSY}, OFL $FRACTION_{max}$), where OFL $FRACTION_{max}$ is the value of E_{MSY} at the upper quartile of observed SST, 17.76°C), times DISTRIBUTION (0.87). The HG is equal to the biomass minus CUTOFF (150,000t), times HG FRACTION, times DISTRIBUTION. The reference points using CalCOFI are calculated in a similar way, but the HG FRACTION and OFL FRACTION (OFL $FRACTION_{max}$ is 24% for CalCOFI, occurring at 16.11°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 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 4 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 3). 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 (~95% 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 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}.

ACKNOWLEDGEMENTS

Kevin Hill and Joshua Lindsay (NOAA) are thanked for providing guidance regarding the evaluation of the harvest control rule variants.

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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	15.19	0.09	113150	-73641	125008	16.18	0.15	186791	0	331561
2001	1182465	17.75	0.15	134737	433005	15.73	0.15	134737	0	185281	15.82	0.15	134737	0	202183
2002	1057599	17.24	0.15	118442	149081	15.50	0.14	110000	-8442	128179	15.47	0.14	106625	-11817	124247
2003	999871	17.31	0.15	110908	165969	14.91	0.05	38097	-72811	44821	15.38	0.12	88639	-22270	104283
2004	1090587	17.46	0.15	122747	246185	15.98	0.15	122747	0	214618	15.46	0.13	109008	-13738	126392
2005	1193515	17.60	0.15	136179	346672	15.78	0.15	136179	0	196454	15.56	0.15	135381	-797	154842
2006	1061391	18.03	0.15	118937	406300	15.36	0.12	93036	-25900	108349	15.71	0.15	118937	0	162261
2007	1319072	18.11	0.15	152564	504941	15.72	0.15	152564	0	203690	15.62	0.15	152564	0	184025
2008	832706	18.12	0.15	89093	318760	15.06	0.07	42989	-46104	52435	15.38	0.12	71394	-17699	87081
2009	662886	17.83	0.15	66932	253753	15.13	0.08	36621	-30311	47331	15.30	0.11	48181	-18750	62272
2010	702024	17.84	0.15	72039	268735	15.15	0.08	40617	-31422	51654	15.11	0.08	38243	-33796	48634
2011	537173	17.90	0.15	50526	205630	15.49	0.14	46600	-3926	64654	15.26	0.10	33950	-16576	47103
2012	988385	17.64	0.15	109409	307746	14.82	0.05	36470	-72939	42995	15.15	0.09	62453	-46956	73627
2013	659539	17.35	0.15	66495	118854	-	-	-	-	-	-	-	-	-	-

Table 3. Values of biomass used in the harvest control rule variants (in ‘000 t).

Quantity	Value
$\overline{B_0}$	1655
0.33 $\overline{B_0}$	551.9
0.20 $\overline{B_0}$	331.1
0.10 $\overline{B_0}$	165.6

Table 4. Results of applying each of 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 (%)	0-26	0-26	0-26	0-26	0-26	0-26	0-26	0-26	18	0-26	0-26	-	0-26
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	128.3	107.1	134.9	114.3	151.2	112.1	147.8	101.5	114.2	103.3	102.5	0.0	108.0
SD catch all	164.8	71.8	164.6	72.4	164.3	72.3	163.4	75.7	68.5	72.0	72.7	0.0	70.7
Mean catch CO	151.8	110.0	145.1	116.9	154.7	115.3	152.0	109.0	116.3	111.0	110.2	0.0	111.0
SD catch CO	169.0	70.6	166.5	71.1	164.6	70.8	163.8	73.2	67.4	68.8	69.7	0.0	69.3
Mean B1+	675.4	1259.6	1215.3	1201.0	1087.3	1222.1	1118.4	1304.7	1176.6	1268.3	1276.9	1598.5	1247.0
SD B1+	768.5	879.5	750.1	880.3	744.4	881.8	751.8	868.3	911.0	881.2	877.9	895.9	884.1
Mean SSB	477.1	978.8	922.5	925.3	804.9	944.3	833.3	1019.8	905.5	988.7	996.4	1326.3	967.8
SD SSB	573.0	752.4	587.0	752.8	576.7	754.0	584.5	743.4	775.8	756.1	753.5	797.3	756.0
%B1+>400	52.7	94.7	96.9	91.9	91.2	92.9	92.5	97.1	86.8	94.3	95.0	99.1	93.6
%No catch	15.5	2.8	7.2	2.3	2.3	2.8	2.8	6.9	1.8	7.1	7.1	100.0	2.7
%Catch<50	39.8	30.4	37.2	27.5	28.3	28.3	29.3	35.9	24.0	31.5	32.6	100.0	29.0
Median catch	77.0	98.8	82.2	110.6	102.6	106.2	98.8	88.9	109.3	93.8	93.0	0.0	99.3
Median B1+	445.7	1037.7	1037.7	972.2	907.2	995.8	937.7	1086.7	948.0	1055.6	1063.7	1430.2	1026.0
Median SSB	304.6	779.2	781.1	719.6	664.6	740.3	691.2	823.5	697.2	795.5	802.9	1163.8	768.4
Mean pop age	2.03	2.84	2.77	2.78	2.64	2.80	2.67	2.88	2.75	2.85	2.86	3.29	2.82
Mean Catch Age	1.30	1.83	1.79	1.79	1.70	1.81	1.72	1.87	1.78	1.84	1.85	NA	1.83
%HCR min	NA	11.88	11.88	33.33	NA	NA	NA	11.88	NA	NA	17.64	NA	NA
%HCR max	NA	52.23	42.10	42.10	NA	NA	NA	42.10	NA	NA	52.01	NA	NA
Mean Yrs HCRmin	NA	2.63	2.63	4.81	NA	NA	NA	2.63	NA	NA	1.59	NA	NA
Mean Yrs HCRmax	NA	7.40	6.01	6.01	NA	NA	NA	6.01	NA	NA	3.14	NA	NA
Mean Yrs NoCatch	139.22	1.66	1.63	1.74	1.75	1.64	1.64	1.64	1.37	1.27	1.27	NA	1.65
% Collapses	28	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	107.1	113.1	102.4	109.2	103.0	97.5	89.8	116.9	108.7	106.6
SD catch all	71.8	70.8	72.5	71.1	73.0	75.5	69.9	70.4	68.2	72.4
Mean catch CO	110.0	115.7	106.0	111.9	106.9	104.9	93.2	119.3	110.4	109.8
SD catch CO	70.6	69.5	71.2	69.9	71.6	73.3	69.0	69.2	67.3	71.1
Mean B1+	1259.6	1279.7	1244.4	1253.4	1271.9	1138.2	1095.7	1339.2	1216.6	1254.2
SD B1+	879.5	702.2	1035.2	877.7	883.2	921.5	783.0	897.4	783.6	866.6
Mean SSB	978.8	991.2	969.5	972.2	991.9	873.4	853.4	1038.8	941.9	974.7
SD SSB	752.4	586.7	895.9	750.5	756.5	775.4	663.5	772.4	671.2	738.4
%B1+>400	94.7	98.6	91.1	94.8	94.6	82.4	92.5	96.0	96.1	94.0
%No catch	2.8	2.3	3.5	2.4	3.7	7.2	3.8	2.0	1.6	2.9
%Catch<50	30.4	26.9	33.3	28.9	33.4	38.0	39.9	24.5	26.5	31.2
Median catch	98.8	110.2	90.4	102.9	91.3	84.1	70.2	116.9	100.7	98.3
Median B1+	1037.7	1112.3	975.9	1029.8	1054.0	912.1	883.3	1128.7	1028.9	1036.7
Median SSB	779.2	839.2	730.3	770.9	794.5	672.0	673.2	841.1	770.7	778.1
Mean pop age	2.84	2.74	2.91	2.83	2.85	2.69	2.85	2.81	2.79	2.83
Mean Catch Age	1.83	1.77	1.88	1.83	1.84	1.74	1.84	1.82	1.80	1.83
%HCR min	11.88	11.88	11.88	11.88	11.88	11.88	16.00	8.96	8.32	12.23
%HCR max	52.23	52.24	52.24	52.24	52.24	52.24	40.14	59.00	52.88	52.00
Mean Yrs HCRmin	2.63	2.64	2.64	2.64	2.64	2.64	2.68	2.55	2.33	2.72
Mean Yrs HCRmax	7.40	7.40	7.40	7.40	7.40	7.40	5.55	8.22	6.02	7.81
Mean Yrs NoCatch	1.66	1.71	1.69	1.72	1.54	2.16	1.69	1.65	1.56	1.69
% 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	107.1	110.1	99.8	108.7	114.7	60.5	89.0	112.9	108.2	107.5
SD catch all	71.8	65.5	85.7	71.9	71.8	60.5	63.2	71.3	72.2	71.6
Mean catch CO	110.0	111.0	117.9	111.7	117.5	72.8	92.4	115.7	111.2	109.9
SD catch CO	70.6	65.0	81.3	70.6	70.4	59.6	61.9	70.0	70.9	70.6
Mean B1+	1259.6	1195.9	1459.2	1285.4	1373.7	768.4	1193.9	1339.4	1287.6	1258.0
SD B1+	879.5	717.8	1335.3	888.7	904.0	726.4	890.8	881.2	917.6	879.3
Mean SSB	978.8	923.7	1149.9	999.5	1084.5	530.4	911.1	1050.3	980.5	977.2
SD SSB	752.4	617.2	1138.7	761.9	783.0	537.4	750.2	758.9	757.7	752.2
%B1+>400	94.7	97.3	82.5	95.2	96.9	64.3	90.6	96.8	94.8	94.8
%No catch	2.8	0.9	15.6	2.7	2.5	17.2	3.8	2.5	2.7	2.2
%Catch<50	30.4	23.7	44.1	29.7	26.8	56.4	36.9	27.2	30.2	30.2
Median catch	98.8	101.9	84.6	101.8	113.0	37.8	79.4	109.6	100.6	99.3
Median B1+	1037.7	1027.3	1065.1	1063.6	1158.9	570.5	970.9	1129.1	1051.9	1034.9
Median SSB	779.2	770.0	803.9	798.2	884.3	386.0	714.9	857.1	778.4	776.2
Mean pop age	2.84	2.77	3.06	2.85	2.69	2.23	2.61	2.72	2.84	2.83
Mean Catch Age	1.83	1.79	1.99	1.97	3.80	1.44	1.71	3.24	1.84	1.83
%HCR min	11.88	6.03	30.48	11.88	11.88	11.80	11.80	11.88	11.88	11.12
%HCR max	52.23	53.21	50.66	52.24	52.24	52.82	52.82	52.23	52.23	52.25
Mean Yrs HCRmin	2.63	2.00	5.33	2.64	2.64	2.67	2.67	2.63	2.63	2.62
Mean Yrs HCRmax	7.40	5.31	19.65	7.40	7.40	7.60	7.60	7.40	7.40	8.08
Mean Yrs NoCatch	1.66	1.40	2.91	1.67	1.69	3.45	1.75	1.69	1.66	1.62
% Collapses	0	0	0	0	0	8	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	107.1	107.1	107.1	107.1	107.1
SD catch all	71.8	71.8	71.8	71.8	71.7
Mean catch CO	110.0	110.0	110.0	110.0	109.8
SD catch CO	70.6	70.6	70.6	70.6	70.6
Mean B1+	1259.6	1259.6	1259.6	1259.5	1258.1
SD B1+	879.5	879.5	879.5	879.5	879.9
Mean SSB	978.8	978.8	978.8	978.7	977.6
SD SSB	752.4	752.4	752.4	752.4	752.7
%B1+>400	94.7	94.7	94.7	94.7	94.6
%No catch	2.8	2.8	2.8	2.7	2.5
%Catch<50	30.4	30.4	30.4	30.4	30.5
Median catch	98.8	98.8	98.8	98.8	98.6
Median B1+	1037.7	1037.7	1037.7	1037.7	1036.8
Median SSB	779.2	779.2	779.2	779.2	778.5
Mean pop age	2.84	2.84	2.84	2.84	2.83
Mean Catch Age	1.83	1.83	1.83	1.83	1.83
%HCR min	11.88	11.88	11.88	11.88	11.88
%HCR max	52.23	52.23	52.23	52.23	52.23
Mean Yrs HCRmin	2.63	2.63	2.63	2.63	2.63
Mean Yrs HCRmax	7.40	7.40	7.40	7.40	7.40
Mean Yrs NoCatch	1.66	1.66	1.66	1.65	1.65
% 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.

Series	AIC	R^2
SST_CC_ann	44.49	0.76
SIO_SST_ann	56.81	0.61
ERSST_ann	55.3	0.63

Table 11. Results of applying each of harvest control rule variants to a 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 temperature index, but changing the relationship between SIO and E_{MSY}.

Mgmt	Biomass	SIO - current				SIO - recalculated relationship			
year	**(July)**	**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	-	-	-	-

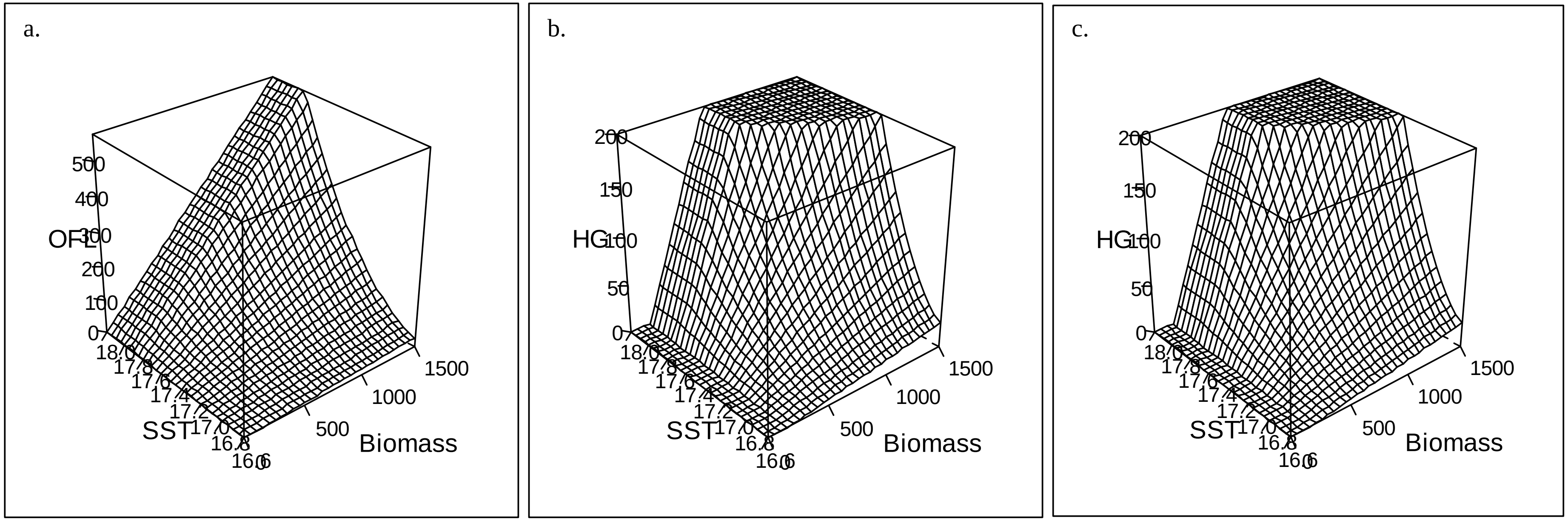


Figure 1. Current OFL control rule (a), HG control rule (b), and HG control rule when the constraint that the HG must be less than the ABC is imposed (c), across a range of 1+ biomass and temperature.

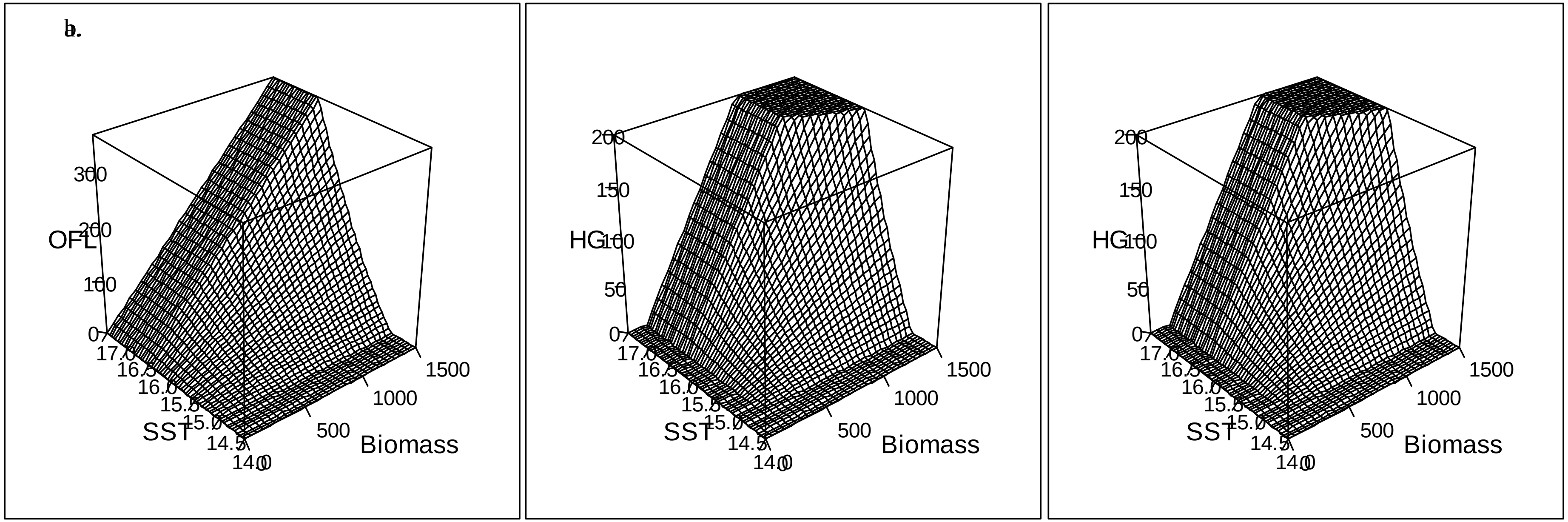


Figure 2. OFL control rule (a), HG control rule (b), and HG control rule when the constraint that the HG must be less than the ABC is imposed (c), across a range of 1+ biomass and temperature when temperature is based on the CalCOFI data.

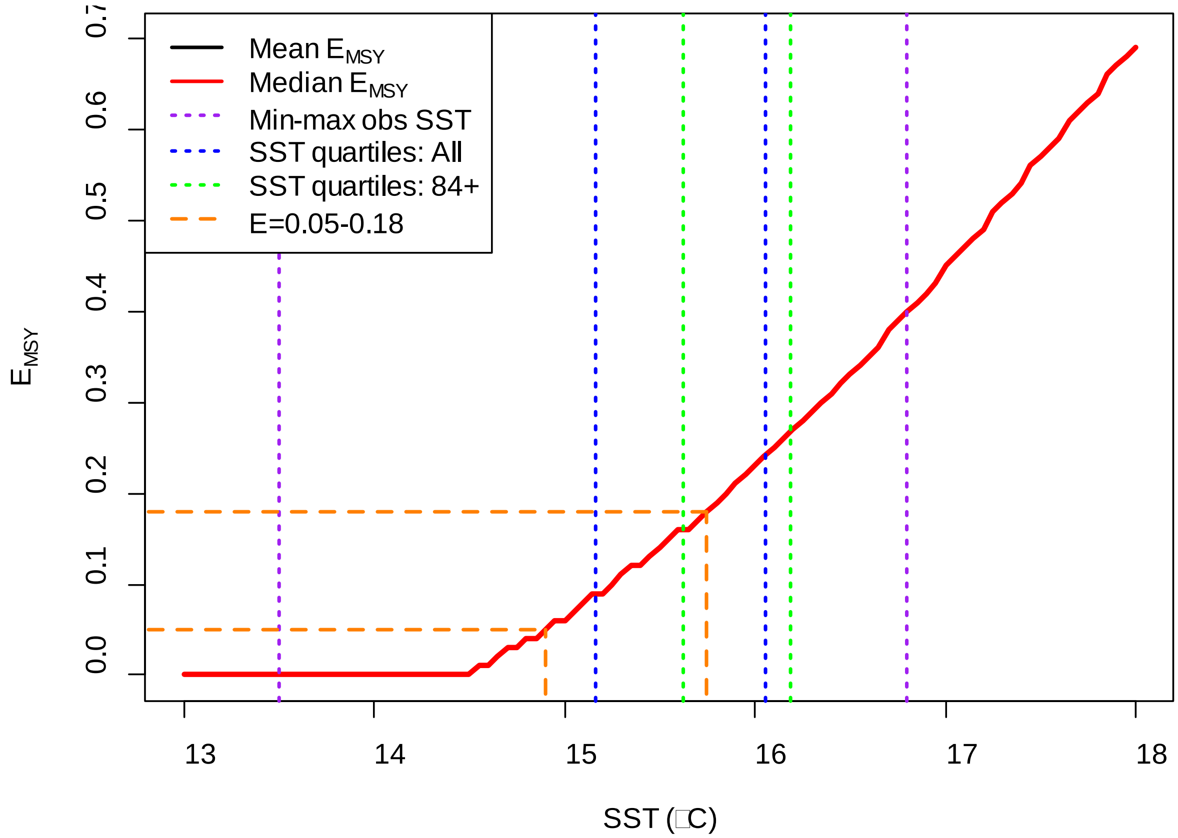


Figure 3. Relationship between CalCOFI SST and E_{MSY}, showing quartiles of observed SST in the SST_CC_ann time series.

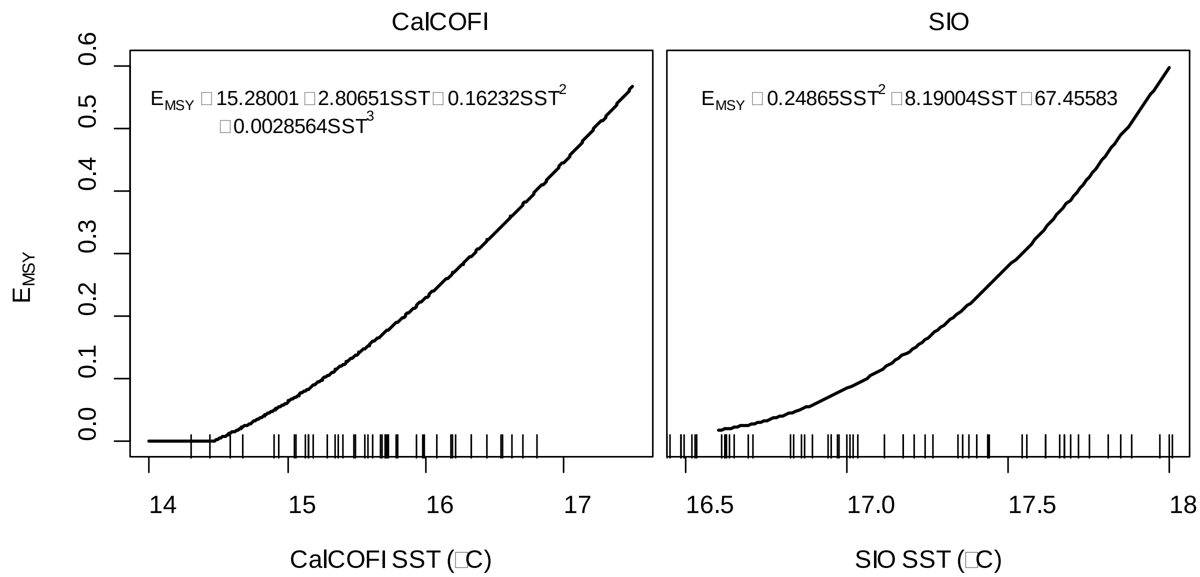


Figure 4. Polynomial approximation to the relationship between CalCOFI SST and E_{MSY} (left), and SIO SST and E_{MSY} (right). Marks at the bottom of each plot represent the spread of each series' SST data. Note that the scale in both plots is different.

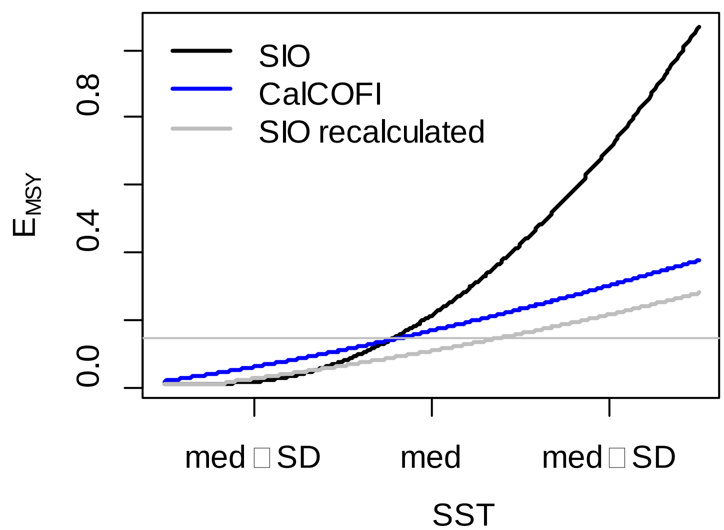


Figure 5. Unitless comparison between the SIO- and CalCOFI-based relationship between SST and E_{MSY}, centered around the median of the observed SST for each time series during the period 1984-2008. The gray horizontal line indicates 0.15.

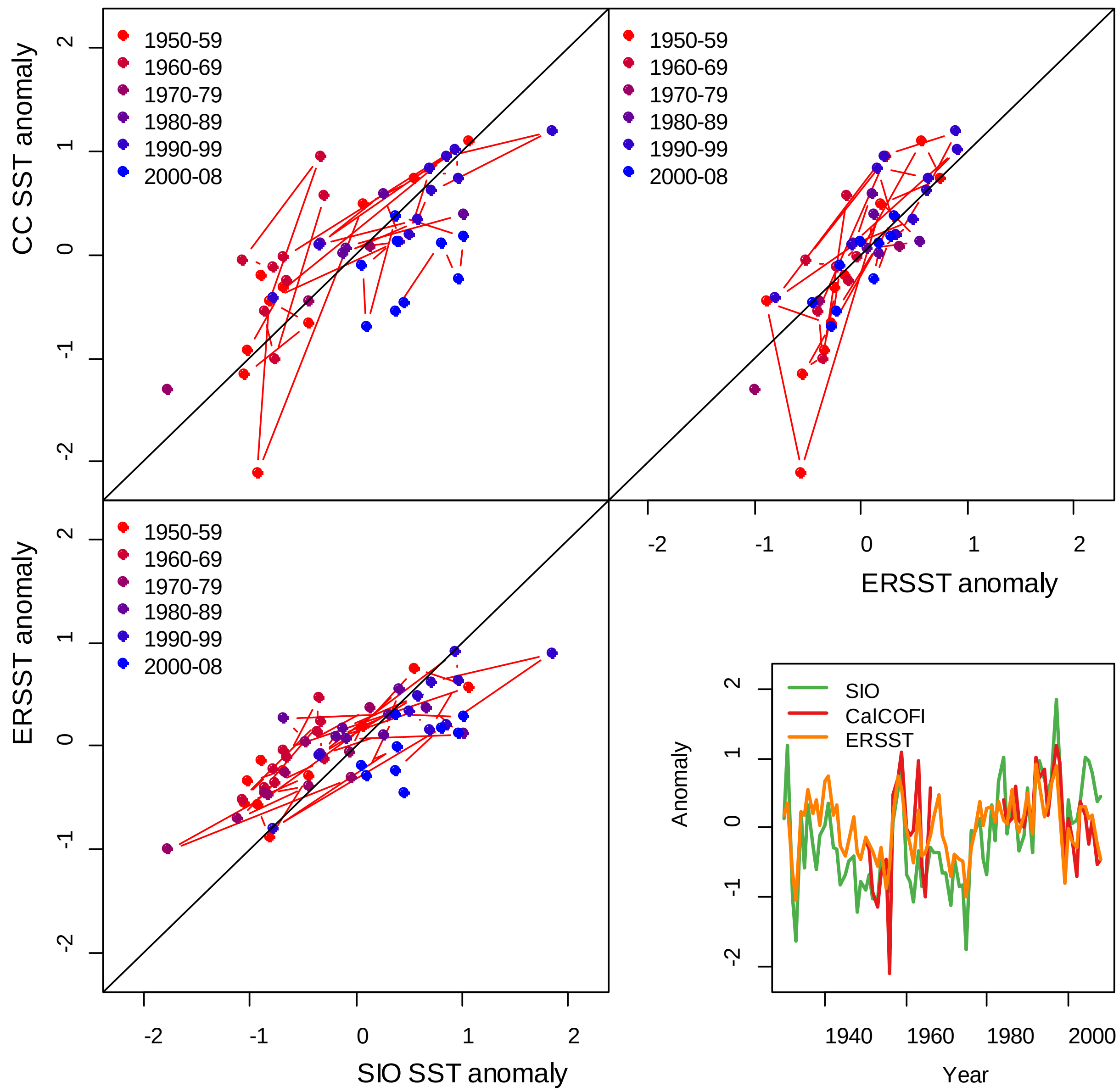


Figure 6. Comparison of the SIO_SST_ann, SST_CC_ann and ERSST_ann time series.

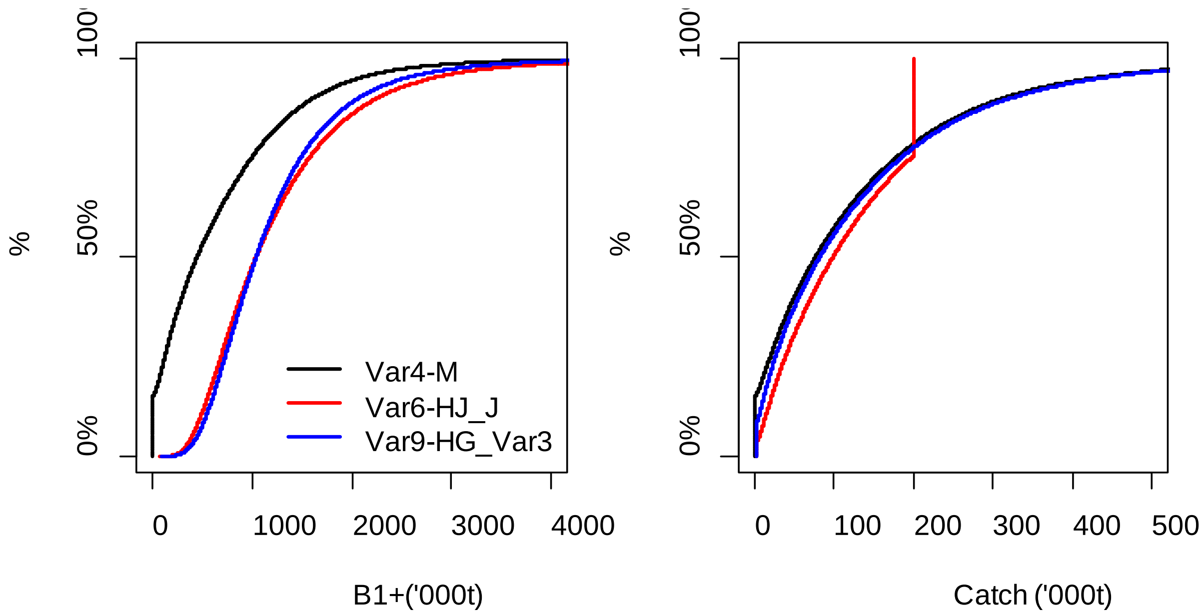


Figure 7. Cumulative distributions for biomass (1+) and catch for three harvest control rule variants.

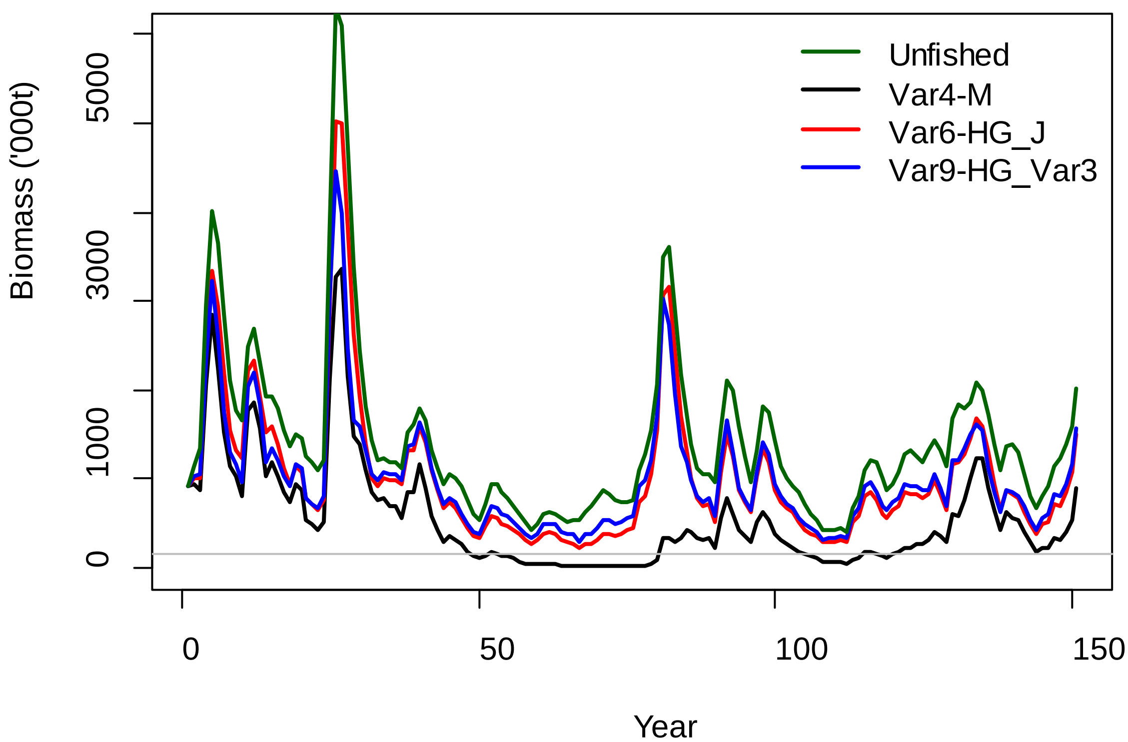


Figure 8. Example 150-year time-trajectories of 1+ biomass for three harvest control rule variants. The horizontal gray line indicates 150,000t.

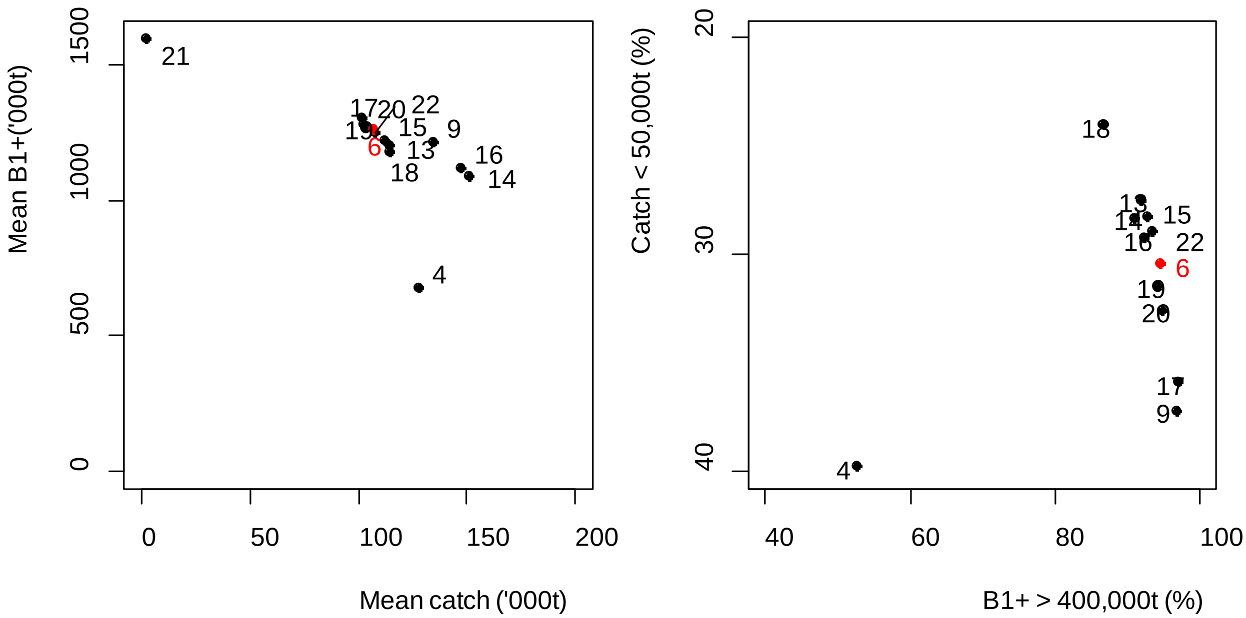


Figure 9. Trade-offs plots (mean annual catch when the catch is non-zero vs 1+ biomass [left]; and the probability of a catch < 50,000t vs. the probability of 1+ biomass exceeding 400,000t [right]) for the base-case scenario. The numbers denote the values used to refer to the harvest control rule variants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

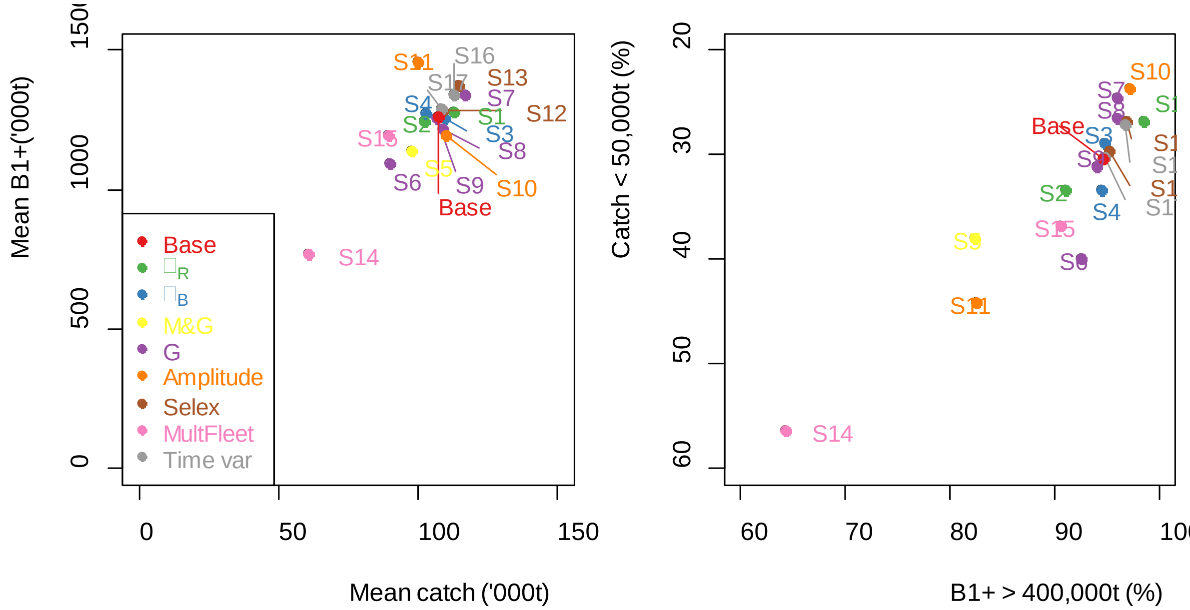


Figure 10. Trade-offs plots (mean annual catch when the catch is non-zero vs 1+ biomass [left]; and the probability of a catch < 50,000t vs. the probability of 1+ biomass exceeding 400,000t [right]) for the various selectivity scenarios. The numbers denote the values used to refer to the sensitivity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

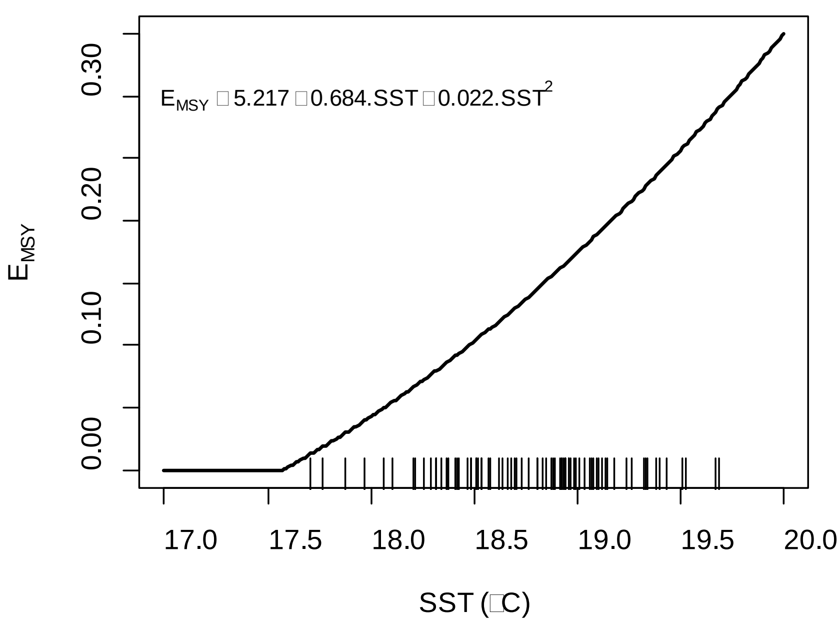


Figure 11. Polynomial approximation to the relationship between ERSST and E_{MSY}. Marks at the bottom of the plot represent the spread of ERSST data.

