ASSESSMENT OF THE PACIFIC SARDINE RESOURCE IN 2014 FOR U.S.A. MANAGEMENT IN 2014-15

Executive Summary

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ACRONYMS AND ABBREVIATIONS

ABC	acceptable biological catch
ACT	annual catch target
ATM	Acoustic-trawl method
BC	British Columbia (Canada)
CA	California
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CCA	Central California fishery
CCE	California Current Ecosystem
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
CV	coefficient of variation
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
PFMC	Pacific Fishery Management Council
S1 & S2	Model Season 1 (Jul-Dec) and Season 2 (Jan-Jun)
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 for recommending annual harvest specifications for the U.S. fishery. This sardine assessment report represents a *full assessment* for advising management in fishing year 2014 (newly-established to span July 1, 2014 - June 30, 2015). The last *full assessment* for Pacific sardine was conducted in 2011 (Hill et al. 2011, includes review report), followed by an *update assessment* in 2012 (Hill et al. 2012, includes review report), and *projection assessment* in 2013 (Hill 2013).

This assessment report presents pertinent discussion and results for important model scenarios highlighted in the formal Stock Assessment Review (STAR) held at NOAA's Southwest Fisheries Science Center in La Jolla, CA, March 3-5, 2014. All model scenarios include updated fishery-dependent and -independent time series and reflect different 'states of nature' (model configurations) that include alternative choices for input data (e.g., biological-composition and survey time series) and/or different assumptions or estimators for particular parameterizations of interest (e.g., underlying stock structure and biology, stock-recruitment relationships, data weighting methods for time series, etc.). In this final assessment report, information pertains generally to sensitivity analysis, review (STAR), and STAR panel decisions associated with categories/model scenarios presented in Table 8, particularly, model G (one of two blended, 'preferred' model scenarios initially presented at the STAR) and base model T (final model from STAR meeting). At the onset of the review, both the STAT and STAR panel supported and prioritized model G (length data/length-based selectivity) over blended model H (age data/age-based selectivity) for carrying on more focused evaluations at the meeting. That is, considerable sensitivity analysis was conducted on model G at the meeting to confirm/refute estimates and results from the initial baseline model, as well as further address details of particular data sets/parameterizations/results/diagnostics as identified by the STAR panel during the meeting. Readers should consult both the initial draft assessment report (Hill and Crone 2014) and final review report (STAR 2014) for background information regarding various model scenarios investigated in the initial sensitivity analysis and bases for final choices, assumptions, and parameterizations associated with base model T. Ultimately, model T represented a nearly similar configuration and outcome as model G, with a few key differences based on work conducted at the meeting.

The main objective in this year's assessment development addressed the overriding recommendation from past reviews concerning the importance of survey time series for accurate determination of total abundance of this and other small pelagic fish stocks. Recent estimates of total stock biomass are often the derived quantities most requested by fishery managers for setting harvest guidelines, as is the case for Pacific sardine of the California Current Ecosystem. Attention to direct information regarding abundance from surveys, particularly the more recent acoustic-trawl method (ATM) survey, served as the basis of the overall sensitivity analysis and associated model scenarios presented here. Indirect information regarding stock abundance from related sources of data and parameterizations, particularly pertaining to fitting biological composition time series in the integrated model, was modeled accordingly and in concert with the main goal to produce robust fits to abundance time series and estimates of current total stock abundance for advising management.

EXECUTIVE SUMMARY

The following Pacific sardine assessment was conducted to inform U.S. fishery management for the fishing year that begins July 1, 2014 and ends June 30, 2015. Model T represented the final base model from the formal stock assessment review (STAR) conducted in March 2014 for advising management in 2014-15.

