Agenda Item G.1.a
Assessment Report Executive Summary
April 2015

ASSESSMENT OF THE PACIFIC SARDINE RESOURCE IN 2015 FOR U.S.A. MANAGEMENT IN 2015-16

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ACRONYMS AND DEFINITIONS

ABC	acceptable biological catch
ATM	Acoustic-trawl method of biomass estimation
BC	British Columbia (Canada)
Bongo	Obliquely-towed ichthyoplankton net (505 micron mesh)
CA	California
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CalVET	California vertical egg tow (333 micron mesh)
CCA	Central California fishery
CDFW	California Department of Fish and Wildlife
CDFO	Canada Department of Fisheries and Oceans
CICIMAR	Centro Interdisciplinario de Ciencias Marinas
CONAPESCA	National Commission of Aquaculture and Fishing (México)
CPS	Coastal Pelagic Species
CPSAS	Coastal Pelagic Species Advisory Subpanel
CPSMT	Coastal Pelagic Species Management Team
CUFES	Continuous Underway Fish Egg Sampler (fixed at 3 meters depth)
DEPM	Daily egg production method
ENS	Ensenada (México)
FMP	fishery management plan
HG	harvest guideline
INAPESCA	National Fisheries Institute (México)
Model Year	July 1 (year) to June 30 (year+1)
mt	metric tons
mmt	million metric tons
MexCal	southern fleet based on ENS, SCA, and CCA fishery data
NMFS	National Marine Fisheries Service
NSP	Northern subpopulation of Pacific sardine, as defined by satellite oceanography data
NWSS	Northwest Sardine Survey (aka 'Aerial Survey')
NOAA	National Oceanic and Atmospheric Administration
ODFW	Oregon Department of Fish and Wildlife
OFL	overfishing limit
OR	Oregon
PacNW	northern fleet based on OR, WA, and BC fishery data
PairoVET	Paired CalVET net (333 micron mesh)
PFMC	Pacific Fishery Management Council
SAFE	Stock Assessment and Fishery Evaluation
SCA	Southern California fishery
SCB	Southern California Bight (Pt. Conception, CA to northern Baja California)
SS	Stock Synthesis model
SSB	spawning stock biomass
SSC	Scientific and Statistical Committee
SST	sea surface temperature
STAR	Stock Assessment Review
STAT	Stock Assessment Team
SWFSC	Southwest Fisheries Science Center
TEP	Total egg production
VPA	Virtual Population Analysis
WA	Washington
WDFW	Washington Department of Fish and Wildlife

PREFACE

The Pacific sardine resource is assessed each year in support of the Pacific Fishery Management Council (PFMC) process of recommending annual harvest specifications for the U.S. fishery. The following assessment update for 2015-16 management is based on data and methods reviewed by a Stock Assessment Review (STAR) Panel during March 2014 (STAR 2014) and more fully described in Hill et al. (2014).

The stock assessment update was conducted using Stock Synthesis (SS), and includes one additional year of data from fishery-dependent and fishery-independent sources. A preliminary draft assessment was reviewed by members of the Scientific and Statistical Committee's CPS Subcommittee on March 6, 2015 in Vancouver, WA. The following final draft incorporates changes recommended during that review and is provided to the Pacific Fishery Management Council for their April 2015 briefing book.

EXECUTIVE SUMMARY

The following Pacific sardine assessment update was conducted to inform U.S. fishery management for the fishing year that begins July 1, 2015 and ends June 30, 2016. Model 'T' represented the final base model from the most recent stock assessment review (STAR) conducted in March 2014 (Hill et al. 2014, STAR 2014). This update assessment appends Model T with one additional year of data from fishery-dependent and -independent sources and is based on similar parameterizations as included in the most recently reviewed Model T.

Stock

This assessment focuses on the Pacific sardine northern subpopulation (NSP) that ranges from northern Baja California, México to British Columbia, Canada and extends up to 300 nm offshore. In all past assessments, the default approach has been to assume that all catches landed in ports from Ensenada (ENS) to British Columbia (BC) were from the northern subpopulation. There is now general scientific consensus that catches landed in ENS and SCA likely represent a mixture of the southern subpopulation (warm months) and northern subpopulation (cool months) (Felix-Uraga et al. 2004, 2005; Garcia-Morales 2012; Zwolinski et al. 2011; Demer and Zwolinski 2014). Although the ranges of the northern and southern subpopulations can overlap within the Southern California Bight, the adult spawning stocks likely move north and south in synchrony each year and do not occupy the same space simultaneously to any significant extent (Garcia-Morales 2012). Satellite oceanography data (Demer and Zwolinski 2014) were used to partition catch data from ENS and southern California (SCA) ports in order to exclude both landings and biological compositions attributed to the southern subpopulation.