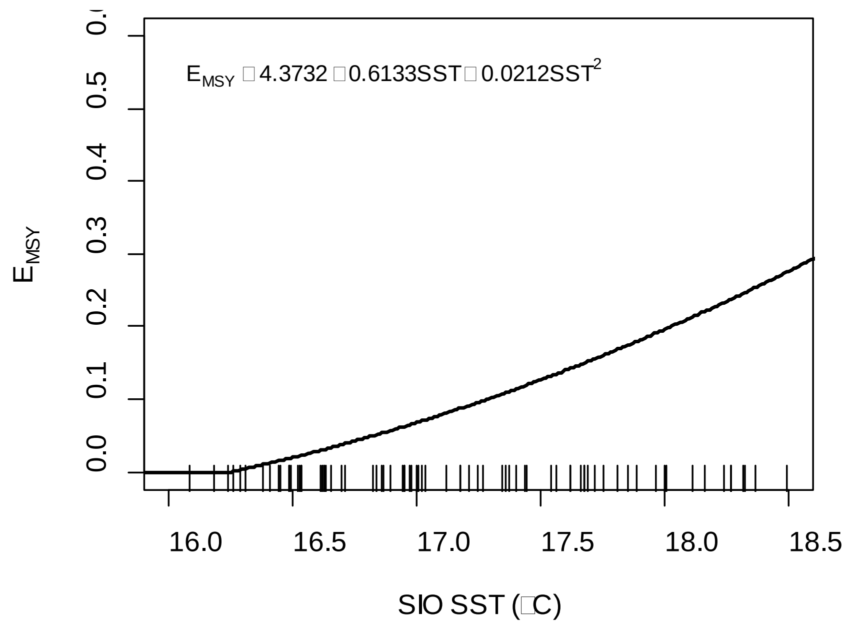


Figure 12. Polynomial approximation to the recalculated relationship between SIO and E_{MSY}. Marks at the bottom of the plot represent the spread of SIO data.

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:

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

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:

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

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:

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

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 *F*s for the MexCal area to the PNW. The selectivity-at-age for the MexCal fleet is:

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

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, $\hat{B}_y^{1+} = B_y^{1+} e^{\psi}; \psi \sim N\left(0, \sigma_B\right)$, which was modified to:

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

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

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-average 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	-13.788
β	-0.001198
ϕ	1.076

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	0.337	
Variance of the environmental variable about its expectation, σ_v	0.477	
Amplitude of the underlying environmental signal, ψ	0.434	
Scaling parameter, ϕ	1.076	
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**)	σ_B =0.268	0.268 is the CV of ending biomass from the 2012 assessment
Higher variation in estimated biomass (**σ_B=0.5**)	σ_B =0.5	
Lower auto-correlation in assessment error (**ρ_B=0.5**)	ρ_B =0.5	
Natural mortality increases when the environment is trending downwards **(M&G)**	[M=0.4 yr^{-1} when ΔG>0; M=0.8 yr^{-1} when ΔG<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)**	ψ =0.217	
The environment fluctuates more than for the base-case **(Amp=2)**	ψ =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

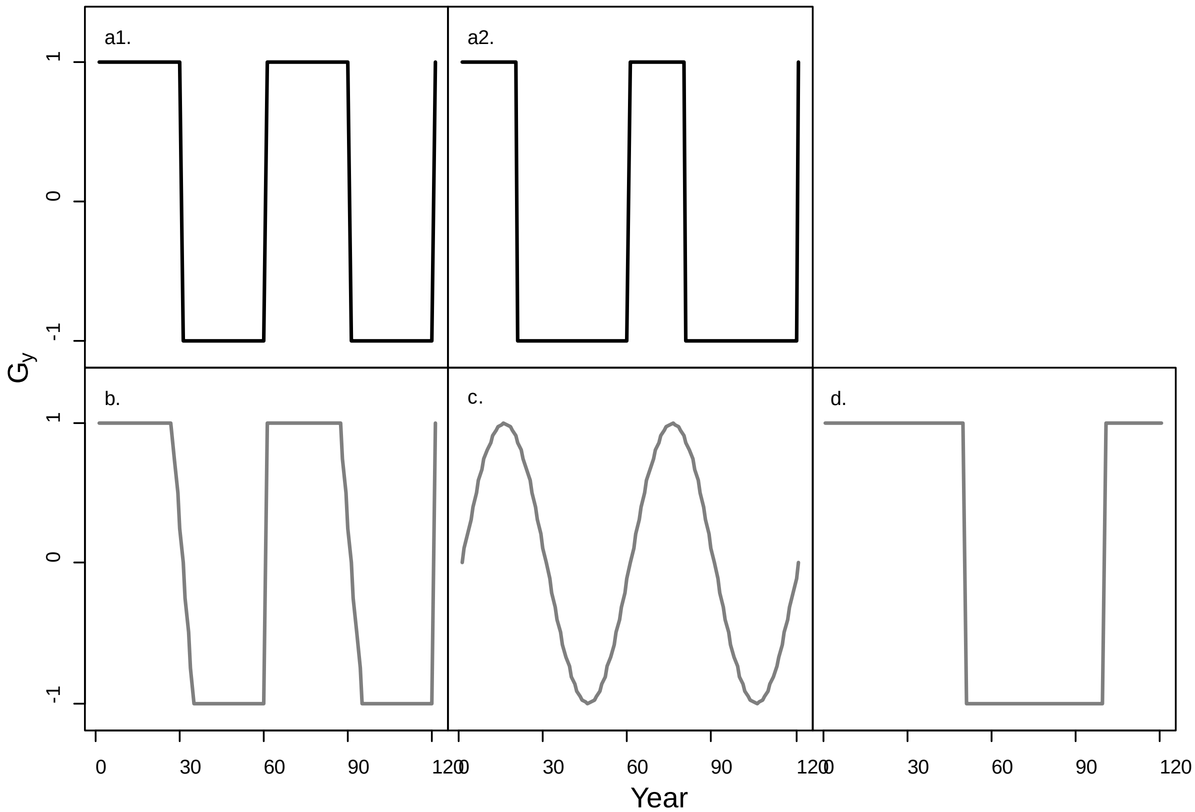


Figure App.A.1. Defined shapes for the environmental signal G_y. a1) is the base case; a2), b), c) and d) are sensitivity tests.

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	0.288	0.613	-	5.0
SQ with AC	0.293	0.601	0.214	5.1
Sin	0.340	0.626	-	6.9

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	0.353	0.582	-	0.500
SQ with AC	0.362	0.564	0.302	-0.312
Sin	0.449	0.592	-	1.959

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

Model	Amplitude	σ_V	ρ_V	AIC
SQ	0.428	0.494	-	-12.832
SQ with AC	0.434	0.477	0.337	-13.744
Sin	0.592	0.488	-	-13.811

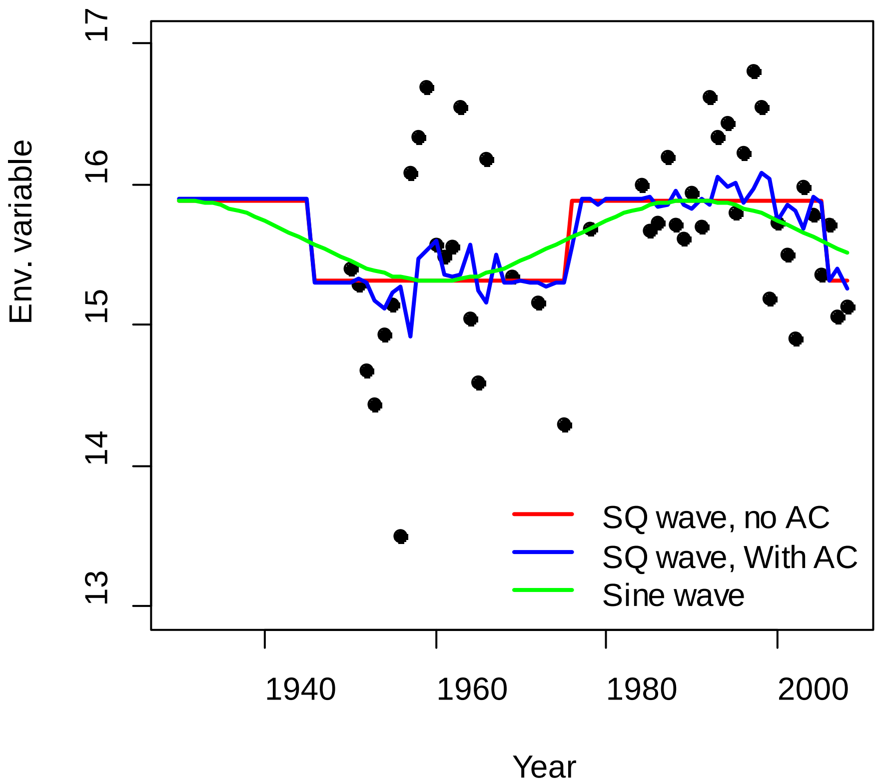


Figure App.B.1. Fits of each model to the SST_CC_ann data

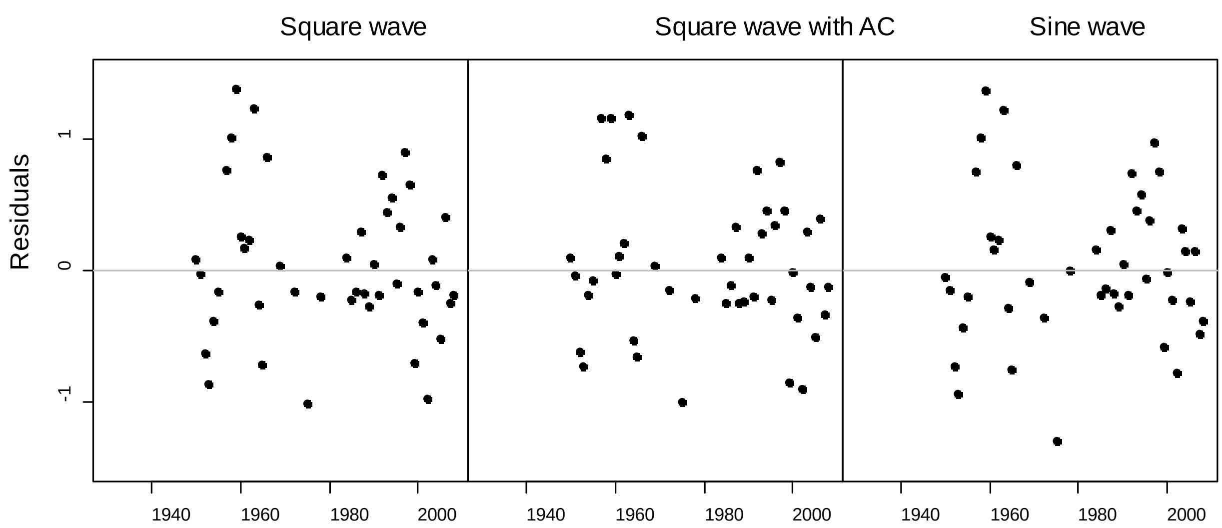


Figure App.B.2. Residual plot for the three models

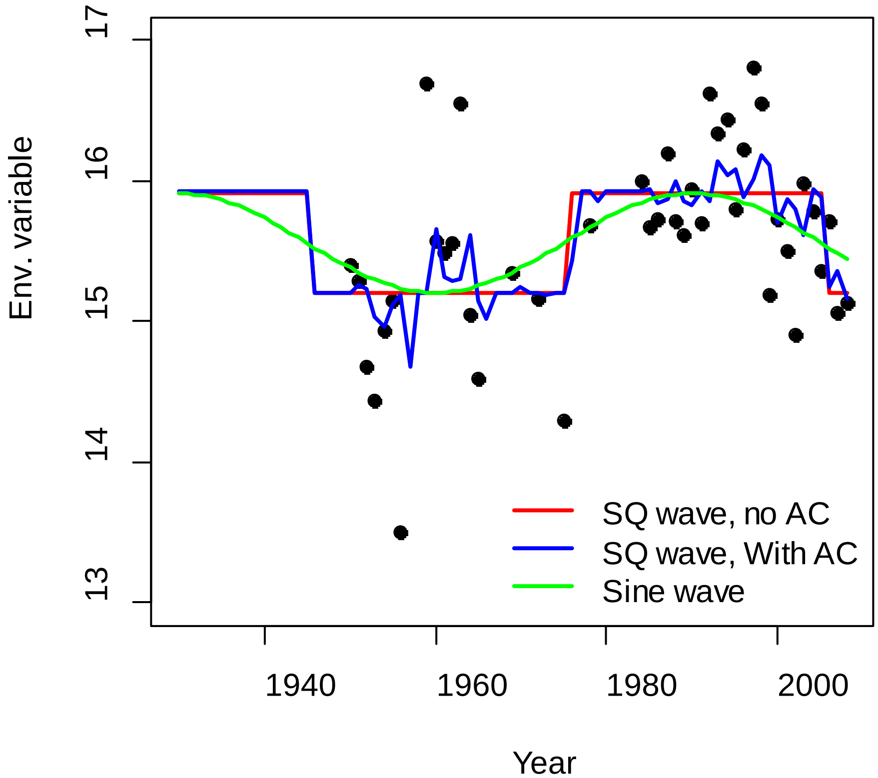


Figure App.B.3. Fits of each model to the SST_CC_ann data removing the three El Nino years

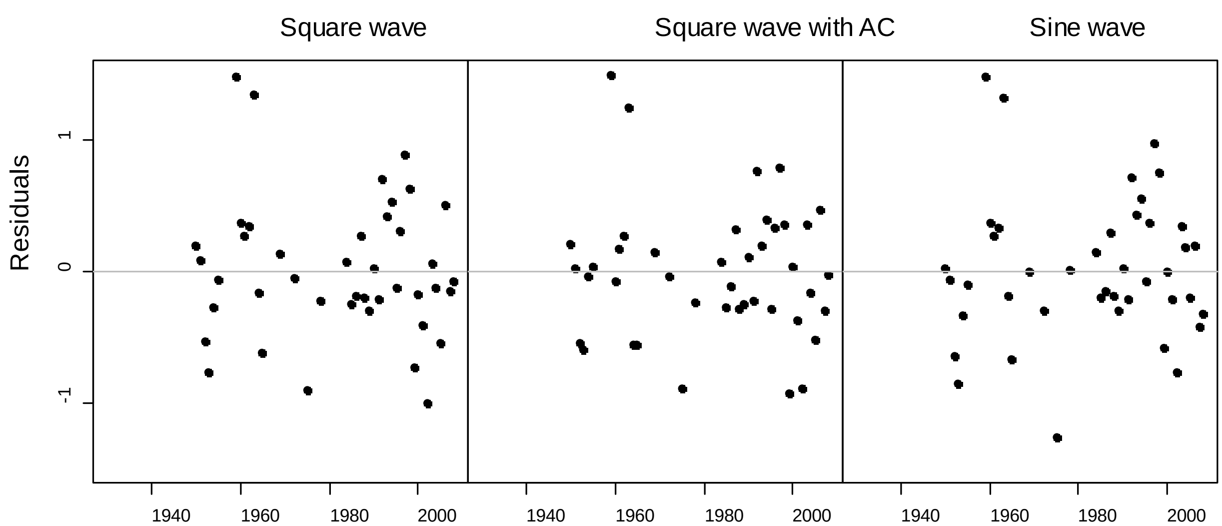


Figure App.B.4. Residual plot for the three models removing the three El Nino years

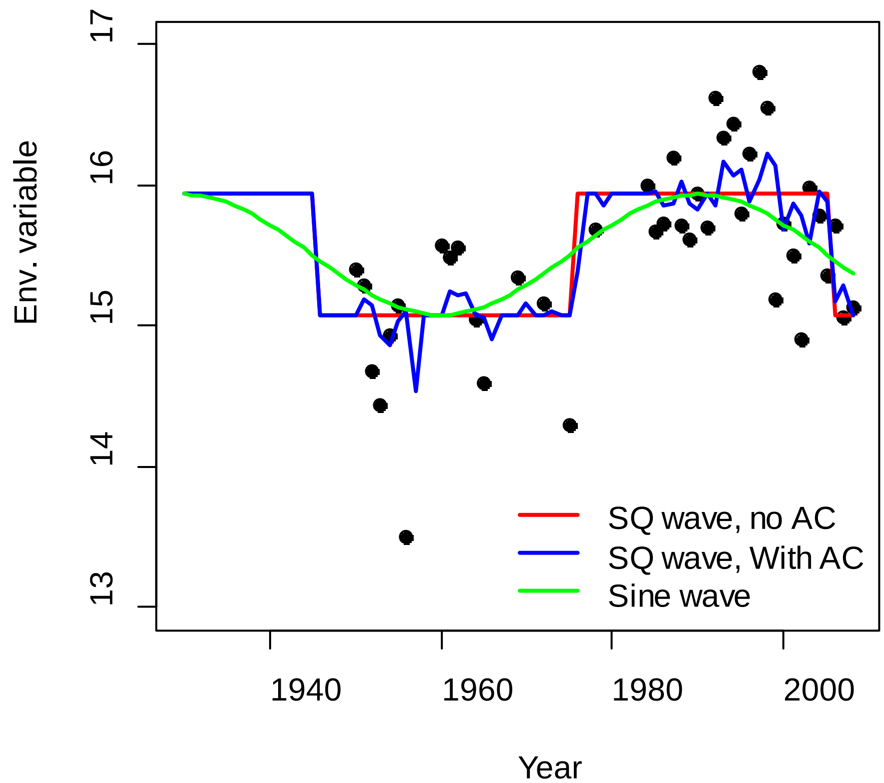


Figure App.B.5. Fits of each model to the SST_CC_ann data removing all five unusual years

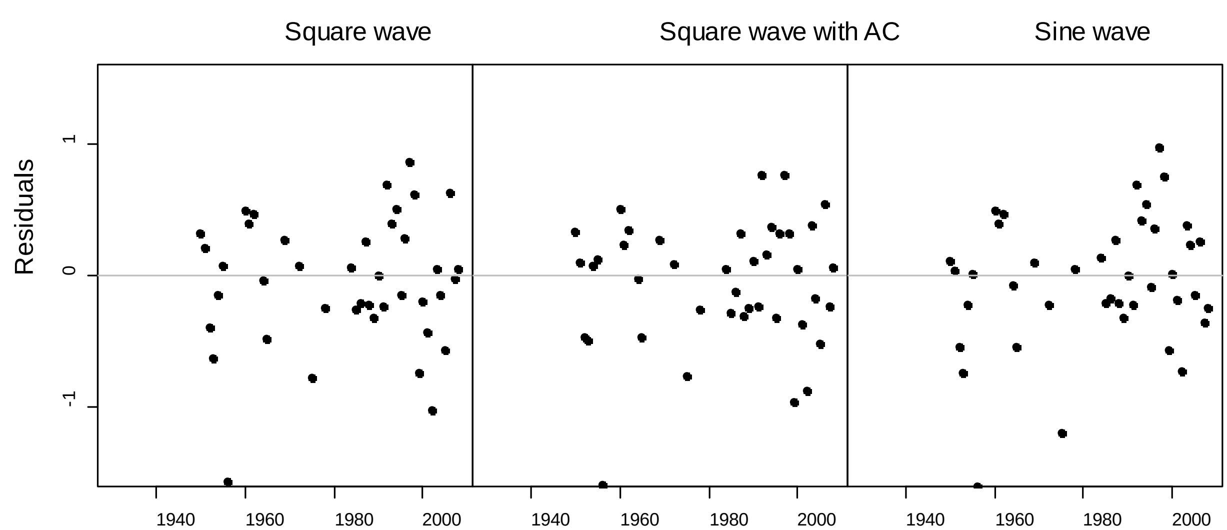
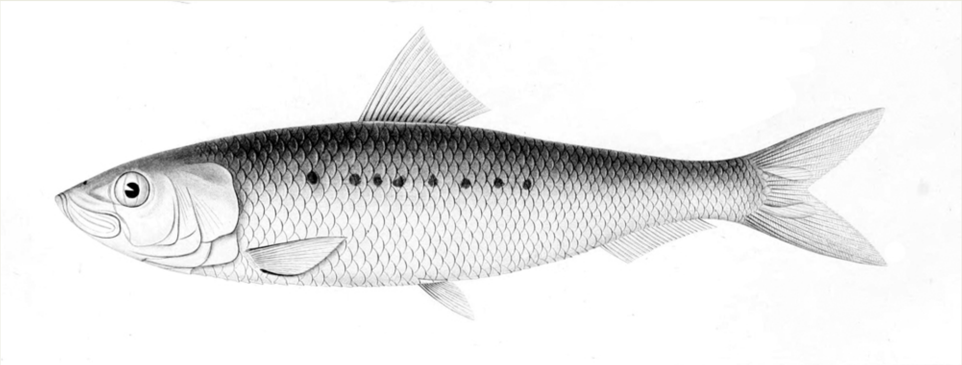


Figure App.B.6. Residual plot for the three models removing all five unusual years

Agenda Item I.4.b
Supplemental Analyses Related to Sardine Harvest Parameters PowerPoint
June 2013

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)

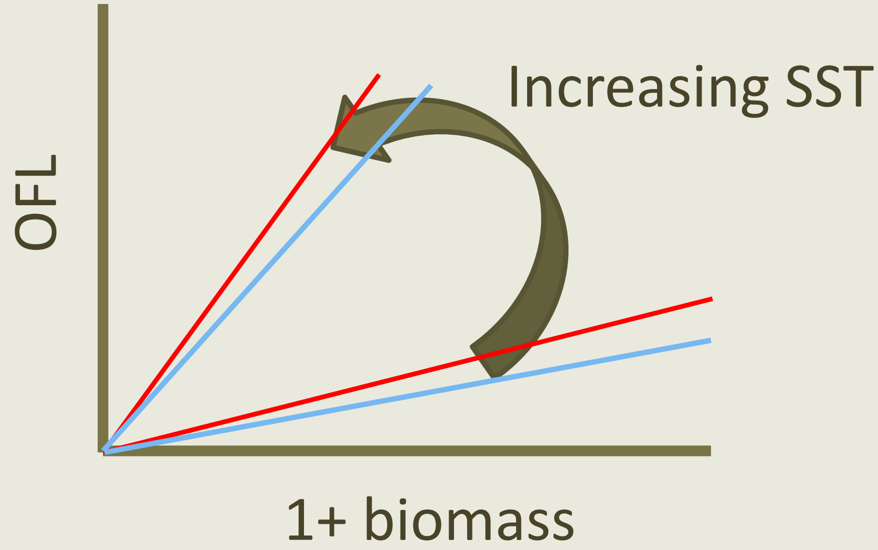
Overfishing Level (OFL)

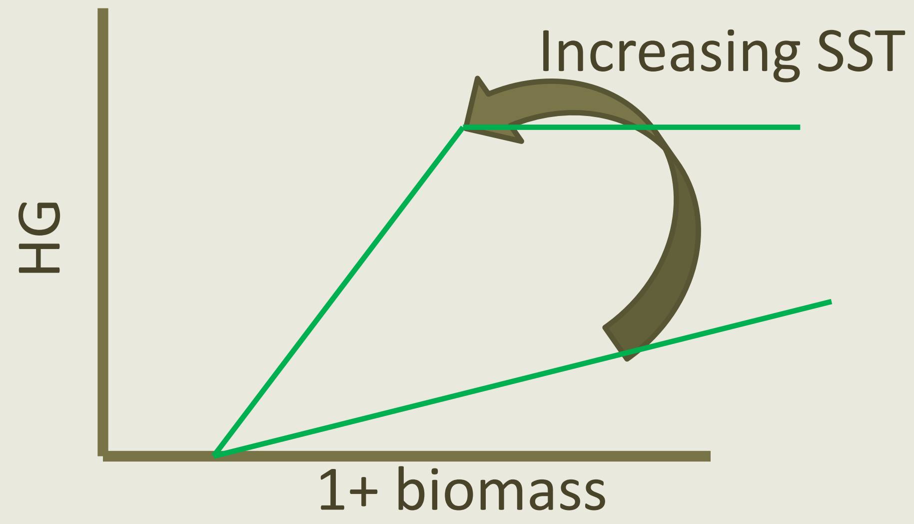
↓ *P**

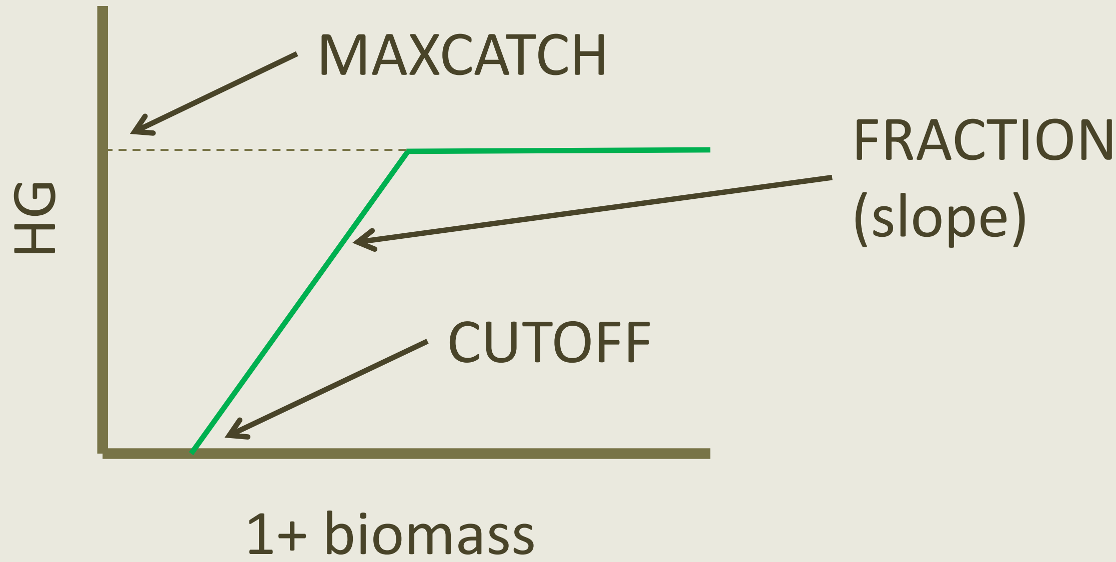
Acceptable Biological Catch (ABC)

↓

Harvest Guideline (HG)







ISSUE:

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

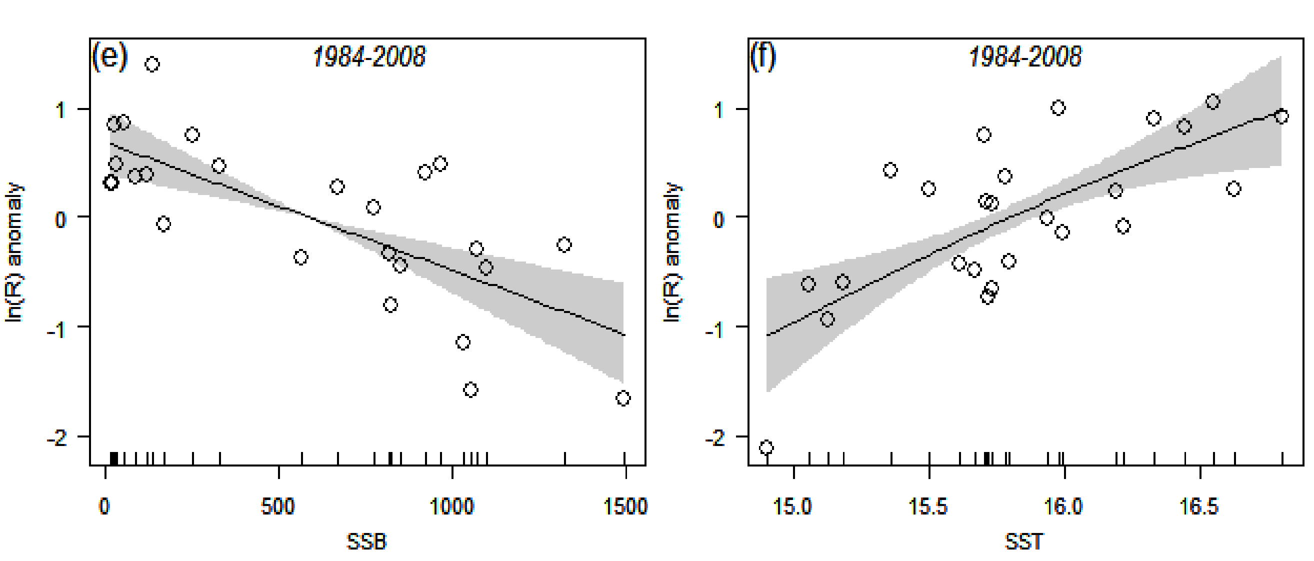
Background

- 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



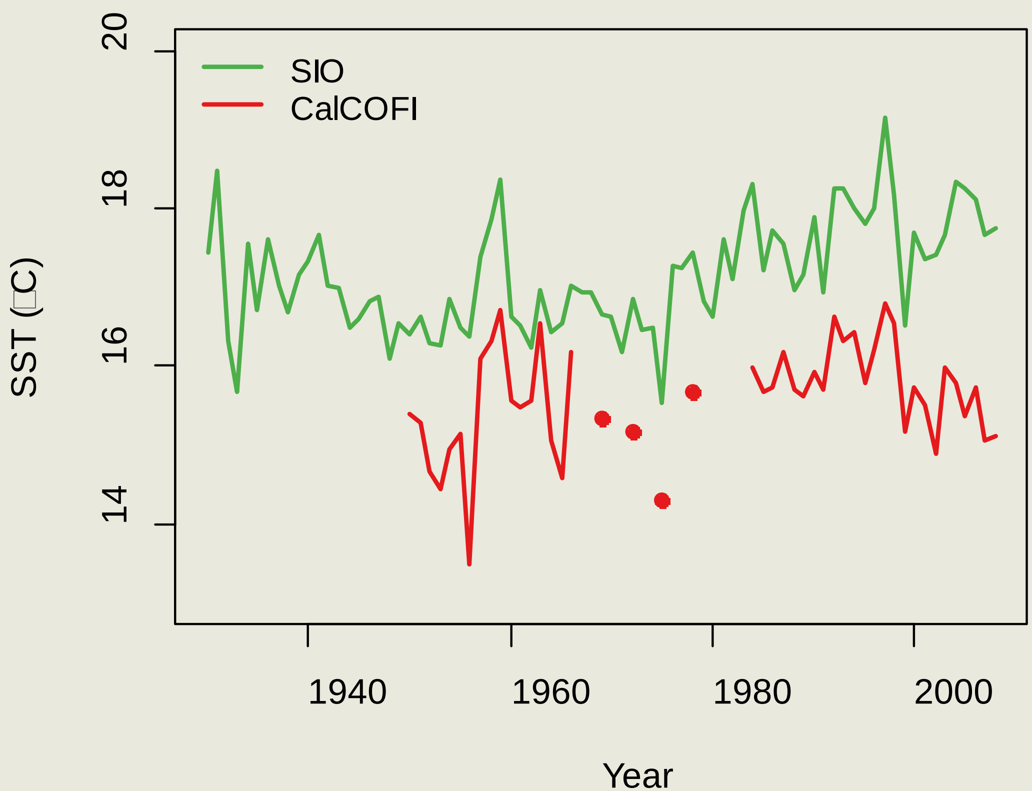
The relation between several environmental indices and recruitment was evaluated.

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

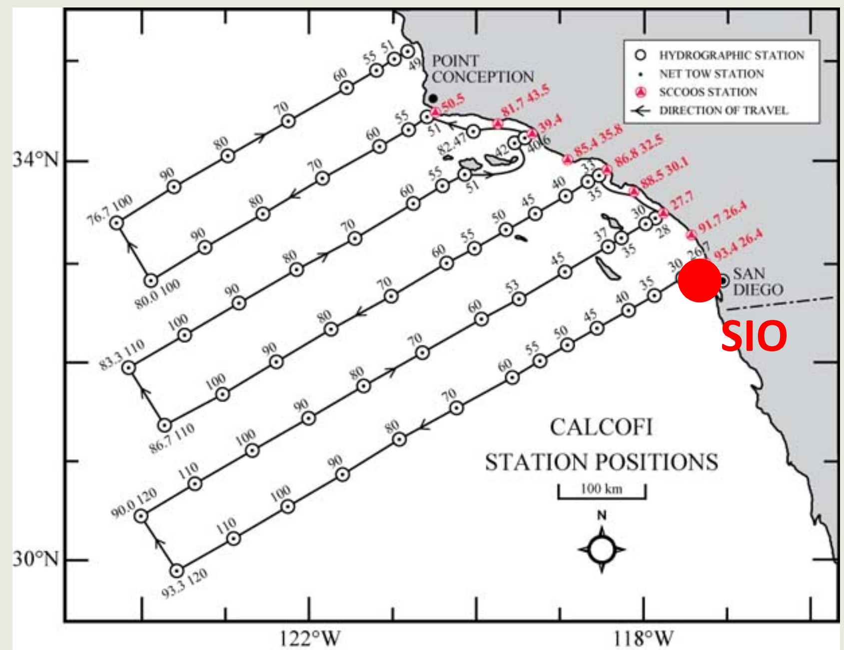
Series	AIC	R^2
SST_CC_ann	44.49	0.76
SIO_SST_ann	56.81	0.61
ERSST_ann	55.3	0.63

From PFMC 2013, Table App.E.6

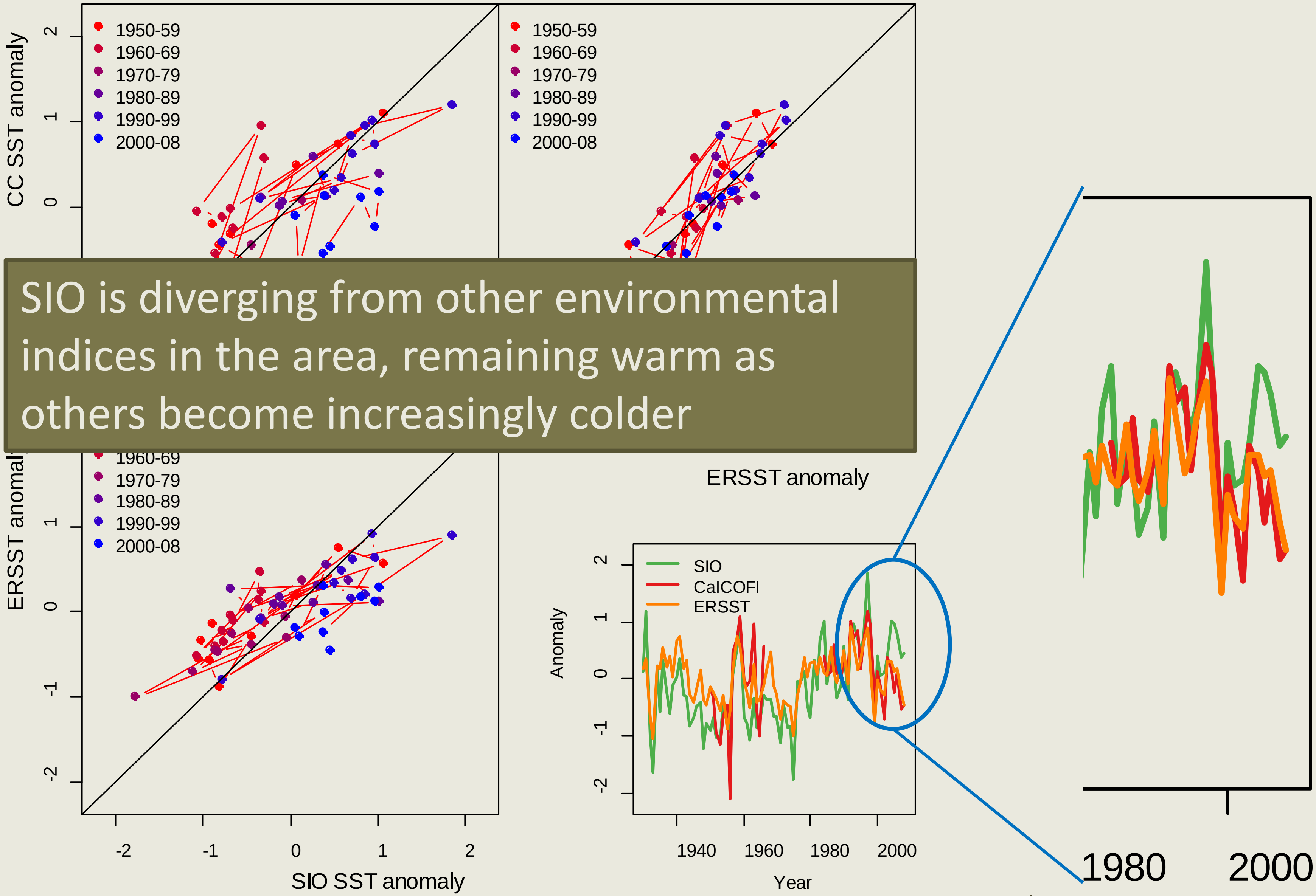
SIO is the index being used in the current harvest control rule. CalCOFI is the index that better explains recruitment



SIO and CalCOFI indices have different scales, and are representative of different geographical areas.