Stock

This annually conducted 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 ENS to BC were from the northern subpopulation. There is now general consensus that catches landed in ENS and SCA likely represent a mixture of southern subpopulation (warm months) and northern subpopulation (cold 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 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 SCA ports in order to exclude 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
2004-1	2003-2	11,212.9	3,922.9	15,232.0	15,232.0	2,145.7	2,203.5	235.3	179.6
2004-2	2004-1	30,684.0	2,373.9	17,161.5	1,512.5	13,162.6	33,908.3	8,564.1	4,258.4
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	10,235.0	6,823.3	11,906.2	10,018.8	3,672.7	2,873.9	2,931.7	0.0
2012-2	2012-1	39,575.0	0.0	6,896.1	883.6	568.7	39,744.1	32,509.6	19,172.0
2013-1	2012-2	9,780.0	6,520.0	2,636.0	769.7	84.2	149.3	1,421.4	0.0
2013-2	2013-1	40,509.0	0.0	3,654.8	0.0	739.0	27,535.9	25,425.2	0.0

Data and Assessment

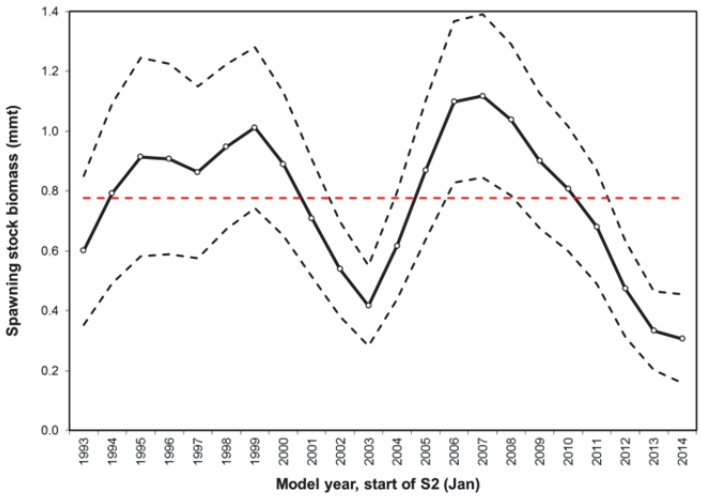
The assessment was conducted using the Stock Synthesis model (SS, version 3.24s), and includes fishery and survey data collected from mid-1993 through 2013. The model is based on a July-June fishing year, with two semester-based seasons per year (S1=Jul-Dec and S2=Jan-Jun). Catches and biological samples 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 combined into a single PacNW fleet (fishery) in the model. 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 (2006-2013). 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 estimated without constraint. The spring and summer ATM time series were modeled with independent, asymptotic selectivities.

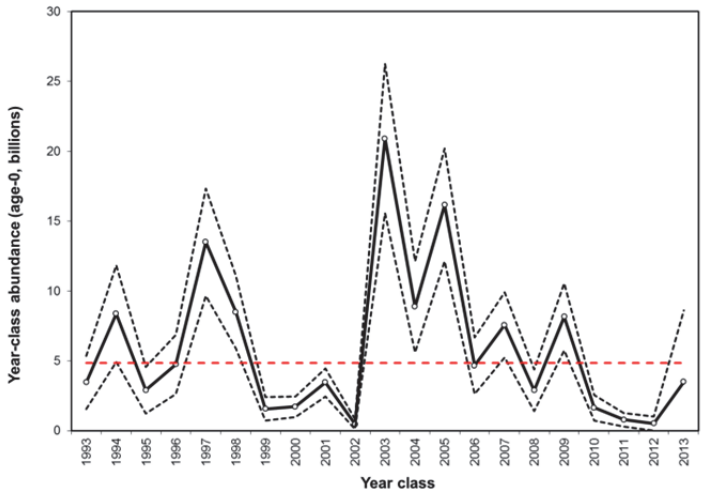
The following data were new to the 2014 assessment:

- Landings for 2012 and 2013 were updated for all fishing regions (ENS to BC), including and projected estimates for the first half of 2014 (2013/semester 2);
- Length compositions from SCA, CCA, OR, WA, and BC fisheries were updated for model year 2012 and the first semester of model year 2013 (July-December 2013 samples). No new length data were available for the ENS fishery;
- Conditional age-at-length data from SCA, CCA, OR, and WA were appended through June 2013;
- DEPM estimate of SSB from the spring 2013 survey off California; and
- ATM-survey estimates of biomass from the spring 2013 survey off California; and the summer 2013 SaKe survey off the U.S. west coast from San Diego to Vancouver Island were added to the model.