Catches

The assessment includes sardine landings (metric tons) from six major fishing regions: Ensenada (ENS), southern California (SCA), central California (CCA), Oregon (OR), Washington (WA), and British Columbia (BC). Landings for each port and for the NSP over the past ten years follow:

Calendar Yr-Sem	Model Yr-Seas	ENS Total	ENS NSP	SCA Total	SCA NSP	CCA	OR	WA	BC
2005-1	2004-2	17,323.0	11,186.6	15,419.0	13,948.1	115.3	691.9	324.0	0.4
2005-2	2005-1	37,999.5	4,396.7	14,833.6	1,508.6	7,824.9	44,316.2	6,605.0	3,231.4
2006-1	2005-2	17,600.9	11,214.6	17,157.7	16,504.9	2,032.6	101.7	0.0	0.0
2006-2	2006-1	39,636.0	0.0	16,128.2	4,909.8	15,710.5	35,546.5	4,099.0	1,575.4
2007-1	2006-2	13,981.4	13,320.0	26,343.6	19,900.7	6,013.3	0.0	0.0	0.0
2007-2	2007-1	22,865.5	11,928.2	19,855.0	5,350.3	28,768.8	42,052.3	4,662.5	1,522.3
2008-1	2007-2	23,487.8	15,618.2	24,127.2	24,114.3	2,515.3	0.0	0.0	0.0
2008-2	2008-1	43,378.3	5,930.0	6,962.1	21.8	24,195.7	22,939.9	6,435.2	10,425.0
2009-1	2008-2	25,783.2	20,244.4	9,250.8	9,221.3	11,079.9	0.0	0.0	0.0
2009-2	2009-1	30,128.0	0.0	3,310.3	29.8	13,935.1	21,481.6	8,025.2	15,334.3
2010-1	2009-2	12,989.1	7,904.2	19,427.7	19,427.7	2,908.8	437.1	510.9	421.7
2010-2	2010-1	43,831.8	9,171.2	9,924.7	562.7	1,397.1	20,414.9	11,869.6	21,801.3
2011-1	2010-2	18,513.8	11,588.5	12,526.4	12,515.4	2,713.3	0.1	0.0	0.0
2011-2	2011-1	51,822.6	17,329.6	5,115.4	11.9	7,358.4	11,023.3	8,008.4	20,718.8
2012-1	2011-2	10,534.0	9,026.1	11,906.2	10,018.8	3,672.7	2,873.9	2,931.7	0.0
2012-2	2012-1	48,534.6	0.0	6,896.1	883.6	568.7	39,744.1	32,509.6	19,172.0
2013-1	2012-2	13,609.2	12,827.9	2,592.2	769.7	84.2	149.3	1,421.4	0.0
2013-2	2013-1	37,803.5	0.0	3,658.1	62.9	811.3	27,599.0	29,203.7	0.0
2014-1	2013-2	17,667.5	2,106.2	1,237.7	666.7	4,404.0	0.0	908.0	0.0
2014-2	2014-1	49,076.6	0.0	320.0	0.0	1,830.8	7,788.4	7,208.5	0.0