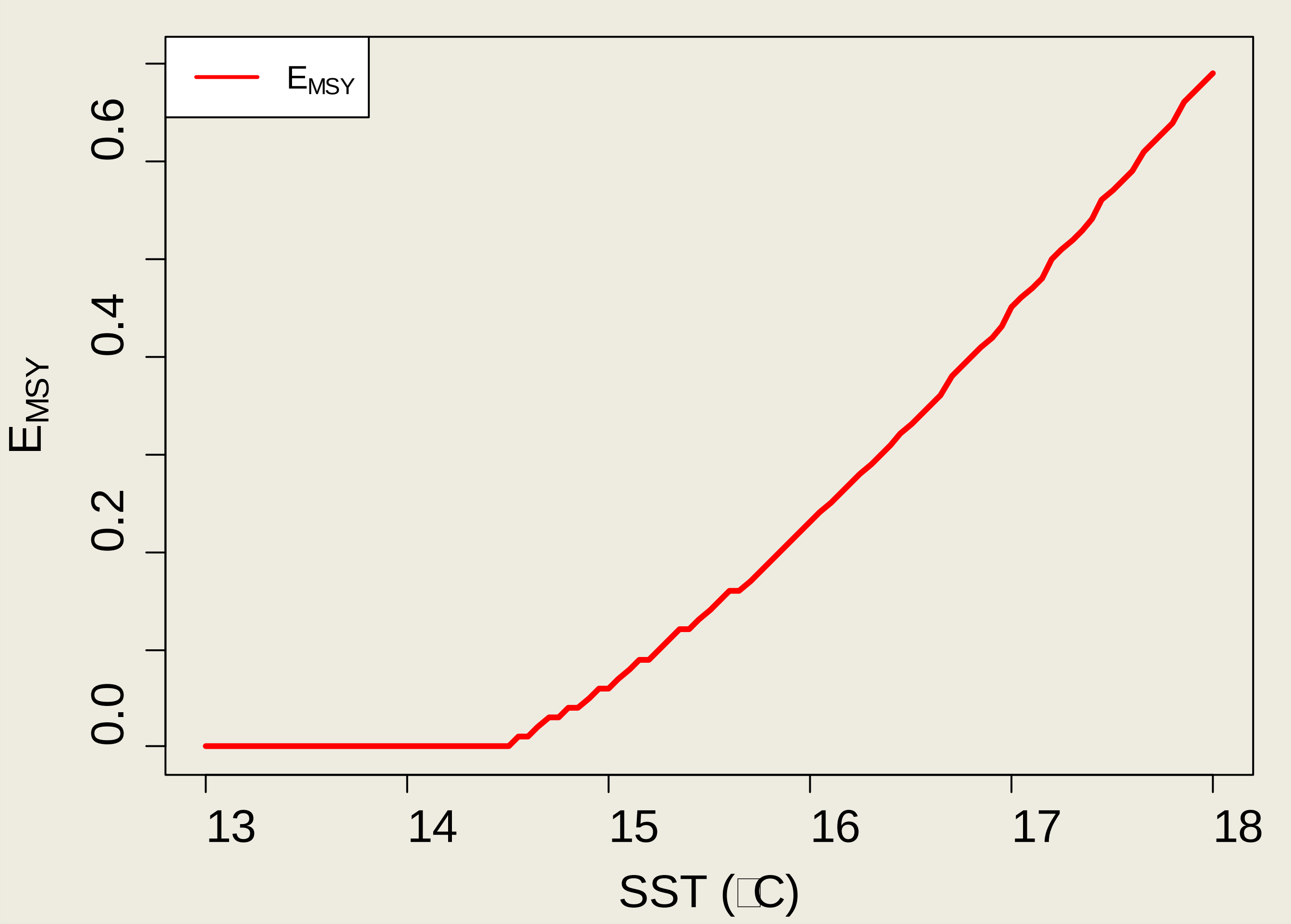
Comparing sea surface temperature time series



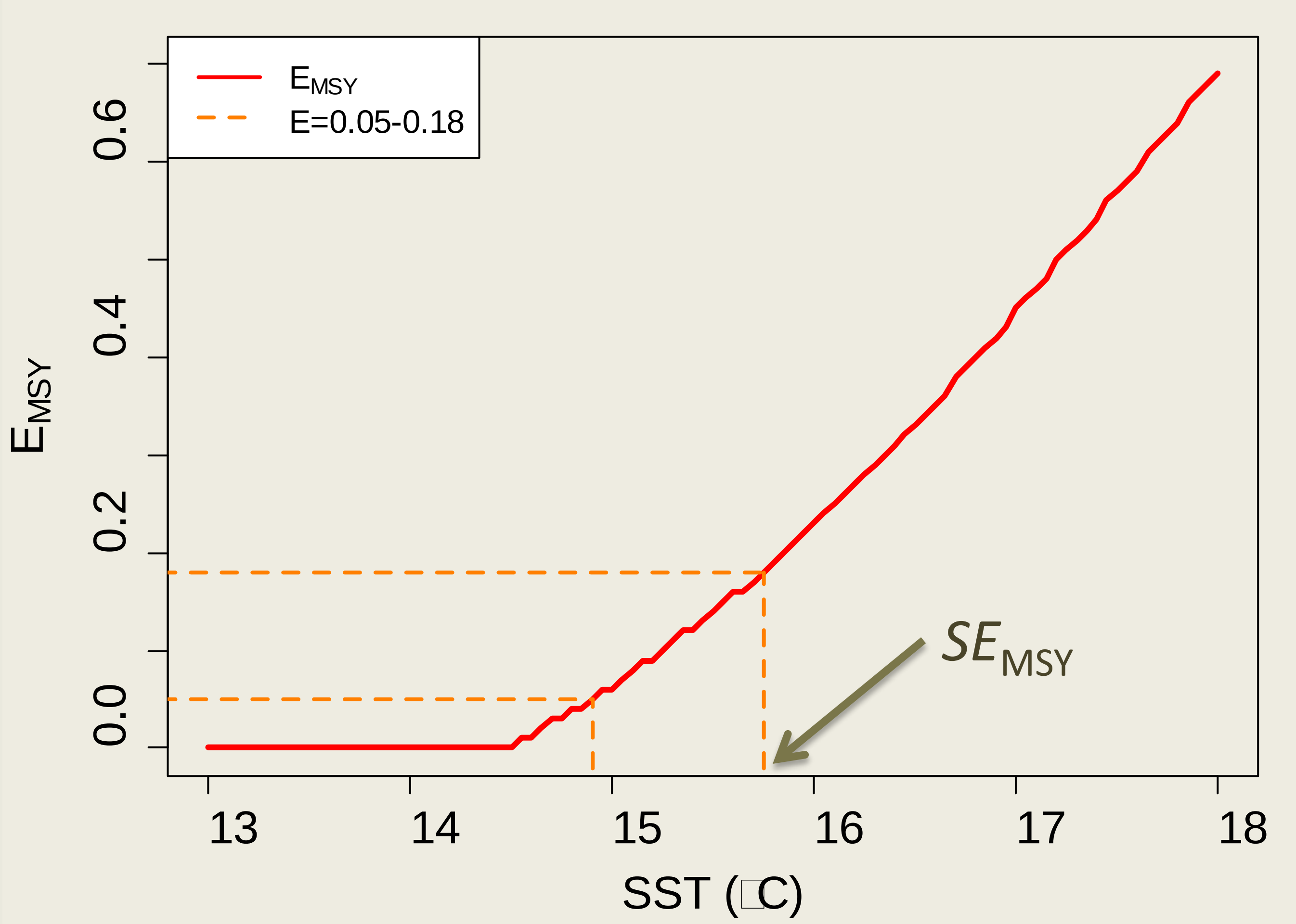
SIO is diverging from other environmental indices in the area, remaining warm as others become increasingly colder

RECALCULATED RELATIONSHIP BETWEEN ENVIRONMENT AND E_{MSY}

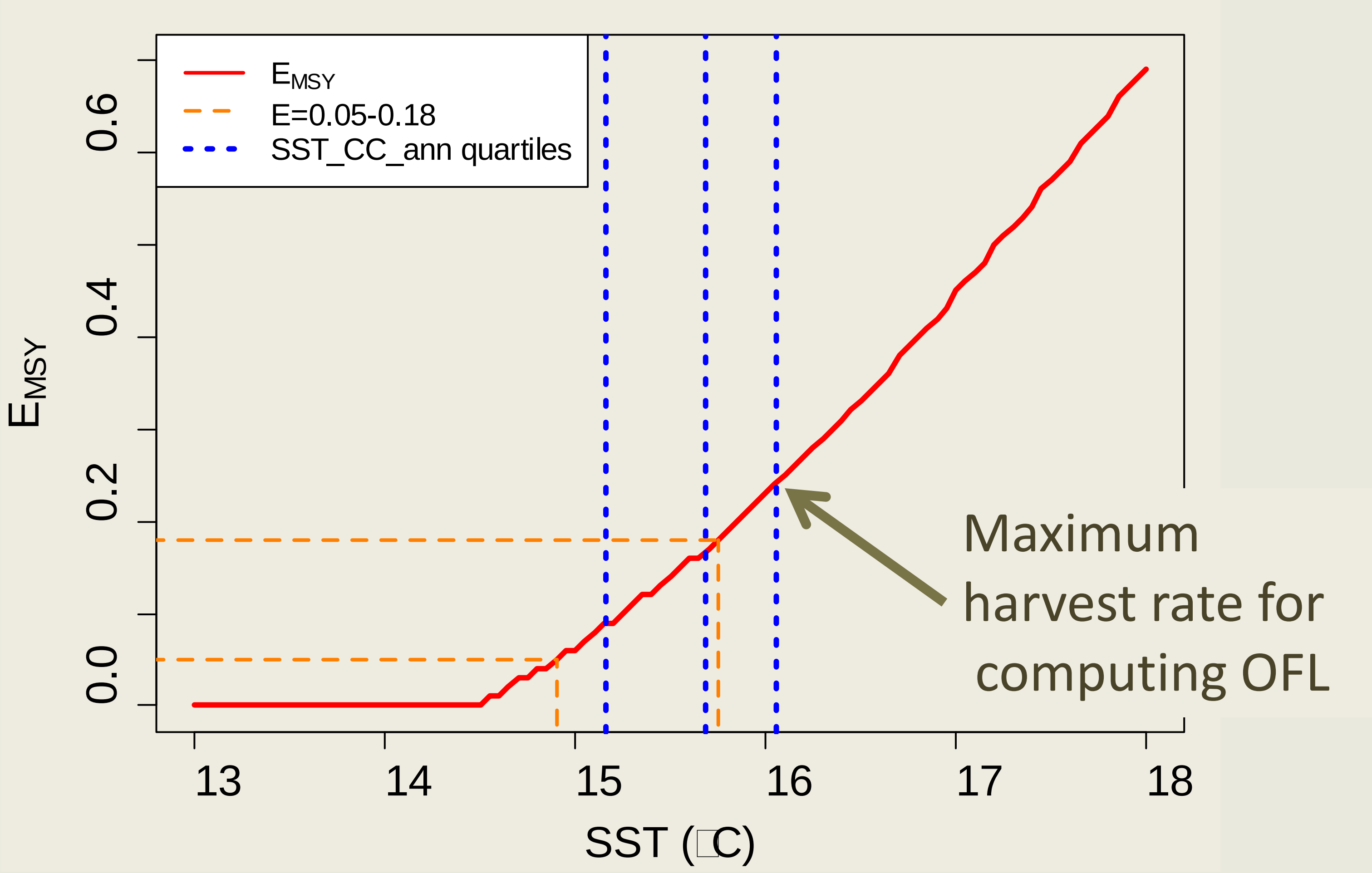
Calibrating the "CalCOFI" HG control rule



Calibrating the "CalCOFI" HG control rule



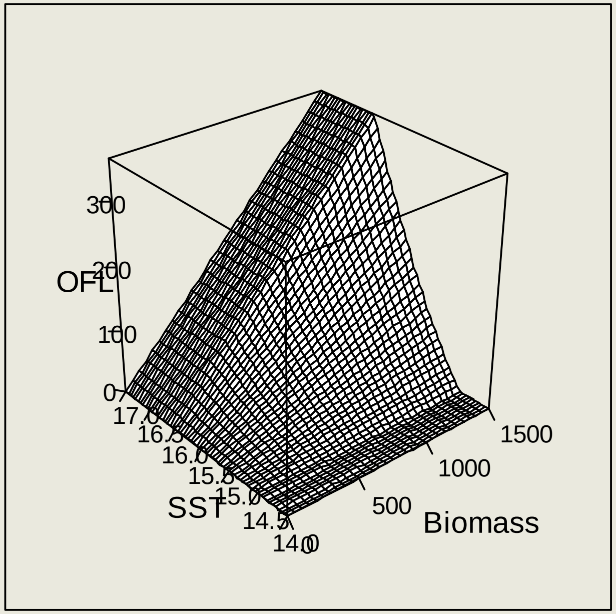
Calibrating the “CalCOFI” HG control rule



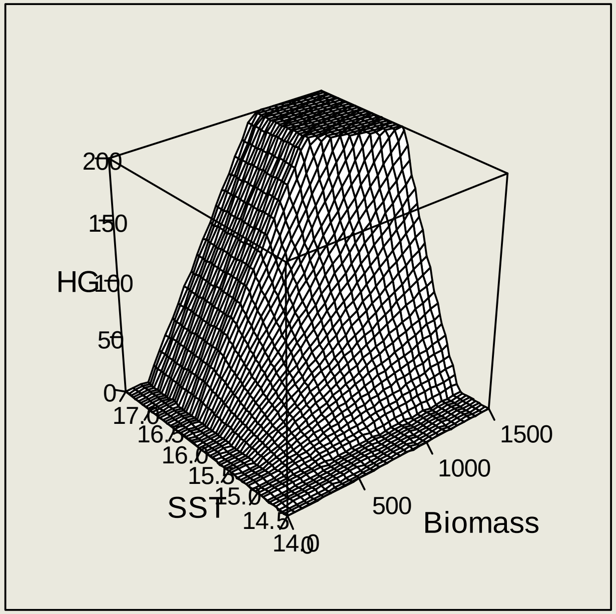
CalCOFI-based harvest control rule

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

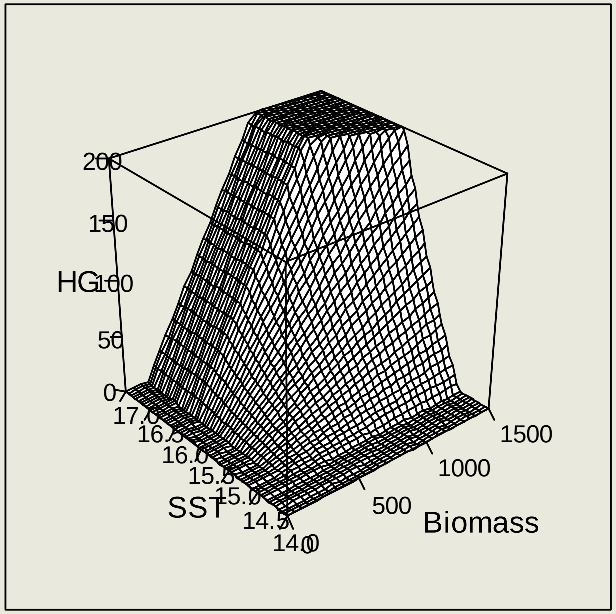
OFL control rule



HG control rule

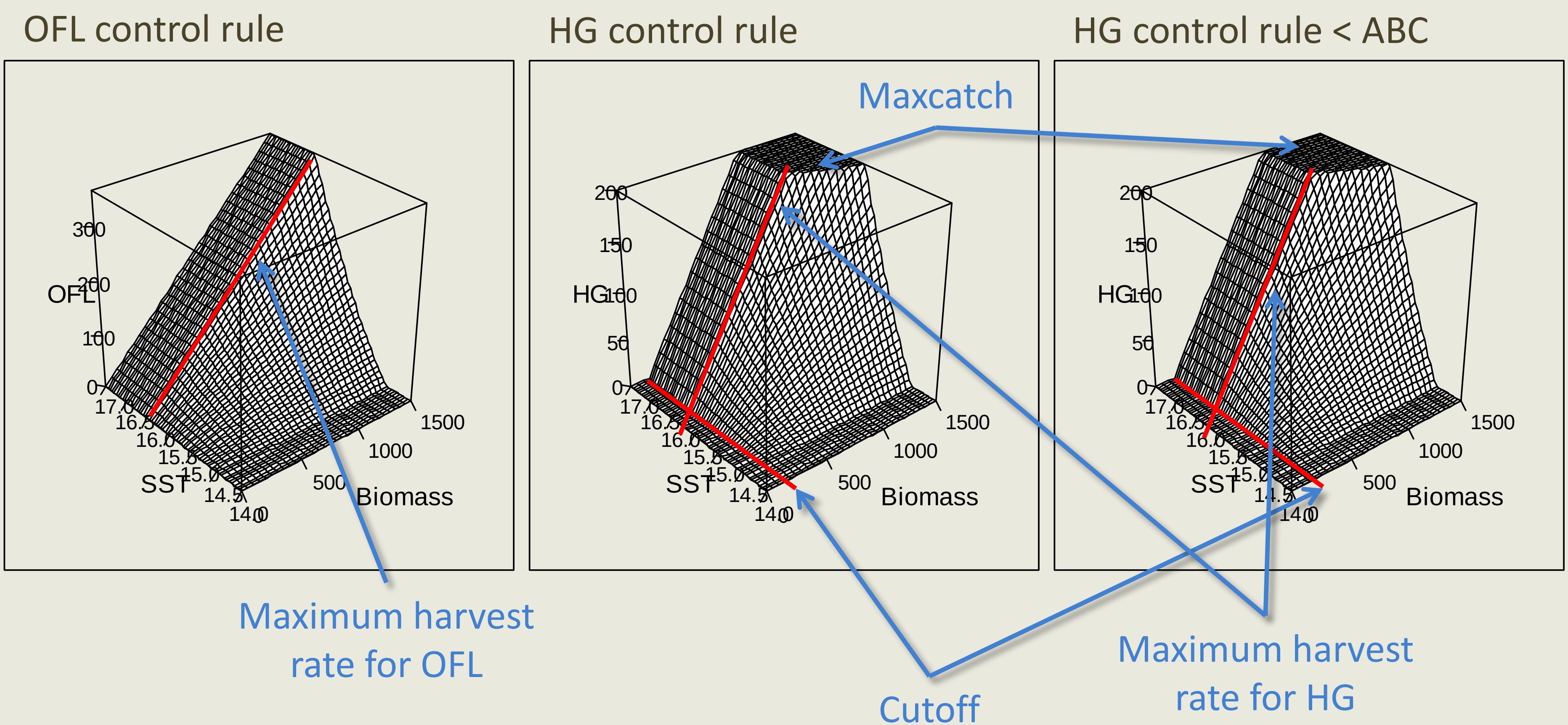


HG control rule < ABC



CalCOFI-based harvest control rule

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



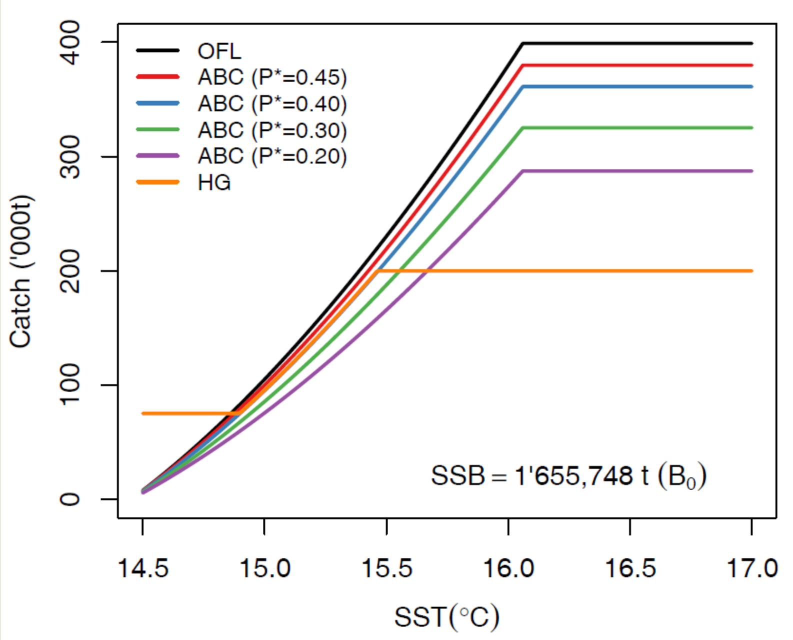
Comparison of the current HCR using CalCOFI as temperature index, revised

Mgmt. Year	Biomass (July)	SIO	
		SST	HG
2000	1581346	18.08	186791
2001	1182465	17.75	134737
2002	1057599	17.24	118442
2003	999871	17.31	110908
2004	1090587	17.46	122747
2005	1193515	17.6	136179
2006	1061391	18.03	118937
2007	1319072	18.11	152564
2008	832706	18.12	89093
2009	662886	17.83	66932
2010	702024	17.84	72039
2011	537173	17.9	50526
2012	988385	17.64	109409
2013	659539	17.35	66495

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”.

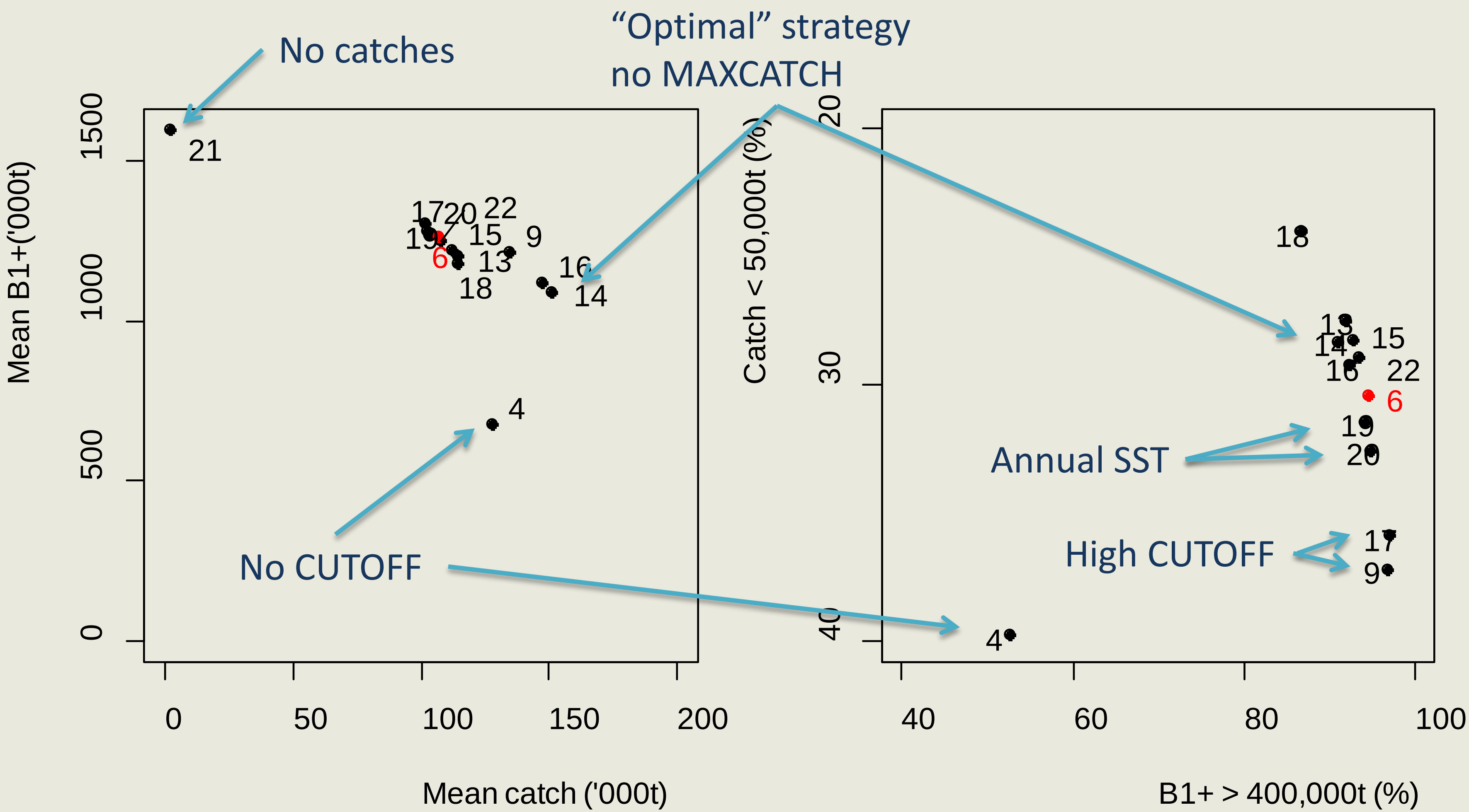


Quantifying trade-offs between different HCR variants: Biomass vs. catch

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



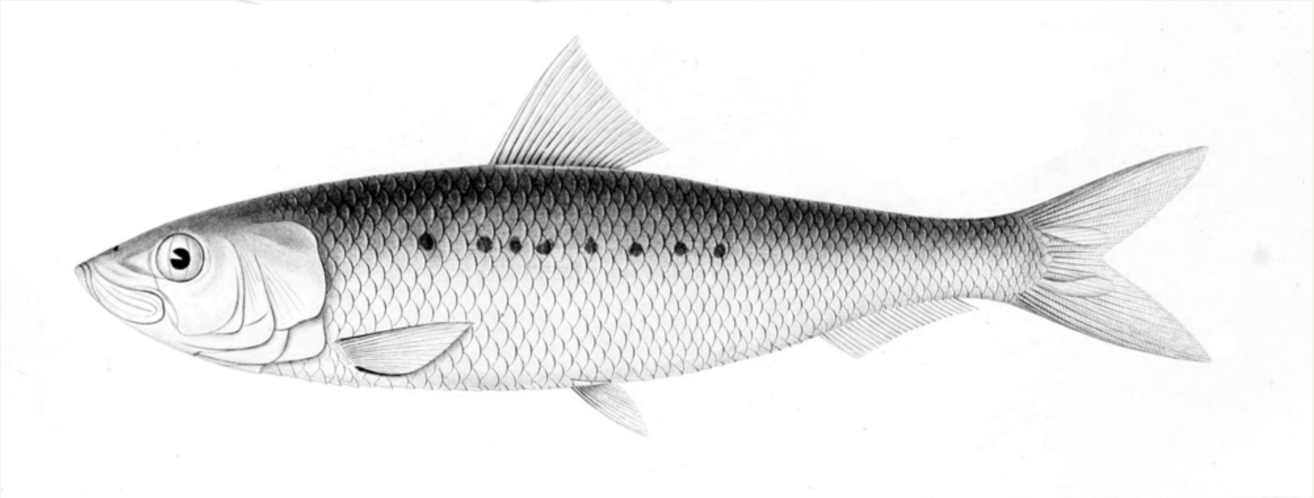
CONCLUSIONS

- 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

HCR variants evaluated for the base case

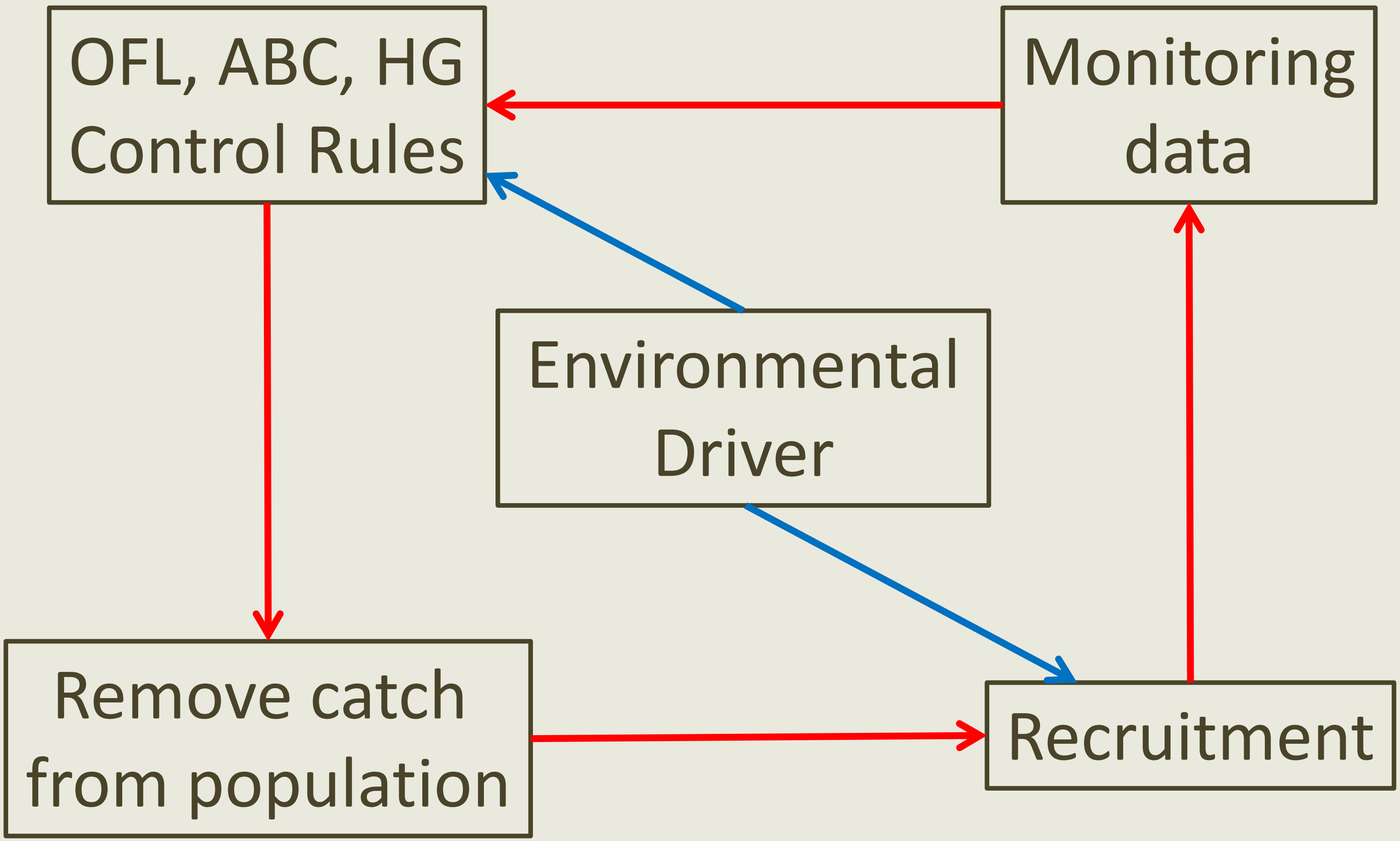
	Variants from Hurtado-Ferro and Punt (2013)				
Variant	**M (4)**	**HG (J) (6)**	**HG Variant-3 (9)**	**Alt-3 (13)**	**Alt-4 (14)**
FRACTION (%)	DE_{MSY}	5-15	5- SE_{MSY}	11- SE_{MSY}	SE_{MSY}
CUTOFF	0	150	$0.20B_0$	50	50
MAXCAT		200		200	-
	Additional analyses				
Variant	**New-1 (15)**	**New-2 (16)**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

* OFL/ABC = 0.18

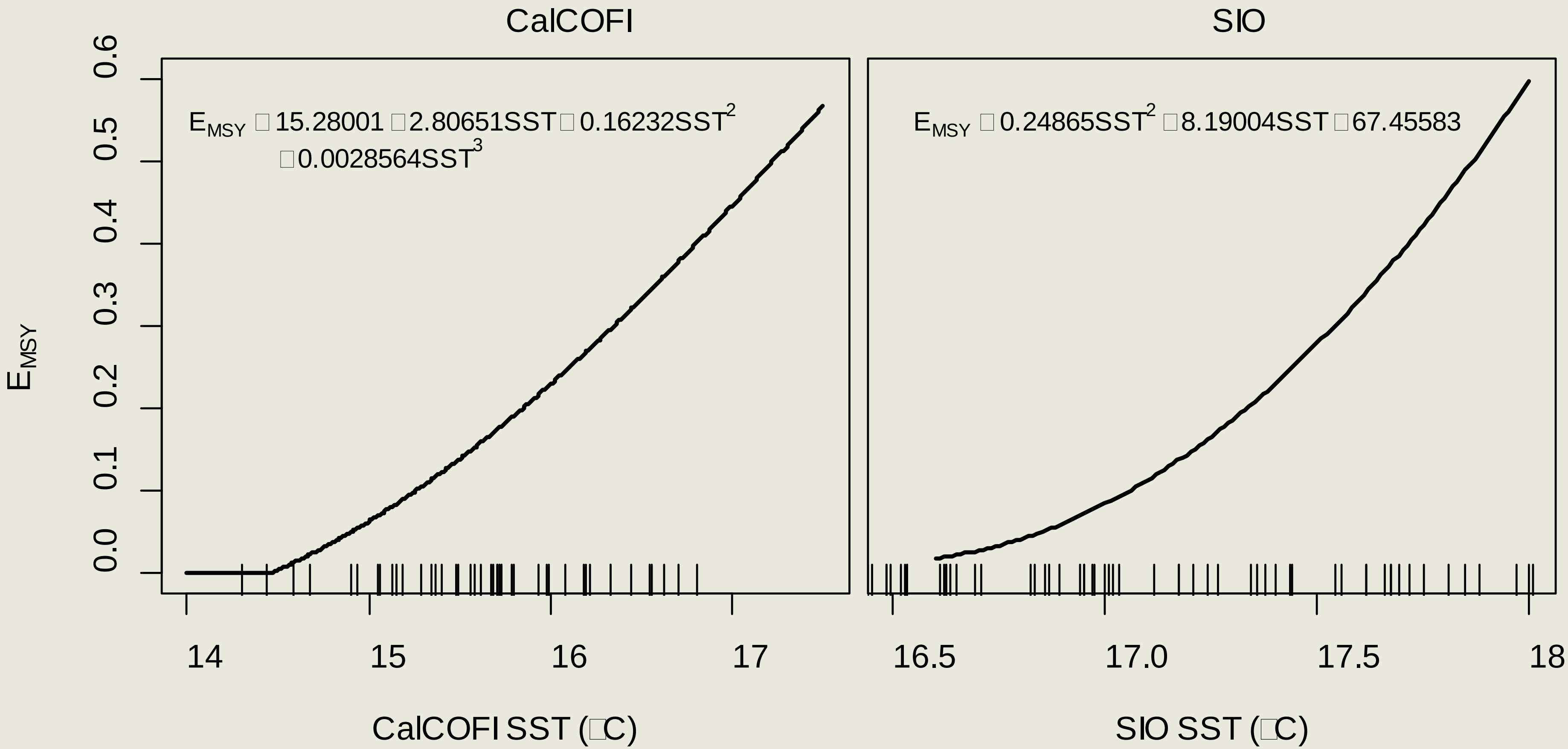
** OFL/ABC based on E_{MSY} (0-0.26), linked to CC_SST_ann

$SE_{MSY} = 0.18$

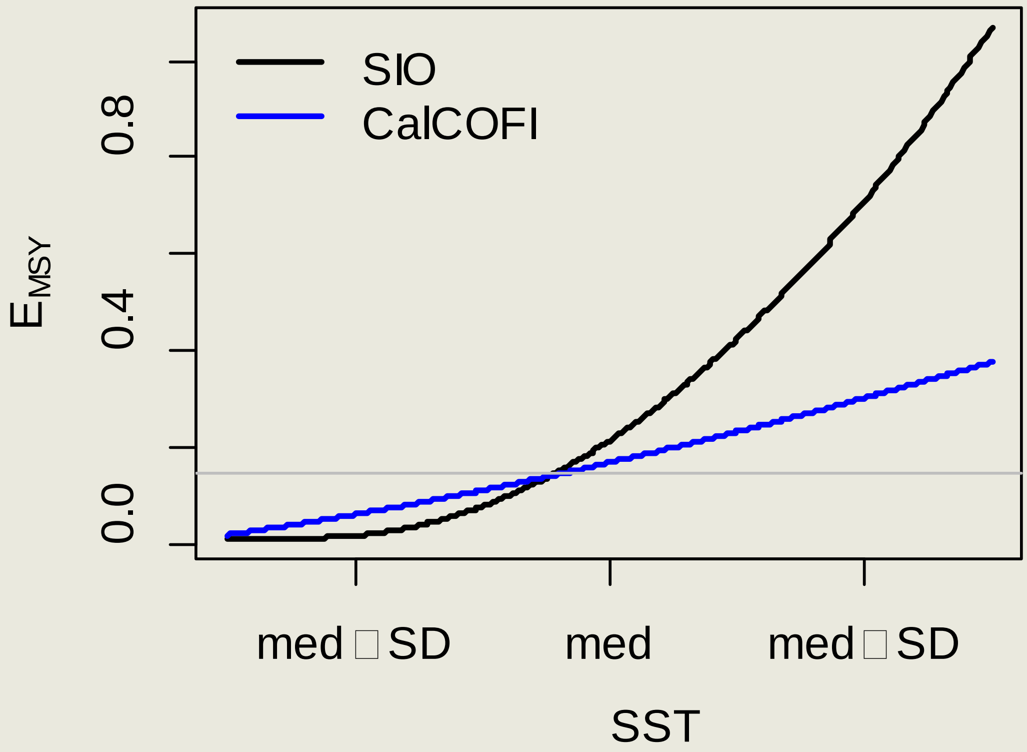
Risk Assessment Framework



Polynomial approximations to revised and current relationship between E_{MSY} and SST

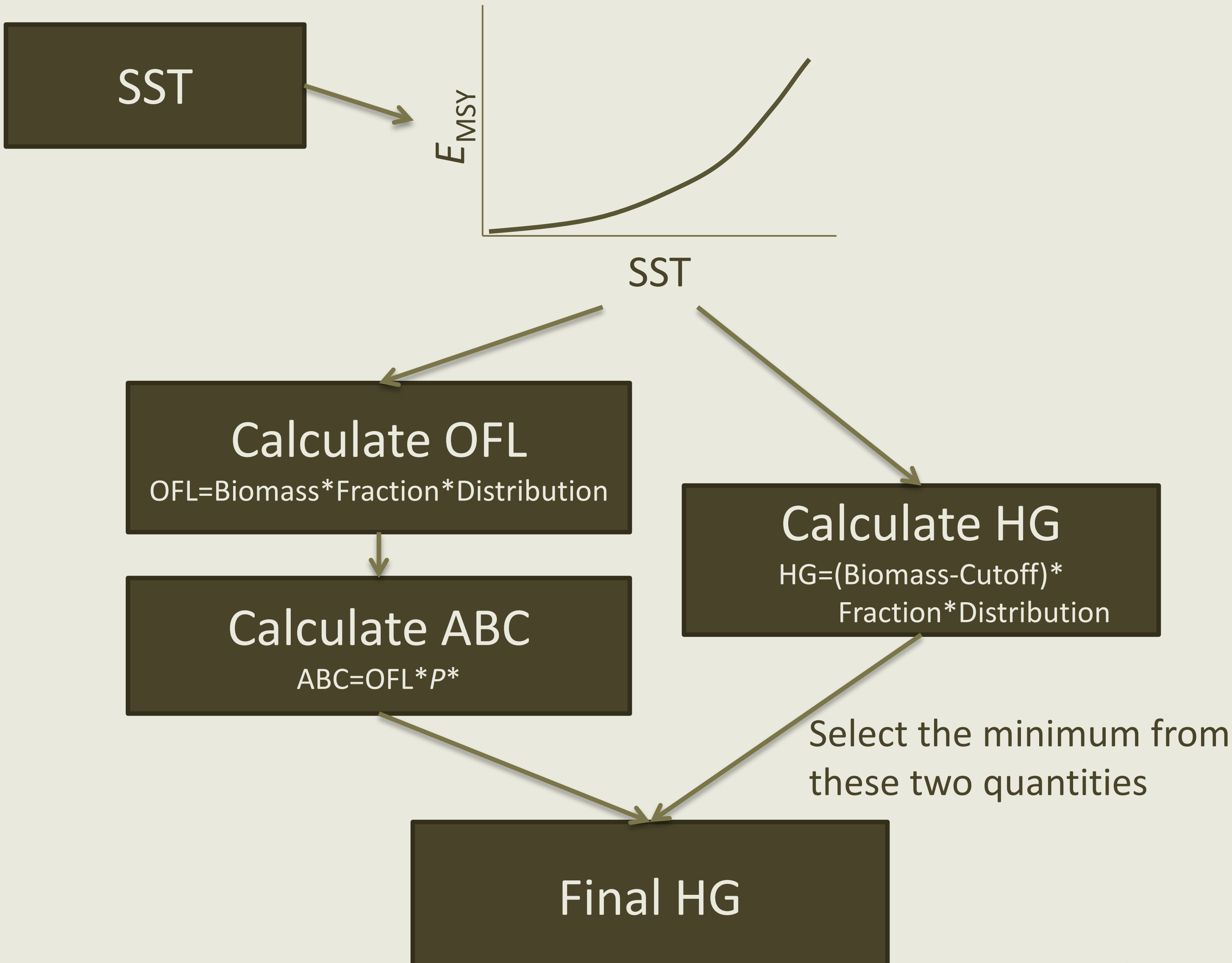


Comparing the relationships between SST and E_{MSY}



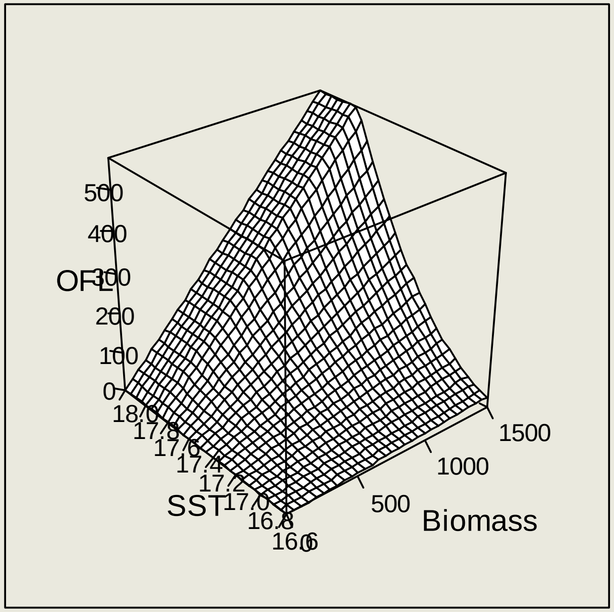
Since the relationship between the different indices and EMSY has different scales, to compare them it is necessary to standardize them based on the median of each time series.