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 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 4.828 billion age-0 fish. The virgin value of the spawning stock biomass (SSB) was estimated to be 0.78 million metric tons (mmt). The SSB increased throughout the 1990s, peaking at 1.01 mmt in 1999 and 1.117 mmt in 2007. Recruitments (age-0 abundance) peaked at 13.5 billion fish in 1997, 20.9 billion in 2003, 16.2 billion in 2005, and 8.1 billion in 2009. The 2010 to 2012 year classes were among the weakest in recent history. The 2013 year class, derived largely from the predicted stock-recruitment curve, was poorly estimated (CV=0.73), but included in calculation of total stock biomass (age 1+ fish, mt) for July 2014.

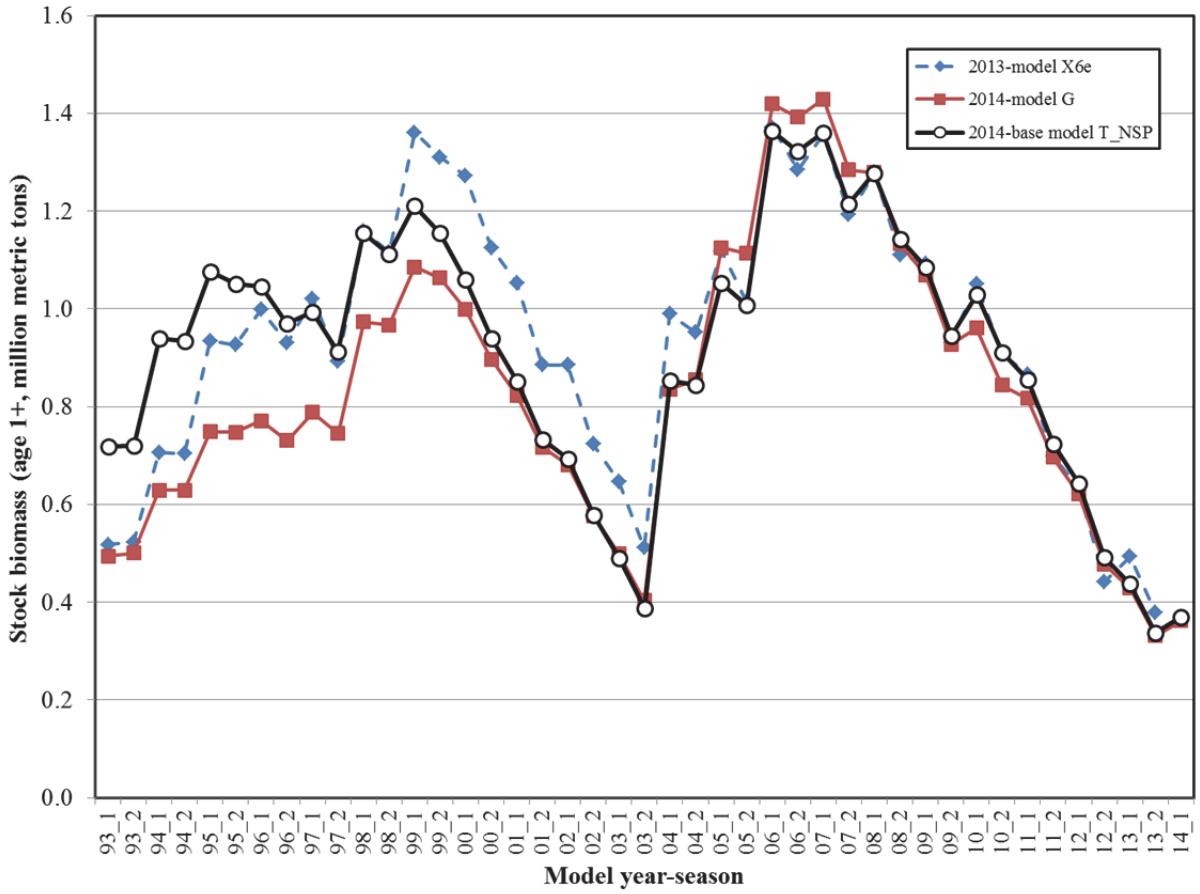




Model year	SSB (mt)	SSB Std Dev	Year class abundance (billions)	Recruits Std Dev