Data and Assessment

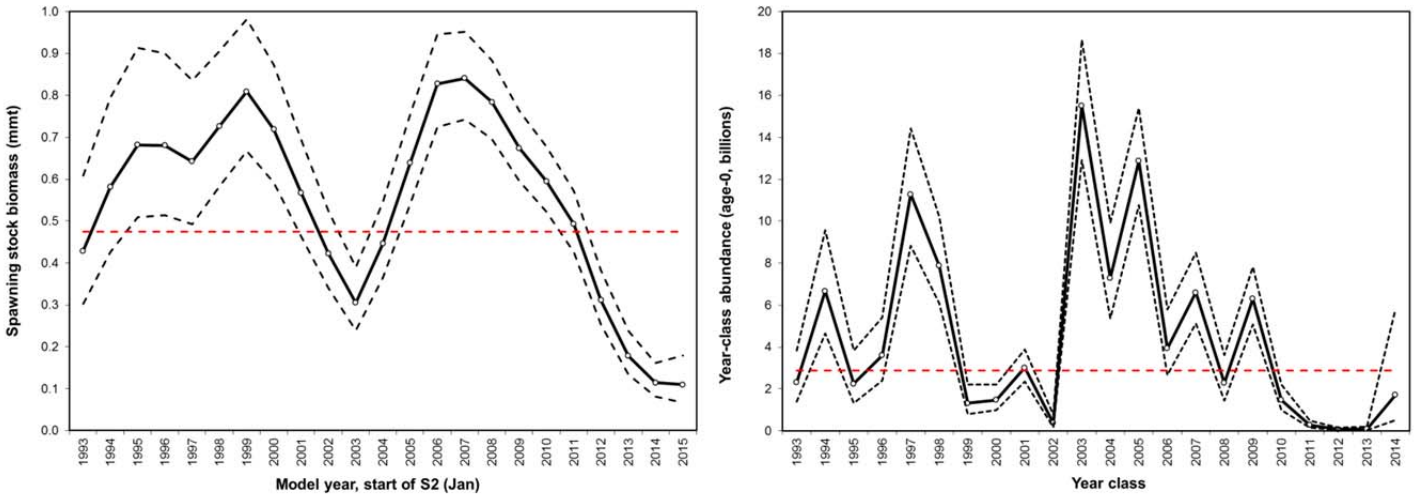
The assessment was conducted using Stock Synthesis (SS version 3.24s), and includes fishery and survey data collected from mid-1993 through 2014. The model is based on a July-June fishing year (aka 'model year'), with two semester-based seasons per year (S1=Jul-Dec and S2=Jan-Jun). Catches and biological samples for the fisheries off ENS, SCA, and CCA were pooled into a single MexCal fleet (fishery), for which selectivity was modeled separately in each season (S1 and S2). Catches and biological samples from OR, WA, and BC were modeled as a single PacNW fleet (fishery). Three indices of abundance from ongoing surveys were included in the base model: daily and total egg production method (DEPM and TEPM) estimates of spawning stock biomass off CA (1994-2013) and acoustic-trawl method (ATM) estimates of biomass along the west coast (2006-2014). Catchability (q) for the ATM surveys (spring and summer) was fixed (1.0) in the final base model T and q's for the egg production surveys were freely estimated. The spring and summer ATM time series were modeled with independent, asymptotic selectivities.

The following data were updated or appended to the update model:

- Landings for 2012 through 2014 were updated for all fishing regions (ENS to WA), including projected estimates for the first half of 2015 (model year 2014-2);
- Length compositions from SCA, CCA, OR, and WA fisheries were updated for model year 2013 and appended with the first semester of model year 2014 (Jul-Dec 2014 samples);
- Conditional age-at-length data from SCA, CCA, OR, and WA were updated through Dec 2013. Age data were not yet available for 2014;
- ATM estimates of biomass from the spring 2014 survey off California and the summer 2014 SaKe survey off the U.S. west coast (San Diego to Vancouver Island) were added to the model; and
- Due to very sparse data collected in the most recent CalCOFI survey conducted in the spring 2014 off California, it was not possible to produce an updated DEPM estimate of SSB for this index of abundance.