The HG is set following this basic process

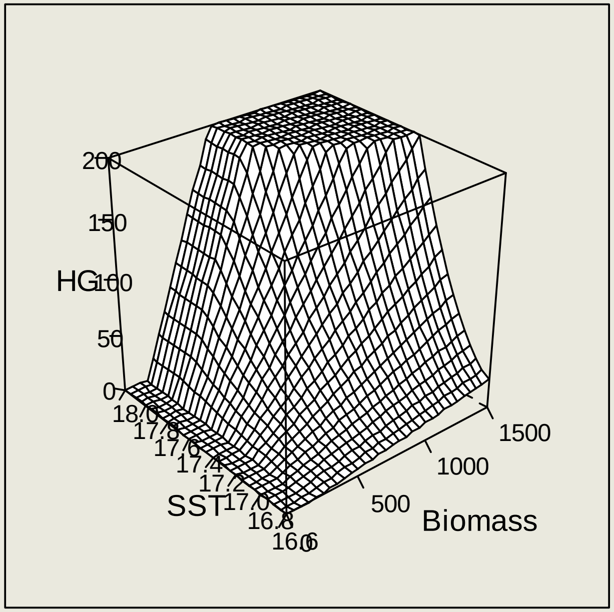


Current (SIO) harvest control rule

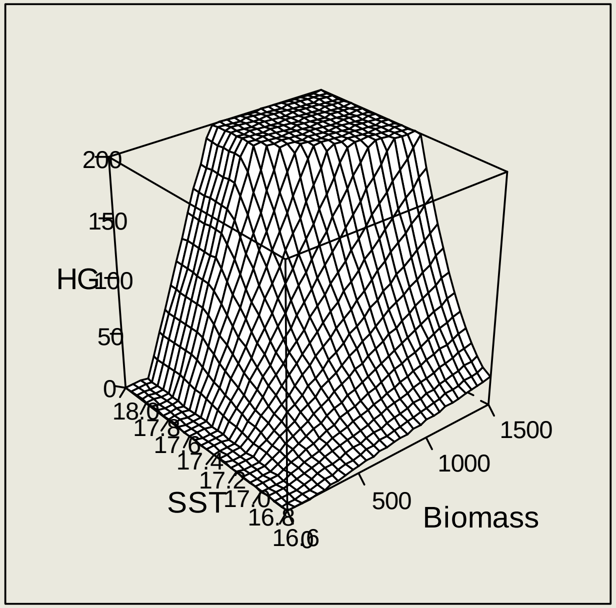
OFL control rule



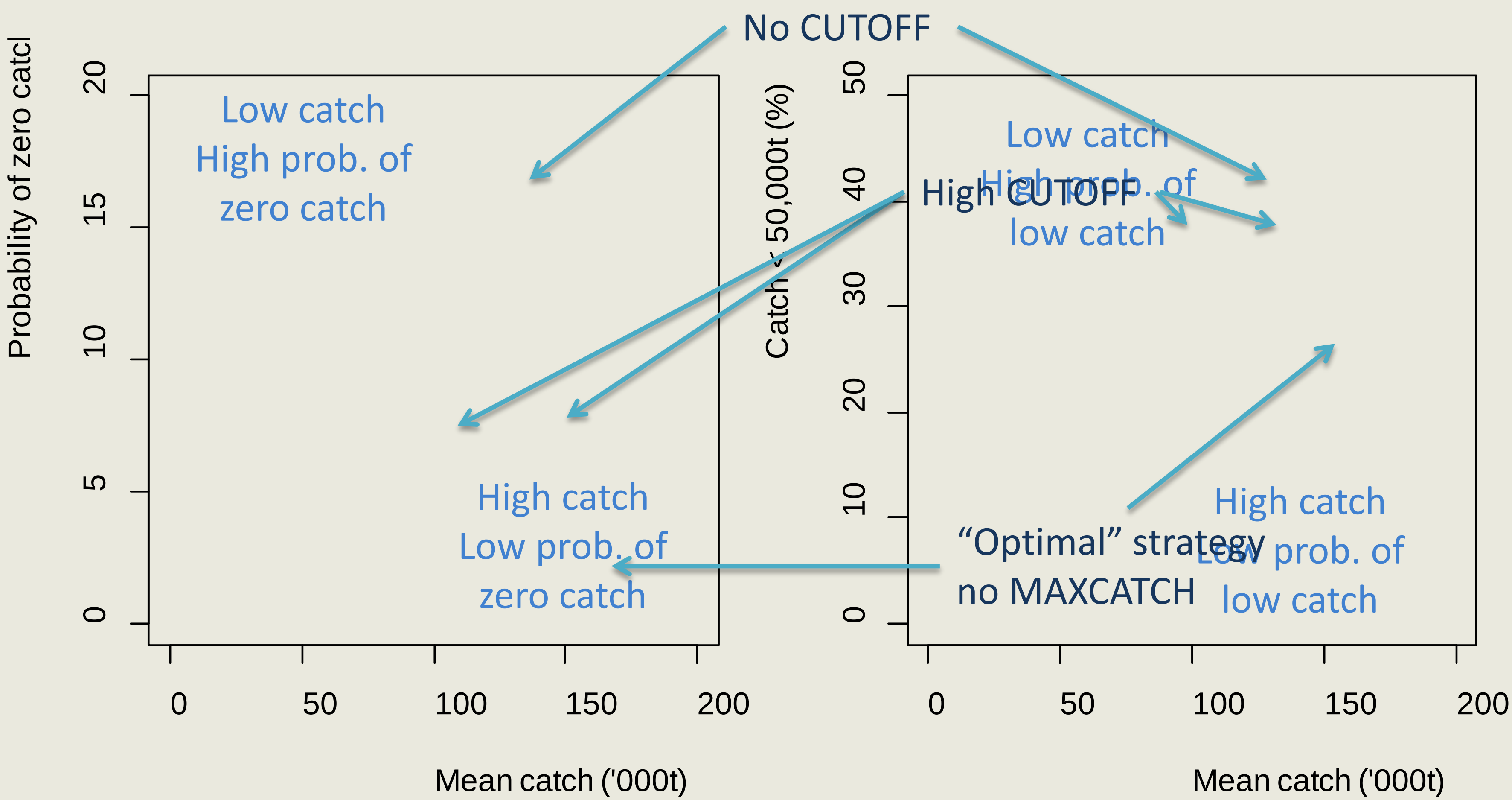
HG control rule



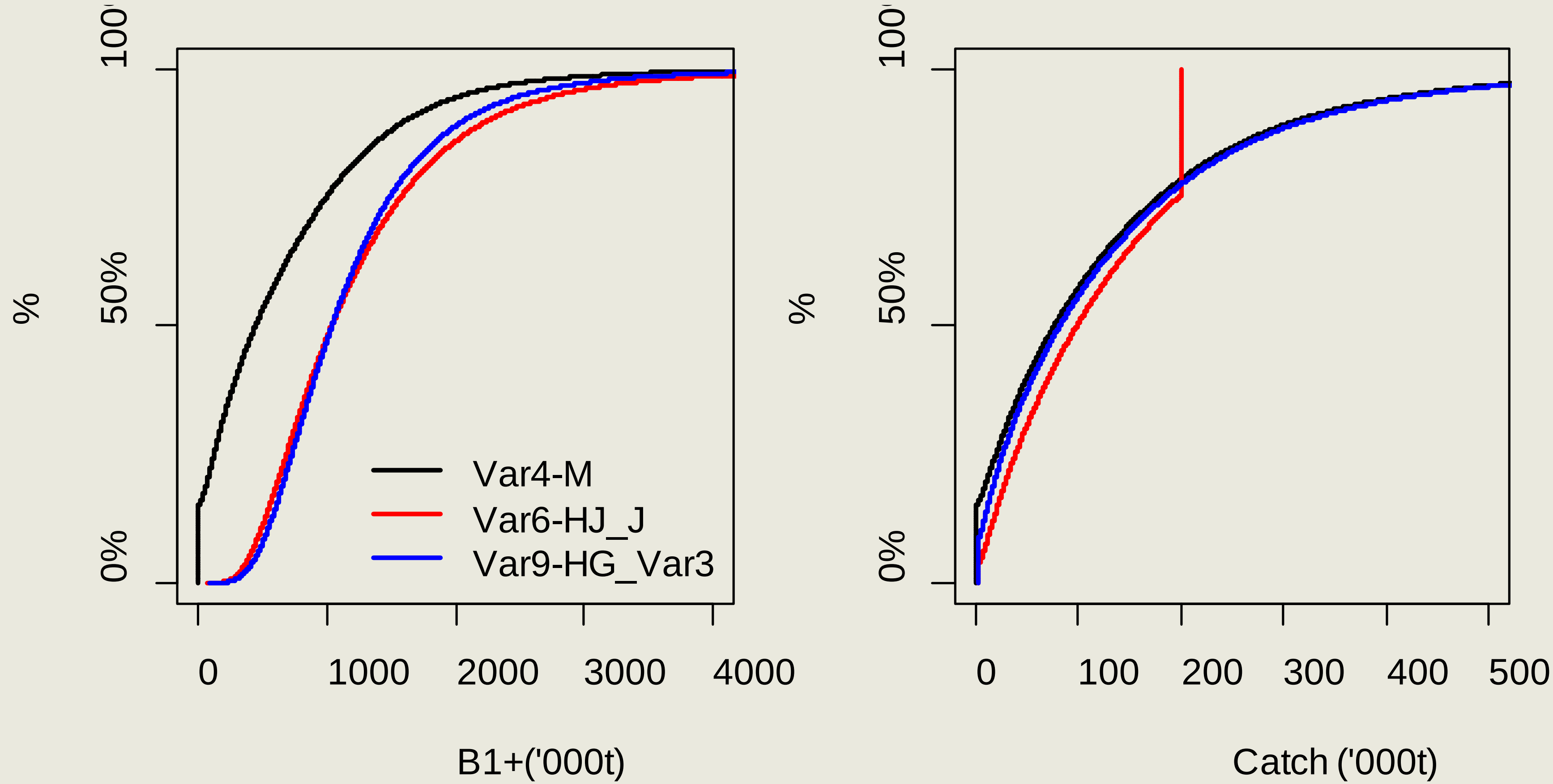
HG control rule < ABC



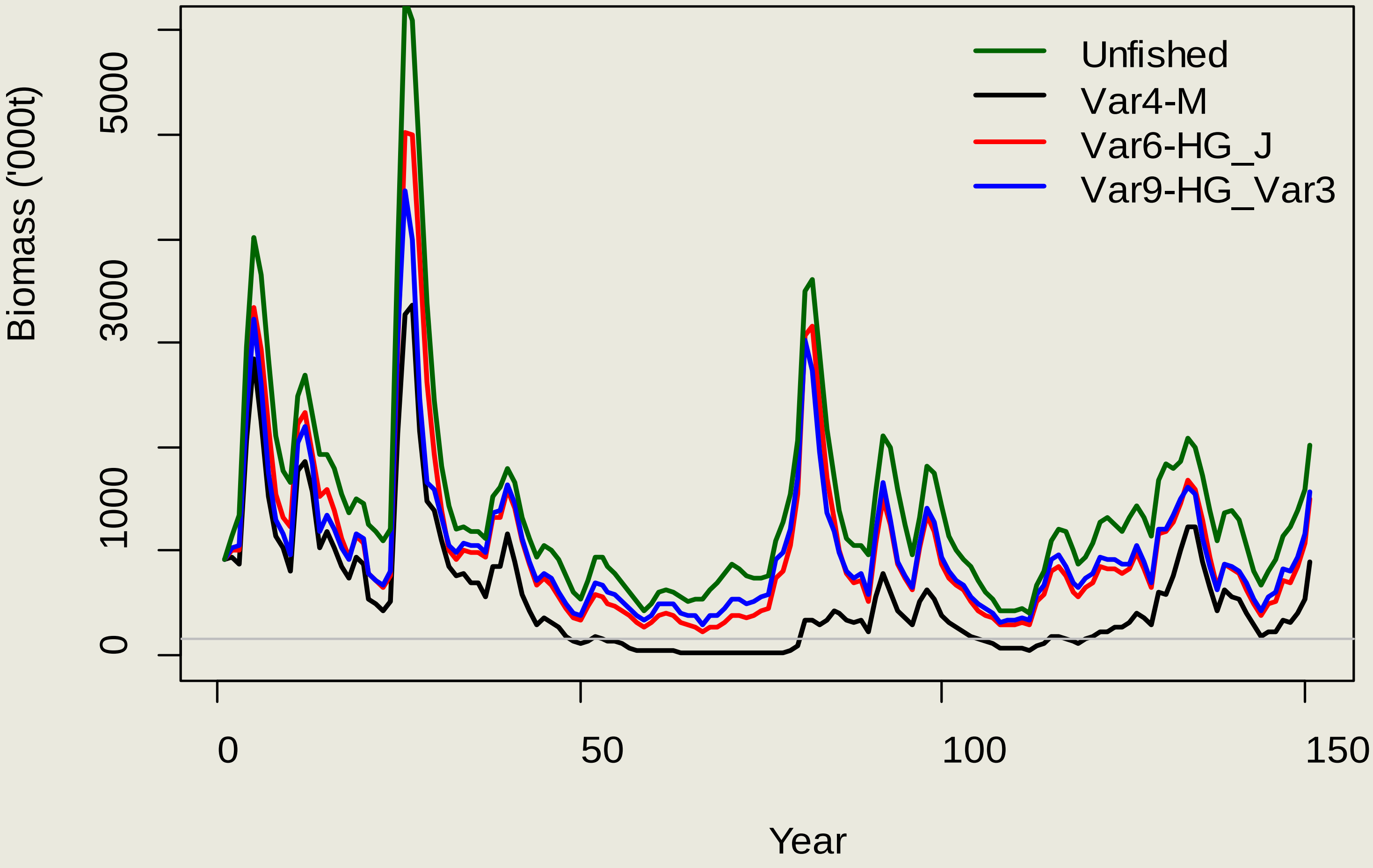
Quantifying trade-offs between different HCR variants: Mean catch vs. catch variability



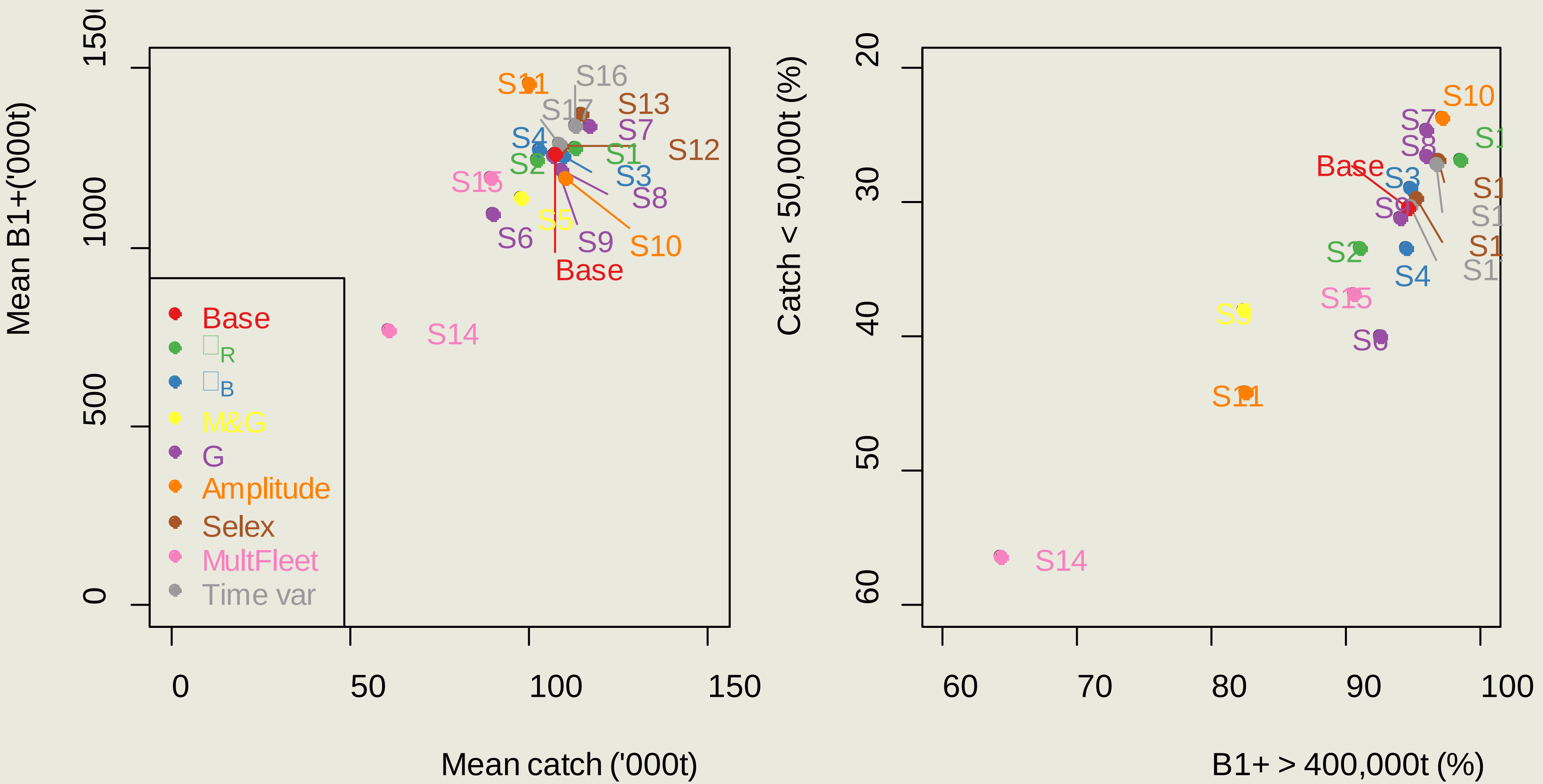
Cumulative distributions for biomass and catch for three HCR variants



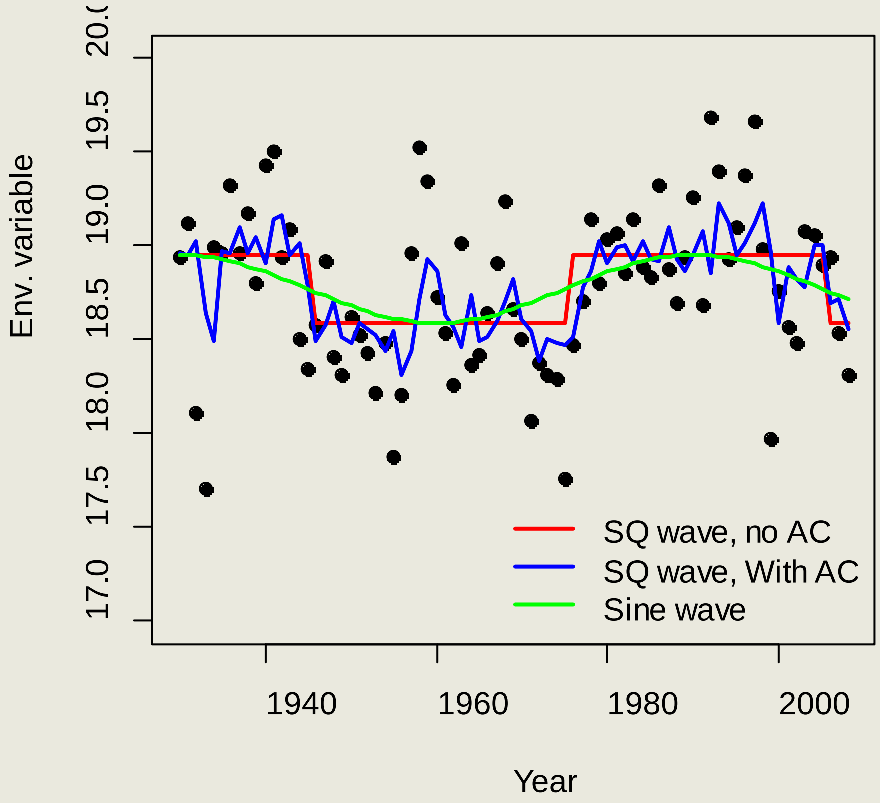
Example 150-year time-trajectory for three HCR variants



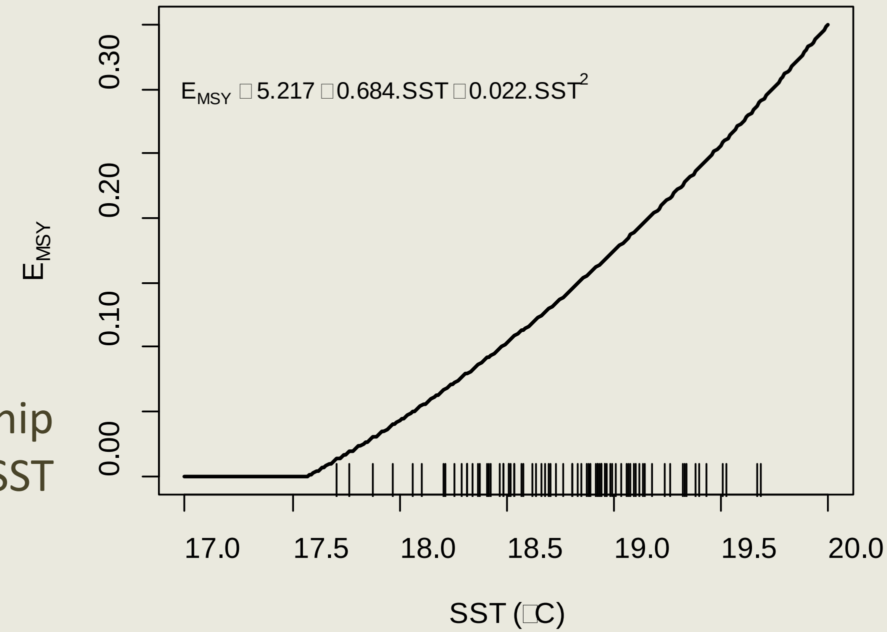
Trade-off plots for sensitivity analyses



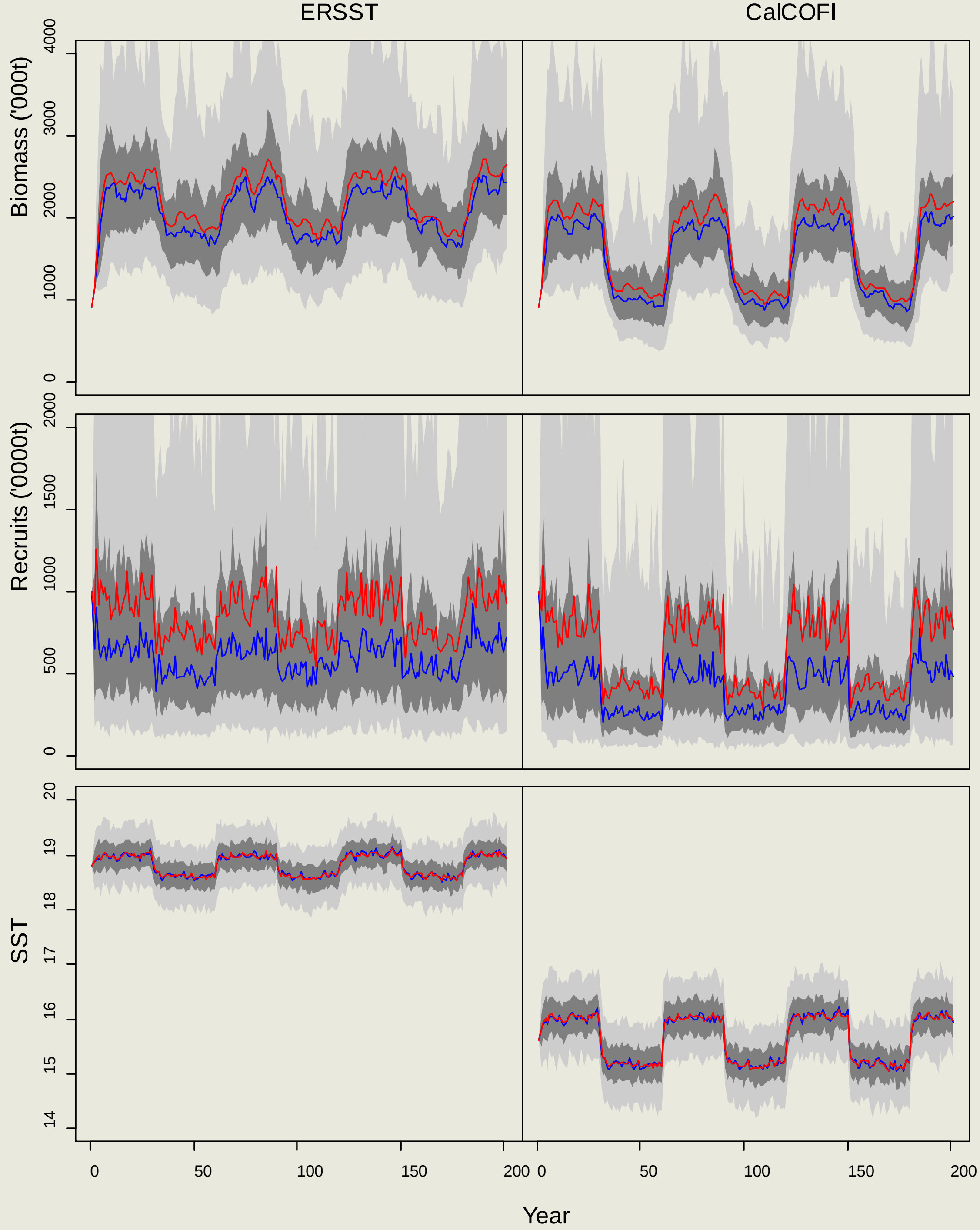
For this request, the analysis was repeated using ERSST as the driver of recruitment



Fit the environmental variable to the ERSTT time series



Recalculate the relationship between E_{MSY} and ERSST



This is a comparison of model runs using ERSST (left) and CalCOFI (right) as the environmental driver of recruitment, and no catches

Remember that CalCOFI provides a better fit than SIO or ERSST to log(RPS) data

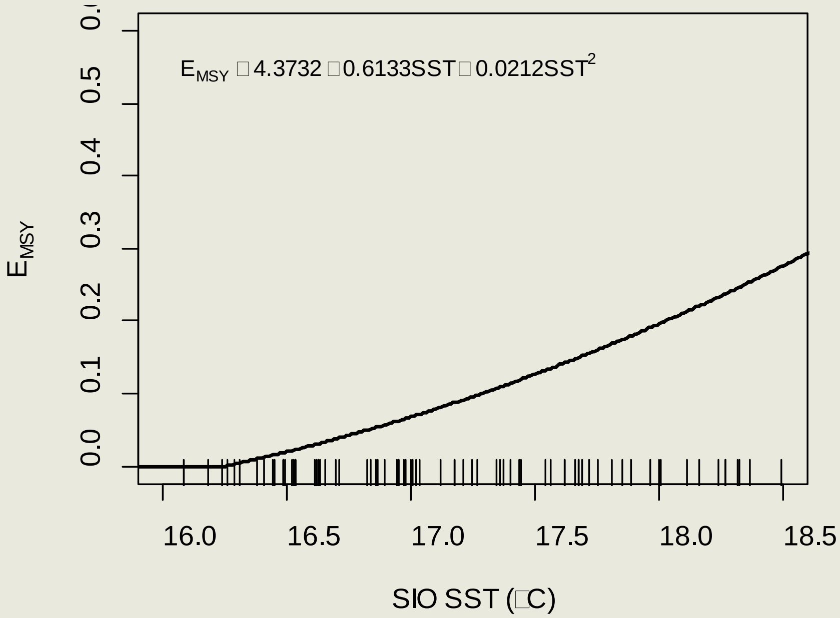
Series	AIC	R^2
SST_CC_ann	44.49	0.76
SIO_SST_ann	56.81	0.61
ERSST_ann	55.3	0.63

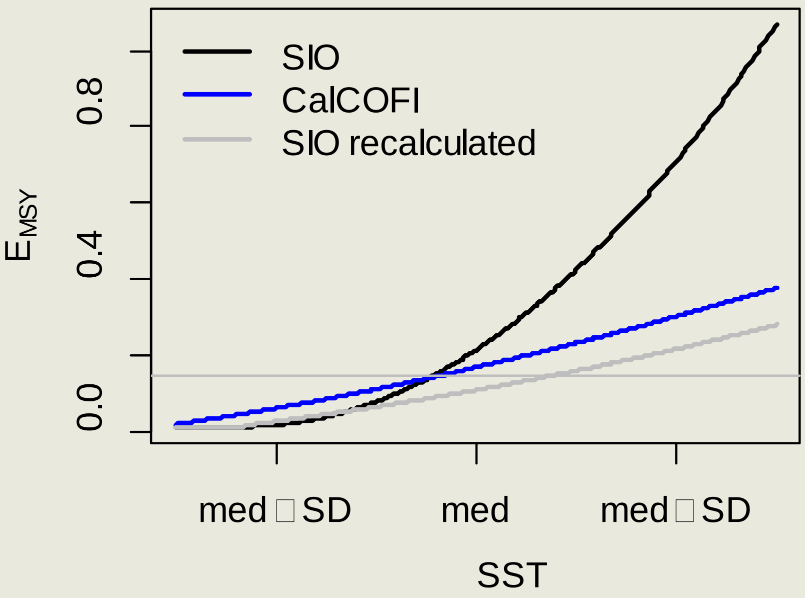
From PFMC 2013, Table App.E.6

Comparison of the current HCR using ERSST as temperature index

Mgmt.	Biomass	SIO		ERSST ann			ERSST 3-year average		
Year	(July)	SST	HG	ann SST	HG	Difference	3-y SST	HG	Difference
2000	1581346	18.08	186791	17.96	62264	-124527	18.87	179224	-7566
2001	1182465	17.75	134737	18.76	114844	-19893	18.57	91337	-43399
2002	1057599	17.24	118442	18.57	80636	-37806	18.43	66319	-52123
2003	999871	17.31	110908	18.49	67125	-43784	18.61	78843	-32066
2004	1090587	17.46	122747	19.08	122747	0	18.71	99086	-23661
2005	1193515	17.6	136179	19.06	136179	0	18.87	131001	-5178
2006	1061391	18.03	118937	18.89	116732	-2205	19.01	118937	0
2007	1319072	18.11	152564	18.94	152564	0	18.97	152564	0
2008	832706	18.12	89093	18.54	57766	-31327	18.79	78462	-10631
2009	662886	17.83	66932	18.32	30881	-36051	18.6	47004	-19927
2010	702024	17.84	72039	-	-	-	-	-	-
2011	537173	17.9	50526	-	-	-	-	-	-
2012	988385	17.64	109409	-	-	-	-	-	-
2013	659539	17.35	66495	-	-	-	-	-	-

Standardized comparison of the relationship between EMSY and SST





Comparison of the current HCR using SIO as temperature index

Mgmt year	Biomass (July)	SIO - current			SIO - recalculated relationship		
		SST	Fraction	HG	Fraction	HG	Difference
2000	1581346	18.08	0.15	186791	0.15	186791	0
2001	1182465	17.75	0.15	134737	0.15	134737	0
2002	1057599	17.24	0.15	118442	0.09	74955	-43487
2003	999871	17.31	0.15	110908	0.1	76481	-34428
2004	1090587	17.46	0.15	122747	0.12	99833	-22914
2005	1193515	17.6	0.15	136179	0.14	127299	-8880
2006	1061391	18.03	0.15	118937	0.15	118937	0
2007	1319072	18.11	0.15	152564	0.15	152564	0
2008	832706	18.12	0.15	89093	0.15	89093	0
2009	662886	17.83	0.15	66932	0.15	66932	0
2010	702024	17.84	0.15	72039	0.15	72039	0
2011	537173	17.9	0.15	50526	0.15	50526	0
2012	988385	17.64	0.15	109409	0.15	106344	-3065
2013	659539	17.35	0.15	66495	-	-	-

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southwest Region
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Agenda Item I.4.c
Supplemental SWFSC Report
June 2013

Mr. Chairman, Members of the Council,

Good morning and thank you for the opportunity to provide comments today. My name is Kristen Koch and I am the Deputy Director of the NOAA National Marine Fisheries Service's Southwest Fisheries Science Center (SWFSC). The purpose of my comments today is to provide complementary information to the discussion on management of Pacific sardine that this year includes a call for the Council's re-consideration of the present harvest control rules.

The Council members are aware of an article jointly authored by a SWFSC scientist and a contractor scientist that appeared in February 2012 in the Proceedings of the National Academy of Sciences (PNAS) entitled *"A cold oceanographic regime with high exploitation rate in the Northeast Pacific forecasts a collapse of the sardine stock"*[(1)]. In March of 2012, Dr. Cisco Werner, Director of the SWFSC, provided comments on the article to this Council.

As the title indicates, the authors claimed, based on their interpretation of the data, that "the northern sardine stock of the west coast of North America is declining steeply and that imminent collapse is likely".

As stated last March 2012, based on current information, expertise, and extensive peer-reviewed research, NOAA's National Marine Fisheries Service believes that the population of Pacific sardines is cyclical and capable of large fluctuations as has taken place in previous decades, with observed increases and decreases in abundance, and is not currently in a state of imminent collapse as referenced in the PNAS article[(1)] of March 2012. Subsequent to Dr. Werner's comments to the Council last year, scientists in the SWFSC and NWFSC collaboratively prepared a response[2] to the results and interpretations presented in the PNAS article.