2000	889,929	119,525	1.707	0.368
2001	709,131	97,968	3.450	0.502
2002	538,750	79,127	0.467	0.175
2003	416,424	67,014	20.895	2.673
2004	616,788	89,430	8.860	1.636
2005	868,822	115,871	16.154	2.017
2006	1,098,180	134,709	4.652	1.012
2007	1,117,080	136,349	7.551	1.166
2008	1,037,970	126,448	2.884	0.742
2009	900,161	112,589	8.147	1.207
2010	806,697	104,196	1.648	0.458
2011	680,004	94,716	0.775	0.239
2012	473,374	80,309	0.514	0.251
2013	333,268	65,697	3.498	2.559
2014	306,237	74,121	---	---

Stock Biomass

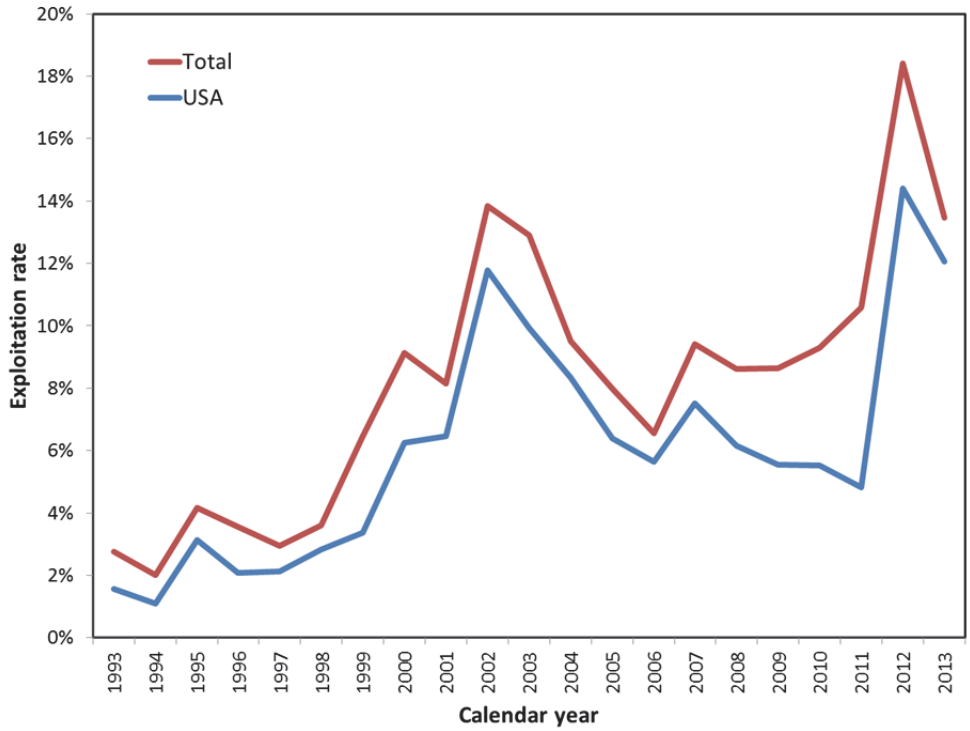
Stock biomass, used for calculating harvest specifications, is defined as the sum of the biomass for sardine ages one and older (age 1+). Stock biomass increased throughout the 1990s, peaking at 1.27 mmt in 1999 and 1.42 mmt in 2007. Stock biomass is projected to be 369,506 mt as of July 2014.