Spawning Stock Biomass and Recruitment

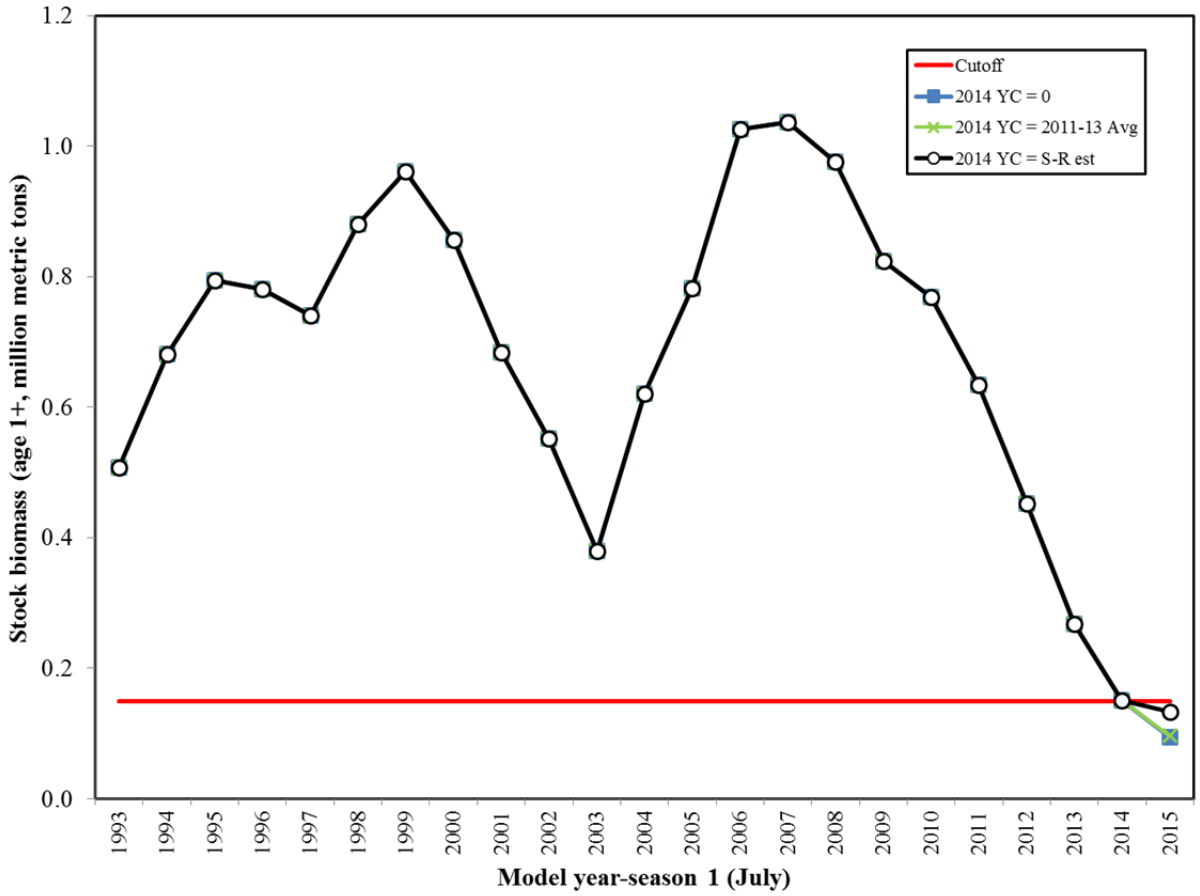
Recruitment was modeled using the Beverton-Holt (B-H) stock-recruitment relationship (σ_R=0.75). Steepness estimates typically bounded at 1.0 for most model scenarios evaluated in sensitivity analysis, with steepness being fixed at 0.8 in the final base model, based on a reasonable range for clupeid stocks indicated from stock-recruitment meta-analysis research. Virgin recruitment (R_0) for the final base model was estimated to be 2.884 billion age-0 fish. The virgin value of the spawning stock biomass (SSB) was estimated to be 0.475 million metric tons (mmt). The SSB increased throughout the 1990s, peaking at 0.809 mmt in 1999 and 0.841 mmt in 2007. Recruitment (age-0 abundance) peaked at 11.3 billion fish in 1997, 15.5 billion in 2003, and 12.9 billion in 2005. The 2010 to 2013 year classes were among the weakest in recent history. The 2014 year class, derived largely from the predicted stock-recruitment curve, was poorly estimated (CV=0.69) and unrealistically high, given the paucity of spawning activity during spring 2014.