We welcome the scientific community's healthy debate that has taken place in the peer reviewed literature [see PNAS[(1,2,3)]]. We also encourage that the discussions presently taking place in the public arena, and within the Council's Scientific and Statistical Committee, the Coastal Pelagic Species Management Team, and on the Council floor recognize the broader nature of this debate.

Related to these discussions, public comments have been submitted for this meeting (under agenda item I.4.d) including a call for the Council's consideration of alternative harvest control rules for Pacific sardine. One proposed alternative is largely based on an unpublished working draft of a paper co-authored by a SWFSC scientist and presented at a public Council-sponsored sardine harvest parameters workshop in February of this year. The draft paper was discussed by fisheries scientists, managers and economists present at the workshop. A revised version of the paper has been submitted to a scientific journal and is undergoing external peer-review. We expect it will be published in some form at a later date.

The Science Center, and indeed the Council process, routinely considers draft science as a way to propose and push new ideas forward. We should welcome opportunities to advance our thinking on fisheries management. The Science Center will continue to ensure draft papers coming from our scientists are subject to rigorous peer review through the scientific publication process. Likewise, we support the Council's Scientific and Statistical Committee and Management Teams processes that ensure rigorous review of published and unpublished work put before them. These unbiased reviews are essential as the Council determines the appropriateness of the available information for use in fishery management decisions.

I again thank the Council for the opportunity to provide these comments, and we are of course available to help in any way we can.

References

1. Zwolinski J.P., Demer D.A. (2012) A cold oceanographic regime with high exploitation rates in the Northeast Pacific forecasts a collapse of the sardine stock. Proc. Natl. Acad. Sci. USA, 109:4175–4180.

2. MacCall A.D., Hill K.T., Crone P., Emmett R. (2012) Weak evidence for sardine collapse. Proc. Natl. Acad. Sci. USA, 10.1073/pnas.1203526109.

3. Demer D.A., Zwolinski J.P., (2012) Reply to MacCall et al.: Acoustic trawl survey results provide unique insight to sardine stock decline, Proc. Natl. Acad. Sci. USA, www.pnas.org/cgi/doi/10.1073/pnas.1203758109.

PFMC
06/25/13

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May 29, 2013

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NOAA Fisheries, West Coast Region
7600 Sand Point Way, NE, Bldg 1
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Mr. Dan Wolford, Chair
Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 101
Portland, OR 97220

RE: Agenda Item I.4. Pacific Sardine Management: Revised Harvest Parameters, Request for Immediate In-season Action, and Proposed Harvest Control Rule Alternative

Dear Mr. Stelle, Mr. Wolford, and Members of the Council:

The Pacific sardine population is in a state of collapse and current management measures are not using the best available science. Unfortunately, the Pacific sardine fishery has **not** been managed for long-term sustainability in a manner that prevents overfishing, achieves optimum yield, and protects the health of our ocean ecosystem. We are now seeing direct impacts of this sardine collapse on the water, including the recent Unusual Mortality Event of yearling California sea lions, which are starving due to a lack of prey, and are also seeing remarkably low landings in the California sardine fishery so far this year. Furthermore, new analysis of temperature data indicates that recent environmental conditions are unfavorable for sardine productivity and that recent exploitation rates have resulted in overfishing. In order to prevent overfishing from occurring again in 2013 and to correct current fundamental flaws in the Pacific sardine control rule, we request the National Marine Fisheries Service (NMFS) and Pacific Fishery Management Council (PFMC):

1. Take immediate action to either close the Pacific sardine fishery due to recently identified overfishing, the current sardine decline and low abundance, or at minimum, correct the 2013 overfishing limit (OFL), allowable biological catch (ABC) and harvest guideline based on biomass estimates at the start of the fishing/calendar year, and using the new CalCofi temperature index;
2. Request the SSC reevaluate the “sigma” value used to assess scientific uncertainty associated with the OFL and in setting the ABC; and
3. Consider, evaluate and adopt Oceana’s proposed Pacific sardine harvest control rule, included in this letter, for 2014 management and beyond.

It has recently become much clearer that the harvest control rule used for setting sardine annual catch specifications is fundamentally flawed and current catch levels (both U.S. and coastwide) have been set significantly higher than intended by the current legal and management framework. The result is that NMFS and the PFMC have not been following the current control rule in the Coastal Pelagic Species Fishery Management Plan (CPS FMP), and, in retrospect, significant overfishing has occurred on a declining sardine population.

1) The Pacific Sardine Population is in Collapse

According to the 2012 stock assessment[1], the Pacific sardine population has declined 52% over the past six years. Recruitment is the lowest it has been in decades, coastwide exploitation rates have increased substantially in recent years, and the stock biomass is far below the "critical biomass" threshold (SSB < 740,000 mt) identified by NMFS sardine stock assessment scientists. NMFS scientists Zwolinski and Demer (2012) published a study last year in the Proceedings of the National Academy of Sciences forecasting this collapse, and the failure of management to respond.[2] The authors concluded in the abstract:

> ***[a]larming is the repetition of the fishery's response to a declining sardine stock - progressively higher exploitation rates targeting the oldest, largest, and most fecund fish.***

The utter dearth of sardines is now having ramifications in the ecosystem as indicated by an unprecedented number of yearling California sea lions starving on the beach.[3] It is also the reason why the fishery has made unprecedentedly low landings at this time, five months into the year. As of May 29 only 715.9 mt of sardine – 3.6% of the seasonal (January 1 to June 30) allocation of 20,123 mt - have been landed.[4] Forage fish like sardine are highly susceptible to overfishing due to their schooling nature and rapid response to environmental conditions, and if the fishery does find them soon, increased catch levels could quickly lead to overfishing.

2) Action Must be Taken to Change the Proposed 2013 Catch Levels

a. The Proposed 2013 Catch Levels Are Based on an Incorrect Biomass Estimate

The proposed 2013 catch levels are based on a biomass estimate of age 1+ sardine from July 2012. Between July 2012 and January 2013 when the fishery commenced, however, the fishery model shows that the population would continue to decline. This means that that the formula used to calculate the 2013 specifications does not represent the most current or accurate biomass estimate, resulting in a substantially inflated OFL and harvest guideline (HG). Table 12 (p. 50)

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[1] Hill et al. 2012. Assessment of the Pacific sardine resource in 2012 for U.S. Management in 2013. PFMC November 2012. Agenda Item G.3.b Supplemental Assessment Report 2.

[2] Zwolinski, J. and D.A. Demer. 2012. A cold oceanographic regime with high exploitation rates in the Northeast Pacific forecasts a collapse of the sardine stock. Proceedings of the National Academy of Sciences (PNAS) 109 (11). 4175-4180. Available at: http://www.pnas.org/content/early/2012/02/24/1113806109.full.pdf and PFMC, Agenda Item C.1b8, supplemental public comment. March 2012. http://www.pcouncil.org/wp-content/uploads/C1b_SUP_PC8_SHESTER_MAR2012BB.pdf.

[3] NOAA. California Sea Lion Unusual Mortality Event in California. http://www.nmfs.noaa.gov/pr/health/mmume/californiasealions2013.htm

[4] PacFIN. May 24, 2013. All W-O-C Commercial Landed Catch Species Report #307

of the 2012 Pacific sardine stock assessment indicates the estimate of the 2012 age 1+ mid-year biomass to be 659,539 mt, while the 2012 age 1+ end of year biomass is estimated at 454,683 mt.

The SSC recently recommended that, "the biomass at the start of the fishing season be used for harvest specification."[5] Although concerns were raised by the SSC and during PFMC discussion, and the PFMC gave direction to change the biomass used in the 2014 specifications, these concerns have not been addressed for 2013 management.

	Age 1+ Biomass	2013 OFL	2013 HG
Mid-year biomass (2012)	659,539 mt	103,284 mt	66,495 mt
End-year biomass (2012)	454,683 mt	71,203 mt	39,761 mt

Table 1. Difference in OFL and HG when using different biomass estimates. 2013 catch levels are based on the 2012 mid-year biomass estimate rather than the biomass estimate from the end of 2012.

Table 1 shows the 2013 U.S. OFLs and U.S. HGs using the current formulas specified in the CPS FMP, using the two different biomass estimates. As this table indicates, the choice of mid-year or end-year biomass is extremely consequential. In particular, the use of the end-year biomass (keeping all other parameters the same) would result in a 31% lower 2013 OFL and a 40% lower 2013 HG than the mid-year biomass as proposed by the PFMC and NMFS in the 2013 specifications.

b. The Proposed 2013 Catch Levels Are Based on a Harvest Control Rule that does not utilize the correct temperature index, and this is resulting in overfishing

In 2010, McClatchie et al. provided strong evidence that temperatures measured at Scripps Pier are an inappropriate indicator of sardine productivity and should thus be "removed from sardine management."[6] In February 2013 the PFMC hosted a workshop to reevaluate the harvest control rule and one of the major conclusions is that while there is a relationship between Sea Surface Temperature (SST) and sardine productivity, the best measure of SST for relating to sardine productivity is the CalCOFI SST index. This has major ramifications for modeling the dynamics of this sardine population and for setting annual catch levels.

Hurtado-Ferro and Punt[7] found that changing the environmental variable from SIO to CalCofi would have resulted in reduced harvest guidelines in nine of the last thirteen years since this population has been under federal management. Oceana updated the table provided on May 27, 2013 with the U.S. and coastwide OFL and actual U.S. and coastwide landings (Table 2). We found that actual landings exceeded the U.S. OFL in four recent years (2008-2010, 2012) and

[5] "[T]the SSC recommends that the biomass at the start of the fishing season be used for harvest specification." PFMC. Agenda Item I.1.b Supplemental SSC Report. April 2013. And see PFMC. Agenda Item G.3.c Supplemental SSC Report November 2012.
[6] 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. Aq. Sci.* 67: 1782-1790.
[7] Hurtado-Ferror, F. and A. Punt. 2013. Revised Analysis Related to Evaluating Parameter Value Choices for Pacific Sardine. Presented to CPSMT/ SSC, March 2013. Updated Table provided on May 27, 2013.

that coastwide landings exceeded the coastwide OFL every year for the last five years. This means managers have inadvertently and substantially overestimated sardine productivity, as well as the U.S. HG, and the OFL, and we now know the population has been overfished the past several years while it has been in decline.

		CalCOFI 3-year average				CalCOFI OFL and Actual Landings				
Mgmt year	**Biomass (July)**	**3-y SST**	**HG Fraction**	**HG**	**Difference From Actual SIO HG**	**OFL Fraction**	**U.S. OFL**	**U.S. Landings**	**Coastwide OFL**	**Coastwide Landings**
2000	1,581,346	16.18	0.15	186,791	0	0.24	331,561	72,496	381,104	142,063
2001	1,182,465	15.82	0.15	134,737	0	0.20	202,183	78,520	232,394	125,857
2002	1,057,599	15.47	0.14	106,625	-11,817	0.14	124,247	101,367	142,812	148,952
2003	999,871	15.38	0.12	88,639	-22,270	0.12	104,283	74,599	119,866	116,919
2004	1,090,587	15.46	0.13	109,008	-13,738	0.13	126,392	92,613	145,278	138,948
2005	1,193,515	15.56	0.15	135,381	-797	0.15	154,842	90,130	177,979	148,684
2006	1,061,391	15.71	0.15	118,937	0	0.18	162,261	90,776	186,506	149,588
2007	1,319,072	15.62	0.15	152,564	0	0.16	184,025	127,695	211,523	166,065
2008	832,706	15.38	0.12	71,394	-17,699	0.12	**87,081**	**87,175**	**100,093**	**164,466**
2009	662,886	15.30	0.11	48,181	-18,750	0.11	**62,272**	**67,083**	**71,578**	**138,328**
2010	702,024	15.11	0.08	38,243	-33,796	0.08	**48,634**	**66,891**	**55,901**	**145,935**
2011	537,173	15.26	0.10	33,950	-16,576	0.10	47,103	46,745	**54,142**	**137,801**
2012	988,385	15.15	0.09	62,453	-46,956	0.09	**73,627**	**101,547**	**84,628**	-
2013	659,539	-	-	-	-	-	-	-	-	-

Table 2. Recalculated Harvest Guidelines (HG) and Overfishing Levels (OFL) (as defined in Amendment 13) using the CalCofi 3-year average index compared with the actual HG based on temperatures from Scripps Pier (SIO) and actual U.S. and Coastwide Landings. Bolded numbers indicate overfishing: where U.S and coastwide landings were greater than the U.S. and coastwide OFL. 2012 U.S. landings from PacFIN and all other landings from Hill et al. 2012 (*supra note* 1).

We are greatly concerned that catch levels this year could once again result in overfishing if the PFMC and NMFS continue to manage the population using the SIO Pier index and mid-year biomass estimate. Oceana requests immediate action to either close the Pacific sardine fishery, or at minimum correct the 2013 catch specifications so that they are based on the best available science regarding the current biomass estimate for the start of the fishing year and so that the harvest guideline and OFL parameters are based on the CalCofi SST index.

Based on the Biomass (1+) at the start of 2013 (454,683 mt), the corrected HG FRACTION of 0.09 based on recent CalCOFI data, and the current HG formula in the CPS FMP (CUTOFF= 150,000; DISTRIBUTION = 87%), we calculate a total corrected U.S. H.G. of 23,857 mt, which we recommend be implemented instead of the current 66,495 mt.[8]

3) **We request the PFMC direct its SSC to reevaluate the "sigma" value in its Allowable Biological Catch calculation to address scientific uncertainty associated**

[8] U.S. HG = (Biomass – Cutoff)*Fraction*Distribution = (454,683-150,000)*0.09*0.87 = 23,856 mt

with the sardine harvest parameters beyond solely the uncertainty associated with current year biomass.

The conclusions from the Pacific sardine workshop highlight the significant uncertainty associated with the various parameters of the sardine harvest control rule. The SSC's current approach to quantify scientific uncertainty through the selection of a sigma value (estimates of variation within and among stock assessments) that is then applied to the calculation of the ABC, does not represent a complete–or sufficient–treatment of uncertainty in the OFL. The sigma of 0.39 for sardine is the result of the SSC's quantification of only one source of uncertainty, *i.e.*, process error (as measured by between stock assessment variability), which is unlikely to be the sole source of significant uncertainty. Sources of error that are not included in the SSC's quantification exercise include forecast error (including the lag between surveys and projected biomass for use in the specifications), uncertainty associated with optimal exploitation rate (Fmsy or Emsy), uncertainty with respect to oceanographic conditions and their effects on stock productivity, and the temperature-recruit relationship. The SSC did not include time lags in updating assessments, the degree of retrospective revision of assessment results, or projections in their estimates of sigma[9], as set forth by National Standard 1.[10]

Indeed, the SSC acknowledged that these sigma values (0.36 for category I stocks and 0.39 for sardine) are "only a first step, in part because it just considers uncertainty in biomass. Going forward, it will be important to consider other sources of uncertainty, such as F_{MSY}. Because of that it was also recognized that *the present analysis underestimates total variance*."[11] Since only one source of uncertainty is contained in the sigma values for sardine, the PFMC and NMFS have implicitly set all other sources of uncertainty equal to zero. This is a highly risky assumption, and because of these recent findings, we request a reevaluation of the current sigma value to address these other important sources of error and uncertainty that can lead to catch levels being set too high.

4) Proposed Alternative Harvest Control Rule

We appreciate and commend the recent updates to the sardine simulation model resulting from the PFMC Harvest Parameters Workshop. In our October 23, 2012 letter to the Council, we raised issues with the updated Pacific sardine simulation model being used at the time to determine a fixed Fmsy value, particularly the lack of oscillations in sardine productivity. It appears that issue has been resolved and we commend the SSC for making improvements to the simulation model based on more recent data and making the new operating model publicly available. Since the new operating model has been posted, we have conducted our own initial

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[9] PFMC. March 2010 Agenda. An Approach to Quantifying Scientific Uncertainty in West Coast Stock Assessments. Agenda Item E4b_SUP_SSC1..

[10] 50 C.F.R. § 600.310(f)(4). "The ABC control rule must articulate how ABC will be set compared to the OFL based on the scientific knowledge about the stock or stock complex and the scientific uncertainty in the estimate of OFL and any other scientific uncertainty. The ABC should consider uncertainty in factors such as stock assessment results, time lags in updating assessments, …."

[11] PFMC March 2010 Agenda, Item E.4.b, Supplemental SSC Report 2 (emphasis added).

analysis and we have developed an alternative harvest control rule which we propose for implementation beginning in the 2014 season.

We respectfully propose the following changes to the parameters of the existing Pacific sardine harvest control rule:

	Current (Am 13)	Proposed
U.S. OFL	BIOMASS * Fmsy * DISTRIBUTION	BIOMASS * Fmsy – Lcanada – Lmexico
U.S. ABC	BIOMASS* BUFFER*Fmsy * DISTRIBUTION	(BIOMASS*Fmsy – Lcanada – Lmexico)* BUFFER
U.S. ACL	Less than or equal to ABC	Less than or equal to ABC
U.S. HG	(BIOMASS – CUTOFF) * FRACTION * DISTRIBUTION	(BIOMASS – CUTOFF) * FRACTION – Lcanada – Lmexico
U.S. ACT	Equal to HG or ACL, whichever is less	Equal to HG or ACL, whichever is less

Where Lcanada and Lmexico refer to Canadian and Mexican landings in the previous year.

- Increase CUTOFF from 150,000 mt to 640,000 mt, which is based on 40% of the estimated unfished biomass (1+).
- Set MSST equal to CUTOFF (640,000 mt).
- Keep FRACTION with the range of 5-15% based on the CalCOFI Index.
- Increase MAXCAT to 300,000 mt.
- Set OFL = E_{MSY}, based on the relationship with the CalCOFI index.
- Replace DISTRIBUTION with a catch-based method determined by the formula:
    - $HG_{US} = HG_{TOTAL} – L_{MEXICO} - L_{CANADA}$
    - $OFL_{US} = OFL_{TOTAL} – L_{MEXICO} - L_{CANADA}$

Parameters	Current HG	Oceana Proposed
CUTOFF (1+, mt)	150,000	640,000
CUTOFF (%B0)	9.4%	40.0%
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
MSST (%B0)	3.1%	40.0%
OFL (TOTAL)	18% of Biomass (1+)	Emsy based on CalCOFI
OFL (US)	87% of TOTAL OFL	TOTAL OFL - Lmexico - Lcanada

Table 3: Summary of Current HG in the CPS FMP and Oceana's proposed Harvest Control Rule.

Rationale and Basis for Proposed Changes:

CUTOFF: Recent scientific analyses of forage fish dynamics indicate that fishing has the greatest impacts and poses the greatest risks to forage fish stocks during periods of low abundance. Based on this information, we analyzed a range of CUTOFF values and consequently we are proposing the CUTOFF be set at 40% of the mean unfished biomass, which aligns with the Lenfest Forage Fish Task Force recommended CUTOFF for Tier 2 stocks (intermediate information level). The increase in CUTOFF results in lower fishing pressure during periods of low relative abundance to minimize risk and increase overall mean biomass.

FRACTION: Our proposed HCR would maintain the current range of FRACTION between 5-15%. We recommend, however, the new CalCOFI SST index be adopted as is being proposed by the SSC to replace the use of SIO pier SST index.

MAXCAT: Increase the maximum catch parameter to 300,000 mt to maintain average catch at similar levels to "Option J" and allow higher catch levels when the stock is at high biomass under favorable productivity. This essentially balances the potential impact of lower catches in times of low abundance, by allowing increased catch at times of high abundance, hence maintaining overall average catch levels in concert with the increase in CUTOFF.

DISTRIBUTION: The Pacific sardine stock is not managed tri-nationally, and the current U.S. HG does not account for landings in Canada, or control the Mexican and Canadian landings. In particular, Mexico does not use quotas and Canada estimates the sardine distribution in Canadian waters based on a three year average that has recently been as high as 27%. Furthermore, the distribution of the stock across its potential habitat in the three nations is likely not constant, not homogenous, and not predictable. Also, the proportions of sardine habitat associated with each country are not equivalent to their fractions of the total landings from the stock. The 87% DISTRIBUTION was set based on aerial spotter data from 1963-1992, and is therefore not reflective of the current distribution of the stock. As a result, the static U.S. DISTRIBUTION value of 87% in the current HG results in the actual total coastwide harvest consistently exceeding the "target" coastwide harvest as intended by the HG. In other words, actual coastwide catch is greatly exceeding the catch specified by the HG in Amendment 8's "Option J".

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 as proposed in Demer & Zwolinski 2013a (attached). While some scientists (including Demer & Zwolinski) believe the stock is differentiated into a "northern" and "southern" stock, the stock assessments to date and existing management structure treat the stock as a single undifferentiated stock. As the current system is based on a single undifferentiated stock, the landing-based formula is the best way to address tri-national landings.

L_{MEXICO} and L_{CANADA} are set based on the prior year's landings, as the U.S. has no control over Mexican or Canadian landings in the absence of an international agreement. If harvest guidelines are known for Mexico and Canada prior to setting the U.S. HG and U.S. OFL, then they could be substituted for L_{MEXICO} and L_{CANADA}, respectively. Otherwise, the values reported for L_{MEXICO} and L_{CANADA} in one year are good estimators for their values during the subsequent year, based on serial correlation in landings data.[12,13]

Demer and Zwolinski (2013a) state the benefits of such an approach based on a retrospective application of it to landings from 1995-2011:

> *"[We] demonstrate that application of the method would reduce the discrepancy between the target fishing fraction and the total tri-national fraction, optimally increase U.S. landings when the stock is primarily off U.S. waters, and inherently reduce U.S. exploitation when large proportions of the landings are at Mexico, Canada, or both."*[14]

Until such time as the U.S. enters into a tri-national agreement, we believe this is the best approach for ensuring the long-term sustainability of the sardine population.

MSST: The minimum stock size threshold (MSST) is intended to indicate when a stock is considered "overfished", prompting rebuilding. While we recognize the difficulty in using this term 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. Therefore, we would set MSST equal to the proposed CUTOFF and fishing for sardine would close whenever the biomass drops below this threshold value.

Initial Analysis:

For the following analysis, we used the code publicly posted at: https://code.google.com/p/sardine-harvest-guideline-parameters/downloads/detail?name=Sardine%20OM.exe&can=2&q=, downloaded on May 15, 2013. For each HCR variant, we conducted 20 simulations, each running for 10,000 years in duration—which was a similar duration to the analyses conducted in Amendment 8. Based on the simulation results, we evaluated each HCR variant according to the performance metrics in Hurtado-Ferro and Punt (2013).[15] For HCR variants with a temperature-dependent Emsy, we used the option to have the HG and OFL temperature-dependent; otherwise the Emsy (for use in OFL) and FRACTION were fixed. Following previous HCR analyses in Amendment 8, Amendment 13, and the Sardine Harvest Parameters Workshop, the performance metrics reflect coastwide catch (not solely the U.S. portion).

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[12] Demer, D.A. and Zwolinski, J.P. 2013a. Optimizing U.S.-harvest quotas to meet the target total exploitation of an internationally exploited stock of Pacific sardine (*Sardinops sagax*). Manuscript (Jan. 28, 2013) presented at 2013 Pacific Sardine Harvest Parameters Workshop. Pacific Fishery Management Council. 20 pp.
[13] Hill, K., Crone, P. R., Lo, N. C. H., Macewicz, B. J., Dorval, E., McDaniel, J. D., and Gu, Y. 2011. Assessment of the Pacific sardine resource in 2011 for U.S. management in 2012. U.S. Department of Commerce. NOAA Technical Memorandum NMFS-SWFSC-487, 16 pp.
[14] Demer and Zwolinski. 2013a, *supra note* 12.
[15] Hurtado-Ferro, F. and Punt, A. 2013. Initial Analyses Related to Evaluating Parameter Value Choices for Pacific Sardine. Agenda Item I.1.b, Attachment 2, April 2013. Pacific Fishery Management Council.

Given that actual coastwide catch has deviated from Option J, we included an additional scenario to generally approximate the actual implementation, called: "Actual Current HCR". This scenario uses a CUTOFF of 150,000 mt, a constant FRACTION of 25%, and a MAXCAT of 300,000 mt. We believe this is a conservative and reasonable approximate of how the current harvest control rule has been implemented since 2000 in the U.S. (using a constant Fraction of 15% and DISTRIBUTION of 87%) given that the actual U.S. portion of coastwide landings has been estimated to be 52% based on data from 1993 to 2011 without stock differentiation, and it has generally been lower in recent years.[16] We have included the DISTRIBUTION analysis by Demer and Zwolinski as Attachment 2 to this letter. The formula for our calculation is:

> FRACTION (ACTUAL) = FRACTION (in U.S. HG) x U.S. DISTRIBUTION (in U.S. HG) / U.S. DISTRIBUTION (ACTUAL) = 15% x 87% / 52% = 25%

We note that while there may be some debate about whether there are two differentiated stocks of Pacific sardine, the current 2012 stock assessment assesses Pacific sardine as one undifferentiated stock. Therefore, until the stock is assessed differently, we use the undifferentiated stock. We also set the MAXCAT at 300,000 mt for this option to reflect that Mexico and Canada are not constrained by a 200,000 mt cap. Coastwide landings could easily reach this level in a time when U.S. landings hit the cap. In the current simulation model, all temperature-based options are based on the CalCOFI index. Therefore, while "Option J" in Amendment 8 was based on the SIO temperature index, the analysis in this document for Scenario "HG-J" assumes the use of the CalCOFI index.

The "Without Fishing" option is intended to serve as a reference for the "unfished" condition for comparison purposes, and is not intended to be a proposed harvest control rule. The "HG-V4", "OFL", and "L (Emsy)" scenarios are meant to be consistent with the scenarios used in the Hurtado-Ferro and Punt 2013 analysis. The "F = 15%" scenario is a constant F scenario shown for illustrative purposes, and does not have a CUTOFF or MAXCAT. The "Lenfest" scenario is based on our interpretation and application of the Lenfest Forage Fish Task Force recommendations for a forage fish stock with an intermediate level of information level (i.e., Tier 2), including a CUTOFF of 40% mean Bzero, a FRACTION of ½ Emsy that includes a temperature relationship, and no MAXCAT.[17]

We added an additional performance metric of the percentage of years the Spawning Stock Biomass (SSB) is greater than 740,000 mt, based on the "critical biomass" threshold identified by Zwolinski & Demer 2012[18], under which sardines progressively disappeared and collapsed in the 1940s and 1950s. The rationale for this threshold is that the combination of unfavorable environmental conditions, continued fishing pressure, and the stock declining below this

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[16] Demer, D. and Zwolinski, J. 2013b. An estimate of the average portion of the northern stock of Pacific sardine (*Sardinops sagax*) residing in the U.S. exclusive economic zone. Manuscript presented at 2013 Pacific Sardine Harvest Parameters Workshop. Pacific Fishery Management Council. 7 pp.

[17] Lenfest Forage Fish Task Force 2012. Pikitch, E., Boersma, P.D., Boyd, I.L., Conover, D.O., Cury, P., Essington, T., Heppell, S.S., Houde, E.D., Mangel, M., Pauly, D., Plagányi, É., Sainsbury, K., and Steneck, R.S.. Little Fish, Big Impact: Managing a Crucial Link in Ocean Food Webs. Lenfest Ocean Program. Washington, DC. 108 pp.
[18] Zwolinski and Demer. 2012, *supra note* 3

threshold together precipitated the historic collapse by preventing the remaining sardine from reproducing successfully. Therefore, this metric provides a key alternative measure of the proportion of the time when the stock is at risk of collapse.

Furthermore, a new performance metric includes the percentage of simulations where the stock becomes completely extirpated (in a mathematical sense, the biomass becomes zero). This is a different definition of "collapse" than is generally used in management, as it refers to actual extirpation rather than the more frequently used definition as commercial extirpation.[19]

Lastly, due to changes to the operating model since the analysis was presented in the April 2013 briefing book, as well as differences in the number of years and simulations, there are some minor discrepancies between the performance metrics presented the Hurtado-Ferrero and Punt April 2013 analysis and our analysis shown here. The relative rankings of the scenarios, however, appear consistent.

Initial Results:

The main results are presented in Table 4 below, comparing the alternative HCR scenarios in terms of the full suite of performance metrics, as well as Figures 1-5 included at the end of this letter. Figures 1 and 2 illustrate the operational differences between the shapes of the HCRs, comparing Oceana's proposed HCR with Option J. Note that the slopes of the lines are parallel in Figure 1 as the FRACTION varies with temperature in the same manner (5-15%), however, the differences result from the different CUTOFF and MAXCAT thresholds. Figure 3 shows an example of a simulated 100-year catch trajectory under Option J and the Oceana proposed scenario, providing a visual depiction of the fundamental strategic difference in which the Oceana proposed scenario results in higher catches during high abundance years and lower catches during low abundance years. In other words, Option J appears to favor stability in the catch with higher catches at times of low sardine abundance when the stock is at most risk.

Figure 4 shows an example of a simulated 100-year biomass (1+) trajectory under 4 scenarios. While Option J and the actual current HCR deviate from the unfished trajectory particularly during years of low relative abundance, the Oceana proposed HCR aligns much closer to the unfished trajectory, during both the peaks and valleys of abundance.

In comparing Oceana's proposed HCR to both the theoretical Option J and the actual current harvest, the Oceana HCR substantially outperforms along the metrics that indicate a high mean biomass and contribution to forage (Fig. 5a), the health of the sardine population (Fig. 5b), and the risk to the stock (Figs. 5c and 5d). In terms of mean sardine catch, the Oceana HCR is roughly equivalent (slightly outperforms) to the Option J HCR, however the actual current HCR results in higher catch than Option J or the Oceana HCR (Fig. 5e). The number of years with low relative catch is higher under the Oceana HCR (Fig. 5f), however this is somewhat offset by higher catch in years with greater sardine abundance (Fig. 4). It is worth noting that the CPS

[19] E.g. Pinski, M.L., O.P. Jensen, D. Ricard, and S. Palumbi. 2011. Unexpected patterns of fisheries collapse in the world's oceans. Proceedings of the National Academy of Science (PNAS). www.pnas.org/cgi/doi/10.1073/pnas.1015313108

fishery targets other species besides sardine (notably market squid in recent years); therefore, it would be incorrect to infer that the capital, employment, and infrastructure associated with CPS fisheries is not being utilized in years of low or zero sardine catch. We hope that the PFMC's analysis can closely examine these tradeoffs, particularly given the multi-species context of the CPS FMP.

Of note is that only two HCRs resulted in complete collapse (extirpation) in these simulations. These two are those that did not include a CUTOFF. In particular, the Emsy (constant exploitation rate of 18%) resulted in extirpation within the 10,000 year window for 13 of the 20 simulation runs. This is significant, as it calls into question whether an OFL set as a fixed percentage of the stock biomass is appropriate or sufficiently conservative to avoid overfishing.

5) Conclusion

In conclusion, Pacific sardine management is currently in a crisis situation, and fishery managers appear to be making the same mistakes that were made with Pacific sardine management over 60 years ago when the fishery collapsed. Today's crisis presents a unique opportunity to make the necessary corrections to end overfishing of this critically important forage species, and provide for long-term sustainable fisheries and a healthy ocean ecosystem.

Rather than simply criticizing existing management, we have gone to great lengths to develop and propose a set of solutions, and we hope NMFS and the PFMC consider and analyze our proposals carefully. Both NMFS and the PFMC currently have the authority and the mandate to make serious changes to correct the current 2013 quota and the system through which quotas are set in 2014 and beyond. For the sake of our public resources, our ocean wildlife, our fishing industries and our coastal communities, we ask you implement these requested near-term and long-term changes to Pacific sardine management.

Sincerely,

Geoffrey Shester, Ph.D.
California Program Director

Ben Enticknap
Pacific Campaign Manager & Senior Scientist

Attachments:
1. Demer & Zwolinski 2013a. Optimizing U.S.-harvest quotas to meet the target total exploitation of an internationally exploited stock of Pacific sardine (*Sardinops sagax*).
2. Demer & Zwolinski 2013b. An estimate of the average portion of the northern stock of Pacific sardine (*Sardinops sagax*) residing in the U.S. exclusive economic zone.

Additional Tables and Figures from Oceana's HCR Analysis:

HCR Variant	Without Fishing	HG-J	HG-V4	OFL	L (Emsy)	F=15%	Oceana	Current HCR*	Lenfest **
Harvest Parameters									
Fmin	0	0.05	0.05	0.45	0.18	0.15	0.05	0.25	0.02
Fmax	0	0.15	0.18	0.45	0.18	0.15	0.15	0.25	0.09
Temp-based OFL, HG	NA	Yes	Yes	No	No	No	Yes	No	Yes
Cutoff (tmt)	NA	150	.33 B0	.33 B0	0	0	.4B0	150	.4 B0
Maxcat (tmt)	NA	200	None	None	None	None	300	300	None
Performance Metrics									
Mean_catch (tmt)	0.0	110.1	141.8	231.0	149.2	144.1	114.2	151.4	88.2
SD_catch (tmt)	NA	70.5	158.0	182.0	151.6	135.5	95.7	101.9	91.6
Median_catch (tmt)	NA	102.9	89.4	204.8	102.4	104.9	84.9	135.5	61.7
Mean_B1+ (tmt)	1,598.5	1,258.8	1,287.8	1,031.5	578.3	937.2	1,375.5	952.8	1,429.3
SD_B1+ (tmt)	895.9	879.8	767.9	747.2	768.8	835.5	836.8	866.2	828.4
Median_B1+ (tmt)	1,430.2	1,036.9	1,113.6	836.0	309.2	737.1	1,186.3	696.7	1,254.1
Mean_SSB (tmt)	1,326.3	978.1	993.0	748.8	413.3	688.5	1,085.7	699.1	1,142.8
SD_SSB (tmt)	797.3	752.6	612.5	571.5	582.5	659.2	705.4	716.2	696.8
Median_SSB (tmt)	1,163.8	778.4	852.3	600.8	213.3	525.5	921.1	480.9	987.8
% Years with B1+ > 400 tmt	99.1	94.7	98.1	90.0	44.8	71.6	98.5	73.0	98.6
% Years with no catch	100.0	2.7	16.0	28.6	30.9	3.1	21.3	5.2	20.1
% Years with Catch < 50 tmt	100.0	30.4	44.4	38.2	49.9	26.3	48.6	25.4	54.1
Mean age (yrs)	3.23	2.81	2.82	2.55	1.67	2.45	2.93	2.51	3.00
Mean_Catch_Age (yrs)	2.14	1.83	1.84	1.65	1.08	1.58	1.92	1.62	1.97
Mean Consec. Years No Catch	NA	1.7	1.8	2.2	390.2	170.8	2.1	1.5	2.1
%HCR_min	100.0	11.9	11.9	100.0	100.0	100.0	11.9	100.0	4.5
%HCR_max	100.0	52.2	42.1	100.0	100.0	100.0	52.2	100.0	74.3
Mean_Yrs_HCRmin	NA	2.6	2.6	NA	NA	NA	2.6	NA	2.0
Mean_Yrs_HCRmax	NA	7.4	6.0	NA	NA	NA	7.4	NA	11.3
% Runs with Full Collapse	0.0	0.0	0.0	0.0	65.0	10.0	0.0	0.0	0.0
Mean Yrs with SSB < 740 tmt	21.0	46.8	38.4	63.8	80.4	64.9	32.8	68.4	28.9

Table 4. Performance of alternative HCR scenarios based on May 2013 sardine simulation model results.

* Based on an approximation incorporating discrepancies in DISTRIBUTION and FRACTION.
** Oceana's interpretation and application of Lenfest Forage Fish Task Force recommendations for Tier 2.

Figure 1. Depiction of two coastwide harvest guidelines as a function of biomass (1+). The actual harvest guideline is determined by the FRACTION, which in both HCRs have a temperature-dependent fraction ranging from 5-15%.

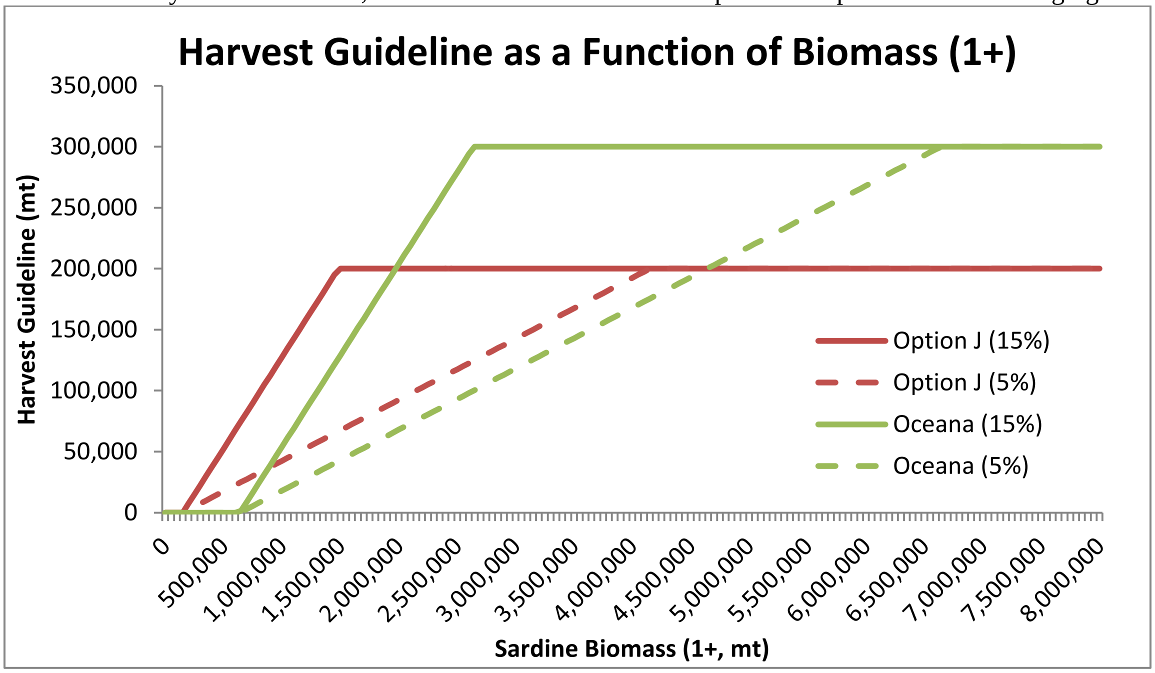


Figure 2. Depiction of two harvest guidelines in terms of the exploitation rate (% of the total biomass (1+) that is harvested) as biomass varies.