Exploitation Status

Exploitation rate is defined as the calendar year catch divided by the total mid-year biomass (July-1, ages 0+). Exploitation rate for the U.S. fishery peaked at 14.4% in 2012 and total exploitation peaked at 18.4% that same year. The U.S. and total exploitation rates for the NSP calculated from the final base model are as follows:

Calendar year	USA	Total
2000	6.25%	9.13%
2001	6.47%	8.16%
2002	11.79%	13.84%
2003	9.93%	12.91%
2004	8.34%	9.51%
2005	6.39%	7.98%
2006	5.63%	6.55%
2007	7.52%	9.40%
2008	6.17%	8.62%
2009	5.55%	8.64%
2010	5.52%	9.29%
2011	4.83%	10.59%
2012	14.40%	18.42%
2013	12.06%	13.47%



Harvest Control Rules

Harvest guideline

Based on results from final base model T, the preliminary harvest guideline (HG) for the U.S. fishery in management year 2014-15 is 28,646 mt. The HG is calculated as follows:

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

where HG is the total U.S. quota for the period July 2014 to June 2015, BIOMASS (369,506 mt) is the stock biomass (ages 1+) projected as of July 1, 2014, CUTOFF (150,000 mt) is the lowest level of biomass for which harvest is allowed, FRACTION (15%) 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. The HG values and catches since 2000 are displayed under Management Performance. The recommended HG will be the lowest since the onset of federal management. The 28,646 mt HG will be divided into seasonal and related allocations during the April 2014 PFMC meeting.

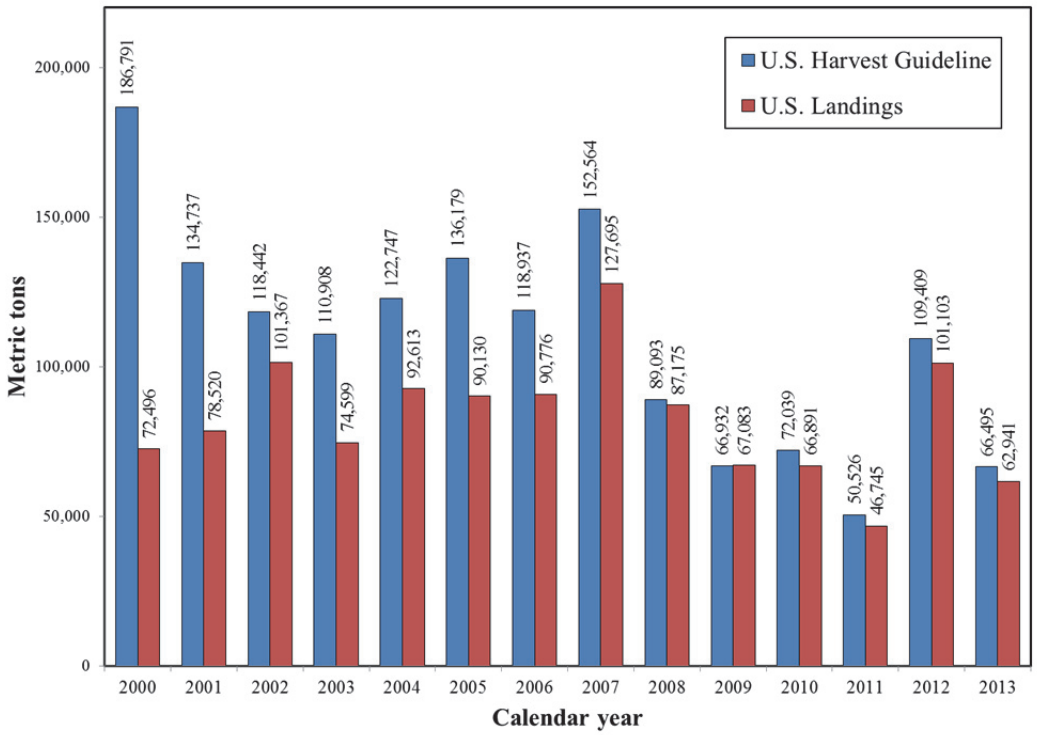
OFL and ABC

Until now, Pacific sardine OFL and ABC calculations have been based on a temperature-independent E_{MSY} average value of 0.18. 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 table of OFL and ABCs is based on an E_{MSY} = 0.122, which corresponds to the three-year running average of CalCOFI SST for 2011-13 (15.335 °C). The OFL for 2014-15 is calculated to be 39,210 mt.

