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DECEMBER 2012

ASSESSMENT OF THE PACIFIC SARDINE RESOURCE IN 2012 FOR U.S. MANAGEMENT IN 2013

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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NOAA Technical Memorandum NMFS
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TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

ABC	acceptable biological catch
ALK	age-length key
ASAP	Age Structured Assessment Program
ATM	Acoustic-trawl method
BC	British Columbia (Canada)
CA	California
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CCA	Central California fishery
CDFG	California Department of Fish and Game
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
NWSS	Northwest Sardine 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
SS	Stock Synthesis
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

EXECUTIVE SUMMARY

Stock

The Pacific sardine (*Sardinops sagax caerulea*) ranges from southeastern Alaska to the Gulf of California, México, and is thought to comprise three subpopulations. In this assessment, we modeled the hypothesized northern subpopulation, which ranges seasonally from northern Baja California, México to British Columbia, Canada, and up to 300 nm offshore. All landings in U.S., Canada, and México (Ensenada) were assumed to be taken from this single northern stock. Future modeling efforts will explore a scenario where Ensenada and San Pedro catches are parsed into northern and southern subpopulations using some objective criteria.

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).

Calendar year	ENS	SCA	CCA	OR	WA	BC	Total
2000	67,845	46,835	11,367	9,529	4,765	1,721	142,063
2001	46,071	47,662	7,241	12,780	10,837	1,266	125,857
2002	46,845	49,366	14,078	22,711	15,212	739	148,952
2003	41,342	30,289	7,448	25,258	11,604	978	116,919
2004	41,897	32,393	15,308	36,112	8,799	4,438	138,948
2005	55,323	30,253	7,940	45,008	6,929	3,232	148,684
2006	57,237	33,286	17,743	35,648	4,099	1,575	149,588
2007	36,847	46,199	34,782	42,052	4,663	1,522	166,065
2008	66,866	31,089	26,711	22,940	6,435	10,425	164,466
2009	55,911	12,561	25,015	21,482	8,025	15,334	138,328
2010	56,821	29,352	4,306	20,852	12,381	22,223	145,935
2011	70,336	17,642	10,072	11,023	8,008	20,719	137,801

Data and Assessment

The assessment update was conducted using Stock Synthesis (SS), version 3.21d, and includes fishery and survey data collected from mid-1993 through mid-2012. The SS is based on a July-June 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, in which selectivity was modeled separately for each season (S1 and S2). Catches and biological samples from OR, WA, and BC were modeled as a single PacNW fleet. Four indices of relative 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 (1994-2012), NWSS aerial survey estimates of biomass off OR and WA (2009-2012), and acoustic-trawl method (ATM) estimates of biomass along the west coast (2006-2012). The catchability coefficient (q) was fixed to a value of 1 for the ATM surveys and estimated without constraints for the other surveys.

The following data were appended to the update model.

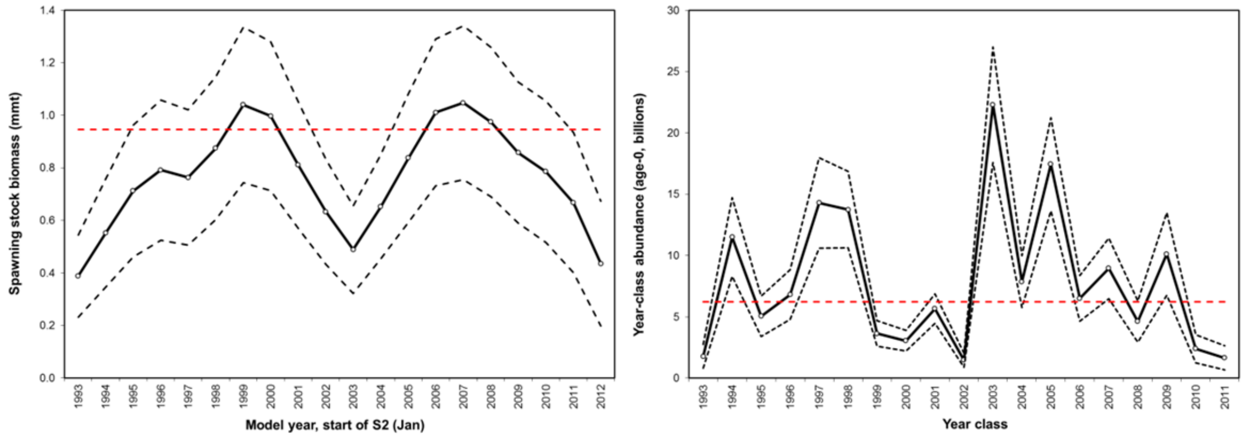
- Landings for 2010 and 2011 were replaced with final numbers for all fishing regions (ENS to BC).

- Landings for 2012 were based on current information (year-to-date) and forecasted through the end of 2012 for fisheries from CA to BC. The ENS catch for 2012 was not available, so was assumed identical to the 2011 tonnage.
- Length compositions from SCA, CCA, OR, WA, and BC fisheries were updated and appended for model year 2011 and the first semester of model year 2012 (July-August 2012 samples). New length data were not available from the ENS fishery.
- Conditional age-at-length data from SCA, CCA, OR, and WA were appended to model year 2011;
- DEPM estimate of SSB from the spring 2012 survey off California were added.
- ATM-survey estimates of biomass from the spring 2012 survey off California; and the summer 2012 survey off the west coast from San Diego to Vancouver Island were added.
- The NWSS aerial survey estimate of biomass for summer 2012 (pooled point sets) was added.

Spawning Stock Biomass and Recruitment

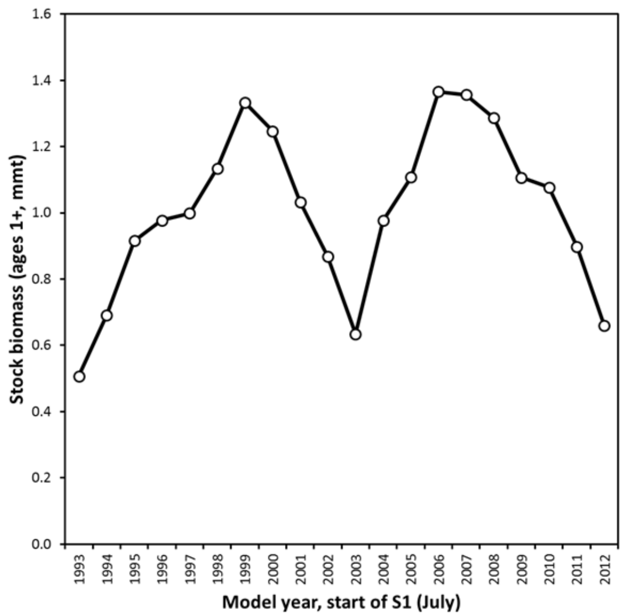
Recruitment was modeled using the Ricker stock-recruitment relationship (σ_R=0.727). The estimate of steepness was high (h=2.79), and virgin recruitment (R_0) was estimated to be 6.22 billion age-0 fish. The virgin value of the spawning stock biomass (SSB) was estimated to be 0.946 mmt. SSB increased throughout the 1990s, peaking at 1.039 million metric tons (mmt) in 1999 and 1.047 mmt in 2007. Recruitment (year-class abundance) peaked at 14.3 billion fish in 1997, 22.3 billion in 2003, 17.4 billion in 2005, and 10.1 billion in 2009. The 2010 and 2011 year classes were the weakest in recent history.

Model year	SSB (mt)	SSB Std Dev	Year class abundance (billions)	Recruits Std Dev
2000	996,883	142,069	3.050	0.423
2001	810,236	120,420	5.669	0.607
2002	632,173	99,976	1.469	0.289
2003	488,308	83,379	22.302	2.359
2004	651,419	99,112	7.863	1.054
2005	837,694	122,477	17.443	1.894
2006	1,010,840	139,967	6.505	0.931
2007	1,047,250	146,350	8.956	1.232
2008	974,298	142,150	4.621	0.836
2009	857,618	134,408	10.123	1.687
2010	785,170	135,020	2.396	0.568
2011	667,141	133,182	1.655	0.494
2012	435,351	118,835	---	---



Stock Biomass

Stock biomass, used for calculating harvest specifications, is defined as the sum of the biomasses for sardine ages one and older (age 1+). Stock biomass increased rapidly throughout the 1990s, peaking at 1.33 mmt in 1999 and 1.37 mmt in 2006. Stock biomass was estimated to be 659,539 mt as of July 2012.



Exploitation Status

Exploitation rate is defined as the calendar year catch divided by the total mid-year biomass (July-1, ages 0+). Modeled U.S. and total exploitation rates are as follows:

Calendar year	U.S.	Total
2000	5.68%	11.13%
2001	7.21%	11.56%
2002	11.48%	16.87%
2003	8.73%	13.68%
2004	8.78%	13.17%
2005	7.04%	11.61%
2006	6.35%	10.46%
2007	8.83%	11.49%
2008	6.54%	12.34%
2009	5.56%	11.47%
2010	6.08%	13.26%
2011	5.11%	15.07%

Harvest Control Rules

Harvest guideline

Using results from the update model X6e, the harvest guideline (HG) for the U.S. fishery in calendar year 2013 is 66,495 mt. The harvest control rule defined in Amendment 8 of the CPS-FMP was used to calculate the HG for 2013 (PFMC 1998). The HG was calculated as follows:

$$HG_{2013} = (BIOMASS_{2012} - CUTOFF) \bullet FRACTION \bullet DISTRIBUTION;$$

where HG_{2013} is the total U.S. (SCA, CCA, OR, and WA) quota for 2013; $BIOMASS_{2012}$ is the estimated July 1, 2012 stock biomass (ages 1+) from the assessment (659,539 mt); CUTOFF (150,000 mt) is the lowest level of estimated biomass at which harvest is allowed; FRACTION (15%) is the percentage of biomass above the CUTOFF that can be harvested by the fisheries; and DISTRIBUTION (87%) is the average portion of BIOMASS assumed in U.S. waters. The U.S. HG values and catches since 2000 are displayed below. The HG for 2013 is 40% lower than the 2012 HG.

OFL and ABC

The Magnuson-Stevens Reauthorization Act requires fishery managers to define an overfishing limit (OFL), allowable biological catch (ABC), and annual catch limit (ACL) for species managed under the federal management plan (FMP). By definition, ABC must always be lower than the OFL based on uncertainty in the assessment approach. The Science and Statistical Committee (SSC) of the Pacific Fisheries Management Council (PFMC) recommended the *P** buffer approach to mitigate scientific uncertainty when defining ABC, which was adopted under Amendment 13 to the coastal pelagic species (CPS) FMP.