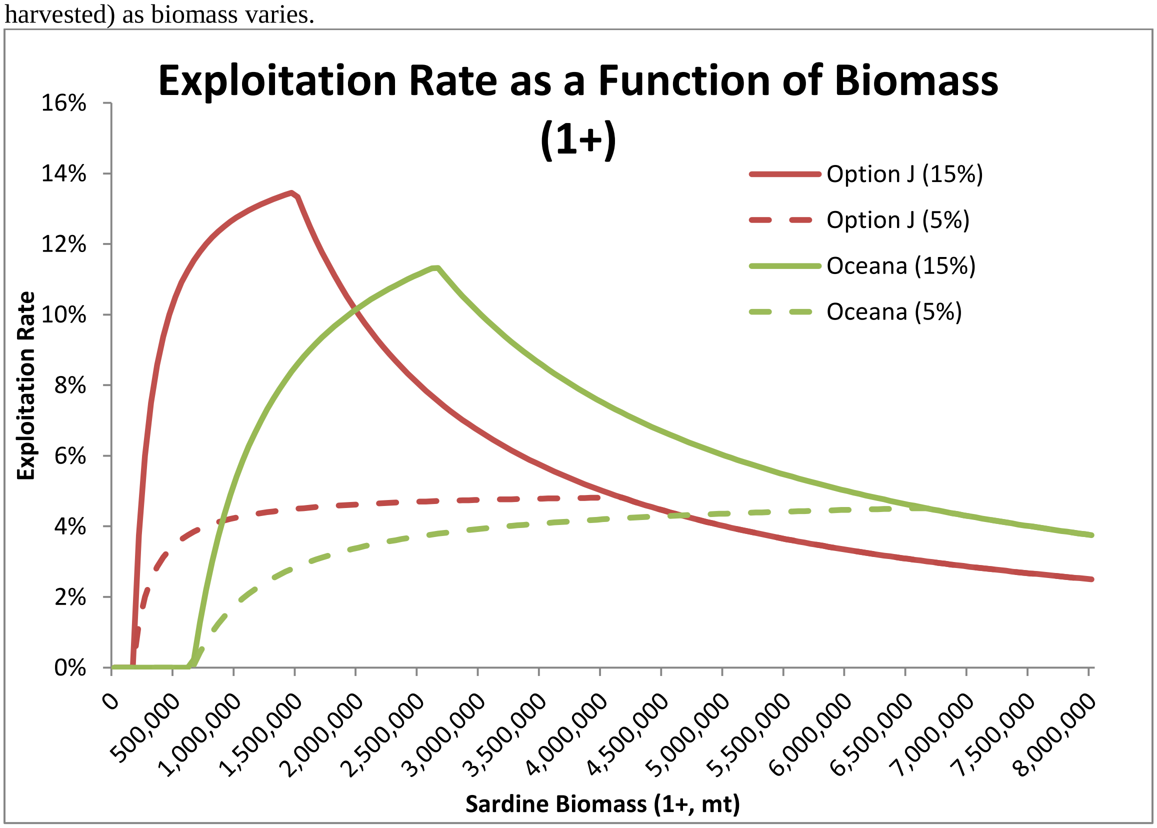


Figure 3. Example 100 years of simulated harvest guidelines under two alternative HCR scenarios.

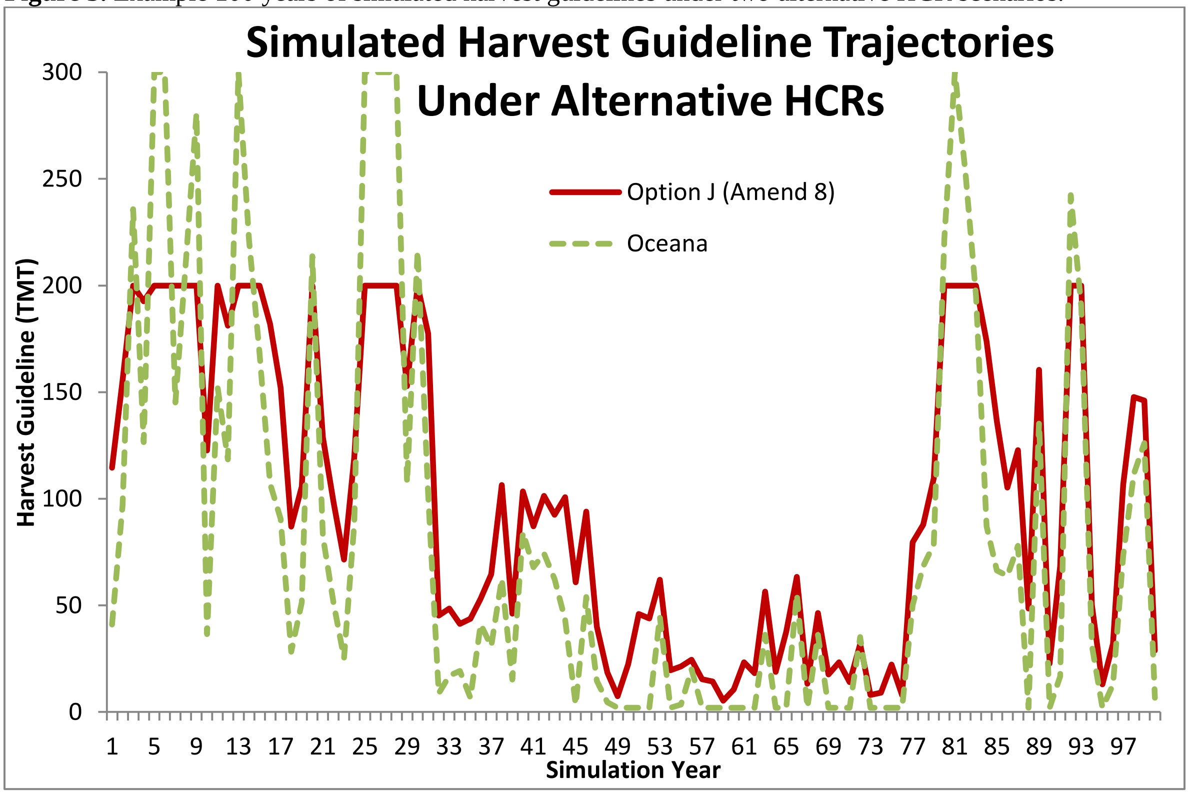


Figure 4. Example 100 years of simulated sardine biomass under four alternative HCR scenarios.

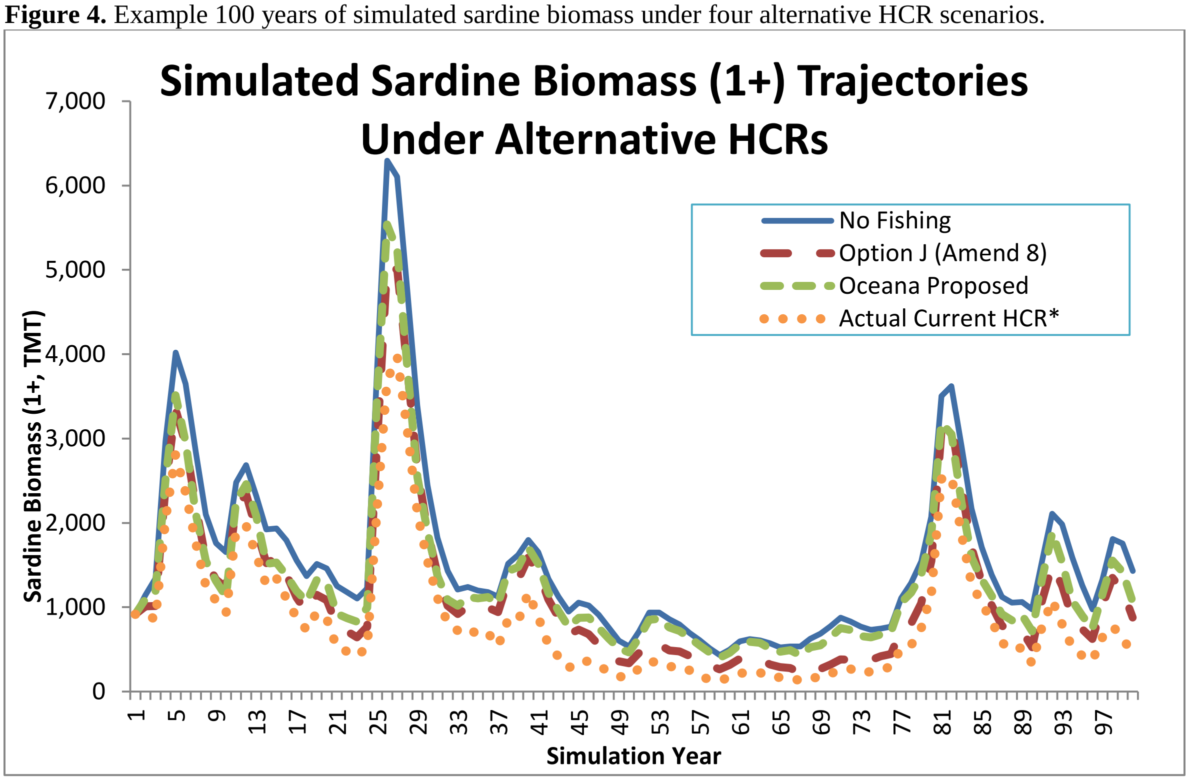
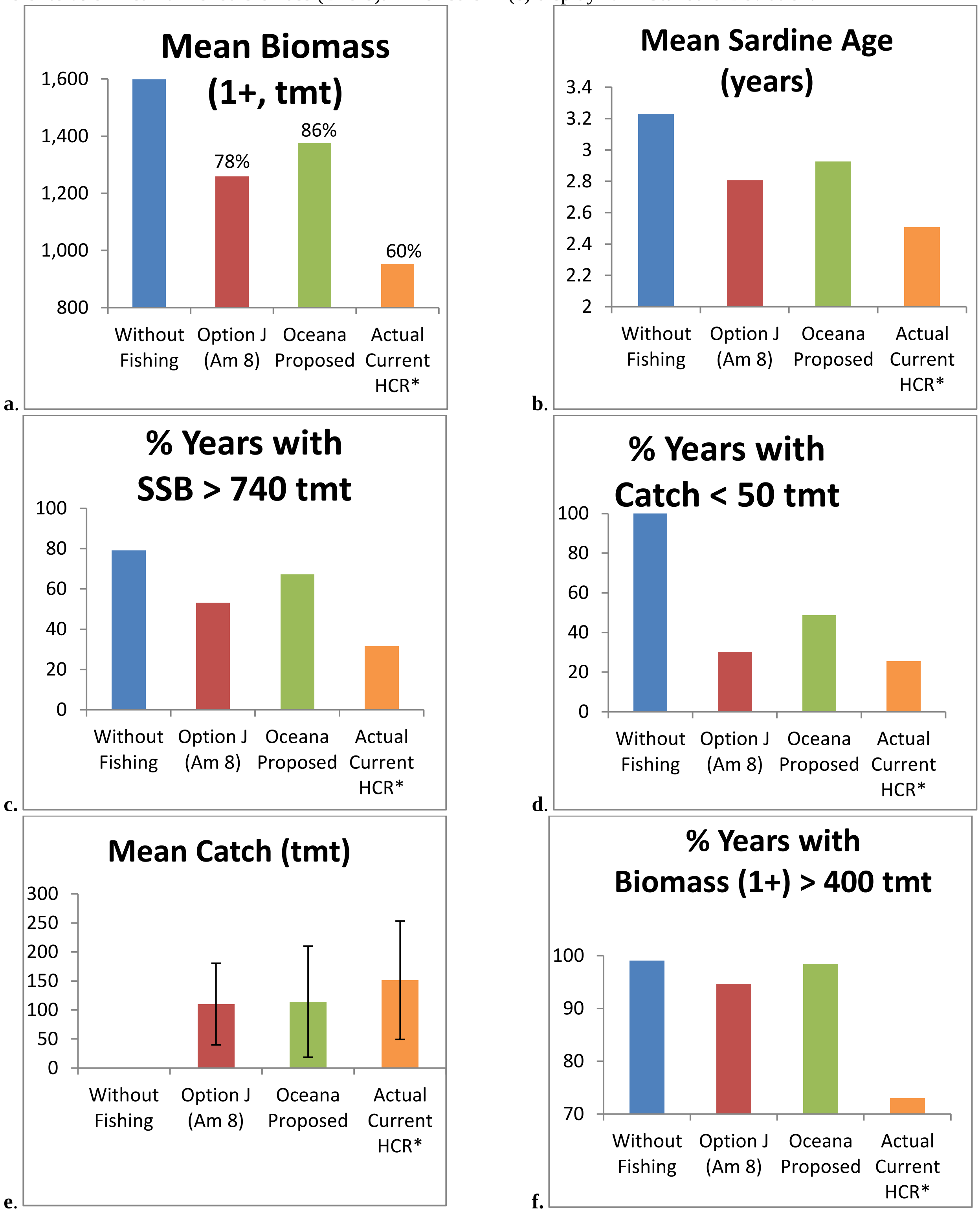


Figure 5. Comparing the unfished scenario with three HCR variants across performance metrics. Data labels in (a) refer to % of mean unfished biomass (Bzero). Error bars in (e) display +/- 1 Standard Deviation.



An estimate of the average portion of the northern stock of Pacific sardine (*Sardinops sagax*) residing in the U.S. exclusive economic zone

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Abstract – The northern stock of Pacific sardine (*Sardinops sagax*) is fished off the west coasts of Mexico, the United States (U.S.), and Canada. Without cooperative management of the fishery, the harvest levels for the U.S. fishery are set by prorating the total target harvest level by $DISTRIBUTION$, the proportion of the stock resident in the U.S. waters. Based on the Over Fishing Limit control rule, biomass estimated from the 2012 assessment, and landings from the three countries, $DISTRIBUTION$ is estimated to be 52 or 59%, during 1993 to 2011, depending on allocation of the landings to the northern stock. The latter value, 59%, equals the average value for $DISTRIBUTION$ estimated from fish egg and larvae data and aerial spotter data, ca. 1963-1992 (PFMC, 2011). During 1993 to 2011, the annual mean estimates of $DISTRIBUTION$ peaked in the 2000s and have since declined to period-low levels.

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♦ This article does not necessarily reflect the official views or policies of the National Marine Fisheries Service, the National Oceanic and Atmospheric Administration, the Department of Commerce, or the Administration.

Introduction

The northern stock of Pacific sardine (*Sardinops sagax*) resides mostly off the west coast of the United States (U.S.), but portions of it may periodically reside off Mexico and Canada. Although sardine landings from this stock were at Ensenada, Mexico, multiple U.S. ports , and Vancouver Island, Canada, there is no international management agreement. The U.S. fishery management plan (FMP) for coastal pelagic species (CPS) states (PFMC, 2011) "*In the absence of a cooperative management agreement, the default approach in the CPS FMP sets harvest levels for U.S. fisheries by prorating the total target harvest level according to the portion of the stock resident in U.S. waters or estimating the biomass in U.S. waters only.*" The FMP also states (PFMC, 2011) that "*… the harvest for the U.S. fishery in a given year depends ultimately on the biomass in U.S. waters.*" This paper responds to a request from the Pacific Fisheries Management Council (PFMC) for information on the proportion of the stock that occurs in U.S. waters under average contemporary oceanographic conditions, or during warm, cool, and transitional oceanographic regimes.

Methods

Based on the FMP, the landings of sardine in the U.S. ($L_{U.S.}$) depend ultimately on the proportion of the stock biomass that is within the U.S. exclusive economic zone (EEZ). Following the same reasoning, the transboundary landings of the stock ($L_{Mexico} + L_{Canada}$) depend ultimately on the proportion of the stock biomass that is outside of the U.S. EEZ. Currently, the FMP uses a constant value ($DISTRIBUTION = 0.87$) for the average proportion of the stock that resides within the U.S. EEZ. By mathematical complement, the average proportion of the stock that is outside of the U.S. EEZ is a constant value (i.e., $1 - DISTRIBUTION = 0.13$).

Presently, the FMP considers multiple harvest control rules (PFMC, 2011). The default rule, the harvest guideline ($HG \geq L_{U.S.}$), sets the harvest level for the U.S. fishery by prorating the target total harvest level [$(\widehat{BIOMASS} - CUTOFF) \times FRACTION$] according to the portion of the stock that is resident in the U.S. waters ($DISTRIBUTION$) (PFMC, 2011). Intrinsically, the HG aims to limit the annual total exploitation of the estimated age-1+ northern stock biomass ($\widehat{BIOMASS}$) to less than or equal to a proportion ($FRACTION = 0.15$) of its age-1+ biomass minus a reserve ($CUTOFF = 150{,}000$ mt):

$$HG = (\widehat{BIOMASS} - CUTOFF) \times FRACTION \times DISTRIBUTION \text{ , or} \tag{1}$$

$$L_{U.S.} \leq \left(\widehat{BIOMASS} - CUTOFF\right) \times FRACTION \times DISTRIBUTION \quad . \tag{2}$$

Substituting and rearranging, we estimate the annual proportion of the stock biomass that is in the U.S. EEZ $\left(\widehat{DISTRIBUTION}\right)$ as:

$$\widehat{DISTRIBUTION} \geq L_{U.S.}/\left[\left(\widehat{BIOMASS} - CUTOFF\right) \times FRACTION\right] \text{ or} \tag{3}$$

$$\widehat{DISTRIBUTION} \leq 1 - (L_{Mexico} + L_{Canada})/\left[\left(\widehat{BIOMASS} - CUTOFF\right) \times FRACTION\right] . \tag{4}$$

Using the over fishing level (*OFL*) control rule, $\widehat{DISTRIBUTION}$ was also estimated as:

$$\widehat{DISTRIBUTION} \geq L_{U.S.}/\left[\widehat{BIOMASS} \times F_{MSY}\right] \text{ or} \tag{5}$$

$$\widehat{DISTRIBUTION} \leq 1 - (L_{Mexico} + L_{Canada})/\left[\widehat{BIOMASS} \times F_{MSY}\right] \quad . \tag{6}$$

$\widehat{DISTRIBUTION}$ values were estimated annually from 1993 to 2011 using equations (3), (4), (5), and (6); mid-year (July) age-1+ biomass ($\widehat{BIOMASS}$) from the 2012 assessment (Hill et al., 2011); $FRACTION = 0.15$; $F_{MSY} = 0.18$; and landings, total (undifferentiated) and only those ascribed to the northern stock (differentiated), from Ensenada, Mexico (L_{Mexico}), the U.S. ($L_{U.S.}$) and Vancouver Island, Canada (L_{Canada}). The stock differentiation procedure (Demer et al., submitted) was used to ascribe portions of the landings at Ensenada, Mexico and San Pedro, California to the southern stock.

Results

Harvest Guideline Method

Solving equations (3) and (4) with undifferentiated landings (**Table 1**), the average $\widehat{DISTRIBUTION}$ ranged from 0.49 (standard deviation (s.d.) = 0.19) to 0.57 (s.d. = 0.15), from 1993 to 2011, with a mean value of 0.52. With stock differentiation, $\widehat{DISTRIBUTION}$ ranged from 0.41 (s.d. = 0.16) to 0.84 (s.d. = 0.10). During this period, the U.S. fisheries accounted for an average of 0.53 (s.d. = 0.11) and 0.72 (s.d. = 0.15) of the undifferentiated and differentiated sardine landings, respectively.

Over Fishing Level Method

Solving equations (5) and (6) without stock differentiated landings, the average $\widehat{DISTRIBUTION}$ ranged from 0.35 (s.d. = 0.13) to 0.70 (s.d. = 0.10), from 1993 to 2011 (**Table 1**). The annual mid-range estimates for $\widehat{DISTRIBUTION}$ (**Fig. 1**) had a maximum of 0.68 in 2007 and a minimum of 0.40 in 2011. The annual $\widehat{DISTRIBUTION}$ values were highest during the period from 2001 to 2007 (**Table 1**; **Fig. 1**). The mean mid-range $\widehat{DISTRIBUTION}$ was 0.52.

With stock differentiation, $\widehat{DISTRIBUTION}$ ranged from 0.29 (s.d. = 0.10) to 0.89 (s.d. = 0.07) (**Table 1**). The annual mid-range estimates for $\widehat{DISTRIBUTION}$ (**Fig. 2**) had a maximum of 0.72 in 2002 and a minimum of 0.43 in 2011. The annual $\widehat{DISTRIBUTION}$ values were highest during the period from 2000 to 2004 (**Table 1**; **Fig. 2**). The mean mid-range $\widehat{DISTRIBUTION}$ was 0.59 (s.d. = 0.07).

Conclusion

Using the Over Fishing Level method (equations (5) and (6)), values for $\widehat{DISTRIBUTION}$, during 1993 to 2011, were 52% without stock differentiation or 59% with stock differentiation. The latter value equals the average $\widehat{DISTRIBUTION}$ estimated from fish egg and larvae data and aerial spotter data, ca. 1963-1992 (PFMC, 2011).

References

Demer, D.A., Zwolinski, J.P., Hill, K. T. Macewicz, B. J., Cutter Jr., G. R. and Byers, K. A., submitted, Differentiating stocks of Pacific sardine (*Sardinops sagax*) in the California Current to improve estimates of stock demography, abundance, distribution, and mortality, to be submitted to ICES Journal of Marine Science.

Hill, K., Crone, P. R., Lo, N. C. H., Demer, D. A., Zwolinski, J. P., and Macewicz, B. J. 2012. Assessment of the Pacific sardine resource in 2012 for U.S. Management in 2013. Pacific Sardine Assessment Update Report, Agenda Item G.3.b. Supplemental Assessment Report 2, 51 pp.

PFMC, 2011, Coastal Pelagic Species Fishery Management Plan as amended through amendment 13, Pacific Fisheries Management Council, Portland, Oregon, 48 pp.

Table 1. Estimated mid-year (July) age-1+ sardine biomass ($\widehat{BIOMASS}$; mt) from the 2012 assessment (Hill et al., 2012); undifferentiated and stock-differentiated sardine biomass landed (mt) at Ensenada, Mexico (L_{Mexico}), the United States ($L_{U.S.}$), and Vancouver Island, Canada (L_{Canada}) and their respective proportions of the total annual catch; and the estimated proportion of the stock that was present in the United States exclusive economic zone ($\widehat{DISTRIBUTION}$) using Harvest Guideline (HG) and Over Fishing Limit (OFL) control rule equations. The 1993-2011 mean estimates of $DISTRIBUTION$ are bold.

		Undifferentiated Landings										
	Age-1+ July	**Mexico**		**United States**		**Canada**		$\widehat{DISTRIBUTION}$				
Year	$\widehat{BIOMASS}$ **(mt)**	L_{Mexico} **(mt)**	**Prop.**	$L_{U.S.}$ **(mt)**	**Prop.**	L_{Canada} **(mt)**	**Prop.**	HG ≥	HG ≤	OFL ≥	OFL ≤	≈
1993	507320	32,044.9	0.66	16,192.4	0.34	0	0	0.30	0.40	0.18	0.65	0.41
1994	691760	20,877	0.62	12,704.8	0.38	0	0	0.16	0.74	0.10	0.83	0.47
1995	915256	35,396.2	0.46	41,511.7	0.54	22.7	0.00	0.36	0.69	0.25	0.79	0.52
1996	977035	39,064.7	0.53	34,056.1	0.47	0	0	0.27	0.69	0.19	0.78	0.49
1997	998922	68,439.1	0.60	46,268.4	0.40	70.7	0.00	0.36	0.46	0.26	0.62	0.44
1998	1134060	47,812.2	0.53	41,544.5	0.46	488.1	0.01	0.28	0.67	0.20	0.76	0.48
1999	1333310	58,569.4	0.50	57,546.6	0.50	24.5	0.00	0.32	0.67	0.24	0.76	0.50
2000	1246290	67,845.2	0.49	69,452.7	0.50	1,721.4	0.01	0.42	0.58	0.31	0.69	0.50
2001	1032760	46,071.3	0.40	68,949.0	0.59	1,265.9	0.01	0.52	0.64	0.37	0.75	0.56
2002	868532	46,845.4	0.35	86,893.9	0.65	739.3	0.01	0.81	0.56	0.56	0.70	0.63
2003	634081	41,341.7	0.39	63,973.1	0.60	977.7	0.01	0.88	0.42	0.56	0.63	0.59
2004	976986	41,897.1	0.31	88,251.8	0.66	4,438.1	0.03	0.71	0.63	0.50	0.74	0.62
2005	1107780	55,322.8	0.38	86,432.7	0.60	3,231.8	0.02	0.60	0.59	0.43	0.71	0.57
2006	1365980	57,236.9	0.39	88,252.7	0.60	1,575.4	0.01	0.48	0.68	0.36	0.76	0.56
2007	1356860	36,846.8	0.23	124,555.2	0.77	1,522.3	0.01	0.69	0.79	0.51	0.84	0.68
2008	1286760	66,865.9	0.40	91,164.8	0.54	10,425.0	0.06	0.53	0.55	0.39	0.67	0.53
2009	1106180	55,911.3	0.38	74,392.1	0.51	15,334.4	0.11	0.52	0.50	0.37	0.64	0.51
2010	1077220	56,820.9	0.37	76,733.3	0.49	22,223.0	0.14	0.55	0.43	0.40	0.59	0.49
2011	898150	70,336.5	0.47	59,455.6	0.40	20,718.7	0.14	0.53	0.19	0.37	0.44	0.40
mean	1027118.0	49765.542	0.445	64649.0	0.53	4462.1	0.030	0.49	0.57	0.35	0.70	**0.52**
s.d.	242297.1	13820.749	0.112	28012.9	0.11	7187.6	0.047	0.19	0.15	0.13	0.10	0.07

	Differentiated Landings										
	Mexico		**United States**		**Canada**		$\widehat{DISTRIBUTION}$				
Year	L_{Mexico} **(mt)**	**Prop.**	$L_{U.S.}$ **(mt)**	**Prop.**	L_{Canada} **(mt)**	**Prop.**	HG ≥	HG ≤	OFL ≥	OFL ≤	≈
1993	9469.3	0.258	27182.8	0.742	0.0	0.000	0.51	0.82	0.30	0.90	0.60
1994	4624.1	0.195	19097.6	0.805	0.0	0.000	0.24	0.94	0.15	0.96	0.56
1995	15958.7	0.198	64683.4	0.802	22.7	0.000	0.56	0.86	0.39	0.90	0.65
1996	16038.1	0.293	38730.7	0.707	0.0	0.000	0.31	0.87	0.22	0.91	0.56
1997	8911.1	0.172	42741.9	0.826	70.7	0.001	0.34	0.93	0.24	0.95	0.59
1998	6214.8	0.097	57573.6	0.896	488.1	0.008	0.39	0.95	0.28	0.97	0.62
1999	37860.5	0.353	69393.1	0.647	24.5	0.000	0.39	0.79	0.29	0.84	0.57
2000	29243.2	0.245	88259.1	0.740	1721.4	0.014	0.54	0.81	0.39	0.86	0.63
2001	13547.1	0.147	77146.1	0.839	1265.9	0.014	0.58	0.89	0.41	0.92	0.67
2002	13552.0	0.140	82765.1	0.853	739.3	0.008	0.77	0.87	0.53	0.91	0.72
2003	18487.3	0.263	50824.8	0.723	977.7	0.014	0.70	0.73	0.45	0.83	0.64
2004	6296.8	0.105	49138.0	0.821	4438.1	0.074	0.40	0.91	0.28	0.94	0.61
2005	15583.4	0.225	50556.3	0.729	3231.8	0.047	0.35	0.87	0.25	0.91	0.58
2006	11214.6	0.166	54700.7	0.810	1575.4	0.023	0.30	0.93	0.22	0.95	0.59
2007	19919.1	0.214	71449.7	0.769	1522.3	0.016	0.39	0.88	0.29	0.91	0.60
2008	19714.2	0.231	55225.1	0.647	10425.0	0.122	0.32	0.82	0.24	0.87	0.55
2009	20244.5	0.353	21812.2	0.380	15334.4	0.267	0.15	0.75	0.11	0.82	0.47
2010	17075.5	0.193	49342.7	0.557	22223.0	0.251	0.35	0.72	0.25	0.80	0.53
2011	31750.9	0.384	30180.1	0.365	20718.7	0.251	0.27	0.53	0.19	0.68	0.43
mean	16616.063	0.223	52673.8	0.72	4462.1	0.058	0.41	0.84	0.29	0.89	**0.59**
s.d.	8806.435	0.081	19918.9	0.15	7187.6	0.093	0.16	0.10	0.10	0.07	0.07

Figure 1. Annual estimates of $DISTRIBUTION$ calculated using the over fishing limit (OFL) control rule and undifferentiated landings. The annual minima (lower line) were estimated using all landings from the United States. The annual maxima (upper line) were estimate using all landings from Ensenada, Mexico and Vancouver Island, Canada. The annual maximum and minimum values were averaged (middle line).

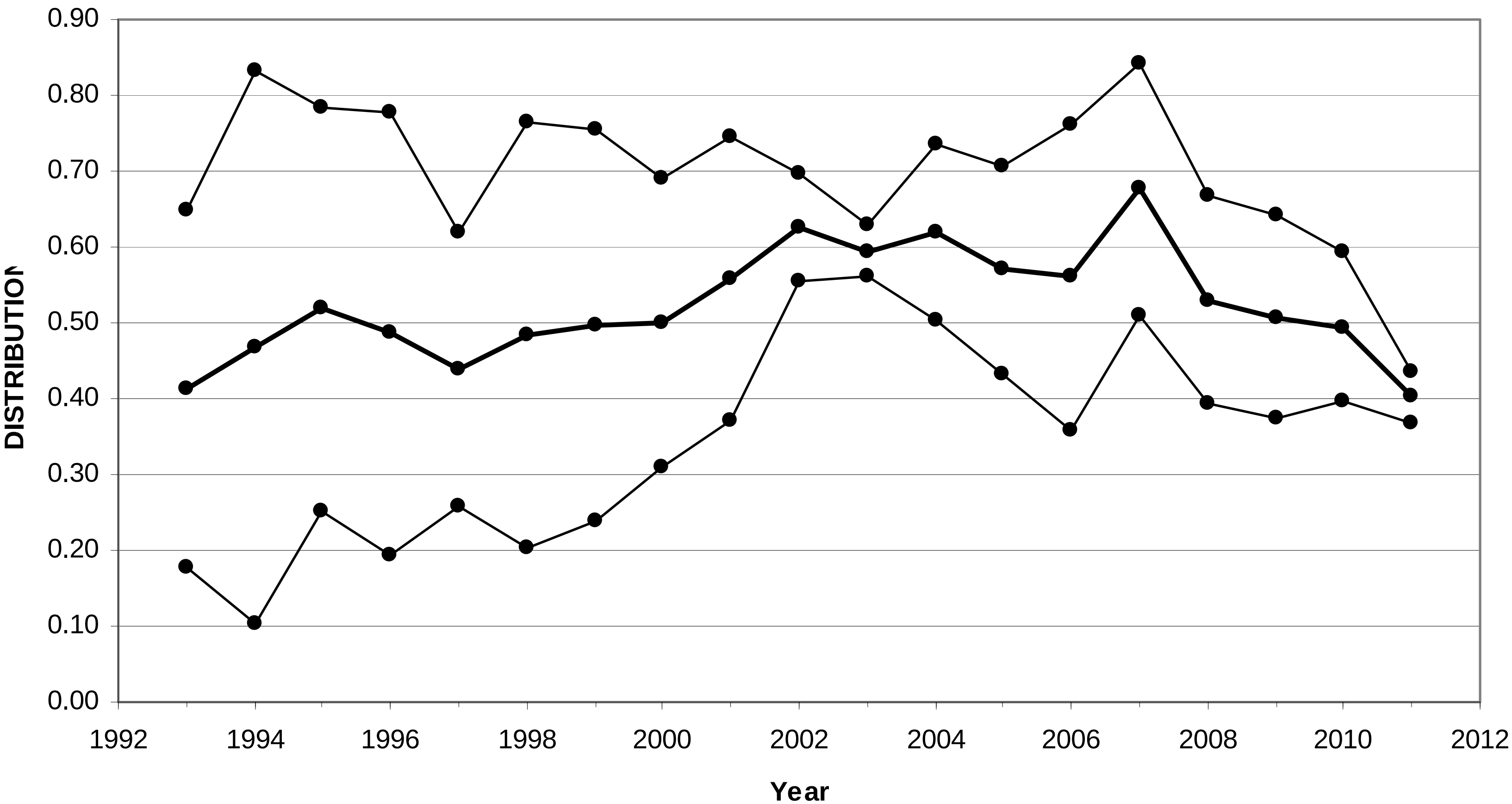
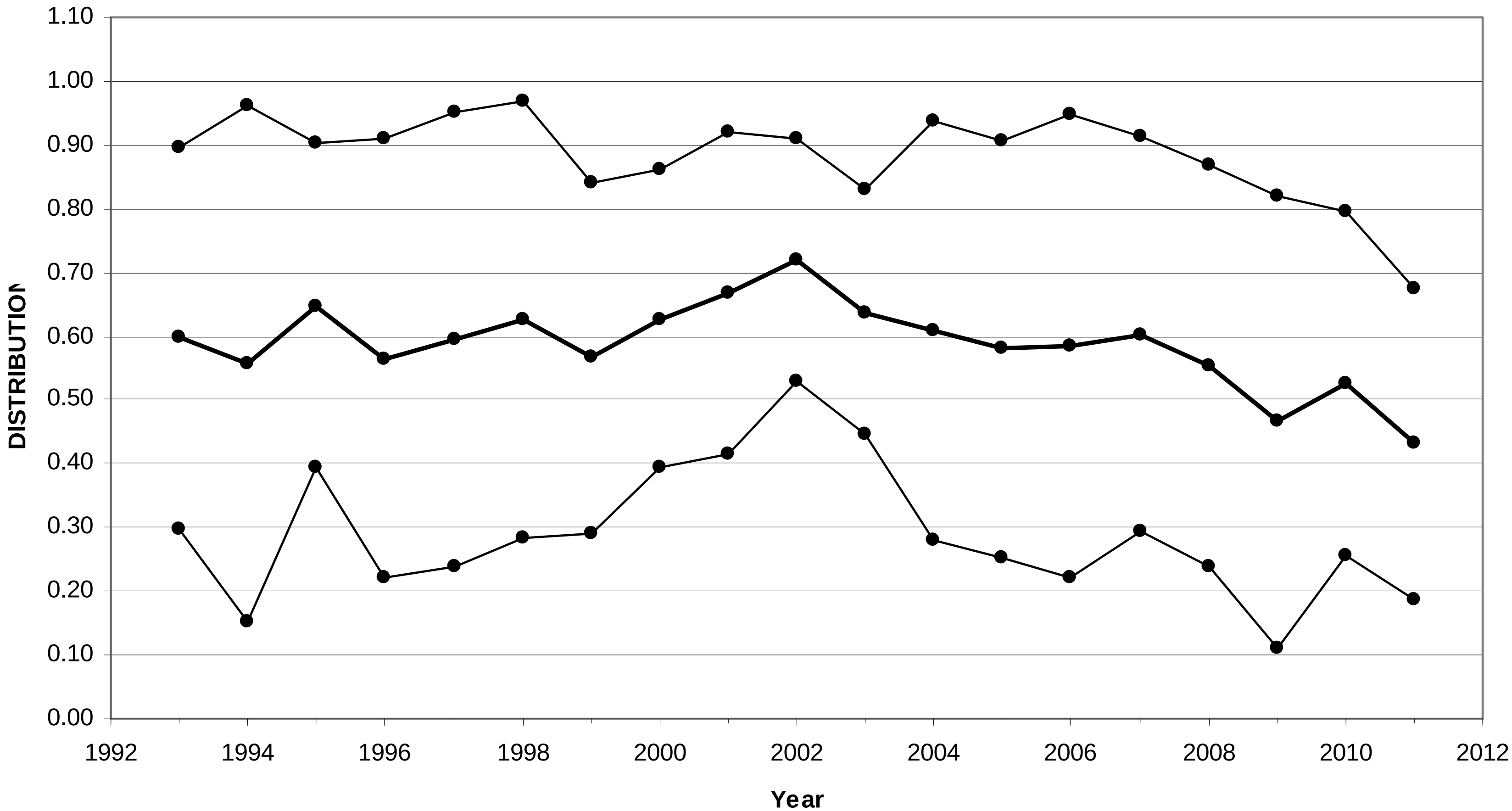


Figure 2. Annual estimates of $DISTRIBUTION$ calculated using the over fishing limit (OFL) control rule and only the putative northern stock landings. The annual minima (lower line) were estimated using stock differentiated landings from the United States. The annual maxima (upper line) were estimate using stock differentiated landings from Ensenada, Mexico and all landings from Vancouver Island, Canada. The annual maximum and minimum values were averaged (middle line).



Optimizing U.S.-harvest quotas to meet the target total exploitation of an internationally exploited stock of Pacific sardine (*Sardinops sagax*)

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Abstract – There are two stocks of Pacific sardine (*Sardinops sagax*) in the California Current. The "southern" stock resides mostly off the west coast of Baja California, Mexico, but portions of it may periodically reside in waters off southern California (CA). The "northern" stock, annually assessed by the United States (U.S.) government, resides mostly off the west coast of the U.S., but portions of it may periodically reside in waters off Mexico and Canada. The segregated stocks migrate seasonally and synchronously along the coast. The latitudinal ranges of the migrations increase with stock biomass and fish size. Different seawater habitats, characterized by predominantly different ranges of sea-surface temperature, may be used to differentiate the landings from the two stocks. The U.S. fishery, presumably of the northern stock, is managed by the Pacific Fisheries Management Council (PFMC). Currently, the PFMC aims to limit the annual total exploitation of the northern stock to less than 15% ("fraction") of the age 1+ biomass minus a 150,000 mt ("cutoff"). However, the stock is not managed tri-nationally, and the U.S. harvest guideline does not currently account for landings at Canada nor control the Mexican and Canadian landings. Therefore, the PFMC currently assumes a constant 87% of the northern stock resides off the U.S. west coast. However, this "distribution" fraction is likely not constant; the distribution of sardine within its potential habitat is neither homogenous nor predictable; and the proportions of sardine habitat associated with each country are not equivalent to their fractions of the total landings from the stock. The total fishing fraction and the

[*] This article does not necessarily reflect the official views or policies of the National Marine Fisheries Service, the National Oceanic and Atmospheric Administration, the Department of Commerce, or the Administration.

proportions of it that are associated with each country may be estimated annually from landings from each country and estimates of the northern stock biomass. Assuming that the landings at Mexico and Canada in one year are good estimates for their values during the following year, a simple model is proposed for setting the U.S. quotas such that the annual total tri-national landings more consistently match the target-fishing fraction.