Harvest Control Rule Formulas									
OFL = BIOMASS * F_{MSY} * DISTRIBUTION									
$ABC_{P\text{-}star}$ = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION									
HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION									
Harvest Formula Parameters									
BIOMASS (ages 1+, mt)	369,506								
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
ABC $Buffer_{Tier\ 2}$	0.9135	0.8333	0.7577	0.6855	0.6153	0.5455	0.4741	0.3974	0.3060
CalCOFI SST (2011-2013)	15.335								
E_{MSY}	0.122								
FRACTION	0.15								
CUTOFF (mt)	150,000								
DISTRIBUTION (U.S.)	0.87								
Harvest Control Rule Values (MT)									
OFL =	**39,210**								
$ABC_{Tier\ 1}$ =	37,475	35,792	34,131	32,464	30,757	28,961	26,999	24,719	21,688
$ABC_{Tier\ 2}$ =	35,818	32,672	29,710	26,879	24,126	21,391	18,591	15,583	11,997
HG =	**28,646**								

Management performance

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



Unresolved Problems and Major Uncertainties

In this stock assessment, four primary areas of uncertainty warrant further research attention to improve current knowledge of this species' biology and provide robust estimates of total abundance for management purposes on an annual basis. First, there exists considerable uncertainty surrounding absolute levels of recruitment (age-0, as well as age-1 fish) in the most recent years of the modeled time series, which are believed to be strongly related to environmental conditions, particularly, large-scale oceanographic phenomena (e.g., PDO, SST, sea-surface height, etc.). Further research is needed to better inform stock-recruitment estimation/parameterization in the present assessment, including best practices for identifying and accommodating such environmental information in the integrated SS model. Second, stock structure/distribution hypotheses and related catch/composition determinations were addressed in this assessment using environment-based indices vs. port-based as was conducted in all past assessments. Although general consensus from both STAT/STAR panel supported using environmental data to more objectively address subpopulation (northern and southern populations that potentially mix seasonally) assumptions in the model than simply assuming subpopulations can be identified directly from landing site data (e.g., ports), further empirical (otoliths, length/weight, reproductive/genetic tissue, meristics etc.) evidence should be collected annually from fish during periods of mixing to corroborate results from the environment-based index approach. Third, uncertainty surrounding catchability (q) for the primary ATM survey indices of abundance remains largely unresolved at this time and thus, q remains a fixed parameter (1.0) in the model, as assumed in past assessments. That is, while preliminary models presented at the 2014 STAR panel (e.g., model G) produced reasonable estimates of q for the ATM survey, further evaluations/review indicated the scale of important management quantities (stock biomass and recruitment), as well as estimates of q for the survey, remained sensitive to relatively small changes made to the model (see stock-recruitment estimation above). In this context, stability concerning the scale of sardine population estimates has been an ongoing issue since the application of fully integrated, age-structured models to assess the status this stock (Deriso et al. 1995). Fourth, and related to survey abundance parameterizations in the model, data weighting considerations associated with both fishery and survey composition time series largely reflect ad hoc practices for de-emphasizing these data to minimize their impacts on abundance estimation relative to the direct information provided in the survey indices. Further research associated with both data weighting and related selectivity parameterization is needed, particularly pertaining to conditional age-at-length compositions, to address potential model misspecification due to the treatment of composition data in the present assessment. Finally, based on the points above, the 2013 year-class strength is highly uncertain and poorly informed by the available data. This estimate, which may be biased high, factors into calculation of the age 1+ biomass for July 2014. One alternative approach would be to base age-1 biomass for 2014 on an average of the most recent few years and to add this value to the age 2+ biomass for purpose of setting management specifications in 2014-15. This issue was not explored during the STAR panel.

Research and Data Needs

See Research and Data Needs below for a summary of critical areas in need of further attention to generally improve the ongoing Pacific sardine assessment.