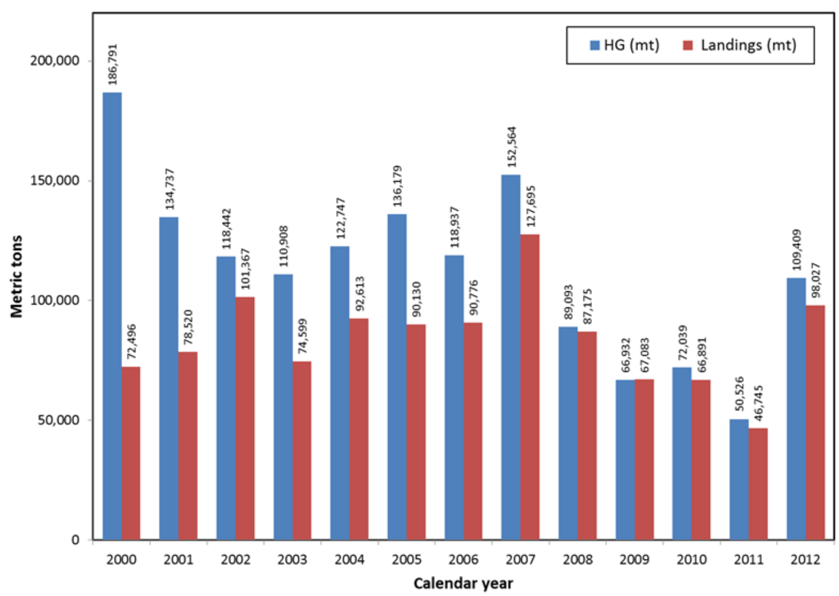
The estimated biomass of 659,539 mt (ages 1+), an F_{MSY} proxy of 0.18, and an estimated 87% of the stock in U.S. waters resulted in a U.S. OFL of 103,284 mt for 2013. For Pacific sardine, the SSC recommended setting scientific uncertainty (σ) to the maximum of either: (1) the coefficient of variation (CV) of the biomass estimate for the most recent year; or (2) a default value of 0.36, based on uncertainty across the full assessment models. The CV of the terminal year biomass was equal to 0.273 (σ =0.268); therefore, σ remained the default value 0.36. The *P** buffer (BUFFER$_{P*}$) depends on the probability of the overfishing level (*P**) chosen by the PFMC. Uncertainty buffers and ABC values associated with a range of discrete *P** values are:

Harvest Formula Parameters	Value			
BIOMASS (ages 1+, mt)	659,539			
*P** (probability of overfishing)	0.45	0.40	0.30	0.20
BUFFER$_{P*}$ (Sigma=0.36)	0.95577	0.91283	0.82797	0.73861
F_{MSY}	0.18			
FRACTION	0.15			
CUTOFF (mt)	150,000			
DISTRIBUTION (U.S.)	0.87			

Amendment 13 Harvest Formulas	MT
OFL = BIOMASS * F_{MSY} * DISTRIBUTION	103,284
$ABC_{0.45}$ = BIOMASS * $BUFFER_{0.45}$ * F_{MSY} * DISTRIBUTION	98,716
$ABC_{0.40}$ = BIOMASS * $BUFFER_{0.40}$ * F_{MSY} * DISTRIBUTION	94,281
$ABC_{0.30}$ = BIOMASS * $BUFFER_{0.30}$ * F_{MSY} * DISTRIBUTION	85,515
$ABC_{0.20}$ = BIOMASS * $BUFFER_{0.20}$ * F_{MSY} * DISTRIBUTION	76,287
HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION	66,495

Management performance

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



Unresolved Problems and Major Uncertainties

The SSC CPS-Subcommittee review focused on two areas of uncertainty in the assessment update: (1) a proposed change to the number of recruitment deviations estimated in the model; and (2) the appropriateness of the 2012 NWSS aerial survey estimate in the current model.

Estimation of recruitment deviations

Upon addition of size composition data to the update model, a noticeable change occurred in both the scale and trend of biomass and recruitments throughout the time series, with both estimated lower in the first half of the time series and higher in the latter half. This change persisted with the addition of other data, and was accompanied by a shift in the trend of recruitment deviations and a loss of fit to survey time series. To evaluate this change, the number of recruitment deviations being estimated in the model was profiled for end year -0 to -3 years. The default setting in the update model was end-year -2, while previous assessments had estimated deviations through end year -1.

There was a clear difference in recruitment deviation trends for models with end-year -0 or -1 compared to those with end-year -2 or -3. The difference was also obvious for recruitment and stock biomass estimates, where models for end-year -2 or -3 had noticeably lower estimates in earlier years and higher estimates for the final six years in comparison to models with end-year -0 or -1. Examination of log deviations [ln(Obs)-ln(Exp)] for modeled survey time series indicated degraded fits to the DEPM, aerial, and ATM time series when recruitments were estimated through end-year -2 or -3 compared to end-year -0 or -1.

To address this problem, the Stock Assessment Team (STAT) strongly recommended returning to past practice of estimating recruitment deviations to end-year -1 instead of -2. While this resulted in a minor change to update model parameterization, the STAT considered this change necessary to correct a problem that was unknowingly introduced in the 2011 assessment model (Hill et al. 2011). The CPS-Subcommittee agreed to this proposed change during the review, so it was carried forward in update model X6e.

2012 NWSS aerial survey

The 2012 aerial survey suffered from lack of representative point sets to inform the relationship between surface area and biomass. The number of acceptable point sets (n=14) was smaller than usual, and there was no spatial-temporal overlap between the aerial transects (stage 1) and point set sampling (stage 2). Moreover, the spatial representation of acceptable point sets was inadequate relative to the spatial distribution of putative sardine observed in the photographs. For these reasons, NWSS survey scientists proposed using a biomass estimate based on point set data pooled across survey years instead of year-specific point sets. Following critical discussion, the review panel and STAT reluctantly agreed to include the pooled estimate in X6e rather than discarding the 2012 aerial estimate in its entirety.

Research and Data Needs

The following model-related research recommendations are excerpted from reports of the 2011 and 2012 assessment reviews.

- Explore use of the results from the mid-water trawl surveys off Vancouver Island conducted by Canada's Department of Fisheries and Oceans (CDFO).
- Temperature-at-catch could provide insight into stock structure and the appropriate catch stream to use for assessments, because the southern subpopulation is thought to inhabit warmer water than the northern subpopulation. Conduct tests of sensitivity to alternative assumptions regarding the fraction of the MexCal (in particular, ENS and SCA) catch from the northern subpopulation.
- Explore models that consider a protracted time period (e.g., 1931 onwards) and evaluate if they provide more information and a broader context for evaluating changes in productivity.
- Explicitly model the sex-structure of the population and the catch.
- Reconsider a model that has separate fleets for Mexico, CA, OR-WA, and Canada.
- Develop a relationship between egg production and age that accounts for the duration of spawning and batch fecundity by age.
- Consider model configurations that use age compositions, rather than length compositions and conditional age-at-length data, given evidence for time- and spatially-varying growth.
- Explore reasons for the discrepancy between the observed and expected proportions of old animals in the length and age compositions. Possible factors include ageing error and bias, and parameterization of the dome-shaped selectivity.
- Explore if replacing the Ricker with a Beverton-Holt or other spawner-recruit relationship will stabilize the SS relative to the number of estimates of recent-years recruitments while providing a biologically realistic relationship.
- Consider the changes within and between years regarding targeting in developing appropriate fishery selectivities, as well as proper blocking and/or weighting of these data.
- Re-review the aerial survey method. Re-consider use of the aerial survey results as minimum estimates of total abundance.

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 2013 management is based on data and methods described by Hill et al. (2011) and reviewed by a Stock Assessment Review (STAR) Panel during September 2011 (STAR 2011). The update was conducted using Stock Synthesis (SS), and includes the most recent data available from fishery-dependent and fishery-independent sources.

A draft assessment update was reviewed by two members of the Scientific and Statistical Committee (SSC) Coastal Pelagic Species (CPS) Subcommittee during October 2-3, 2012. The CPS Subcommittee reviewed one minor change to model parameterization and one change to input data. The following report reflects changes agreed during that review and subsequently presented to the PFMC's advisory bodies at meetings held in November 2012, in Costa Mesa, CA. Reports of the PFMC's advisory bodies are provided in Appendix C.

INTRODUCTION

Distribution, Migration, Stock Structure, Management Units

Information regarding Pacific sardine (*Sardinops sagax caerulea*) biology and population dynamics is available in Clark and Marr (1955), Ahlstrom (1960), Murphy (1966), MacCall (1979), Leet et al. (2001), as well as references cited below.

The Pacific sardine has at times been the most abundant fish species in the California Current. When the population is large, it is abundant from the tip of Baja California (23^{o} N latitude) to southeastern Alaska (57^{o} N latitude) and throughout the Gulf of California. Occurrence tends to be seasonal in the northern extent of its range. When sardine abundance is low, as during the 1960s and 1970s, sardines do not occur in commercial quantities north of Baja California.

It is generally accepted that sardine off the West Coast of North America consist of three subpopulations or stocks. A northern subpopulation (northern Baja California to Alaska), a southern subpopulation (outer coastal Baja California to southern California), and a Gulf of California subpopulation were distinguished on the basis of serological techniques (Vrooman 1964) and in a study of temperature-at-capture (Felix-Uraga et al., 2004; 2005). An electrophoretic study (Hedgecock et al. 1989) showed, however, no genetic variation among sardines from central and southern California, the Pacific coast of Baja California, or the Gulf of California. Although the ranges of the northern and southern subpopulations overlap, the adult spawning stocks may move north and south in synchrony and do not overlap significantly. The northern subpopulation is exploited by fisheries off Canada, the U.S., and northern Baja California, and is included in the CPS Fishery Management Plan (CPS-FMP; PFMC 1998).

Pacific sardines probably migrated extensively during historical periods when abundance was high, moving north as far as British Columbia in the summer and returning to southern California and northern Baja California in the fall. Tagging studies indicate that the older and larger fish moved farther north (Janssen 1938, Clark & Janssen 1945). Migratory patterns were probably complex, and the timing and extent of movement were affected by oceanographic conditions (Hart 1973) and stock biomass. During the 1950s to 1970s, a period of reduced stock size and unfavorably cold sea surface temperatures apparently caused the stock to abandon the northern portion of its range. In recent decades, the combination of increased stock size and warmer sea surface temperatures resulted in the stock re-occupying areas off Central California, Oregon, Washington, and British Columbia, as well as distant-offshore areas off California. During a cooperative U.S.-U.S.S.R. research cruise for jack mackerel in 1991, several tons of sardine were collected 300 nm west of the Southern California Bight (SCB) (Macewicz and Abramenkoff 1993). Resumption of seasonal movement between the southern spawning habitat and the northern feeding habitat has been inferred by presence/absence of size classes in focused regional surveys (Lo et al. 2011) and measured directly using the acoustic-trawl method (Demer et al. 2012).

Life History Features Affecting Management

Pacific sardines may reach 41 cm in length, but are seldom longer than 30 cm. They may live up to 15 years, but fish in California commercial catches are usually younger than five years. Sardine are typically larger and two to three years older in regions off the Pacific Northwest. . There is evidence for regional variation in size-at-age, with size increasing from south to north and from inshore to offshore (Phillips 1948, Hill 1999). Size- and age-at-maturity may decline with a decrease in biomass, latitude, and temperature (Butler 1987). At relatively low biomass levels, sardines appear to be fully mature at age one, whereas at very high biomass levels only some of the two-year-olds are mature (MacCall 1979).

Until 1953, sardines fully recruited to the fishery when they were ages three and older (MacCall 1979). Recent fishery data indicate that sardines begin to recruit at age zero and are fully recruited to the southern California fishery (SCA) by age two. Age-dependent availability to the fishery likely depends upon the location of the fishery; young fish are unlikely to be fully available to fisheries located in the north, and old fish are less likely to be fully available to fisheries south of Point Conception.

Age-specific mortality estimates are available for the entire suite of life history stages (Butler et al. 1993). Mortality is high at the egg and yolk sac larvae stages (instantaneous rates in excess of 0.66 d^{-1}). The adult natural mortality rate has been estimated to be M=0.4 yr^{-1} (Murphy 1966; MacCall 1979) and 0.51 yr^{-1} (Clark and Marr 1955). A natural mortality rate of M=0.4 yr^{-1} means that 33% of the adult sardine stock would die each year of natural causes.