Introduction

Stocks of Pacific sardine

In the California Current Ecosystem (CCE), there are two migrating stocks of Pacific sardine (*Sardinops sagax*) (Clark and Janssen, 1945; Félix-Uraga et al., 2004, 2005) that that exhibit large fluctuations in abundance (e.g., Zwolinski and Demer, 2012) and distribution (e.g., Zwolinski et al., 2011; Lo et al., 2011; Garcia-Morales et al., 2012). The "southern" stock spans seasonally from southern Baja California, México to Point Conception, California (CA); and the "northern" stock from San Quintín, México northwards to southern Alaska (Vrooman, 1964; Smith, 2005; Demer et al., 2012). The seasonal north-south migrations of the two stocks are approximately synchronous within their respective domains, resulting in segregated spawning and different identities (Murphy, 1966; Smith 2005).

Seasonal migration

During 1900 to 1940, the abundance of sardine reached 3.6 million metric tons (Mt; MacCall, 1979) and the northern stock then migrated from offshore of CA in the spring to the coastal areas near Oregon (OR), Washington (WA), and Vancouver Island (VI) in the summer. In the 1940s, the sardine stock collapsed, their migration stopped, and the few remaining sardine schools concentrated in the coastal region off southern CA, year-round, for the next 50 years. The stock gradually recovered in the late 1980s and resumed its seasonal migration between regions off southern CA and Canada. Thus, the sardine migration appears to be density dependent (Zwolinski and Demer, 2012). In recent years, during spring, sardine aggregated offshore of central and southern California to spawn (Lo et al., 2009). During summers, the stock moved north to feed and often compressed close to the coasts of OR, WA, and VI (Lo et al., 2011; Demer et al., 2012). The latitudinal extent of the migration increased with fish size (Lo et al., 2011), with the largest, most fecund fish reaching VI (Zwolinski and Demer, 2012). Between

2006 and 2012, the results of acoustic-trawl surveys indicated that the sardine stock declined[1] from 1.95 Mt (*CV*=30.3%) to 0.494 Mt (*CV*=30.4%) (Zwolinski et al., 2012a; Demer et al., submitted), but continued, during this period, to migrate as far north as VI during the summer.

Stock habitats

Using more than twenty years (1981-2002) of commercial catch data from various coastal regions and all monthly periods, Félix-Uraga et al. (2004, 2005) identified ranges of sea-surface temperature (*SST*) associated with maximum catches of sardine from the putative southern (17 °C < *SST* < 22 °C) and northern (*SST* < 17 °C) stocks. To predict the potential habitat and its seasonal dynamics for the northern stock of sardine, Zwolinski et al. (2011) developed a model parameterized with satellite-sensed *SST*, chlorophyll-a concentration, and the gradient of sea-surface height. The habitat predictions were successfully validated using data from sardine surveys using the daily egg production method (Lo et al., 2009); scientific trawl surveys off the Columbia River mouth (Emmett et al., 2005); commercial sardine landings off OR, WA, and VI; and results from acoustic-trawl method (ATM) surveys of the stock during the spring and summer of 2008 (Demer et al., 2012). As previously described for the sardine migration, the model clearly shows that, during spring, the potential sardine habitat is located offshore of central and southern CA (**Fig. 1**). Also, during summer, the potential sardine habitat is compressed along the coast, extending north to VI. During winter, the habitat distribution, coupled with virtually no landings in the north, suggests that the sardine return south offshore. As might be expected, the ATM survey data show (**Fig. 2**) that sardine did not span their entire potential habitat; and the proportion of their habitat which they occupied depended on the stock size.

Stock differentiation

The central CA (CCA), OR, WA, and VI fisheries are seasonal, generally between May and November, depending on the region. During this period, the potential habitat of the northern stock develops along the northeast Pacific coast from the south and progresses northwards.

[1] Other survey-based estimators either seasonally sample an unknown portion of the migrating stock biomass (i.e., the industry-sponsored aerial-photogrammetric survey or the Canadian trawl survey) or indirectly estimate the spawning stock biomass using the daily egg production method (DEPM). Nevertheless, all of the measures indicate a decline in the sardine stock between 2006 and 2011. A modest 2009/2010 cohort was observed in 2011. For more details and a comparison of the various survey results, see Zwolinski and Demer (2012) and references therein, and Demer and Zwolinski (2012).

Consequently, sardine fishing begins and ends first off OR, then off WA, and lastly off VI (Zwolinski et al., 2011). In contrast, the Ensenada (ENS) and southern CA (SCA) fisheries can span all months (**Fig. 3**) (Demer et al., submitted). Accurate apportionment of the landings data from the two stocks is critical for successful assessment and management of these stocks (Smith, 2005).

Demer et al. (submitted) noted that the maximum *SST* that Félix-Uraga et al. (2004, 2005) associated with potential habitat for the northern stock is similar to that described by Zwolinski et al. (2011). Demer et al. (submitted) showed that fishery landings from central CA (CCA) and northwards are consistently from the migrating northern stock; and both Félix-Uraga et al. (2004, 2005) and Demer et al. (submitted) showed that the landings at Ensenada (ENS) and San Pedro, southern CA (SCA), may be from either the southern or northern stock depending on the local presence of appropriate potential habitat. These analyses indicated that the catches off SCA were entirely from the northern stock during winter and spring and the southern stock during summer, clearly transitioning during the months of June-July and November-December. The transition from northern to southern habitat is characterized by *SST* in the range of approximately 16.5 - 17.5 °C (Félix-Uraga et al., 2004) or 16.4 – 16.7 °C (Demer et al., submitted). Because few sardine were landed at ENS or SCA when the local *SST* was in the transitional range, it appears that the stocks maintained separation. Therefore, Félix-Uraga et al. (2004, 2005) and Demer et al. (submitted) proposed using ranges of *SST* to partition and attribute catch data from each fishing zone to each respective sardine stock. Future assessments of sardine should be improved by accurate apportioning of the landings data to their respective stocks (Smith, 2005; Demer et al., submitted).

Distribution of the northern stock

The U.S. fishing areas span both the spring spawning and summer feeding areas of the northern stock migration (**Fig. 2**). Depending on the time of the year (**Fig. 3**) and the latitudinal extent of the stock-size-dependent sardine migration, potentially little to all of the stock may reside in or pass through U.S. waters. For example, during the 2006-2011 spring surveys, the large majority of the sardine stock was located off the U.S. west coast. While a small amount may have resided off Mexico during spring (Zwolinski et al., 2011; Demer et al., 2012), fishery landings indicate that few to none resided off Canada at that time (**Fig. 3**). In contrast, during the 2008 summer survey, the sardine migrated north (Demer et al., 2012) and few to none of the sardine from the northern stock resided off Mexico (Zwolinski et al., 2011; Demer et al., submitted). This case for the U.S. management area is similar to that for regional areas, such as Quinault Tribal Usual and Accustomed fishing area (U&A), which is also in the migration path of the northern stock (**Fig. 2**). That is, the proportion of the northern stock that resides in any U.S. management area (e.g., off the west coast of the U.S. or the Quinault Tribal U&A) is not constant because the northern stock migrates and seasonally extends into Mexico and Canada. Furthermore, the proportions of sardine catches and habitat associated with each country are not equivalent.

Harvest guidelines and control rule

The PFMC uses the most recent sardine assessment to set their annual harvest guideline *HG* values for fishing in each season and region such that they total less than or equal to a "*fraction*" (currently 0.15) of the estimated stock minus a "*cutoff*" biomass (currently 150,000 mt) (Hill et al., 2011). The U.S. harvest-control rule (HCR) prorates the *HG*, assuming a fraction of the northern stock resides inside U.S. waters (PFMC, 1998). This "distribution" parameter (currently 0.87), based on an analysis of sardine egg and larvae distributions and aerial logbook data, is a weighted-average distribution of the northern stock between waters governed by the U.S. and Mexico (i.e., 87% and 13% of the northern stock is assumed to reside inside U.S. and México waters, respectively). Currently, the HCR does not account for sardine off Canada.

The fishery in Mexico is not regulated by quotas, but is restricted to fish larger than 155 mm standard length (Lo and Schott, 2012). The fishery in Canada is restricted by a three-year running average of the estimated proportion of the U.S.-assessed sardine biomass that migrates into Canadian waters (Ware, 1999), e.g., 27.2% in 2010 (DFO, 2011). To derive these estimates, Canada conducts summer trawl surveys off western VI (DFO, 2012).

For the fisheries in Mexico, the U.S., and Canada, the respective HCR and *HG* values depend on accurate knowledge of the seasonal boundaries of the northern and southern sardine stocks. Uncertainties in sardine-stock boundaries result in uncertainties in the intended and actual fishing fractions and exploitation rates. Therefore, the PFMC called for a revised estimate of *distribution*, the average fraction of the northern sardine stock that resides off the U.S. west coast.

Study objective

There appears to be serial correlations in the annual landings of the northern stock (Hill et al., 2011). Therefore, the total tri-national fishing fraction and the proportions of it that are associated with each country may be estimated annually from landings from each country from the previous year, and projected estimates of the northern stock biomass for the management year. Assuming that the landings in Mexico and Canada in one year are good estimates for their values during the following year, the U.S. quotas could be set such that the total landings more consistently match the target fishing fraction. In the following paragraphs we develop a practical method to optimize the U.S.-harvest quotas to meet the target total exploitation of the internationally-exploited northern stock of Pacific sardine. We then apply it to actual landings from 1995 to 2011 and demonstrate that application of the method would reduce the discrepancy between the target fishing fraction and the total tri-national fraction, optimally increase U.S. landings when the stock is primarily off U.S. waters, and inherently reduce U.S. exploitation when large proportions of the landings are at Mexico, Canada, or both.

Methods

Fishery landings

For the period 1995 to 2011, the sardine landings at Mexico (ENS), the U.S. (SCA, CCA, OR, and WA), and Canada (VI) were summed to estimate the total annual landings from the northern stock. Landings from each country were divided by the total landings to estimate their respective proportions of the total landings. Then, using the method detailed in Demer et al. (submitted), the sardine landings in ENS and SCA were apportioned, based on associated sea-surface temperatures, to northern and southern stocks. The “differentiated” northern-stock landings were used to refine the estimates of total landings and the proportions from each country.

Fishing fraction and harvest guideline

The U.S. HG, the total U.S. (SCA, CCA, OR, and WA) quota for a calendar year, is calculated by:

$$HG = \left(\hat{B} - C\right) \times \hat{F} \times \widehat{D}\ , \quad (1)$$

where $\hat{B}$ is the assessment-estimated, northern stock biomass (age 1+) from 1 July of the previous year (or, alternatively, from 1 January of the same year); the *cutoff* C (currently 150,000 mt) is the lowest level of estimated biomass at which harvest is allowed; the fishing *fraction* $\hat{F}$ (currently 0.15) is the target proportion of biomass above the C to be harvested by the fisheries;

and the *distribution* $\widehat{D}$ is the average proportion of $\widehat{B}$ assumed in U.S. waters (Hill et al., 2012). Note that this $\widehat{F}$ is different than the total exploitation rate defined as the total landings in a year divided by the total mid-year (1 July) age 0+ biomass (Hill et al., 2012).

Assuming that the total landings from the northern stock (L) equals the sum of all landings from the northern stock in Mexico (L_{Mexico}), the U.S. (L_{US}), and Canada (L_{Canada}); and the northern stock resides entirely off the coasts of these three countries (i.e., $\widehat{D}$ = 1); then F, the actual proportion of age 1+ biomass above the C that was harvested by the fisheries in a year, may be calculated by:

$$F = L/\left[\left(\hat{B} - C\right)\right] . \tag{2}$$

The annual proportions of F associated with landings in Mexico (F_{Mexico}), the U.S. (F_{US}), and Canada (F_{Canada}) are equal to the quotients of their respective landings (L_{Mexico}, L_{US}, and L_{Canada}) and $\left(\hat{B} - C\right)$, e.g.:

$$F_{US} = L_{US}/\left[\left(\hat{B} - C\right)\right] . \tag{3}$$

Without tri-national management of the stock, the U.S. has no control of the Mexican and Canadian landings. Therefore, if the actual proportion of biomass above the C to be harvested by the fisheries is to equal the target proportion (i.e., $F = \hat{F}$), then the HG may be calculated by substituting $L = L_{Mexico} + L_{US} + L_{Canada}$ into equation (2) and solving for L_{US}:

$$HG = L_{US} = F\left(\hat{B} - C\right) - L_{Mexico} - L_{Canada} . \tag{4}$$

If harvest guidelines are known for Mexico and Canada prior to setting the U.S. HG, then they could be substituted for L_{Mexico} and L_{Canada}, respectively. Otherwise, the values reported for L_{Mexico} and L_{Canada} in one year are good estimators for their values during the subsequent year. The performance of this method was evaluated retrospectively by solving equation (4) with the actual landings for each year.

Results

Fishery landings

For the period 1995 to 2011, the annual sardine landings at Ensenada, Mexico (ENS), the U.S. (SCA, CCA, OR, and WA), and Canada (VI) were summed to estimate the total landings from the northern stock (**Table 1**). Without differentiating landings from the northern stock, landings at Mexico peaked at about 70,000 mt in 1997, 2000, 2008, and 2011, comprising 41 to 60% of the total annual landings. Landings at the U.S. exceeded 100,000 mt in 2002 and 2007, comprising about 68-77% of the total landings. Only since 2009 have the landings at Canada comprised an appreciable portion (11-15 %) of the total landings.

Using associated sea-surface temperatures to differentiate the landings at ENS and SCA (Demer et al., submitted), the landings of the northern stock at Mexico and the U.S. were reduced from the aforementioned estimates, and the proportions of the catches at Canada were consequently increased (**Table 1**). More specifically, the peak annual landings of the northern stock at Mexico were less than 40,000 mt, and comprised less than 50% of the total landings, often less than 20%. The peak landings at the U.S. were approximately 107,000 mt in 2007, but even smaller landings comprised larger (more than 80%) of the total catches in 1998, 2001, 2001, 2004, 2005, 2006, and 2007. Stock differentiation did not affect the landings of the northern stock at Canada, but it did increase the proportions of the total catch to between 15 and 23% during 2009 to 2011. If the assessment estimated biomass was calculated with account for stock-differentiated landings, these numbers would be different.

Fishing fraction and harvest guideline

Irrespective of stock differentiation, the total tri-national exploitation rate (landed biomass divided by the estimated age 0+ biomass) trended upward during 1995 to 2011, peaking in 2002 and 2011 due to a peak in the U.S. landings, and increased landings at Mexico and Canada, respectively (**Fig. 4**). Without differentiation, the total tri-national exploitation rate exceeded the more conservative target fishing fraction (landed biomass divided by the estimated age 1+ biomass minus the cutoff) of 0.15 in 2002 and 2011. With differentiation, from 1995 to 2007, the trend in the exploitation rate of the northern stock was dominated by landings at the U.S. Subsequently, however, the upward trend in the exploitation rate mostly resulted from increased harvest rates at Mexico and especially Canada.

The exploitation fraction was estimated for the northern stock using the undifferentiated and differentiated landings (**Fig. 5, upper plots**). The undifferentiated exploitation fraction (**Fig. 5, upper left**) exceeded the target value of 0.15 from 2002 to 2006 and during 2008, 2010, and 2011. During 2003-2006, the rise in the total fraction was driven mostly by landings at the U.S. In contrast, the increase in total fraction during recent years has resulted from increases in landings at Mexico and Canada. The differentiated exploitation fraction (**Fig. 5, upper right**) only exceeded the target value in 2004. Since then, because the U.S. rate has decreased while the rates for Mexico and Canada have increased, the total exploitation rate for the northern stock has remained relatively stable, between approximately 0.10 and 0.13.

The total tri-national exploitation fraction, and the proportions of it that were associated with each country, were estimated annually using Eq. (4) parameterized with landings from each country and assessment estimates (Hill et al., 2012) of the northern stock biomass (**Fig. 5, lower plots**). The analysis was performed without (**Fig. 5, lower left**) and with (**Fig. 5, lower right**) differentiation of the landings. Without differentiation, the U.S. could have increased its *HG* while maintaining its target total tri-national exploitation fraction (0.15), except during 2002 to 2006 and during 2008, 2010, and 2011 when the target fraction was exceeded (**Fig. 5, upper left**). If the ENS and SCA landings were apportioned to southern and northern stocks, then the U.S. *HG* values could have been much higher, between 0.10 to 0.15, for all years during the study period, except 2004 when the target fraction was exceeded (**Fig. 5, upper right**). The proposed method for setting the U.S. *HG* values tends to underestimate and overestimate the *HG* values needed to meet the target tri-national fishing fraction when the stock is increasing and decreasing, respectively. On average, however, the method maintained a relatively stable actual fishing fraction that was within approximately ±20% of the target value (**Fig. 5, lower plots, dashed black**). These results were also plotted in terms of landed biomass, computed with and without stock differentiation (**Fig. 6**).

Conclusion

The abundance, distribution, and migration of the northern stock of sardine in the California Current are highly variable. Depending on the size of the stock, sardine migrate seasonally, spawn offshore of southern and central California during spring and forage off OR, WA, and VI during summer. The seasonal migration spans waters off Mexico, the U.S., and Canada. To set the annual U.S. harvest guideline for this stock, the PFMC wishes to know the average distribution fraction of the northern stock that resides in waters off the U.S. west coast. However, depending on the time of the year and the latitudinal extent of the stock-size-dependent sardine migration, this proportion may approach 100% or be significantly less. Instead of assuming a mean value for the distribution fraction, the total fishing fraction and the proportions of it that are associated with each country may be estimated annually from landings from each country and estimates of the northern stock biomass. Assuming that the landings in Mexico and Canada in one year are good estimates for their values during the following year, we propose a simple model for setting the U.S. quotas such that the total landings from Mexico, the U.S. and Canada more consistently match the U.S. target tri-national fishing fraction. The method would serve to stabilize the actual fishing fractions about the target value; permit more U.S. sardine fishing during most periods when the stock resides largely off the U.S. west coast; and curtail U.S. sardine fishing during periods when a large proportion of the stock resides and is fished off the coast of Mexico, Canada, or both. The results of our simulations would differ if the assessment-estimated biomasses were calculated with account for stock-differentiated landings.

Acknowledgment

We are grateful to Roger Hewitt for reviewing a draft of this paper.

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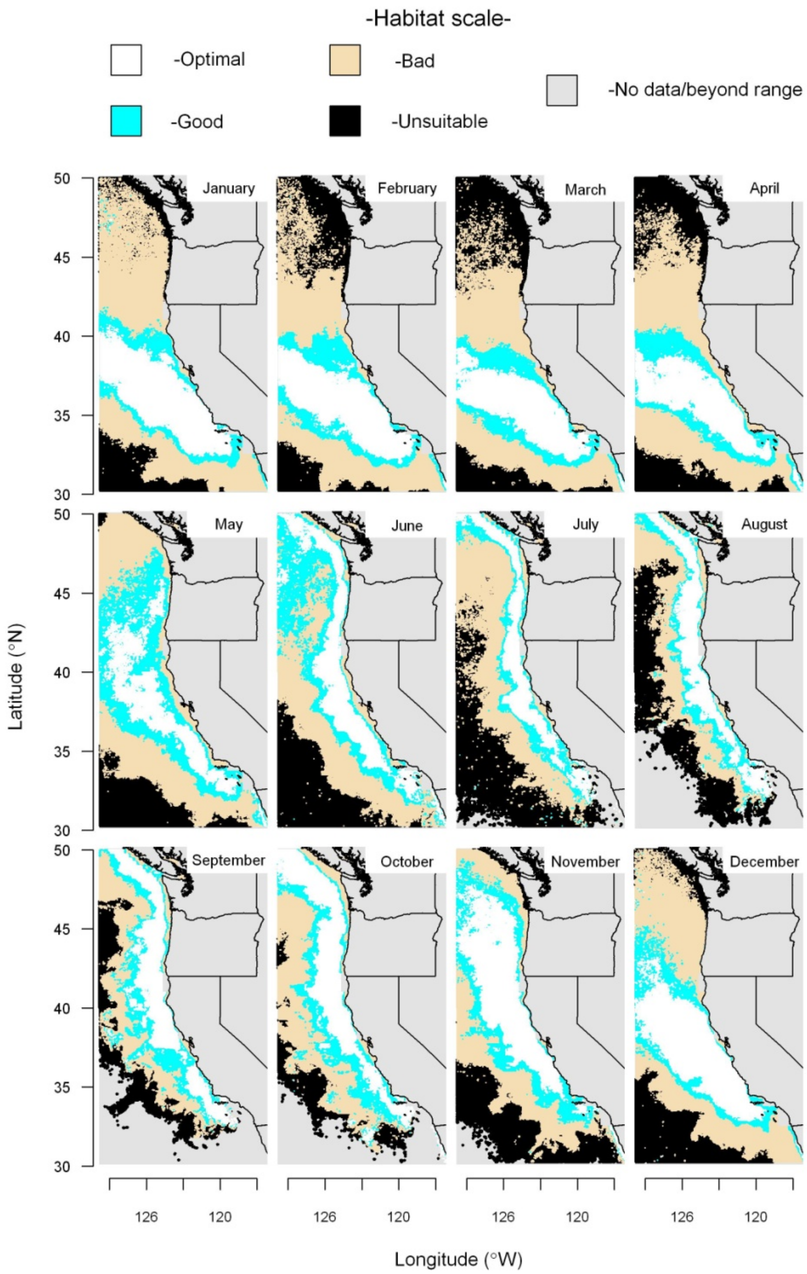
Table 1. Total annual landed sardine biomass (catch; mt), undifferentiated and apportioned to the northern stock; and proportions landed at Mexico (Ensenada), the U.S. (southern and central California, Oregon, and Washington), and Canada (Vancouver Island).

	Undifferentiated Landings						Differentiated, Northern Stock Landings					
	Mexico		U.S.		Canada		Mexico		U.S.		Canada	
	Catch (mt)	Proportion	Catch (mt)	Proportion	Catch (mt)	Proportion	Catch (mt)	Proportion	Catch (mt)	Proportion	Catch (mt)	Proportion
1995	35396.2	0.46	41489.0	0.54	22.7	0.00030	15958.7	0.33	33049.8	0.67	22.7	0.00046
1996	39064.7	0.53	34056.1	0.47	0.0	0.00000	16038.1	0.42	22445.0	0.58	0.0	0.00000
1997	68439.1	0.60	46197.7	0.40	70.7	0.00062	8911.1	0.28	23265.8	0.72	70.7	0.0022
1998	47812.2	0.54	41056.4	0.46	488.1	0.0055	6214.8	0.15	34681.0	0.84	488.1	0.012
1999	58569.4	0.50	57522.1	0.50	24.5	0.00021	37860.5	0.48	41189.2	0.52	24.5	0.00031
2000	67845.2	0.48	72496.7	0.51	1721.4	0.012	29243.2	0.30	67086.2	0.68	1721.4	0.016
2001	46071.3	0.37	78520.1	0.62	1265.9	0.010	13547.1	0.18	60343.0	0.80	1265.9	0.017
2002	46845.4	0.32	101366.7	0.68	739.3	0.0050	13552.0	0.14	85400.2	0.86	739.3	0.0074
2003	41341.7	0.35	74599.2	0.64	977.7	0.0084	18487.3	0.22	64845.8	0.77	977.7	0.012
2004	41897.1	0.30	92613.1	0.67	4438.1	0.032	6296.8	0.072	76964.1	0.88	4438.1	0.051
2005	55322.8	0.37	90129.9	0.61	3231.8	0.022	15583.4	0.16	80181.2	0.81	3231.8	0.033
2006	57236.9	0.38	90776.3	0.61	1575.4	0.011	11214.6	0.12	78905.2	0.86	1575.4	0.017
2007	36846.8	0.22	127695.4	0.77	1522.3	0.0092	19919.1	0.16	106747.9	0.83	1522.3	0.012
2008	66865.9	0.41	87175.0	0.53	10425.0	0.063	19714.2	0.18	80221.9	0.73	10425.0	0.095
2009	55911.3	0.40	67082.9	0.49	15334.4	0.11	20244.5	0.20	63772.9	0.64	15334.4	0.15
2010	56820.9	0.39	66890.9	0.46	22223.0	0.15	17075.5	0.18	57528.8	0.59	22223.0	0.23
2011	70336.5	0.51	46745.3	0.34	20718.7	0.15	31750.9	0.34	41641.8	0.44	20718.7	0.22

Figure 1. Monthly-average potential habitat for the northern sardine stock, 1998 to 2009 (Zwolinski et al., 2011). “Optimal” habitat should included 80% of the sardine, “good” plus “optimal” habitat should included 90%; “bad” plus “good” plus “optimal” habitat should included 99%; and “unsuitable” habitat should included <1% of the total sardine. In the spring, the potential habitat of the northern stock mostly is located offshore of southern California, with a filament extending south off northern Baja California. In



the summer, the potential habitat for the northern stock is compressed along the coasts of Oregon, Washington, and Vancouver Island and is absent off Baja California.

Figure 2. Relative sardine biomass densities averaged over 2 km intervals off the west coast of the U.S., estimated from acoustic—trawl surveys conducted during spring 2006, 2008, 2010, and 2011, and summer 2008. Confined by their dynamic potential habitat (dashed lines), the sardine were located offshore of central and southern California in spring and close to the coast in the northeast Pacific in summer. During the summer 2008 survey, the grey area of Stratum 1 (25,971 nmi^2) and the adjacent coastal stratum (2,848 nmi^2; not shown) contained more than 92% of the stock (Demer et al., 2012). The Quinault Tribal Usual and Accustomed fishing area (U&A; hash), between latitudes 47°40.10' N and 46°53.30' N and east of longitude 125°44' W, is in the northwards summer migration path of sardine.

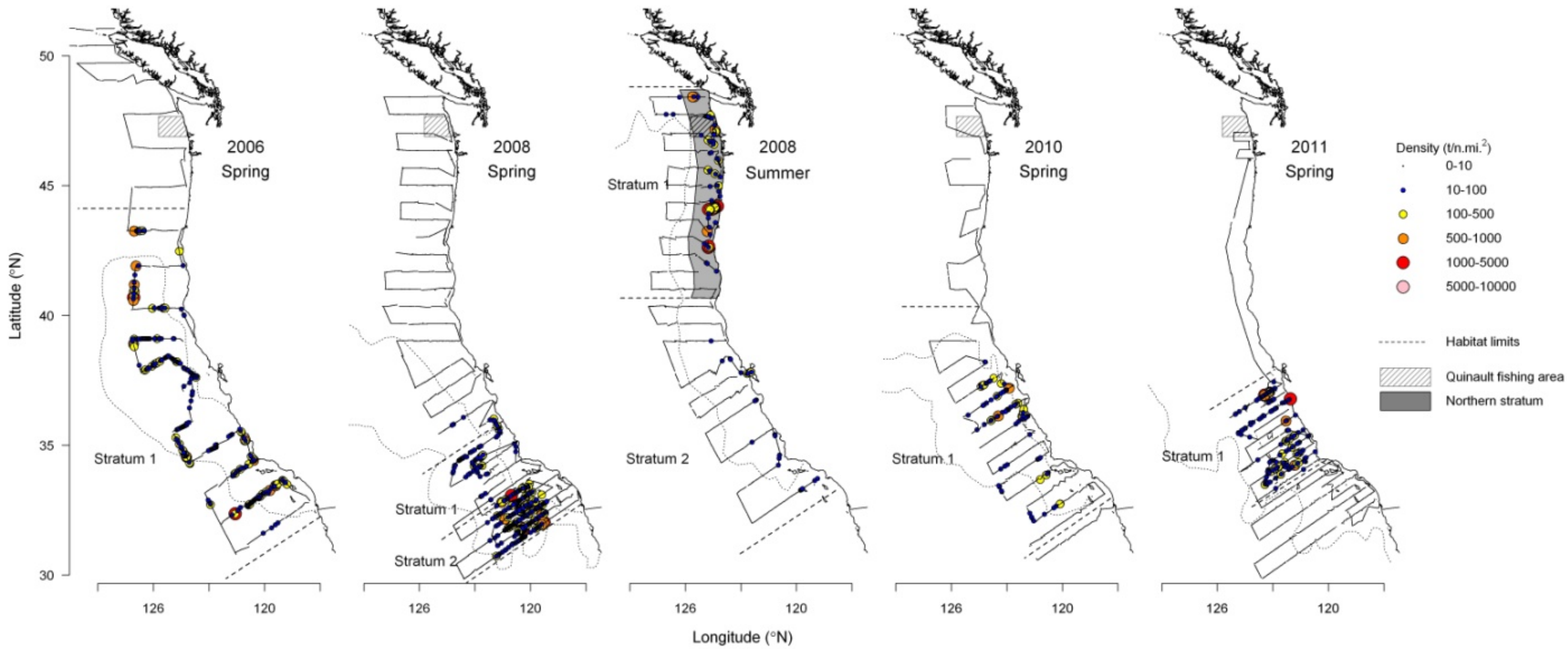


Figure 3. Monthly averages, from 2006-2011, of: a potential northern sardine stock habitat index (grey area; proportion); sea-surface temperature (black line; *SST*; °C); and commercial sardine landings (bars; relative within each region) in fisheries spanning from Vancouver Island, Canada to Ensenada, Mexico. The habitat index is defined as the proportion of the respective fishing area (see **Fig. 1** in Demer et al., submitted) containing good or optimal potential habitat for the northern sardine stock (Zwolinski et al., 2011). The landings were attributed to the northern stock (black bars) if the associated mean *SST* was between the lower (10.6 °C) and upper (16.4 °C) 99.5%-confidence bounds (dashed lines) for the *SST* of the northern stock habitat. Else, the landings were attributed to the southern stock (grey bars). There are a few exceptions to these rules in the Oregon area because some fish landed there were fished off Washington. Note, the San Pedro (southern California) fishery was subjected to seasonal closures during and after 2008, resulting in lower catches during summer and fall.

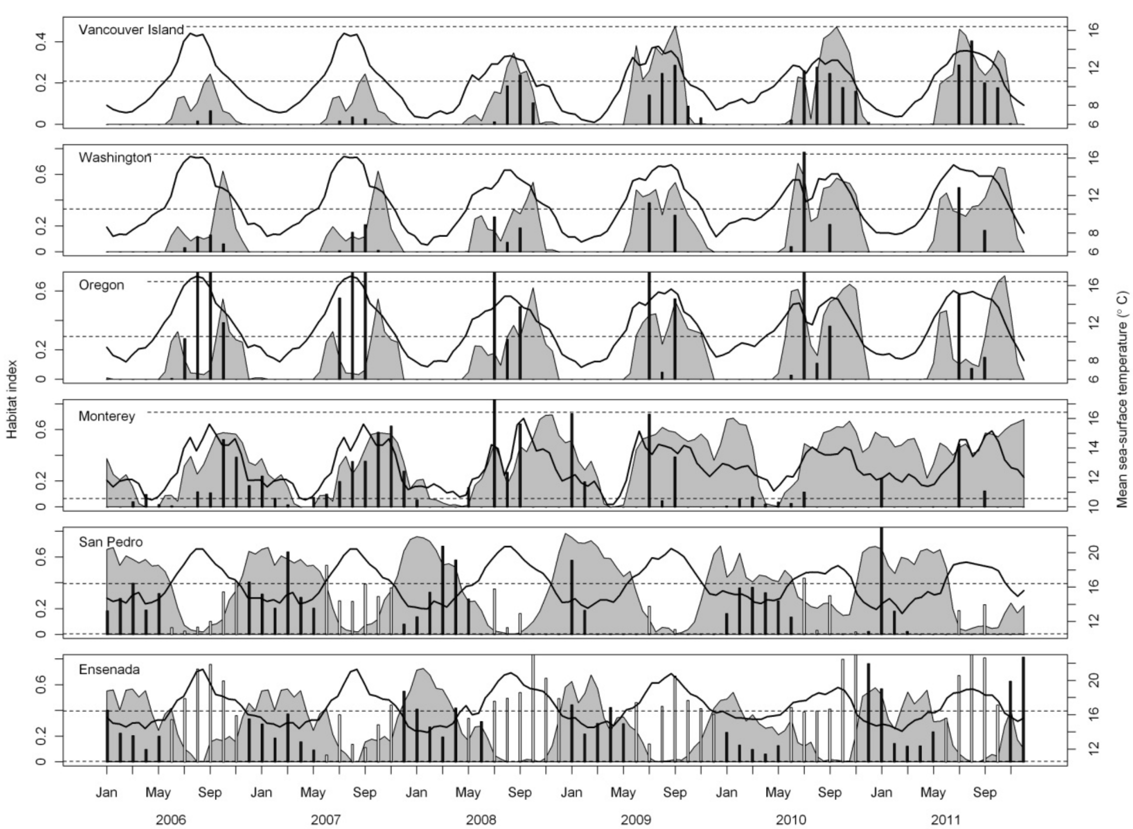
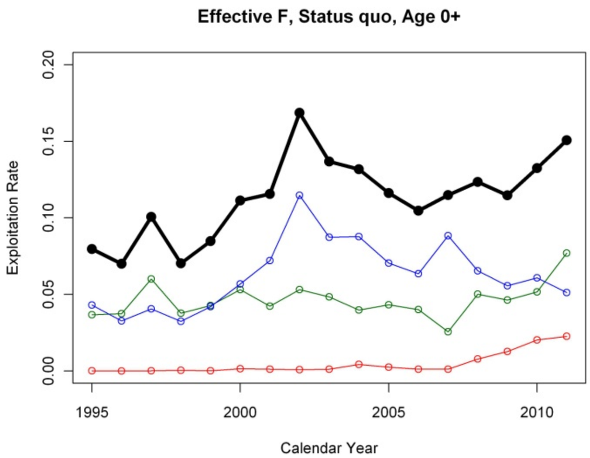


Figure 4. Total (black) and national exploitation rates for Mexico (green), the U.S. (blue), and Canada (red)), defined as the respective annual landings, undifferentiated (left) and northern-only (right), divided by the mid-year (1 July) assessment-estimated (Hill et al., 2012) age 0+ biomass.



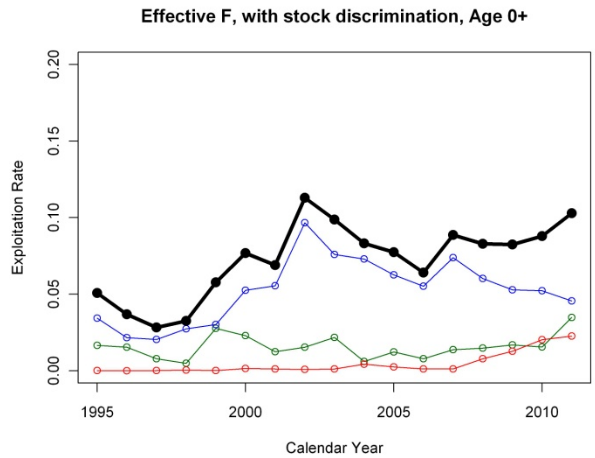


Figure 5. Total (black) and national exploitation fractions for Mexico (green), the U.S. (blue), and Canada (red), defined as the respective annual landings, undifferentiated (left) and northern-only (right), divided by the beginning-of-the-year (1 January) assessment-estimated (Hill et al., 2012) age 1+ biomass minus the cutoff (150,000 mt) (upper plots). The optimal U.S. harvest guidelines (dashed blue), calculated using Eq. (3) and the landings from Mexico and Canada during the previous year, undifferentiated (left) and northern-only (right), assure that the total landings (dashed black) approximate the target (0.15) proportion of biomass above the cutoff (lower plots).