Calendar Yr-Sem	Model Yr-Seas	SSB (mt)	SSB Std Dev	Year class abundance (billions)	Recruits Std Dev
2004-1	2003-2	305,319	38,207	---	---
2004-2	2004-1	---	---	7.294	1.155
2005-1	2004-2	445,992	45,653	---	---
2005-2	2005-1	---	---	12.867	1.182
2006-1	2005-2	639,018	54,433	---	---
2006-2	2006-1	---	---	3.936	0.787
2007-1	2006-2	827,400	56,420	---	---
2007-2	2007-1	---	---	6.597	0.853
2008-1	2007-2	840,513	53,143	---	---
2008-2	2008-1	---	---	2.288	0.542
2009-1	2008-2	783,997	47,716	---	---
2009-2	2009-1	---	---	6.302	0.701
2010-1	2009-2	673,537	42,702	---	---
2010-2	2010-1	---	---	1.473	0.309
2011-1	2010-2	595,091	39,326	---	---
2011-2	2011-1	---	---	0.275	0.080
2012-1	2011-2	492,999	37,406	---	---
2012-2	2012-1	---	---	0.076	0.029
2013-1	2012-2	310,918	32,865	---	---
2013-2	2013-1	---	---	0.087	0.037
2014-1	2013-2	178,656	26,352	---	---
2014-2	2014-1	---	---	1.718	1.177
2015-1	2014-2	114,566	20,330	---	---
2015-2	2015-1	---	---	---	---
2016-1	2015-2	109,441	27,938	---	---

Stock Biomass

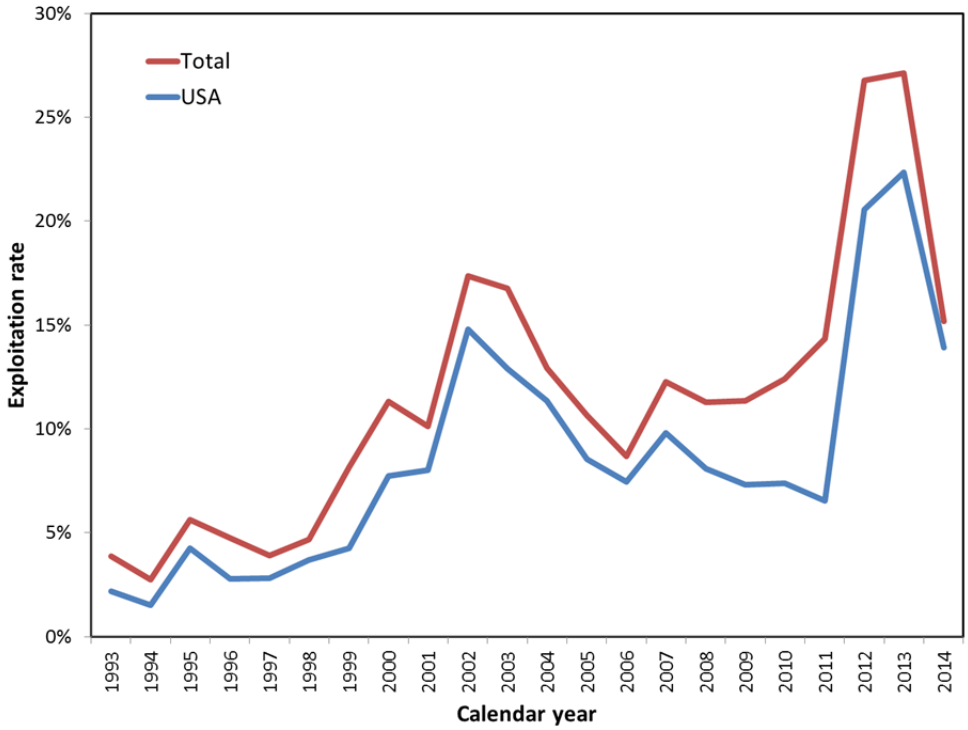
Stock biomass, used for calculating harvest specifications, is defined as the sum of the biomass for sardine ages one and older (age 1+). Stock biomass increased throughout the 1990s, peaking at 0.961 mmt in 1999 and 1.037 mmt in 2007. Stock biomass is projected to be less than 150,000 mt as of July 2015. When the 2014 year class is freely estimated, then stock biomass is projected to be 132,884 mt in July 2015. When the 2014 year class is based on an average of recruitments from 2011-2013, then stock biomass is projected to be 96,688 mt in July 2015. Given the lack of evidence for spawning in 2014, and the fact that recent recruitments have been over-estimated in the past several assessments, the latter is considered to represent the most likely scenario and is recommended for calculating harvest control rules (HCR) in 2015-2016.