Pacific sardines spawn in loosely aggregated schools in the upper 50 meters of the water column. The northern subpopulation spawning begins in January off northern Baja California and ends by August off the Pacific Northwest (Oregon, Washington, and Vancouver Island), typically peaking off California in April. Sardine eggs are most abundant at sea-surface temperatures of 13 to 15 ^{o}C, and larvae are most abundant at 13 to 16 ^{o}C. The spatial and seasonal distribution of spawning is influenced by temperature. During periods of warm water, the center of sardine spawning shifts northward and spawning extends over a longer period of time (Butler 1987; Ahlstrom 1960). Recent spawning has been concentrated in the region offshore and north of Point Conception (Lo et al. 1996 & 2005). Sardines are oviparous, multiple-batch spawners, with annual fecundity that is indeterminate and age- or size-dependent (Macewicz et al. 1996).

Abundance, Recruitment, and Population Dynamics

Extreme natural variability is characteristic of clupeoid stocks such as the Pacific sardine (Cushing 1971). Estimates of sardine abundance from 300 AD through 1970 have been reconstructed from the deposition of fish scales in sediment cores from the Santa Barbara basin off SCA (Soutar and Issacs 1969, 1974; Baumgartner et al. 1992). Sardine populations existed throughout the period with biomass levels varying widely. Both sardine and anchovy populations tend to vary over periods of roughly 60 years, although sardines have varied more than anchovies. Estimates of sardine biomass inferred from scale-depositions in the 19th and 20th centuries suggest that it peaked at approximately six mmt in 1925 (Soutar and Isaacs 1969;

Smith 1978). Declines in sardine populations have lasted an average of 36 years and recoveries an average of 30 years.

Sardine spawning biomass, estimated from catch-at-age analysis, averaged 3.5 mmt from 1932 through 1934, fluctuated from 1.2 to 2.8 mmt over the next ten years, then declined steeply from 1945 to 1965, with some short-term reversals following periods of particularly successful recruitment (Murphy 1966, MacCall 1979). During the 1960s and 1970s, spawning biomass levels were less than about five to ten thousand mt (Barnes et al. 1992). The sardine stock began to increase by an average rate of 27% per annum in the early 1980s (Barnes et al. 1992).

Pacific sardine recruitment is highly variable. Analyses of the sardine stock recruitment relationship have been controversial, with some studies showing a strong density-dependent relationship (production of young sardines declines at high levels of spawning biomass) and others finding no relationship (Clark and Marr 1955; Murphy 1966; MacCall 1979). Jacobson and MacCall (1995) found both density-dependent and environmental factors to be important.

Relevant History of the Fishery

The sardine fishery was first developed in response to demand for food during World War I. Landings increased from 1916 to 1936, peaking at over 700,000 mt. Pacific sardines supported the largest fishery in the western hemisphere during the 1930s and 1940s, with landings in BC, WA, OR, CA, and México. The population and fishery declined, beginning in the late 1940s and with some short-term reversals, to extremely low levels in the 1970s. There was a southward shift in catch as the fishery collapsed, with landings ceasing in the Pacific Northwest in 1947 through 1948, and in San Francisco in 1951 through 1952. Sardines were primarily reduced to fish meal, oil, and canned food, with small quantities used for bait.

In the early 1980s, sardines were taken incidentally with Pacific and jack mackerel in the SCA mackerel fishery. As sardine continued to increase in abundance, a directed purse-seine fishery was reestablished. The incidental fishery for sardines ended in 1991. Besides SCA and CCA, substantial quantities of Pacific sardines are now landed at OR, WA, BC, and ENS. Total annual harvest by the Mexican fishery is not regulated by quotas, but there is a minimum legal size limit.

Recent Management Performance

Management authority for the U.S. Pacific sardine fishery was transferred to the PFMC in January 2000. The Pacific sardine was one of five species included in the federal CPS-FMP (PFMC 1998). The CPS-FMP includes harvest control rules intended to prevent Pacific sardines from being overfished and to maintain relatively high and consistent, long-term catch levels. Harvest control rules for the sardine are provided at the end of this report. A thorough description of PFMC management actions for sardines, including HG values, may be found in the most recent CPS SAFE document (PFMC 2011). U.S. HG values and landings since 2000 are displayed in Table 1 and Figure 1a. Harvests at major fishing regions from ENS to BC are provided in Table 2 and Figure 1b.

ASSESSMENT DATA

Biological Parameters

Stock structure

For this assessment, we model the northern subpopulation (cold stock) that ranges from northern Baja California, México to British Columbia, Canada and extends up to 300 nm offshore (Macewicz and Abramenkoff 1993). Specifically, all landings, biological samples, and survey data collected between ENS and BC are assumed to be taken from a single stock. Future modeling scenarios may consider an alternative case that separates the catches in ENS and SCA into respective northern (cold) and southern (temperate) stocks using temperature-at-catch and otolith morphometric criteria proposed by Felix-Uraga et al. (2004, 2005). Subpopulation differences in growth, maturation, and natural mortality would also be taken into account.

Growth

The weight-at-length relationship for Pacific sardines (combined sexes) was modeled by the standard power function

$$W = a\ (L^b);$$

where W is weight (kg) at length L (cm), and a and b are regression coefficients. The coefficients, a = 1.68384e-05 and b = 2.94825 (corrected R^2 = 0.928; n = 155,814), were estimated from a least-squares fit to fishery samples collected from 1981 to 2011. These coefficients were fixed in all models (Figure 2a).

The largest recorded Pacific sardine was standard length SL = 41.0 cm (Eschmeyer et al. 1983), but the largest Pacific sardine commercially captured fish since 1981 was SL = 29.7 cm. The heaviest sardine weighed 0.323 kg. The oldest recorded Pacific sardine was 15 years old, but commercially-caught Pacific sardine are typically less than seven years old.

Sardine ageing using otolith methods were first described by Walford and Mosher (1943) and elaborated by Yaremko (1996). Pacific sardines are routinely aged by fishery biologists in México, CA, and the PNW using annuli enumerated in whole sagittae. A birth date of July 1 is assumed when assigning year class. Lab-specific ageing errors were calculated and applied as described in Hill et al. (2011).

Sardine growth was first estimated outside the SS model to provide initial parameter values and CV values for length at Age_{min} (0.5 yrs), length at Age_{max} (15 yrs), and growth coefficient K. An analysis of size-at-age from fishery samples (1993-2010) did not indicate sexual dimorphism (Figure 2b), so a single-sex model was applied.

During the 2009 STAR panel, examination of residuals for the age- and length-composition data revealed that growth was apparently variable versus time. Specifically, there was evidence for a shift in growth rates in 1991. To address this in past assessments, growth parameters were modeled in two periods: 1981-1990 and 1991-2009 (Hill et al. 2009, 2010). It is still unclear whether the growth rate varied with density during the early stages of population recovery (compensatory growth), or is due to another factor. For example, differences in size-at-age could be due to size-selective schooling, as many of the sardines were sampled from incidental catches (mixed with larger mackerel). Uncertainty in the modeled growth and representativeness of early samples are among several reasons for starting the base model in 1993.

Maturity
Maturity-at-length was estimated using sardines sampled from survey trawls conducted from 1986 to 2011. Their reproductive state was primarily established through histological examination, although some immature individuals were simply identified through gross visual inspection. Maturity parameters were estimated over two periods to match different SS model scenarios. The full range of available samples was included for models beginning in the early 1980s, resulting in an inflexion = 16.05 cm and slope = -0.78849. A subset of survey samples (1994 to 2011) was used to parameterize maturity in abbreviated SS models (e.g., the base model), where inflexion = 15.88 cm and slope = -0.90461. Parameters for the logistic maturity function

$$\text{Maturity} = 1/(1+\exp(slope{*}L\text{-}L_{\text{inflexion}})))$$

were fixed in the SS. Fecundity was fixed at 1 egg/gram body weight. Resultant maturity- and fecundity-at-size and age during the spawning season, derived from the final base model, are presented in Figures 2c and 2d.

Natural mortality
The instantaneous rate of adult natural mortality was estimated to be $M = 0.4$ yr^{-1} (Murphy 1966; MacCall 1979) and 0.51 yr^{-1} (Clark and Marr 1955). A natural mortality rate of $M = 0.4$ yr^{-1} means that 33% of the stock die of natural causes each year. Consistent with all previous sardine assessments, the base model was parameterized with $M = 0.4$ yr^{-1} for all ages and years (Murphy 1966, Deriso et al. 1996, Hill et al. 1999).

Fishery Data

Overview
Commercial landings and biological samples were available from six regional fisheries operating off ENS, SCA, CCA, OR, WA, and BC. Biological samples typically (most but not all cases) included individual weight, length, sex, maturity, and otoliths for age estimation. Complete lists of available landings and port samples by fishing region, model year, and season are provided in Tables 2 and 3.

Fishery catches and compositions were compiled using the sardine's biological year (model year) to match the assumed July-1 birth date (See **Biological Parameters**, *Growth*). Each model year is labeled with the first of two calendar years spanned (e.g., model year 1993 includes data from July 1, 1993 through June 30, 1994). Fisheries data are aggregated into southern MexCal (ENS, SCA, and CCA) and northern PacNW (OR, WA, and BC) fleets, and span 1993 to 2012 in the update model. Catches and biological compositions were updated from agency sources described by Hill et al. (2011). Fisheries data are presented in Tables 1-4 and Figures 1-10.

Updated landings

Recent landings for each fishery were appended to the update model following Hill et al. (2011). Landings for calendar years 2010 and 2011 were updated with final numbers for all fishing regions (ENS to BC). Landings data for 2012 were based on current information (year-to-date) and forecast through the end of 2012 for fisheries from SCA to BC. ENS catch for 2012 was not available, so was substituted with 2011 tonnage. Landings by model year, semester, and fleet are presented in Table 4 and Figure 3.

Updated length and age compositions

Fishery length, conditional age-at-length, and implied (ghost) age compositions were updated following the methods in Hill et al. (2011). Length compositions for each fleet and semester were calculated from monthly catch-weighted-length observations. Length compositions ranged from SL = 9 to 28 cm with 0.5-cm bins. Length composition data from SCA to BC were updated and appended for model year 2011 and the first semester of model year 2012 (July-August 2012 samples). New length data from ENS have not been available since mid-2009. Length-compositions by fleet are displayed in Figures 4a, 5a, and 6a.

Conditional age-at-length compositions were also constructed using methods described in Hill et al. (2011). Age bins included 0, 1, 2, 3, 4, 5, 6, 7, 8-10, 11-15 (10 bins total). The age 11-15 bin served as an accumulator allowing growth to approach L_{∞}. Age-compositions were input as proportions of fish in 1-cm length bins. For this update, conditional age-at-length data from SCA to WA were appended to model year 2011. Conditional age-at-length compositions for each fleet are presented in Figures 7-9. Implied age compositions are presented adjacent to corresponding length compositions in Figures 4b, 5b, and 6b.

Ageing-error vectors for fisheries data were unchanged from Hill et al. (2011) (Figure 10). Refer to Appendix 2 of Hill et al. (2011) for more details regarding age-reading data sets, model development, and assumptions.