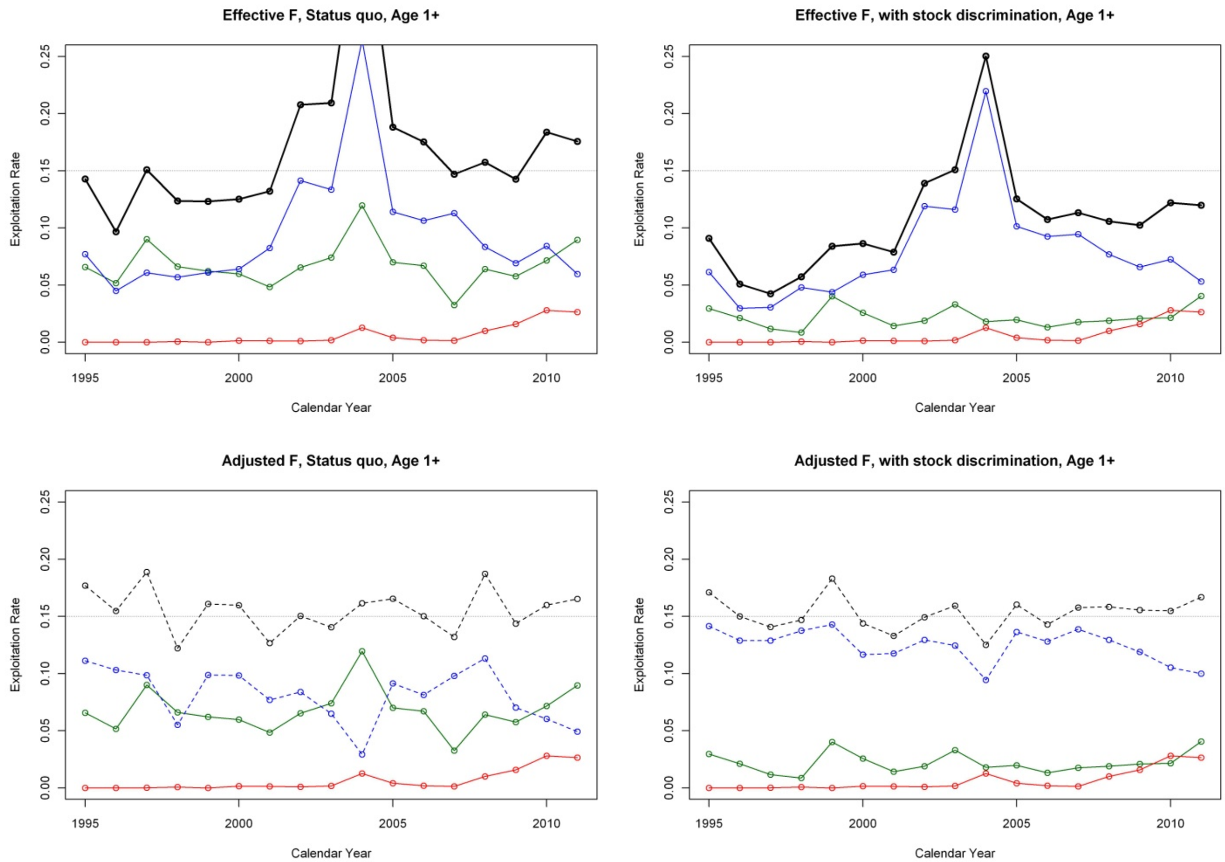
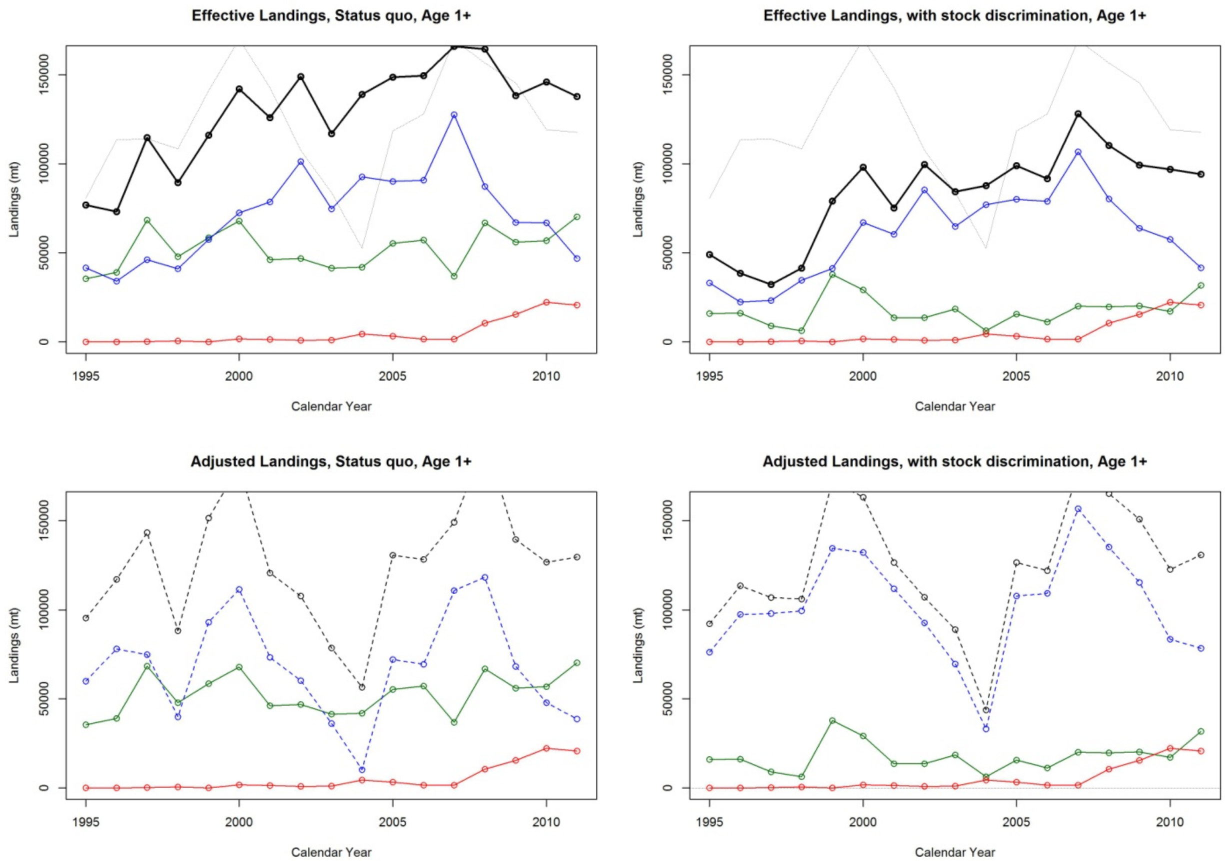


Figure 6. Total tri-national (black) and national harvested sardine biomasses for Mexico (green), the U.S. (blue), and Canada (red) from the undifferentiated (left) and northern-only (right) annual landings; and the biomass that is equivalent to the target exploitation fraction (0.15) of the assessment-estimated (Hill et al., 2012) age 1+ biomass minus the cutoff (150,000 mt) (upper plots). The optimal U.S. harvest landings (dashed blue), calculated using Eq. (3) and the landings from Mexico and Canada during the previous year, undifferentiated (left) and northern-only (right), assure that the total tri-national landings (dashed black) approximate the target (0.15) proportion of biomass above the cutoff (lower plots).



Audubon CALIFORNIA

June 12, 2013

Mr. Dan Wolford, Chairman
Pacific Fishery Management Council
7700 NE Ambassador Place, #101
Portland, OR 97220

RE: Agenda item 1.3, Sardine Harvest Parameters

Dear Chairman Wolford,

We are writing to express concern about the status of Pacific sardine (*Sardinops sagax*) in the California Current Ecosystem, and to request the Council seek to evaluate and apply a harvest control rule that adequately protects sardine as a resource for wildlife and people.

Sardine is an essential prey item for piscivorous seabirds including brown pelican, elegant tern, Heerman's gull and the federally threatened marbled murrelet. National Marine Fisheries Service scientists have recently reported that sardines are in a collapsed condition,[1] and in central California, sardines have been scarce since 2010. This is especially worrisome given that anchovies, a primary alternative prey to sardines, have been scarce in trawl surveys in central California since 2008[2] and have been absent from the diets of breeding Brown Pelicans in southern California in recent years.[3]

Brown Pelican

Diet studies of breeding brown pelicans at the Channel Islands found that pelicans rely on local (~50km radius) availability of coastal pelagic species, primarily northern anchovy and sardine. Sardines comprised 25%-67% of the diets of breeding pelicans in six years of surveys that took place between 1991-2005.[4]

Brown pelicans were listed as endangered under the U.S. Endangered Species Act in 1970 and were delisted in 2009, in part because pelicans were meeting criteria for reproductive success as defined in the Recovery Plan. However, biologists at Channel Islands National Park, the only U.S breeding colony for the species, have noted a general decline in reproductive success since 2010, culminating in near-total nesting failure in 2012[5] and a likely nesting failure in 2013, according to preliminary data.[6] Biologists have noted that:

…in the absence of contaminant, disease, or disturbance effects, local prey availability during the breeding season is most likely the primary driver of the reproductive failures.[7]

Additionally, unusual adult Brown Pelican mortality events during the non-breeding season on the California and Oregon coasts were observed in 2009-2010 and attributed primarily to starvation.[8]

The Pacific Fisheries Management Council has a statutory responsibility to ensure a forage reserve for brown pelicans. The Federal Register notice of removal of the brown pelican from the Endangered Species List notes that:

The Coastal Pelagic Species Management Plan (CPSMP) will continue to ensure that adequate forage is available to pelicans if economic conditions change and northern anchovies become more intensively fished. The CPSFMP will also ensure that other forage fishes used by pelicans, such as Pacific sardines and Pacific mackerel, are also managed to preserve adequate forage reserves...food supplies are assured by the CPSFMP.[9]

Regarding the status of sardines and forage stocks outside of the U.S., the Federal Register further notes that:

...we do not believe that commercial fishing will endanger the brown pelican or its prey throughout the United States, Mexico, and Caribbean portion of its range in the foreseeable future. We do not have information from other countries on commercial fishery impacts to brown pelican prey abundance. However, we have no evidence to suggest that commercial fishing is limiting brown pelican populations.

The California Department of Fish and Wildlife Status Review of the California Brown Pelican found that:

...long term protection of food supplies has been addressed through the coastal pelagic species fishery management plan, which should ensure that adequate forage reserves are available to pelicans and other species along the Pacific coast. Food supplies in Mexico are not assured in the long term because pelagic fisheries are not managed, although there are not currently any known threats to food supplies."[10]

These statements are contradicted by information on sardine fisheries in the Gulf of California, and on dependent seabirds including elegant terns, brown pelicans and Heermann's gulls, which are finding sardines less available:

Sardine catches by the fishing fleet in the Gulf of California from 1969 to 1990 increased at an average rate of 53% per year (estimated from data in Cisneros et al. 1991). Data from the Centro Regional de Investigaci6n Pesquera of the Instituto Nacional de Pesca in Guaymas revealed that the Pacific sardine population of the Gulf of California began to show symptoms of overexploitation in the late 1980s: for example, a reduction in average size of individuals in the catches, and a smaller size at first reproduction (see Cisneros et al. 1990). These were the same signs shown by the Pacific sardine population when the northern anchovy began to replace it and before the sardine fishery collapsed in the California Current during the 1940s.[11]

Marbled Murrelet

Marbled murrelet is a federally threatened and declining species in California, Oregon and Washington. It nests in remnant coastal old-growth redwood and spruce forests and typically forages within 3 km of the coast. The California central coast population is designated as critically imperiled by the U.S. Fish and Wildlife Service[12] due to its extremely low population size and continued decline. Long-term decline of marbled murrelets in central Calfornia is attributable in part to a switch in diet from sardines to lower trophic level prey:

…murrelets switched their diet from sardines to less energetically valuable anchovies following the collapse of the sardine fishery. The increased proportion of low- and midtrophic level organisms currently in the diet of murrelets suggests that fisheries declines may have fundamentally altered seabird prey availability and the trophodynamics of these marine predators and could have contributed to their listing as an endangered species in conjunction with cutting of coastal old-growth forests.[13]

In sum, we are concerned with the ecosystem impacts of what appear to be low availability and presence of sardines and anchovies in California leading to reproductive failure and starvation in seabirds and other marine wildlife, and are looking forward to Council leadership on precautionary management through an appropriate harvest control rule for sardine.

Thank you for the opportunity to comment.

Sincerely,

Anna Weinstein

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[1] Zwolinski, J. and D. Demer. 2012. A cold oceanographic regime with high exploitation rates in the northeast Pacific forecasts a collapse of the sardine stock. Proceedings of the National Academy of Sciences (PNAS)109(11).
[2] Bjorkstedt, E. et al. 2012. State of the California Current 2011-2012: ecosystems respond to local forcing as La Nina wavers and wanes. CalCOFI Rep., Vol. 53.
[3] Harvey, L. 2013. California Institute of Environmental Studies. California Brown Pelican reproductive decline on the Channel Islands colonies. Unpublished data. March.
[4] Ibid.
[5] Ibid.
[6] Harvey, L. Unpublished data.
[7] Harvey, L. 2013. Ibid.
[8] Nevins, H., Melissa Miller, Laird Henkel, Dave Jessup**1**, Nicole Carion, Carol Meteyer, KrystenSchuler, Judy St. Leger, Leslie Woods, Julie Skoglund and Deborah Jaques. 2011. Summary of unusual stranding events affecting Brown Pelican along the US Pacific Coast during two winters, 2008-2009 and 2009-2010.
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50 CFR 17 Endangered and Threatened Wildlife and Plants; Removal of the Brown Pelican (*Pelecanus occidentalis*) From the Federal List of Endangered and Threatened Wildlife; Final Rule
[10] Burkett, E. et al. 2007. Status Review of California Brown Pelican in California. Department of Fish and Game.
[11] Velarde, E. et al. Seabirds as indicators of important fish populations in the Gulf of California.
CalCOFl Rep., Vol. 35, 1994
[12] USFWS 2005. Regional Seabird Conservation Plan, Pacific Region. Migratory Birds and Habitats Program, Pacific Region, Portland, OR.
[13] Becker, B. and S. Beissinger. 2006. Centennial Decline in the Trophic Level of an Endangered Seabird after Fisheries Decline. Conservation Biology Volume 20, No. 2, 470–479

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June 10, 2013

Mr. Dan Wolford, Chair
Pacific Fishery Management Council
7700 NE Ambassador Place #200
Portland, OR 97220-1384

Re: Agenda Item I4.d CPS Harvest Parameters Public Comment

Dear Chair Wolford and Council Members,

I have fished for sardine out of Astoria, Oregon since 1999. I appreciate the opportunity to comment on the Harvest Control Rule (HCR) for Pacific Sardine.

In June 2009 I submitted a letter expressing my unease about the harvest fraction (F) relationship with sea surface temperature (SST). I understand one of the purposes in assigning a SST index to F is to permit more harvest opportunity when conditions are favorable and a reduction when things are less favorable. Looking back at the Scripps SST data this did not appear to be the case. The earliest temperature data from Scripps pier was in 1917. From that point until the mid-1930's was when sardine populations on the west coast were known to be expanding. This was a highly productive time period but, due to SST, there would have been many years with F set at the minimum of 5%.

CalCofi was formed in 1949 so data is not available for the 1917 – 1930's time period. However, the data presented in Table 2 of agenda item I.4.b illustrates my concern with F related to SST. In 2003 CalCofi SST would have resulted in a lower F. 2003 was one of the largest recruitment episodes since the reemergence of the fishery but SST results in a harvest reduction during a time when the population was increasing and more robust.

Whether the SST is derived from Scripps Pier or CalCofi there are still too many years where the SST relationship to F falls short. There are periods of decline where F is high and periods of increase where F is low. Though I am inclined to agree that SST is an important driver of productivity I am not yet compelled to think that tying it to the HCR in this manner will result in any assurance of better stock productivity or stability in the long term. There are surely more drivers of reproduction and recruitment than only using SST.

In closing, the outcomes of the simulation show the sardine biomass will continue to go up and down over periods of time regardless of harvest being set at 5, 10, 15%, or anywhere in between. The biggest part of the HCR will always be the stock assessment. Changing F from 15% to 12% or 10% seems arbitrary no matter what SST index is used when there could be anywhere from 300,000 to 900,000 tons or more of biomass depending on what survey or modeling method is used. The workshop was a good exercise and the results of the simulation models are interesting but I am not convinced SST incorporation into the HCR is necessary. I would think it more prudent to maintain focus on the biomass estimates before altering the existing conservative HCR.

Best Regards,
Ryan Kapp

Agenda Item I.4.d
Coastal Pelagic Species
Adjustment to Pacific Sardine
Harvest Parameters

June 11, 2013

Dan Wolford, Chairman
Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 101
Portland, Oregon 97220-1384

RE: Revisions to Sardine Control Rule

Dear Chairman Wolford,

Wild Oceans appreciates the opportunity to provide recommendations for updating the sardine harvest guideline in order to improve its performance in relation to meeting the objectives of the Coastal Pelagic Species Fishery Management Plan (CPS FMP). We are pleased that the Council dedicated resources to host a workshop to review the temperature control rule parameter in detail. Based on the workshop report and recent analyses of sardine control rule variations, we support the following revisions:

1. In the determination of **FRACTION**, use CalCOFI temperature data instead of the sea surface temperature data collected at the Scripps Institute of Oceanography, as the CalCOFI index more closely correlates with sardine recruitment.[1]

2. Change the **fishery start date** to July 1st to better align with the sardine assessment, so an estimate of current biomass at the start of the fishing season is used in setting the harvest specification, consistent with SSC advice.[2]

3. Pursue alternative methodologies that better account for **DISTRIBUTION**, other than the static .87 multiplication factor, which was established at a time when stock distribution was most likely contracted and does not take into account distribution in Canadian waters.[3]

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[1] *Revised Analyses Related to Pacific Sardine Harvest Parameters*, Felipe Hurtado-Ferro and André E. Punt , School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA. Briefing Book, June 2013, Agenda Item I.4.b Attachment 1. http://www.pcouncil.org/wp-content/uploads/I4b_ATT1_Rev_Sardine_Analyses_JUN2013BB.pdf.
[2] Briefing Book, April 2013, Agenda Item I.1.b, Supplemental SSC Report. http://www.pcouncil.org/wp-content/uploads/I1b_SUP_SSC_APR2013BB.pdf.
[3] PFMC. 1998. Amendment 8 to the Coastal Pelagic Species Fishery Management Plan. Appendix B, pp B-86-B-89.

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4. Consider alternative **CUTOFF** values. The council should prioritize the control rule performance metric for maintaining biomass in the water to provide adequate forage for dependent predators, specifically in terms of how it measures up to National Standard 1 guidance to "manag(e) forage stocks for higher biomass than B_{MSY} to enhance and protect the marine ecosystem."[4] We note that Hertado-Ferro and Punt[5], in the analyses they use to evaluate alternative control rule variants, use 400,000 metric tons as a performance measure for maintaining adequate sardine biomass to serve both future productivity of the fishery and ecological services, notably forage for the California Current ecosystem. This figure, which equates to $0.25B_0$, already considerably below the emerging standard for minimum stock size threshold for a key forage species[6], stands in stark contrast to the present CUTOFF value of 150,000 MT.

Thank you for your consideration.

Sincerely,

Pam Lyons Gromen
Executive Director

[4] 50 CFR Part 600.310(e)(3)(iv)(C)
[5] *See note 1.*
[6] Smith, Anthony D.M., et al. 2011. *Impacts of Fishing Low-Trophic Level Species on Marine Ecosystems.* Science. 1209395. 21 July 2011 *and* Pikitch, E., Boersma, P.D., Boyd, I.L., Conover, D.O., Cury, P., Essington, T., Heppell, S.S., Houde, E.D., Mangel, M., Pauly, D., Plagányi, É., Sainsbury, K., and Steneck, R.S. 2012. Little Fish, Big Impact: Managing a Crucial Link in Ocean Food Webs. Lenfest Ocean Program. Washington, DC. 108 pp.

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June 25, 2013

Mr. Dan Wolford, Chair
And Members of the Pacific Fishery Management Council
7700 NE Ambassador Place #200
Portland OR 97220-1384

RE: Agenda Item I.4. Adjustments to Sardine Harvest Parameters

Dear Mr. Wolford 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 participated in the sardine harvest parameters workshop and was designated CPSAS representative at the May CPS management team meeting. We appreciate your consideration of the following points and concerns, many of them reiterated in the CPSAS report.

First, please understand 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 **Emsy 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 planktivorous forage pool**, which is only part of the forage available overall. This harvest level is decidedly NOT overfishing, nor harming the ecosystem. In the recent district court decision re: CPS FMP Amendment 13, the judge found, based on an administrative record encompassing 291 documents and thousands of pages, **"In this case, Amend. 13 is not a mixed impact action but an action that by its very terms has no negative impacts at all."** (SF District Court Decision Case 3:11-cv-06257-EMC Document 62, page 37)

• 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 clearly illuminates the **significant conflict in scale** derived from various survey methods.

• **Variability characterizes all the indices** used to measure sardine. Survey timing is crucial, and each survey measures only a spot in time. **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.

Re: changing the environmental proxy from Scripps Pier sea surface temperature (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 consideration of the following points:

• 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 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 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.**

• At the recent CPSMT meeting, discussion ensued on applying the [3-year mean] temperature to the OFL fraction vs. the HG fraction. It would be helpful to provide explicit examples illustrating harvest guidelines derived from both formulas (i.e. comparing HGs using option 6 (HG-J) vs. Option 15 (New 1), Option 16 (New 2) and Option 22 (New 8)) to determine which provides the most effective and balanced way to achieve Optimum Yield (OY).

• 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 harvest parameters workshop and reanalysis of the Amendment 8 HCR provided by Dr. Richard Parrish, an architect of the original sardine HCR who attended both the workshop and the CPSMT meeting. I have summarized some key points, and attached for reference his complete letter to the Council.

EXCERPTS

Letter from Richard Parrish (I.4.d, Supplemental Public Comment 2, June 2013)

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

<u>Comparison of Old vs. New HCR Analysis</u>

• *The stochastic proxy MSY with the new Hertado-Ferro and Punt analysis (Emsy=0.18) is* **50% higher** *than the Amendment 8 proxy (Emsy=0.12).*

In Amendment 8 of the CPS FMP, the Council adopted option J, a harvest control rule with a CUTOFF of 150,000 mt., a MAXCAT of 200,000 mt., and a FRACTION based on SST at Scripps Pier that varied from 0.05 to 0.15

• ***In the new analysis, the Option J control rule (HG J–6) is much more conservative that it was in Amendment 8.*** *For example, in Amendment 8 Emsy was 0.12 and the FRACTION extended above and below Emsy (i.e. from 0.05 to 0.15). In the new analysis Emsy is 0.18 and* ***Option HG J–6 is always below Emsy (i.e. 0.05 to 0.15). The maximum fraction in new Option HG J–6 is 17% below Emsy.***

• *In the Amendment 8 analysis, Option J had an average biomass equal to 64% of the unfished biomass.* ***In the new analysis, option HG J–6 has an average biomass equal to 79% of unfished biomass.***

<u>Stock Structure, Distribution and International Landings</u>

Dr. Parrish noted the Council's inability to regulate total coast-wide sardine landings and reported evidence presented at the sardine workshop by Tim Baumgartner, from the Mexican research institute CICESE, that *"showed that the sardine landed in Ensenada are primarily from the southern stock and that some of the sardine available in Southern California are also from the southern stock."*

• Dr. Parrish suggested: *"Instead of an assessment that includes all sardine from central Baja California to Vancouver Island, future assessments should include all sardine from the U.S.–Mexican border to Vancouver Island. This assessment would represent the sardine population off the United States and Canada and it would result in a more realistic estimate of the biomass that is actually under the control of the Council. "* [i.e. the northern stock]

He continued: *"This assessment could be assumed to result in a smaller biomass estimate than an assessment for the larger geographical area. The distribution parameter would then only apply to the Canadian landings* ***and I would recommend that the distribution fraction retain its present value."***

<u>Ecological and Economic Trade-offs with the New Sardine Analysis</u>

Dr. Parrish constructed trade-off plots to compare the various options presented in the Hertado-Ferro and Punt and Shester and Enticknap analyses; HCRs were identified by the numbers and letters used in the two reports. He noted that the newest HCR in the Hurtado-Ferro and Punt analysis (New 8, option 22) is visually indistinguishable from HG J–6 on the plots and it was therefore not plotted; the performance of option 6 in the trade-offs can be used to evaluate option 22.

• Dr. Parrish found that the average catches in the Oceana analysis are incorrect because they were calculated by omitting catch from years with no fishery. He corrected the average catch values using the percentage of years with no catch. ***"The corrected value for the Oceana preferred HCR is 89.9 tmt instead of 114.2 tmt."***

More summary highlights:
The ***first trade-off is between the most serious economic problem (closing the fishery) and the second-most serious ecological problem (low biomass)****. The most serious ecological problem (collapse of the population) occurred in the three policies with CUTOFF = 0.*

• The OFL and L-Emsy HCRs have no fishery in 29% and 31% of the years, while ***Oceana's preferred HCR (Oc) and the Lenfest HCR (Le) have no fishery in 20-21% of the years****. ....* ***Control rules Le, Oc, OFL and L-Emsy all have the fishery closed between one year in five and one year in three, and these policies do not result in an economically sustainable fishery.***

• In contrast, the three remaining control rules 6, 15, and 16, are all close variants of the original option J rule and all have no fishery in 2.8% of the years. Option 22 also is very close to 6, with no fishery in 2.7% of the years.

The second trade-off is between mean catch and mean biomass*. The traditional reference points of deterministic MSY (4) and stochastic MSY (L-Emsy) have values in the vicinity of 40% of unfished biomass, and the rest of the policies produce average biomass levels well above these reference points.*

• When the two sets of trade-offs are considered together, the policies that provide the best balance between ecological and economic considerations appear to be policies 6, 15, 16, 20 and 22 (with very similar performance to 6). *Policies 6, 15, and 16 and 22 are essentially identical in the first set of trade-offs between low biomass levels and percentage of years with no catch.*

Dr. Parrish's Conclusion:

• In my opinion, HCR 16 provides the best balance between ecological and economic considerations. It has an average biomass level that is 70% of the unfished biomass and it maintains biomass above 400 tmt 93% of the time. It has an average catch of 148 tmt and maintains a fishery 97% of the time.

In comparison to HCR 16, Options 6, 15, and 22 achieve an increase of about 100 tmt in average biomass at the expense of about 40 tmt in average catch.

To demonstrate just how conservative control rules 6, 15, 16, and 22 are, a comparison with Pacific hake is useful; "the current $F_{40\%}$-40:10 management strategy with perfect knowledge of current biomass resulted in a median long-term average depletion of less than 30%" (2013 Hake Assessment p. 15).

Thank you for your attention to these comments.

Best regards,

Diane Pleschner-Steele

Diane Pleschner-Steele
Executive Director

Attachment: Assessment of Sardine Harvest Control Rules
Richard Parrish
June 16, 2013

Mr. Dan Wolford, Chair
and Members of the Pacific Fishery Management Council
7700 NE Ambassador Place #200
Portland OR 97220-1384

RE: Agenda Item I.4. Adjustments to Sardine Harvest Parameters

Dear Mr. Wolford and Council members,

As one of the developers of the Amendment 8 sardine harvest control rule, and after having participated in the sardine harvest parameters workshop in February and the recent CPS management team meeting, I prepared the following analysis for the Council's consideration regarding sardine harvest control rule options:

Assessment of Sardine Harvest Control Rules
Richard Parrish
June 20, 2013

The development of harvest control rules for sardine has evolved into a very complicated process. This analysis is an attempt to place this development in context with rules used in other fisheries, to describe the differences between the Amendment 8 harvest control rule (HCR) and newer sardine harvest policy options and to comment on trade-offs between harvest control rules that have recently been submitted to the Council.

The most common maximum sustainable yield proxy used by the Pacific Fisheries Management Council is deterministic Fmsy (or the associated Emsy). These proxies are usually derived from equilibrium-based analyses and they determine the maximum sustainable harvest (i.e OFL). The present best deterministic estimate for sardine is Emsy = 0.19.

The MSY proxy used for the Amendment 8 sardine analysis was a stochastic proxy (Emsy = 0.12). This stochastic proxy, and a very extensive series of potential harvest policies, was developed with a simulation model that had annual and decadal variation in the spawner/recruit model, based on sea surface temperature at Scripps Pier, and in addition there was extensive annual variation in the estimates of annual biomass. Hurtado-Ferro and Punt's analysis (Agenda Item I.4.b: Attachment 1: June 2013) is similar to the Amendment 8 analysis; however, it is enhanced by inclusion of a more realistic age composition and additional years of data including recent warm-water years of high sardine productivity. It also includes a new temperature index: 5-15 meter sea temperature from a grid of stations from the CalCOFI Surveys. This temperature time series has much higher statistical significance than the Scripps Pier SST time series used in Amendment 8. Maximum sustainable yield in the new analysis changes yearly and it is calculated by a polynomial equation that describes the relationship between Emsy and sea temperatures in the CalCOFI time series.

The stochastic proxy MSY with the Hertado-Ferro and Punt analysis (Emsy=0.18) is 50% higher than the Amendment 8 proxy (Emsy=0.12).

Over the range of temperatures seen in the CalCOFI time series the model produces Emsy values from 0.0 to about O.40. This range of values was apparently trimmed at the 75% quartile (i.e. 0.26) at the request of the SSC, so the Hurtado-Ferro and Punt analyses have a potential maximum Emsy of 26%, and the OFL FRACTION varies from 0 to 26%, or some smaller maximum value defined by individual HCRs. It is unclear what combination of harvest control rule parameters results in the maximum average catch (MSY) with the new analysis; although the parameters that produced the maximum average catch in the Amendment 8 analysis are included in the analysis submitted by Shester and Enticknap (i.e. option OFL in Agenda Item I.4.d: Public Comment: June 2013). Note that the Hertado-Ferro and Punt analysis and the Shester and Enticknap analysis use the same basic model.

In Amendment 8 of the CPS FMP, the Council adopted option J, a harvest control rule with a CUTOFF of 150,000 mt., a MAXCAT of 200,000 mt., and a HG FRACTION based on SST at Scripps Pier that varied from 0.05 to 0.15

In the new analysis, the Option J control rule (i.e. HG J or 6) is much more conservative that it was in Amendment 8. For example, in Amendment 8 Emsy was 0.12 and the FRACTION extended above and below Emsy (i.e. from 0.05 to 0.15). In the new analysis Emsy is 0.18 and Option HG J is always below Emsy (i.e. 0.05 to 0.15). The maximum FRACTION in the new Option HG J is 17% below Emsy.

In the Amendment 8 analysis, Option J had an average biomass equal to 64% of the unfished biomass. In the new analysis, HG J–Option 6 has an average biomass equal to 79% of unfished biomass.

Stock Structure, Distribution and International Landings.

The Council's inability to regulate total coast-wide landings of the northern stock of Pacific sardine is a continuing problem in the management of sardine. Three interrelated factors contribute to the problem.

1. The Council cannot regulate the landings in Canada and Mexico.
2. The dividing line between the northern stock and the southern (Baja) stock is not well known and it undoubted varies seasonally and annually depending upon environmental conditions
3. The international distribution of the northern stock is confounded with the stock structure problem.

Tim Baumgartner, from the Mexican research institute CICESE, presented information on sardine size structure and water mass analyses (SST and salinity) at the February 2013 sardine harvest parameters workshop at Scripps. His data showed that the sardine landed in Ensenada are primarily from the southern stock and that some of the sardine available in Southern California are also from the southern stock. Fishery scientists in Mexico are convinced that their Ensenada sardine fishery is dominated by the southern stock and it is therefore unrealistic to assume that Mexico would regulate their fishery based on U.S. biomass estimates of the northern stock.

Given the above, it appears that the pragmatic solution is to alter the way the sardine stock assessments are made. Instead of an assessment that includes all sardine from central Baja California to Vancouver Island, future assessments should include all sardine from the U.S.- Mexican border to Vancouver Island. This assessment would represent the sardine population off the United States and Canada and it would result in a more realistic estimate of the biomass that is actually under the control of the Council.

This assessment could be assumed to result in a smaller biomass estimate than an assessment for the larger geographical area. The distribution parameter would then only apply to the Canadian landings, and I would recommend that the distribution fraction retain its present value.

The only viable alternative that I can visualize is an international agreement on catch quotas between Mexico, Canada and the United States.

Ecological and Economic Trade-offs with the New Sardine Analysis.

To compare the various options presented in the Hertado-Ferro and Punt and the Shester and Enticknap analyses, I have constructed two trade-off plots using the most likely harvest control rules and the most relevant reference rules presented in the two analyses.

Note that the mean catch in the Shester and Enticknap analysis for HG J is equal to the mean catch C0 in the Hertado-Ferro and Punt analysis (i.e. 110.1) and that it is less than the latter's mean catch (i.e. 107.1). The mean catch CO value was calculated after omitting the catch in years with no fishery. The SSC noted that an earlier Hertado-Ferro and Punt analysis had this same problem (Draft April 2013 SSC Minutes: June 2012 p. 9). Therefore, it appears that all the mean catches in the Shester and Enticknap analysis are actually the mean catch when zero catches are omitted. To make the two analyses comparable I corrected the average catch values in the Shester and Enticknap analysis using the percentage of years with no catch. For example; Oceana's HC J has a listed average catch of 110.1 tmt and 2,7% of the years with no catch; its corrected average catch is the same value as the Hertado-Ferro and Punt mean catch (i.e. 110.1 * (1-0.027) = 107.1). The corrected value for the Oceana preferred HCR is 89.9 tmt instead of 114.2 tmt.

The HCRs in the plots are identified by the numbers and letters used in the two reports mentioned above (Figure 1). The original Option J is HG J– 6. Except for the MSY reference policies (4 and L-Emsy), I excluded HCRs from both reports that were poor performers in comparison to the other HCRs shown. The newest HCR in the Hurtado-Ferro and Punt analysis (New 8, option 22) is visually indistinguishable from HG J–6 on the plots and it was therefore not plotted; the performance of option 6 in the trade-offs can be used to evaluate option 22.

The first trade-off is between the most serious economic problem (closing the fishery) and the second-most serious ecological problem (low biomass). I note that the most serious ecological problem (collapse of the population) occurred in the three HCRs with CUTOFF = 0; i.e. deterministic MSY (4), and stochastic MSY (L-Emsy) and F=15% (not plotted).

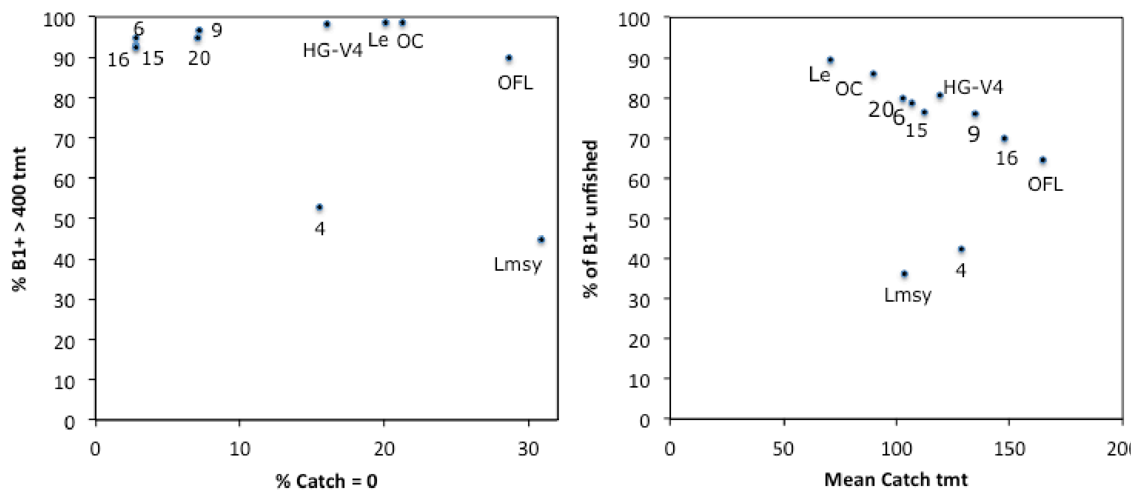

Figure 1. Trade-off plots (the percentage of years with no catch vs the percentage of years with biomass of age 1+ less than 400 tmt) and (mean catch vs mean biomass of age 1+ as a percentage of the unfished age1+ biomass).

Table 1. Performance measures in Figure 1. (mean B1+ %Bun is the mean biomass of age 1+ expressed as a percentage of the unfished mean biomass, also known as the depletion of age 1+ biomass).

Hurtado-Ferro and Punt

Control Rule	% no catch	% B1+>400	Mean catch	Mean B1+ %Bun
4	15.5	52.7%	128.3	42.3%
6	2.8	94.7%	107.1	78.8%
9	7.2	96.9%	134.9	76.0%
15	2.8	92.9%	112.1	76.5%
16	2.8	92.5%	147.8	70.0%
20	7.1	95.0%	102.5	79.9%
22	2.7	93.6%	108.0	78.0%

Shester and Enticknap

Control Rule	% no catch	% B1+>400	Mean catch	Mean B1+ %Bun
HG-V4	16.0	98.1%	119.1	80.6%
OFL	28.6	90.0%	164.9	64.5%
L Emsy	30.9	44.8%	103.1	36.2%
Oceana	21.3	98.5%	89.9	86.0%
Lenfest	20.1	98.6%	70.5	89.4%

The two MSY HCRs resulted in biomass falling lower than 400 tmt in about half of years: HCR 4 (53%) and HCR L-Emsy (45%). All of the rest of the HCRs, including the no fishing policy, have biomass remaining above the 400 tmt level in 90-99% of the years.

The differences on the other axis are more marked: the OFL and L-Emsy HCRs have no fishery in 29% and 31% of the years, while Oceana's preferred HCR (Oc) and the Lenfest HCR (Le) have no fishery in 20-21% of the years. Control rules 4 and HG-V4 have no fishery in 16% of the years, and HCRs 9 and 20 have no fishery in 7% of the years. Control rules Le, OC, OFL and L-Emsy all have the fishery closed between one year in five and one year in three, and these policies do not result in an economically sustainable fishery.

In contrast, the three remaining control rules 6, 15, and 16, are all close variants of the original option J rule and all have no fishery in 2.8% of the years. Option 22 also is very close to 6, with no fishery in 2.7% of the years. Option 6 is better than options 15 and 16 in having a slightly higher average biomass level. Option 22 biomass falls between 6 and 15-16.

The second trade-off is between mean catch and mean biomass. The traditional reference points, deterministic MSY (4) and stochastic MSY (L-Emsy), have values in the vicinity of 40% of unfished biomass, and the rest of the HCRs produce average biomass levels well above these reference HCRs.

The Lenfest and Oceana's preferred HCRs have the lowest annual catches (71 and 90 tmt) and the highest biomass levels (89% and 86% of unfished biomass). Control rules HG-V4, 20, 6, and 15 all have high average biomass levels (between 76-79% of unfished biomass) and moderate catches (i.e. between 103-119 tmt). Control rules 9, 16, and OFL have decreasing biomass and increasing catches. With the exception of the reference polices (4 and L-Emsy), the HCRs have a nearly linear relationship between biomass and catch, with the Lenfest HCR having the highest biomass (89%) and lowest catch (71 tmt) and the OFL rule having the lowest biomass (65%) and highest catch (165 tmt). However, note that the OFL rule has a biomass level (65%) well above the levels occurring with the deterministic MSY (4) and stochastic MSY (L-Emsy) reference policies. It is also well above the 40% level commonly used for groundfish species.

Average biomass vs average catch with HCRs 20, 6 and 15 are quite similar and they achieve high average biomass levels at the expense of moderate catches. Control rule 9 has considerably higher landings with essentially the same biomass levels as the other three policies. Control rule 16 achieves a high catch level while maintaining a high average biomass level (70% of unfished).

When the two sets of trade-offs are considered together, the policies that provide the best balance between ecological and economic considerations appear to be policies 6, 9, 15, 16, 20 and 22 (with very similar performance to 6). Policies 6, 15, and 16 and 22 are essentially identical in the first set of trade-offs between low biomass levels and percentage of years with no catch. Policies 9 and 20 are somewhat inferior to the other three policies in this regard.

Conclusion:

In my opinion, HCR 16 provides the best balance between ecological and economic considerations. It has an average biomass level that is 70% of the unfished biomass and it maintains biomass above 400 tmt 93% of the time. It has an average catch of 148 tmt and maintains a fishery 97% of the time.

In comparison to HCR 16, Options 6, 15, and 22 achieve an increase of about 100 tmt in average biomass at the expense of about 40 tmt in average catch. With these control rules, average biomass is 77-79% of the unfished biomass and biomass is above 400 tmt 93-94% of the time. Average landings are 107-112 tmt and the fishery is maintained 93% of the time. All three control rules have CUTOFFs of 150 tmt and MAXCATs of 200 tmt. The new HCR 22 is a very close variant of the original harvest guideline HG J - 6 and it has the added feature of a simple maximum FRACTION. Control rules 6 and 22 have slightly higher average biomass levels and HCR 15 has slightly higher catch levels.

In comparison, the stochastic (L-Emsy) control rule has an average biomass that is 36% of the unfished biomass and biomass is above 400 tmt only 55% of the time.

To demonstrate just how conservative control rules 6, 15, 16, and 22 are, a comparison with Pacific hake is useful; “the current $F_{40\%}$-40:10 management strategy with perfect knowledge of current biomass resulted in a median long-term average depletion of less than 30%” (2013 Hake Assessment p. 15).

Richard Parrish
Fisheries Biologist