Exploitation Status

Exploitation rate is defined as the calendar year NSP catch divided by the total mid-year biomass (July-1, ages 0+). Based on update model estimates, exploitation rate for the U.S. fishery peaked at 22.4% in 2013. U.S. exploitation rate was 13.9% in 2014. U.S. exploitation rate has averaged about 11% since the onset of Council management in 2000. U.S. and total exploitation rates for the NSP, calculated from the update model, are:

Calendar year	USA	Total
2000	7.74%	11.31%
2001	8.02%	10.11%
2002	14.78%	17.36%
2003	12.90%	16.77%
2004	11.35%	12.93%
2005	8.52%	10.65%
2006	7.47%	8.68%
2007	9.80%	12.26%
2008	8.07%	11.29%
2009	7.30%	11.37%
2010	7.37%	12.41%
2011	6.54%	14.33%
2012	20.57%	26.79%
2013	22.36%	27.13%
2014	13.91%	15.20%



Harvest Control Rules

Harvest guideline

The annual HG is calculated as follows:

$$HG = (BIOMASS - CUTOFF) \bullet FRACTION \bullet DISTRIBUTION;$$

where HG is the total U.S. quota for the period July 2015 to June 2016, BIOMASS is the stock biomass (ages 1+) projected as of July 1, 2015, CUTOFF (150,000 mt) is the lowest level of biomass for which directed harvest is allowed, FRACTION (5-20%) is the percentage of biomass above the CUTOFF that can be harvested, and DISTRIBUTION (87%) is the average portion of BIOMASS assumed in U.S. waters. Based on results from the update model, and regardless of assumptions regarding strength of the 2014 year-class, stock biomass is projected to be below the 150,000 mt threshold. Therefore, HG for 2015-2016 is calculated to be 0 mt.

OFL and ABC

On March 11, 2014, the PFMC adopted the use of CalCOFI SST data for specifying environmentally-dependent E_{MSY} each year, beginning July 2014. Based on this recent decision, the following tables of OFL and ABCs are based on an $E_{MSY} = 0.157239$, which corresponds to the three-year running average of CalCOFI SST for 2012-2014 (15.562 °C). OFL and ABC values for 2015-2016 will depend on assumptions regarding strength of the 2014 year-class used to project stock biomass to July 1, 2015. As noted above, when the 2014 year class is freely estimated (albeit primarily derived from the spawner-recruit relationship) then stock biomass is projected to be 132,884 mt in July 2015. When the 2014 year class is based on an average of recruitments from 2011-2013, then stock biomass is projected to be 96,688 mt in July 2015.

Given the lack of spawning activity observed during spring 2014, the latter scenario is considered more realistic. The OFLs and ABCs for these two recruitment scenarios and for a range of P-star values follow:

a) HCRs when 2014 YC is derived from S-R Curve.

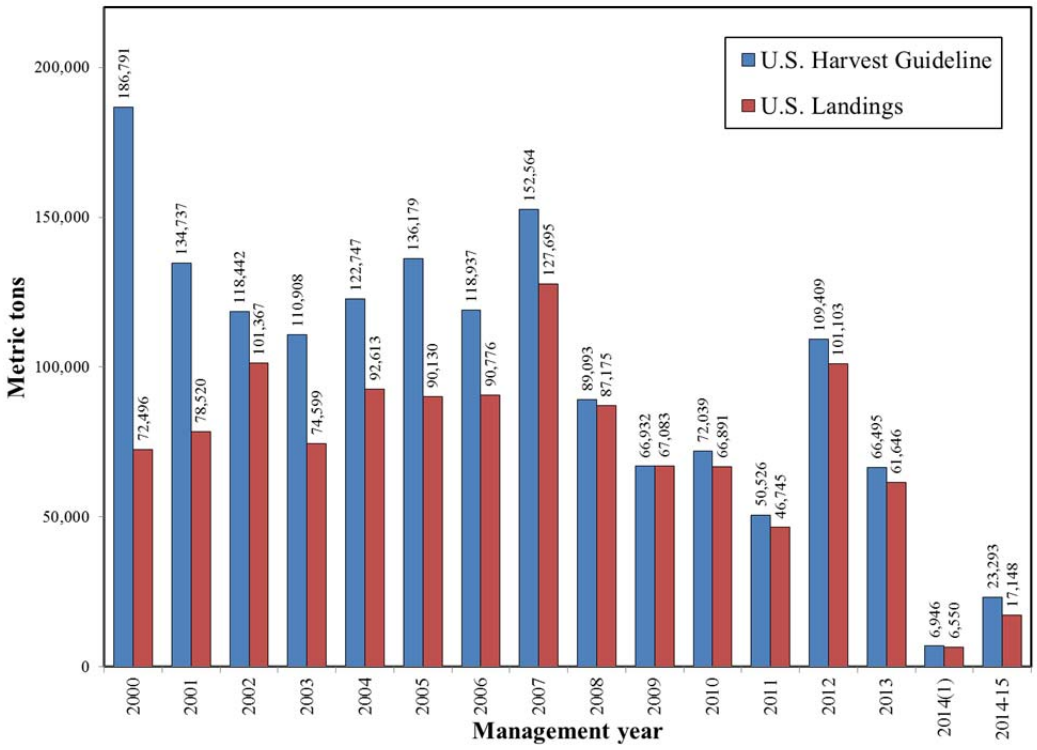
Harvest Control Rule Formulas									
OFL = BIOMASS * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
$ABC_{P\text{-star}}$ = BIOMASS * $BUFFER_{P\text{-star}}$ * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION; where FRACTION is E_{MSY} bounded 0.05 to 0.20									
Harvest Formula Parameters									
BIOMASS (ages 1+, mt)	132,884								
P-star	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
ABC $Buffer_{Tier\ 1}$	0.9558	0.9128	0.8705	0.8280	0.7844	0.7386	0.6886	0.6304	0.5531
CalCOFI SST (2012-2014)	15.562								
E_{MSY}	0.157239								
FRACTION	0.157239								
CUTOFF (mt)	150,000								
DISTRIBUTION (U.S.)	0.87								
Harvest Control Rule Values (MT)									
OFL =	**18,178**								
$ABC_{Tier\ 1}$ =	17,374	16,594	15,824	15,051	14,259	13,427	12,517	11,460	10,055
HG =	**0**								