Fishery-Independent Surveys

Overview

This assessment includes four time series obtained from fishery-independent surveys: 1) Daily Egg Production Method (DEPM) estimates of female spawning biomass; 2) Total Egg Production (TEP) estimates of total spawning biomass; 3) Aerial photogrammetric surveys of biomass; and 4) Acoustic-trawl method (ATM) surveys of biomass. . All of these surveys and estimation methods have been vetted through PFMC-SSC Methodology Reviews (panels included representatives from the PFMC-SSC and the Center for Independent Experts). For this update we include: 1) a new DEPM estimate of the SSB from the spring 2012 survey off CA; 2) ATM estimates of biomass from the spring 2012 survey off CA and the summer 2012 survey spanning San Diego to northern Vancouver Island, Canada; and 3) an Aerial survey estimate of biomass from the summer 2012 survey off OR and WA (Jagielo et al. 2012). These new survey data are presented in Tables 5-7 and Figures 11-15 of this report, as well as in Appendices A and B.

Daily egg production method spawning biomass

The spring 2012 DEPM survey was conducted aboard a chartered fishing vessel and a NOAA research vessel. The R/V *Ocean Starr* surveyed from March 26-April 29 and covered the area off of the west coast of US from Cape Flattery, WA to Point Conception, CA. Most of the stations off CA, located within the area north of San Francisco to Point Conception (CalCOFI lines 56.3 to 80.0), were sampled from April 5 to April 28. The NOAA ship *Bell M. Shimada* surveyed from April 11-April 30, and covered the area from San Diego, CA (CalCOFI line 90.0) to Monterey Bay (CalCOFI line 68.3). *Shimada* also occupied the primary CalCOFI lines, 76.7 to 93.3, from March 23 to April 7 for the spring CalCOFI cruise. During the DEPM and the CalCOFI surveys, CalVET tows, Bongo tows, and CUFES were conducted aboard both vessels while surface trawls were conducted only during the DEPM surveys. Data from DEPM sampling aboard both ships were included in the estimation of spawning biomass of Pacific sardines. Data from the CalCOFI survey during March, 2012 were not used due to the low number of positive catches (including sardines) in all nets.

The standard DEPM index area off California (San Diego to San Francisco; CalCOFI lines 95 to 60) was 270,991 km^2 (Figure 11). The egg production (P_0) estimate was 0.84/0.05m^2 (CV = 0.27). Although the area between Cape Mendocino and San Francisco was sampled by *Ocean Starr,* only two CUFES stations were positive for sardine eggs north of CalCOFI line 60 and only one trawl catch on line 56.2 included sardines. Female spawning biomass for the standard area was taken as the sum of female spawning biomass in regions 1 and 2 (Table 6). The female spawning biomass and the total spawning biomass (sum) for the standard DEPM area was estimated to be 113,178 mt (CV = 0.27) and 255,391 mt (CV = 0.32) respectively (Table 6).

Adult reproductive parameters for the survey area are presented in Table 7. The estimated daily specific fecundity was 16.14 (number of eggs/population weight (g)/day) using the following estimates of reproductive parameters from 126 mature female Pacific sardines collected from 16 positive trawls: *F*, mean batch fecundity, 38,682 eggs/batch (CV = 0.06); *S*, fraction spawning per day, 0.138 females spawning per day (CV = 0.24); W_f, mean female fish weight, 141.4 g (CV = 0.04); and *R*, sex ratio of females by weight, 0.429 (CV = 0.12). Since 2005, trawling has been conducted randomly or at CalCOFI stations, which resulted in sampling adult sardines in both high (Region 1) and low (Region 2) sardine egg-density areas. In 2012, the number of trawl catches including mature female sardines was the same in Region 1 and Region 2 (8 trawls).

The 2012 DEPM estimate is lower than that of 2011 (Tables 5 & 6, Figure 14), primarily due to lower egg production in Region 2 compared to past years. Yet the spawning biomass in 2012 is larger than those in 2008-2010. In the SS, the DEPM series represents the female SSB (length selectivity option 30) in the middle of S2 (April).

Total egg production spawning biomass

Adult sardine samples are needed to calculate the daily specific fecundity for true DEPM estimates. Trawls were not always conducted during the egg production surveys. Beginning in 2007, we chose to include these data as a Total Egg Production (TEP) series, which is simply the product of egg density (P_0) and spawning area (km^2). Calculated TEP values are provided in Table 5 & 6 and displayed in Figure 15. TEP was also taken to represent relative SSB (length selectivity option 30) in the model, but in this case the female fraction was unknown (Tables 5 & 6; Figure 15).

Acoustic-trawl method biomass

The ATM time series is based on SWFSC surveys conducted along the Pacific coast since 2006 (Cutter and Demer 2008; Zwolinski et al. 2011 and 2012a-c). The acoustic-trawl surveys and estimation methods were reviewed by a panel in February 2011 and the results from these surveys have been incorporated into the assessment since 2011 (Hill et al. 2011).

Two new ATM-based biomass estimates were included in this update; one from the spring 2012 survey off CA and the other from the summer 2012 survey spanning San Diego to northern Vancouver Island, Canada. Biomass estimates and associated size distributions from these two surveys are described in detail by Zwolinski et al. (2012b,c; see Appendices A and B of this report). The ATM biomass series are presented in Table 5 and Figure 15, and the ATM length compositions are shown in Figure 13. The ATM biomass estimates were treated as absolute (q = 1) for the range of *SL* values observed in the trawls (Figure 13), which were modeled using asymptotic-length-selectivity assumptions.

A backlog of otoliths from survey trawls were aged, so conditional age-at-length distributions were added from surveys conducted in summer 2008, spring 2011, and spring 2012 (Figure 14). The ageing error vector used for the SWFSC trawl ages was also updated (Figure 10).

Aerial survey

The Pacific sardine industry (Northwest Sardine Survey, LLC; NWSS) funded aerial photogrammetric surveys of sardine abundance off the coast of OR and WA, beginning with a pilot survey in summer 2008. The pilot survey was critiqued by a PFMC-SSC Methodology Review panel in May 2009. Surveys were subsequently conducted during summer 2009 through 2012 (Jagielo et al. 2009-2012).

Aerial survey methods and results are described by Jagielo et al. (2009-2012). The Aerial survey employs two sampling elements: 1) high-resolution aerial photographs, collected using spotter planes, to estimate the number and surface areas of sardine schools; and 2) point sets on schools, deployed from fishing vessels, to estimate the relationship between surface area and biomass and the size composition of the schools. Weighted length compositions from the three surveys are displayed in Figure 12. The assessment fits aerial survey sizes with domed-selectivity assumptions and treats the time series as relative (Figure 15), i.e., q is estimated.

The 2012 aerial survey included an insufficient number of representative point sets to estimate the relationship between surface area and biomass. The number of acceptable point sets was smaller than usual (n=14), and there was no spatial-temporal overlap between the aerial transects (stage 1) and the point sets (stage 2). Moreover, the locations of acceptable point sets did not span the distribution of sardines observed in the photographs. For these reasons, NWSS survey scientists proposed using a biomass estimate based on point set data pooled across survey years instead of year-specific point sets. Following critical discussion, the review panel and STAT agreed to include the pooled estimate (696,251 mt) in the update model (X6e), rather than discarding the 2012 estimate in its entirety. Results from alternative models explored during the October 2012 review are presented in **Uncertainty and Sensitivity Analyses**.

ASSESSMENT MODEL

History of Modeling Approaches

The Pacific sardine population, prior to the collapse in the mid-1900s, was first modeled by Murphy (1966). MacCall (1979) refined Murphy's virtual population analysis (VPA) model using additional data and prorated portions of Mexican landings to exclude the southern subpopulation. Deriso et al. (1996) modeled the recovering population (1982 forward) using CANSAR, a modification of Deriso's (1985) CAGEAN model. CANSAR was subsequently modified by Jacobson (NOAA) into a *quasi* two-area model CANSAR-TAM to account for net losses from the core model area. CANSAR and CANSAR-TAM were used for annual stock assessments and management advice from 1996 through 2004 (e.g., Hill et al. 1999; Conser et al. 2003). In 2004, a STAR panel endorsed the use of an Age Structured Assessment Program (ASAP) model for routine assessments. ASAP was used for sardine assessment and management advice from 2005 to 2007 (Conser et al. 2003, 2004; Hill et al. 2006a,b). In 2007, a STAR panel reviewed and endorsed an assessment using Stock Synthesis 2 (Methot 2005, 2007), and the results were adopted for management in 2008 (Hill et al. 2007) as well as an update for 2009 management (Hill et al. 2008). The sardine model was transitioned to Stock Synthesis version 3.03a in 2009 (Methot 2009) and was again used for an updated assessment in 2010 (Hill et al. 2009 & 2010). Stock Synthesis version 3.21d was used for the 2011 full assessment (Hill et al. 2011).

Model Description

Assessment program with last revision date
Stock Synthesis version 3.21d (SS; Methot 2005, 2011) is based on AD Model Builder software (Otter Research 2001). The SS allows the integration of both size and age structure. The general estimation approach used in the SS accounts for most relevant sources of variability and expresses goodness of fit in terms of the original data, potentially allowing final estimates of model precision to capture most relevant sources of uncertainty.

SS comprises: 1) a population dynamics sub-model, where estimates of abundance, mortality, and growth are used to synthesize estimates of the true population; 2) an observation sub-model that defines various processes and filters to derive expected values for the different type 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 the goodness of fit. These sub-models are fully integrated, and the SS uses forward-algorithms, which begin estimation prior to or in the first year of available data and continues forward up to the last year of data (Methot 2005, 2011).

Definitions of fleets and areas
Data from major fishing regions are aggregated to represent southern and northern fleets. The southern MexCal fleet includes data from three major fishing areas at the southern end of the stock's distribution: northern Baja California (Ensenada, Mexico), southern California (Los Angeles to Santa Barbara), and central California (Monterey Bay). Fishing can occur throughout the year in the southern region. However, availability-at-size/age changes due to migration. Selectivity for the southern MexCal fleet was therefore modeled separately for seasons 1 and 2 (S1 & S2).

The PacNW fleet includes data from the northern range of the stock's distribution, where sardines are typically abundant between late spring and early fall. The PacNW fleet includes aggregate data from Oregon, Washington, and Vancouver Island (British Columbia, Canada). The majority of fishing in the northern region typically occurs between July and October (S1).

Selectivity assumptions
Length data from the MexCal and PacNW fleets were fit using a length-based selectivity. The MexCal fleet was fit using the domed selectivity (double-normal function), as we assumed that not all larger sardines were available to the Baja California and California fisheries from 1993 onward. At that stage in the population's recovery, large spawning events were observed off central California (Lo et al. 1996), and sardines were captured in trawls 300 nm off the California coast (Macewicz and Abramenkoff 1993). Selectivity for the MexCal fleet was estimated by season and in two time blocks (1993-1998, 1999-2012) to better account for both seasonal- and decadal-scale shifts in sardine availability to the southern region. PacNW fleet lengths were fit using asymptotic selectivity (simple logistic). Large sardines are typically found in the northern region, and it is assumed the largest sardines are best able to migrate to northern feeding habitats in summer.

Stock-recruitment constraints and components
Pacific sardine are believed to have a broad spawning season, beginning in January off northern Baja California and concluding by July off the Pacific Northwest. The SWFSC's annual egg production surveys are timed to capture the peak of spawning activity off the central and southern California coast during April. In SS, SSB was calculated at the beginning of S2 and recruitment was calculated in S1 of the subsequent model year (consistent with the July-1 birth date assumption) using the Ricker stock-recruitment function.

Virgin recruitment (R_0), initial recruitment offset (R_1), and steepness (h) were all freely estimated. Recruitment variability (σ_R) was initially set at the 2011 model value (0.622), and later fixed at 0.727 to match the model RMSE. Recruitment deviations were estimated as separate vectors for the early and main data periods. Early recruitment deviations for the initial population were estimated from beginning in 1987 (start year minus 6). A recruitment bias adjustment ramp was applied to the early period (Figure 39d).

The last year for the main recruitment deviations was set at 2010, which means that the 2011 year class was freely estimated from the data and the 2012 year class was derived from the Ricker curve. The number of recruitment deviations estimated from the final model year was changed from end-year -2 (per Hill et al. 2011) to end-year -1. Rationale for this change is documented in the following section '**PRELIMINARY UPDATE MODEL RUNS AND DIAGNOSTICS**'.

Selection of first modeled year and treatment of initial population
The initial population was calculated by estimating early recruitment deviations from 1987-1992, six years prior to the model start year. Initial *F* values were fixed to zero, following recommendations of the 2011 STAR panel (STAR 2011; request N).

Likelihood components and model parameters
A complete list of model parameters is provided in Table 9. The objective function for the base model included likelihood contributions from 1) fits to catch, 2) fits to the DEPM, TEP, Aerial, and Acoustic surveys; 3) fits to length compositions from the three fleets, Aerial and Acoustic surveys; 4) fits conditional age-at-length data from the three fleets and the Acoustic survey; 5) deviations about the spawner-recruit relationship; and 6) minor contributions from parameter soft-bound penalties (Table 9).

The update model (X6e) incorporates the following specifications:

- model year spans July 1-June 30 (July 1 birth date assumption);
- two seasons (S1=Jul-Dec and S2=Jan-Jun) (assessment years 1993 to 2012);
- sex is ignored;
- two fleets (MexCal, PacNW), with an annual selectivity pattern for the PacNW fleet, and seasonal selectivity patterns for the MexCal fleet;
- length-frequency and conditional age-at-length data for all fisheries;
- length-based, double-normal selectivity with time-blocking (1993-1998, 1999-2012) for the MexCal fleet; asymptotic length-selectivity for the PacNW fleet;
- Ricker stock-recruitment relationship with estimated steepness; σ_R = 0.727 (tuned);
- virgin (R_0) and initial recruitment offset (R_1) were estimated;
- spawning occurs in S2 and recruitment in S1;
- initial recruitment estimated; recruitment residuals estimated for SSB years 1987-2010;
- initial *F* set to 0 for all fleets;
- hybrid-*F* fishing mortality (option 3);
- $M = 0.4$ yr^{-1} for all ages;
- DEPM and TEP measures of spawning biomass; *q* estimated;
- aerial survey biomass, 2009-2012, *q* estimated, domed selectivity;
- acoustic survey biomass, 2006-2012, *q*=1, asymptotic selectivity.

Convergence criteria and status
The iterative process for determining numerical solutions in the model was continued until the difference between successive likelihood estimates was <0.00001. Final gradient for the update model was 0.0000221373.

PRELIMINARY MODEL RUNS AND DIAGNOSTICS

Addition of New Data to the Update Model

New data were sequentially added to the final 2011 model (X5) to examine sensitivity to each additional component, specifically catch, length compositions, conditional age-at-length compositions, and survey estimates. Likelihoods and derived quantities for stepwise additions of data are presented in Table 8a. Upon addition of the first fishery length composition (MexCal_S1), a noticeable change occurred in both the scale and trend of biomass and recruitments throughout the time series. Specifically, biomass and recruitments were estimated lower in the first half of the time series and higher in the latter half (Figure 16). This change persisted with the addition of other data sources and was accompanied by a shift in the trend of recruitment deviations and loss of fit to survey time series of abundance (Table 8a).

Profile of Last Year for Estimating Recruitment Deviations

To diagnose this change to model fit, we revisited the number of recruitment deviations being estimated by the model. The 2011 model was specified to estimate recruitment deviations until end year -2, i.e. the final two recruitments were drawn from the spawner-recruit curve (Hill et al. 2011). Models were run for a range of recruitment deviation end-years, where the last year ranged from model end-year -0, -1, -2, and -3.

There was a clear difference in recruitment deviation trends for models with end-year -0 or -1 compared to those with end-year -2 or -3 (Figure 17). This difference in trend is also obvious for recruitment and stock biomass estimates (Figure 18), where models for end-year -2 or -3 have noticeably lower estimates in earlier years and higher estimates for the final six years in comparison to models with end-year -0 or -1. Profiled model fits to survey time series are displayed in Figure 19. Examination of log deviations [ln(Obs)-ln(Exp)] indicated degraded fits to the DEPM, Aerial, and ATM time series when recruitments were estimated through end-year -2 or -3 compared to end-year -0 or -1 (Figure 19).

Update Model Change

To address the above problem, the STAT strongly recommend changing the last year for estimated recruitment deviations from model end-year -2 to end-year -1. While this results in a minor change to update model parameterization, this change was necessary to correct a problem that was unknowingly introduced in the 2011 assessment model (Hill et al. 2011).

Prior to the 2011 stock assessment, the last year for which recruitment deviations was estimated was consistently model end-year -1 (Hill et al. 2007-2010). Early in the process of conducting the 2011 assessment, the STAT had considerable difficulty identifying a model design that did not result in implausibly high F-rates (e.g. F ranging 3 to 4) in the terminal year(s). One change made to ameliorate this problem was to reduce the number of recruitment deviations estimated by one year (i.e., from end-year -1 to -2). The rationale for this change was that there was little information on recent recruitment available from the final years of survey or fishery data. Changing from end-year -1 to -2 appeared to provide more plausible model results. Additional changes to 2011 model designs (e.g., pooling fisheries, truncating the start year for the model) also improved model scaling issues, however, the change to number of recruitment deviation years (-2) remained in the final model design.

Given the degree of misfit introduced to the current update, it was decided to return to the past practice and estimate recruitment deviations to model end year -1. The update model based on this configuration will be referred to as model X6b. The following assessment update results are based on model X6b.

ASSESSMENT RESULTS

Update Model X6e

Parameter estimates and errors
Model X6e parameter estimates and standard errors are presented in Table 9. Most model parameters were within a reasonable range of bounds and had relatively small standard errors. Model X6f estimates are included for comparative purposes.

Growth
Modeled length-at-age is displayed in Figure 20. Length at age 0.5 was estimated to be 11.0 cm SL, L_∞ was 23.2 cm, and the growth coefficient K was 0.454. L_∞ was slightly lower and K was slightly higher than in the 2011 assessment (Hill et al. 2011). Standard deviations for the growth parameters are provided in Table 9. Fits to fleet and ATM survey conditional age-at-length data are shown in Figures 21-24. Most conditional age-at-length compositions fit reasonably well, with the exceptions of MexCal_S1 in 1993 and 2001-2003 (Figure 21) and PacNW in 2008-2011 (Figure 23).

Selectivity estimates and fits to composition data
Length selectivity estimates for each fleet and time period are displayed in Figure 25a. Implied age selectivities (product of length selectivity and the age-length key) for each fleet and period are shown in Figure 25b. The MexCal fleets (S1 & S2) captured progressively smaller fish between the early and latter time blocks (Figure 25a).

Model fits to fleet length frequencies, implied age-frequencies, Pearson residuals, and observed and effective samples sizes are displayed in Figures 26-31. Results are grouped by fleet so, for example, the reader can examine fits to length compositions, bubble plots of the input data, and bubble plots of Pearson residuals across facing pages. Corresponding fits to implied age compositions for the same fishery are found on the following two pages. Results indicate random residual patterns for most data and fleets. The PacNW fleet displayed notable residuals patterns for strong year classes (1997, 1998, and 2003) moving through the fishery (Figure 30-31).

Length selectivity estimates for each survey are displayed in Figure 32a. Selectivity for the ATM survey made a notable shift to larger sardine with the addition of two new length distributions (Figure 32b). The ATM survey selectivity is now similar to the shape estimated for the PacNW fleet (Figure 25a). Model fits to Aerial and Acoustic survey compositions, Pearson residuals, and observed and effective samples sizes are displayed in Figures 33-35. A clear trend is evident in the residual pattern for the Aerial length data (Figure 33). Fits to the Acoustic-trawl survey length and age data are likewise less than optimal (Figures 34-35).

Fits to indices
Model fits to the DEPM, TEP, Aerial and ATM survey time series are displayed in Figure 36a-d. Model expected values all fit within error bounds of the observed data, with the exception of the ATM estimate for model year 2005 (2006 survey), which was under-estimated by the model (Figure 36d). Catchability coefficient (q) for the DEPM series of female SSB was estimated at 0.17. The TEP series was best fit with q=0.54. The Aerial survey fit best with q=0.92.

Fishing mortality and exploitation rates
Harvest rates (catch per selected biomass, continuous-F) by fleet are displayed in Figure 37a. Instantaneous F estimates were all within a plausible range of values and less than 0.6 in most seasons. The F-rate for MexCal_S1 in 2012-1 was estimated relatively high (~0.95), however, there is uncertainty about this estimate as the total catch in 2012-1 is not yet known. Ensenada catch for this season is unknown and the analysis is based on catch from the previous year. Size composition of the Ensenada catch in 2012-1 is also not known.

Exploitation rates (calendar year catch/total mid-year biomass, ages 0+) for the U.S. and total fisheries are displayed in Figure 37b. The U.S. exploitation rate trended upwards from 3% in 1993 to approximately 12% in 2002. Total exploitation rate peaked at 17% in 2002, and was about 15% in 2011.

Spawning stock biomass
Base model estimates of total SSB are presented in Tables 11-12 and Figure 38a. SSB increased throughout the 1990s, peaking at 1.04 mmt in 1999 (=Jan of calendar year 2000) and at 1.05 mmt in 2007. SSB-zero was approximately 0.946 mmt, a value consistent with previous SS assessment results (Hill et al. 2007, 2009-2011).

Recruitment
Time series of recruit (age-0) abundance are provided in Tables 11-12 and Figure 38b. Virgin recruitment (R_0) was estimated at 6.22 billion age-0 fish. Recruitment increased rapidly through the mid-1990s, peaking at 14.3 billion fish in 1997, 13.7 billion in 1998, and 22.3 billion fish in 2003. The 2009 year-class was estimated to be 10.1 billion fish. The 2010 and 2011 year classes were among the lowest in recent history (Table 11, Figure 38b).

Stock-recruitment relationship
The Ricker stock-recruitment relationship for the base model is displayed in Figure 39a. The estimate of steepness (h) was 2.79 for the base model (Table 9). Recruitment deviations for the main era were estimated from SSB years 1993 to 2010 (2011 Year Class) (Figure 39b). Sigma-R was fixed at 0.727 in the final tuned model. Asymptotic standard errors for recruitment deviations are displayed in Figure 39c and the S-R bias adjustment ramp is shown in Figure 39d.

Stock biomass for management
Stock biomass, used for setting management specifications, is defined as the sum of the biomass for ages 1 and older. Model estimates of stock biomass are provided in Table 12 and displayed in Figure 40. Stock biomass increased rapidly through the 1990s, peaking at 1.33 mmt in 1999 and 1.37 mmt in 2006. Stock biomass was estimated at 659,539 mt as of July 1, 2012 (HCR quantity), but is projected to be 454,683 mt as of January 1, 2013.