b) HCRs when 2014 YC is based on the average of 2011-2013 YC sizes.

Harvest Control Rule Formulas									
OFL = BIOMASS * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
$ABC_{P\text{-star}}$ = BIOMASS * $BUFFER_{P\text{-star}}$ * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION; where FRACTION is E_{MSY} bounded 0.05 to 0.20									
Harvest Formula Parameters									
BIOMASS (ages 1+, mt)	96,688								
P-star	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
ABC $Buffer_{Tier\ 1}$	0.95577	0.91283	0.87048	0.82797	0.78442	0.73861	0.68859	0.63043	0.55314
CalCOFI SST (2012-2014)	15.562								
E_{MSY}	0.157239								
FRACTION	0.157239								
CUTOFF (mt)	150,000								
DISTRIBUTION (U.S.)	0.87								
Harvest Control Rule Values (MT)									
OFL =	**13,227**								
$ABC_{Tier\ 1}$ =	12,642	12,074	11,514	10,951	10,375	9,769	9,108	8,338	7,316
HG =	**0**								

Management performance

U.S. HG values and catches since the onset of federal management follow:



Unresolved Problems and Major Uncertainties

Population estimates from this update model scaled an average 26% lower than stock biomass estimated in the 2014 assessment (Model T). This change was attributed to a shift in the spring ATM length selectivity to small sizes as well as the updated fit to the ATM surveys that included the very low estimated biomass observed in 2014. This selectivity sensitivity was observed previously in the 2014 full assessment (see sections *Retrospective analyses* and *Likelihood profile for virgin recruitment*) and was part of the STAR 2014 panel deliberations (see STAR 2014), but was unable to be effectively resolved in 2014. During the SSC CPS Subcommittee's review of this update, it became apparent that the final 2014 assessment did not correspond to the best overall fit to the data. This was due to an uneven likelihood surface and the 2014 model converging to a local minimum. This problem was discovered by re-running the 2014 model from a lower initial R_0 value and estimating this parameter in a later phase. The 2015 update model was subsequently run through a series of convergence tests to ensure the current model represents the optimal solution.

The 2014 year-class strength is highly uncertain and poorly informed by the available data. The model estimate of recruitment in 2014 is unrealistically high given the lack of spawning observed from the surveys during spring 2014. This is important, given the 2014 year-class is part of the calculation of the age 1+ stock biomass for July 2015. The STAT's proposed alternative approach would be to base the 2014 year-class estimate on average recruitment levels from 2011-13, account for natural and fishing mortality throughout 2014, and add the resulting age-1 biomass to the age 2+ biomass from the update model to determine the stock biomass for July 2015.