Uncertainty and Sensitivity Analyses

Models considered during the October 2012 review

The October 2012 update review focused primarily on two aspects of the assessment: 1) the number of recruitment deviations estimated until the model end-year, where end-year -1 was the STAT's proposed method and end-year -2 was the default method from 2011 (Hill et al. 2011); and 2) the 2012 aerial survey estimate and whether it's appropriate to use an estimate based on point set data from 2012 alone, or an estimate based on point-set data pooled from 2009-2012. The SSC-CPS Subcommittee requested several model variants to explore sensitivity to combinations of these parameterizations and aerial estimates, briefly summarized as follows:

<u>Request E</u> (model X6e, update presented in this report): Estimate recruitment deviations to end-year -1; include 2012 aerial survey based point-set data pooled across survey years and size composition from the 2012 point sets; model retuned.

<u>Request F</u> (model X6f): Estimate recruitment deviations to end-year -1; include 2012 aerial survey based 2012 point-set and size composition data; model retuned.

<u>Request G</u> (model X6g): Estimate recruitment deviations to end-year -1; include the full time series of pooled aerial survey estimates (2009-2012) and compositions from year-specific point sets; model retuned.

<u>Request H</u> (model X6h, strict update): Estimate recruitment deviations to end-year -2; include 2012 aerial survey based 2012 point-set and size composition data; model retuned.

Recruitment deviations from these model variants are displayed in Figure 41. Stock biomass and recruitment series for these models are presented in Figure 42. Estimates from the 2011 final assessment model X5 are included for comparison. Biomass and recruitment from models X6e, X6f, and X6g were nearly identical in terms of trend and scale. These three variants estimated recruitment deviations through end-year -1, and differed with respect to treatment of the aerial survey data. The assessment model is relatively insensitive to changes in aerial survey abundance, likely due to the relatively large survey CVs and additional model variance included to account for process error. As documented earlier in this report, the strict update model X6h displayed the greatest departure from the final 2011 model with respect to both trend and scale (Figures 40 and 42).

Historical analysis

Model X6e estimates of stock biomass and recruitment are compared to recent assessments in Figures 43a,b. Full and updated SS models from Hill et al. (2007-2011) were included in the comparison. Trends in biomass and recruitment were generally comparable among models, with the 2008 update model showing the greatest difference in scale.

HARVEST CONTROL RULES

Harvest Guideline

Using results from the update model X6e, the harvest guideline (HG) for the U.S. fishery in calendar year 2013 is 66,495 mt. The harvest control rule defined in Amendment 8 of the CPS-FMP was used to calculate the HG for 2013 (PFMC 1998). The HG was calculated as follows:

$$HG_{2013} = (BIOMASS_{2012} – CUTOFF) \bullet FRACTION \bullet DISTRIBUTION;$$

where HG_{2013} is the total U.S. (California, Oregon, and Washington) quota for 2013, $BIOMASS_{2012}$ is the estimated July 1, 2012 stock biomass (ages 1+) from the assessment (659,539 mt), CUTOFF (150,000 mt) is the lowest level of estimated biomass at which harvest is allowed, FRACTION (15%) is the percentage of biomass above the CUTOFF that can be harvested by the fisheries, and DISTRIBUTION (87%) is the average portion of BIOMASS assumed in U.S. waters. The U.S. HG values and catches since 2000 are displayed below. The HG for 2013 represents a 40% reduction from the 2012 HG.

OFL and ABC

The Magnuson-Stevens Reauthorization Act requires fishery managers to define an overfishing limit (OFL), allowable biological catch (ABC), and annual catch limit (ACLs) for species managed under federal FMPs. By definition, ABC must always be lower than the OFL based on uncertainty in the assessment approach. The PFMC's SSC recommended the *P** approach for buffering against scientific uncertainty when defining ABC, and this approach was adopted under Amendment 13 to the CPS-FMP.

The estimated biomass of 659,539 mt (ages 1+), an F_{MSY} proxy of 0.18, and an estimated distribution of 87% of the stock in U.S. waters resulted in a U.S. OFL of 103,284 mt for 2013. For Pacific sardine, the Science and Statistical Committee (SSC) has recommended that scientific uncertainty (σ) be set to the maximum of either (1) the CV of the biomass estimate for the most recent year or (2) a default value of 0.36, which was based on uncertainty across full assessment models. The terminal year biomass CV was equal to 0.273 (σ =0.268); therefore, σ remained at the default value of 0.36. The Amendment 13 ABC buffer depends on the probability of the overfishing level chosen by the Council (*P**). Uncertainty buffers and ABCs associated with a range of discreet *P** values are presented in Table 13.

RESEARCH AND DATA NEEDS

The following model-related research recommendations are excerpted from reports of the 2011 and 2012 assessment reviews.

- Explore use of Canada DFO's mid-water trawl survey off Vancouver Island.
- Temperature-at-catch could provide insight into stock structure and the appropriate catch stream to use for assessments, because the southern subpopulation is thought to inhabit warmer water than the northern subpopulation. Conduct tests of sensitivity to alternative assumptions regarding the fraction of the MexCal (in particular, Ensenada and Southern California) catch that comes from the northern subpopulation.
- Explore models that consider a much longer time period (e.g., 1931 onwards) to determine whether it is possible to model the protracted period and determine whether this leads to a more informative assessment and provides a broader context for evaluating changes in productivity.
- Consider a scenario that explicitly models the sex-structure of the population and the catch.
- Reconsider a model that has separate fleets for Mexico, CA, OR-WA, and Canada.
- Develop a relationship between egg production and age that accounts for the duration of spawning and batch fecundity by age.
- Consider model configurations that use age compositions, rather than length compositions and conditional age-at-length data, given evidence for time- and spatially-varying growth.
- Explore reasons for the discrepancy between the observed and expected proportions of old animals in the length and age compositions. Possible factors to consider in this investigation include ageing error / ageing bias and the way dome-shaped selectivity has been parameterized.
- Consider a Beverton-Holt or other spawner-recruit relationship in place of the Ricker to see if such a change will stabilize the model relative to the number of recent years of recruitments estimated, while providing a biologically realistic relationship.
- Consider the changes within and between years regarding targeting in developing appropriate fishery selectivities, as well as proper blocking and/or weighting of these data.
- Conduct a methods review to consider how best to use data from the aerial survey. Consider incorporating the aerial survey as a minimum estimate of total abundance.

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Table 1. Sardine harvest guidelines and U.S. landings since the onset of federal management.

Year	HG (mt)	Landings (mt)
2000	186,791	72,496
2001	134,737	78,520
2002	118,442	101,367
2003	110,908	74,599
2004	122,747	92,613
2005	136,179	90,130
2006	118,937	90,776
2007	152,564	127,695
2008	89,093	87,175
2009	66,932	67,083
2010	72,039	66,891
2011	50,526	46,745
2012	109,409	98,027

Table 2. Pacific sardine landings (mt) for major fishing regions off northern Baja California (Ensenada, Mexico), the United States, and British Columbia (Canada), calendar years 1981 to 2011[\1].

Calendar year	ENS	SCA_Inc	SCA_Dir	CCA	OR	WA	BC	Grand Total
1981	0.0	5.8	0.0	0.0	0.0	0.0	0.0	5.8
1982	0.0	131.1	0.0	0.0	0.0	0.0	0.0	131.1
1983	273.6	352.4	0.0	0.0	0.0	0.0	0.0	626.0
1984	0.0	170.6	0.0	63.9	0.0	0.0	0.0	234.5
1985	3,722.3	558.6	0.0	34.4	0.0	0.0	0.0	4,315.2
1986	242.6	721.1	330.1	112.9	0.0	0.0	0.0	1,406.7
1987	2,431.6	1,691.8	363.9	38.9	0.0	0.0	0.0	4,526.2
1988	2,034.9	2,790.3	984.3	10.2	0.0	0.0	0.0	5,819.7
1989	6,224.2	2,605.1	838.2	237.7	0.0	0.0	0.0	9,905.2
1990	11,375.3	1,266.1	1,241.9	306.6	0.0	0.0	0.0	14,189.9
1991	31,391.8	1,174.9	5,599.1	975.7	0.0	0.0	0.0	39,141.5
1992	34,568.2	0.0	16,061.0	3,127.6	3.9	0.0	0.0	53,760.7
1993	32,044.9	0.0	15,487.7	704.5	0.2	0.0	0.0	48,237.3
1994	20,877.0	0.0	10,345.9	2,359.0	0.0	0.0	0.0	33,581.9
1995	35,396.2	0.0	36,561.4	4,927.9	0.0	0.0	22.7	76,908.1
1996	39,064.7	0.0	25,170.9	8,885.1	0.0	0.0	0.0	73,120.7
1997	68,439.0	0.0	32,836.8	13,360.8	0.0	0.0	70.8	114,707.3
1998	47,812.2	0.0	31,974.6	9,080.8	1.0	0.0	488.1	89,356.7
1999	58,569.4	0.0	42,863.0	13,884.0	775.1	0.0	24.5	116,115.9
2000	67,845.3	0.0	46,834.8	11,367.3	9,529.0	4,765.4	1,721.3	142,063.1
2001	46,071.3	0.0	47,661.7	7,241.4	12,780.0	10,837.0	1,265.9	125,857.3
2002	46,845.3	0.0	49,365.9	14,077.8	22,711.0	15,212.1	739.4	148,951.5
2003	41,341.8	0.0	30,289.1	7,448.3	25,258.0	11,603.9	977.7	116,918.7
2004	41,896.9	0.0	32,393.4	15,308.3	36,111.8	8,799.4	4,438.0	138,947.9
2005	55,322.5	0.0	30,252.6	7,940.1	45,008.1	6,929.0	3,231.8	148,684.2
2006	57,236.9	0.0	33,285.8	17,743.1	35,648.2	4,099.0	1,575.4	149,588.4
2007	36,846.8	0.0	46,198.6	34,782.1	42,052.3	4,662.5	1,522.3	166,064.6
2008	66,866.1	0.0	31,089.3	26,711.0	22,939.9	6,435.2	10,425.0	164,466.4
2009	55,911.2	0.0	12,561.1	25,015.0	21,481.6	8,025.2	15,334.3	138,328.4
2010	56,820.9	0.0	29,352.4	4,305.8	20,852.0	12,380.5	22,223.1	145,934.8
2011	70,336.5	0.0	17,641.8	10,071.8	11,023.4	8,008.4	20,718.8	137,800.7

[\1] Southern and central California landings (incidental and directed) are from CDFG's monthly Wetfish tables, which included bucket sampling of mixed loads to account for incidental catches not included on landing receipts. OR and WA landings were obtained from the PacFIN database. British Columbia landings were provided by the Canada Department of Fisheries and Oceans. Ensenada (Mexico) landings were obtained from INAPESCA annual reports, INAPESCA scientists, and CONAPESCA (2005-2011).

Table 3. Pacific sardine landings (mt) and corresponding number of fish sampled (length data available for the assessment) for major fishing regions off northern Baja California (Mexico), the United States, and Canada, by model year and season, 1981 to 2012[\1\2]. Update model begins in 1993-1.

Model year	Model sem	ENS mt	ENS N_len	SCA Inc mt	SCA Inc N_fish	SCA Dir mt	SCA Dir N_fish	CCA mt	CCA N_fish	OR mt	OR N_fish	WA mt	WA N_fish	BC mt	BC N_len
1981	1	0	0	6	179	0	0	0	0	0	0	0	0	0	0
1981	2	0	0	57	204	0	0	0	0	0	0	0	0	0	0
1982	1	0	0	74	361	0	0	0	0	0	0	0	0	0	0
1982	2	150	0	263	580	0	0	0	0	0	0	0	0	0	0
1983	1	124	0	89	411	0	0	0	0	0	0	0	0	0	0
1983	2	0	0	159	188	0	0	0	0	0	0	0	0	0	0
1984	1	0	0	12	0	0	0	64	0	0	0	0	0	0	0
1984	2	3,174	0	312	214	0	0	10	0	0	0	0	0	0	0
1985	1	548	0	247	371	0	0	24	0	0	0	0	0	0	0
1985	2	99	0	530	482	325	297	65	0	0	0	0	0	0	0
1986	1	143	0	191	447	5	14	48	0	0	0	0	0	0	0
1986	2	975	0	918	767	364	289	22	0	0	0	0	0	0	0
1987	1	1,457	0	773	728	0	0	17	0	0	0	0	0	0	0
1987	2	620	0	2,028	1,365	984	762	8	0	0	0	0	0	0	0
1988	1	1,415	0	763	562	0	0	3	0	0	0	0	0	0	0
1988	2	461	34	1,081	810	838	262	235	0	0	0	0	0	0	0
1989	1	5,763	97	1,524	1,018	0	0	3	0	0	0	0	0	0	0
1989	2	5,900	73	645	556	1,242	588	245	0	0	0	0	0	0	0
1990	1	5,475	395	621	350	0	0	62	92	0	0	0	0	0	0
1990	2	9,271	1,216	601	441	4,481	1,514	90	113	0	0	0	0	0	0
1991	1	22,121	1,073	574	0	1,118	412	885	495	0	0	0	0	0	0
1991	2	3,327	469	0	0	5,884	912	1,113	221	0	0	0	0	0	0
1992	1	31,242	1,195	0	0	10,177	2,098	2,014	0	4	0	0	0	0	0
1992	2	18,648	853	0	0	11,759	1,585	369	0	0	0	0	0	0	0
1993	1	13,397	2,068	0	0	3,729	363	335	0	0	0	0	0	0	0
1993	2	5,712	816	0	0	7,738	785	629	0	0	0	0	0	0	0
1994	1	15,165	913	0	0	2,607	644	1,730	0	0	0	0	0	0	0
1994	2	18,227	958	0	0	28,122	3,024	443	0	0	0	0	0	0	0
1995	1	17,169	1,283	0	0	8,439	863	4,485	0	0	0	0	0	23	0
1995	2	15,666	665	0	0	14,409	1,492	2,486	271	0	0	0	0	0	0
1996	1	23,399	1,065	0	0	10,762	837	6,399	2,182	0	0	0	0	0	0
1996	2	13,498	534	0	0	11,524	1,441	343	49	0	0	0	0	44	0
1997	1	54,941	1,250	0	0	21,313	1,325	13,018	1,374	0	0	0	0	27	0
1997	2	20,239	458	0	0	19,094	1,482	2,747	124	1	0	0	0	0	0
1998	1	27,573	1,034	0	0	12,881	1,315	6,334	1,286	0	0	0	0	488	175
1998	2	34,760	1,461	0	0	24,050	1,514	7,741	348	50	31	0	0	24	165
1999	1	23,810	1,014	0	0	18,813	1,215	6,143	0	725	76	0	0	0	290
1999	2	33,933	1,156	0	0	34,119	1,457	1,285	0	205	106	62	0	162	0

Table 3 (cont'd). Pacific sardine landings (mt) and corresponding number of fish sampled (length data available for the assessment) for major fishing regions off northern Baja California (Mexico), the United States, and Canada, by model year and season, 1981 to 2012[\1\2]. Update model begins in 1993-1.

Model year	Model sem	ENS mt	ENS N_len	SCA Inc mt	SCA Inc N_fish	SCA Dir mt	SCA Dir N_fish	CCA mt	CCA N_fish	OR mt	OR N_fish	WA mt	WA N_fish	BC mt	BC N_len
2000	1	33,912	1,281	0	0	12,716	1,405	10,082	0	9,324	796	4,703	899	1,559	2,909
2000	2	16,545	1,145	0	0	29,343	1,699	774	92	2,288	168	49	100	0	648
2001	1	29,526	720	0	0	18,318	1,670	6,467	690	10,492	702	10,789	1,350	1,265	1,206
2001	2	17,422	930	0	0	26,621	1,621	1,575	302	2,724	250	412	419	1	300
2002	1	29,424	891	0	0	22,745	1,153	12,503	758	19,987	1,249	14,800	3,113	739	9,323
2002	2	15,514	460	0	0	20,380	1,739	5,086	471	503	25	94	186	0	300
2003	1	25,827	1,036	0	0	9,909	1,511	2,363	195	24,755	943	11,510	2,726	977	9,227
2003	2	11,213	5,028	0	0	15,232	1,669	2,146	197	2,204	124	235	298	180	0
2004	1	30,684	5,113	0	0	17,161	1,715	13,163	563	33,908	872	8,564	1,578	4,258	6,689
2004	2	17,323	4,191	0	0	15,419	1,756	115	23	692	50	324	147	0	0
2005	1	38,000	2,885	0	0	14,834	1,810	7,825	587	44,316	349	6,605	1,348	3,231	6,451
2005	2	17,601	1,336	0	0	17,158	3,322	2,033	1,530	102	0	0	0	0	0
2006	1	39,636	1,154	0	0	16,128	1,517	15,711	1,446	35,547	300	4,099	375	1,575	0
2006	2	13,981	553	0	0	26,344	1,789	6,013	1,138	0	75	0	0	0	0
2007	1	22,865	1,138	0	0	19,855	1,802	28,769	1,701	42,052	1,999	4,663	250	1,522	2,336
2007	2	23,488	1,080	0	0	24,127	1,318	2,515	370	0	0	0	0	0	0
2008	1	43,378	2,074	0	0	6,962	637	24,196	746	22,940	2,000	6,435	360	10,425	22,894
2008	2	25,783	1,251	0	0	9,251	497	11,080	497	0	0	0	0	0	0
2009	1	30,128	0	0	0	3,310	325	13,935	575	21,482	2,050	8,025	300	15,334	28,527
2009	2	12,989	0	0	0	19,457	1,550	2,909	925	437	84	511	50	0	200
2010	1	43,832	0	0	0	9,925	625	1,397	325	20,415	1,599	11,870	200	21,801	28,689
2010	2	18,514	0	0	0	12,526	549	2,713	275	0	0	0	0		0
2011	1	51,823	0	0	0	5,115	550	7,358	550	11,023	850	8,008	250	20,719	36,191
2011	2	18,514	0	0	0	12,053	1,207	3,673	400	2,874	0	2,971	0	0	0
2012	1	51,823	0	0	0	8,964	512	5,838	0	33,304	5,053	27,888	474	19,316	6,000

[\1] Southern and central California landings (incidental and directed) are from CDFG's monthly Wetfish tables, which included bucket sampling of mixed loads to account for incidental catches not included on landing receipts. OR and WA landings were obtained from the PacFIN database. British Columbia landings were provided by the Canada Department of Fisheries and Oceans. Ensenada (Mexico) landings were obtained from INAPESCA annual reports, INAPESCA scientists, and CONAPESCA (2005-2011).

[\2] Sardine lengths for the Oregon fishery in 2012-1 include fish measured by the NWSS (non-point set, n=4,628) and ODFW (n=425).

Table 4. Pacific sardine landings (mt) and effective sample sizes (ESS) by model year, semester, and fishery for the update model.

Model year	Model sem	MexCal mt	MexCal ESS	PacNW mt	PacNW ESS
1993	1	17,460.8	68.60	0.0	0.00
1993	2	14,078.9	75.58	0.0	0.00
1994	1	19,503.0	34.15	0.0	0.00
1994	2	46,792.1	184.41	0.0	0.00
1995	1	30,093.3	54.40	22.7	0.00
1995	2	32,561.2	50.12	0.0	0.00
1996	1	40,559.5	76.02	0.0	0.00
1996	2	25,364.6	39.90	43.5	0.00
1997	1	89,272.0	72.64	27.2	0.00
1997	2	42,079.7	42.44	0.8	0.00
1998	1	46,787.9	67.85	488.2	0.00
1998	2	66,550.5	66.15	74.4	0.00
1999	1	48,765.8	44.67	725.2	3.04
1999	2	69,337.6	52.39	429.6	4.24
2000	1	56,709.8	53.24	15,586.2	63.93
2000	2	46,662.7	62.74	2,336.9	10.72
2001	1	54,311.7	58.90	22,546.0	78.15
2001	2	45,617.1	62.32	3,136.8	26.75
2002	1	64,671.9	73.64	35,525.7	172.79
2002	2	40,979.6	62.30	597.3	8.44
2003	1	38,099.5	50.43	37,242.3	145.33
2003	2	28,590.5	124.63	2,618.4	16.88
2004	1	61,008.1	149.06	46,730.8	95.17
2004	2	32,857.3	122.39	1,016.3	7.88
2005	1	60,658.0	108.68	54,152.6	67.68
2005	2	36,791.2	77.23	101.7	0.00
2006	1	71,474.7	78.73	41,220.9	27.00
2006	2	46,338.3	91.44	0.0	3.00
2007	1	71,489.2	109.86	48,237.1	87.86
2007	2	50,130.3	56.13	0.0	0.00
2008	1	74,536.0	71.40	39,800.1	129.64
2008	2	46,113.9	45.51	0.0	0.00
2009	1	47,373.4	36.00	44,841.1	159.41
2009	2	35,325.5	99.08	1,369.7	5.36
2010	1	55,153.6	38.00	54,085.9	159.59
2010	2	33,753.6	32.96	0.1	0.00
2011	1	64,296.5	44.00	39,750.5	214.20
2011	2	34,239.8	64.28	5,844.4	0.00
2012	1	66,624.6	21.00	80,508.0	114.88
2012	2	34,239.8	0.00	5,844.4	0.00

Table 5. Fishery-independent indices of Pacific sardine relative abundance. Complete details regarding calculation of DEPM and TEP values can be found in Tables 6 and 7. In the SS model, indices had a lognormal error structure with units of standard error of $\log_e$(index). Variance of the observations was only available as a CV, so the S.E. was approximated as sqrt($\log_e(1+CV^2)$).

Model year-sem	DEPM	S.E. ln(index)	TEP	S.E. ln(index)	Aerial	S.E. ln(index)	Acoustic	S.E. ln(index)
1993-2	69,065	0.29	---	---	---	---	---	---
1995-2	---	---	97,923	0.40	---	---	---	---
1996-2	---	---	482,246	0.21	---	---	---	---
1997-2	---	---	369,775	0.33	---	---	---	---
1998-2	---	---	332,177	0.34	---	---	---	---
1999-2	---	---	1,252,539	0.39	---	---	---	---
2000-2	---	---	931,377	0.38	---	---	---	---
2001-2	---	---	236,660	0.17	---	---	---	---
2002-2	---	---	556,177	0.18	---	---	---	---
2003-2	145,274	0.23	---	---	---	---	---	---
2004-2	459,943	0.55	---	---	---	---	---	---
2005-2	---	---	651,994	0.25	---	---	1,947,063	0.30
2006-2	198,404	0.30	---	---	---	---	---	---
2007-2	66,395	0.27	---	---	---	---	751,075	0.09
2008-1	---	---	---	---	---	---	801,000	0.30
2008-2	99,162	0.24	---	---	---	---	---	---
2009-1			---	---	1,236,911	0.90	---	---
2009-2	58,447	0.40	---	---			357,006	0.41
2010-1			---	---	173,390	0.40	---	---
2010-2	219,386	0.27	---	---			493,672	0.30
2011-1	---	---	---	---	201,888	0.29	---	---
2011-2	113,178	0.27	---	---	---	---	469,480	0.28
2012-1	---	---	---	---	696,251	0.37	340,831	0.33

Table 6. The spawning biomass related parameters: daily egg production/0.05m^2 (P_0),daily mortality rate (z), survey area (km^2), two daily specific fecundities: (RSF/W), and (SF/W); s. biomass, female spawning biomass, total egg production (TEP) and sea surface temperature for 1986, 1987, 1994, 2004, 2005 and 2007-2012.

Calendar year	Season	Region	[1]P_0/0.05m^2 (cv)	Z (CV)	[2]RSF/W based on S_1	[3]RSF/W based on S_{12}	[3]FS/W based on S_{12}	[4]Area (km^2)	[5]S. biomass (cv)	S. biomass females (cv)	S. biomass females (Sum of R1andR2) (cv)	Total egg production (TEP)	Mean temper-ature (°C) for positive eggs	Mean temper-ature (°C) from Calvet
1986(Aug)	1986	[6]S	1.48(1)	1.59(0.5)	38.31	43.96	72.84	6478	4362 (1.00)	2632 (1)		9587.44		
		N	0.32(0.25)		8.9	13.34	23.89	5333	2558 (0.33)	1429 (0.28)		1706.56		
		whole	0.95(0.84)		23.61	29.89	49.97	11811	7767 (0.87)	4491 (0.86)	4061 (0.66)	11220.45	18.7	18.5
1987 (Jul)	1987	1	1.11(0.51)	0.66(0.4)	38.79	37.86	57.05	22259	13050 (0.58)	8661 (0.56)		24707.49		
		2	0					15443	0	0		0		
		whole	0.66(0.51)		38.79	37.86	57.05	37702	13143 (0.58)	8723 (0.56)	8661 (0.56)	25637.36	18.9	18.1
1994	1993	1	0.42(0.21)	0.12(0.91)	11.57	11.42	21.27	174880	128664 (0.30)	69065 (0.30)		73449.6		
		2	0(0)	-				205295	0	0		0		
		whole	0.193(0.21)		11.57	11.42	21.27	380175	128531 (0.31)	68994 (0.30)	69065 (0.30)	73373.775	14.3	14.7
2004	2003	1	3.92(0.23)	0.25(0.04)	27.03	26.2	42.37	68204	204118 (0.27)	126209 (0.26)		267359.68		
		2	0.16(0.43)		-	-	-	252416	30833 (0.45)	19065 (0.44)		40386.56		
		whole	0.96(0.24)		27.03	26.2	42.37	320620	234958 (0.28)	145297 (0.27)	145274 (0.23)	307795.2	13.4	13.7
2005	2004	1	8.14(0.4)	0.58(0.2)	31.49	25.6	46.52	46203	293863 (0.45)	161685 (0.42)		376092.42		
		2	0.53(0.69)		3.76	3.2	7.37	207417	686168 (0.86)	298258 (0.89)		109931.01		
		whole	1.92(0.42)		15.67	12.89	27.11	253620	755657 (0.52)	359209 (0.50)	459943 (0.60)	486950.4	14.21	14.1
2007	2006	1	1.32(0.2)	0.13(0.36)	12.06	13.37	27.54	142403	281128 (0.42)	136485 (0.36)		187971.96		
		2	0.56(0.46)		24.48	23.41	38.94	213756	102998 (0.67)	61919 (0.62)		119703.36		
		whole	0.86(0.26)		15.68	16.17	31.52	356159	380601 (0.39)	195279 (0.36)	198404 (0.31)	306296.74	13.7	13.6
2008	2007	1	1.45(0.18)	0.13(0.29)	57.4	53.89	68.54	53514	29798 (0.20)	22642 (0.19)		77595.3		
		2	0.202(0.32)		13.84	12.6	22.57	244435	78359 (0.45)	43753 (0.42)		49375.87		
		whole	0.43(0.21)		21.82	20.31	32.2	297949	126148 (0.40)	79576 (0.35)	66395 (0.28)	128118.07	13.1	13.1
2009	2008	1	1.76(0.22)	0.25(0.19)	19.50	20.37	36.12	74966	129520 (0.31)	73048 (0.29)		131940.16		
		2	0.15(0.27)		14.25	14.34	22.97	199929	41816 (0.38)	26114 (0.38)		29989.35		
		whole	0.59(0.22)		17.01	17.53	29.11	274895	185084 (0.28)	111444 (0.27)	99162 (0.24)	162188.05	13.6	13.5
2010	2009	1	1.70(0.22)	0.33(0.23)	21.08	24.02	51.56	27462	38875 (0.44)	18111 (0.39)		46685.4		
		2	0.22(0.42)		14.55	16.20	26.65	244311	66345 (0.58)	40336 (0.58)		53748.42		
		whole	0.36(0.29)		16.08	18.07	31.49	271773	108280 (0.46)	62131 (0.46)	58447 (0.42)	97838.28	13.7	13.9
2011	2010	1	5.57(0.24)	0.51(0.14)	19.03	24.26	41.16	41878	192332 (0.31)	113340 (0.30)		233260.5		
		2	0.487(0.33)		11.40	14.67	25.04	272603	181016 (0.48)	106046 (0.49)		132757.7		
		whole	1.16(0.26)		14.85	19.04	32.40	314481	383286 (0.32)	225155 (0.32)	219386 (0.28)	364798.0	13.5	13.6
2012	2011	1	5.28 (0.27)	0.66(0.11)	17.76	19.25	42.17	32322	177289 (0.37)	80930 (0.33)		170660.16		
		2	0.24 (0.27)		15.34	14.67	35.52	238669	78102 (0.60)	32248 (0.46)		57280.56		
		whole	0.84 (0.27)		16.14	16.14	37.65	270991	282110 (0.43)	120902 (0.36)	113178 (0.27)	227632.44	13.57	13.3

1: P_0 for the whole is the weighted average with area as the weight.

2. The estimates of adult parameters for the whole area were unstratified and RSF/W was based on original S_1 data of day-1 spawning females. For 2004, 27.03 was based on sex ratio= 0.618 while past biomass used RSF/W of 21.86 based on sex ratio = 0.5.(Lo et al. 2008)

3. The estimates of adult parameters for the whole area were unstratified. Batch fecundity was estimated with error term. For 1987 and 1994, estimates were based on S_1 using data of day-1 spawning females. For 2004, all trawls were in region 1 and value was applied to region 2,

4. Region 1, since 1997, is the area where the eggs/min from CUFES $\geq$1 and prior to 1997, is the area where the eggs/0.05m^2 >0 from CalVET tows

5: For the spawning biomasses, the estimates for the whole area uses unstratified adult parameters

6. Within southern and northern area, the survey area was stratified as Region 1 (eggs/0.05m2>0 with embedded zero) and Region 2 (zero eggs)

Table 7. Pacific sardine female adult parameters for surveys conducted in the standard daily egg production method (DEPM) sampling area off California (1994 includes females from off Mexico).

		1994	1997	2001	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012
Midpoint date of trawl survey		22-Apr	25-Mar	1-May	21-Apr	25-Apr	13-Apr	2-May	24-Apr	16-Apr	27-Apr	20-Apr	8-Apr	19-Apr
Beginning and ending dates of positive collections		04/15-05/07	03/12-04/06	05/01-05/02	04/18-04/23	04/22-04/27	03/31-04/24	05/01-05/07	04/19-04/30	04/13-04/27	04/17-05/06	04/12-04/27	03/23-04/25	04/08-04/28
N collections with mature females		37	4	2	6	16	14	7	14	12	29	17	30	16
N collection within Region 1		19	4	2	6	16	6	2	8	4	15	3	14	8
Average surface temperature (°C) at collection locations		14.36	14.28	12.95	12.75	13.59	14.18	14.43	13.6	12.4	12.93	13.62	13.12	13.18
Female fraction by weight	**R**	0.538	0.592	0.677	0.385	0.618	0.469	0.451	0.515	0.631	0.602	0.574	0.587	0.429
Average mature female weight (grams): with ovary	W_f	82.53	127.76	79.08	159.25	166.99	65.34	67.41	81.62	102.21	112.40	129.51	127.59	141.36
without ovary	W_{of}	79.33	119.64	75.17	147.86	156.29	63.11	64.32	77.93	97.67	106.93	121.34	119.38	131.58
Average batch fecundity[a] (mature females, oocytes)	**F**	24283	42002	22456	54403	55711	17662	18474	21760	29802	29790	39304	38369	38681
Relative batch fecundity (oocytes/g)		294	329	284	342	334	270	274	267	292	265	303	301	274
N mature females analyzed		583	77	9	23	290	175	86	203	187	467	313	244	126
N active mature females		327	77	9	23	290	148	72	187	177	463	310	244	125
Spawning fraction of mature females[b]	**S**	0.074	0.133	0.111	0.174	0.131	0.124	0.0698	0.114	0.1186	0.1098	0.1038	0.1078	0.1376
Spawning fraction of active females[c]	S_a	0.131	0.133	0.111	0.174	0.131	0.155	0.083	0.134	0.1187	0.1108	0.1048	0.1078	0.1388
Daily specific fecundity	$\frac{RSF}{W}$	11.7	25.94	21.3	22.91	27.04	15.67	8.62	15.68	21.82	17.53	18.07	19.04	16.14

[a] 1994-2001 estimates were calculated using F_b = -10858 + 439.53 W_{of} (Macewicz et al. 1996), 2004 used F_b = 356.46W_{of}. (Lo and Macewicz 2004), 2005 used F_b = -6085 + 376.28 W_{of} (Lo and Macewicz 2006), 2006 used F_b = -396 + 293.39 W_{of} (Lo et al. 2007a); 2007 used F_b = 279.23W_{of} (Lo et al. 2007b), 2008 used F_b = 305.14W_{of} (Lo et al. 2008), 2009 used F_b = -4598 + 326.78W_{of} + e (Lo et al. 2009), 2010 used F_b = 5136 + 287.37W_{of} + e (Lo et al. 2010), and 2011 used F_b = -2252 + 347.6W_{of} + e (Lo et al. 2009).

[b] Mature females include females that are active and those that are postbreeding (incapable of further spawning this season). S_1 was used for years prior to 2009 and S_{12} was used staring 2009.

[c] Active mature females are capable of spawning and have ovaries containing oocytes with yolk or postovulatory follicles less than 60 hours old

Table 8a. Likelihood components and derived quantities for the final 2011 model (X5) and preliminary update model X6a with stepwise addition of new data.

NEW DATA / PROCESS:	**X5_final**	**+Catch**	**+MexCal_S1_len**	**+MexCal_S2_len**	**+PacNW_len**	**+All Fshy Lengths**	**+All Fshy CondAL**	**+DEPM**	**+ATM**	**X6a**
Revised & New Catch										
MexCal_S1 Length Comp										
MexCal_S2 Length Comp										
PacNW Length Comp										
New Fishery CondAL Comps										
DEPM 2012 Estimate										
ATM 2012 Estimate & Comps										
Est RecDevs to End Year -2										
Est RecDevs to End Year -1										
Use 'X5_final' Var. Adj. & SigR										
Retune model (Adj. Vars. & SigR)										
LIKELIHOOD COMPONENT:	**X5_final**	**+Catch**	**+MexCal_S1_len**	**+MexCal_S2_len**	**+PacNW_len**	**+All Fshy Lengths**	**+All Fshy CondAL**	**+DEPM**	**+ATM**	**X6a**
DEPM Survey	0.37279	0.62202	1.21319	0.96228	0.63478	1.21570	1.34967	1.01326	1.23637	1.77398
TEP Survey	-0.02801	0.17266	-0.04059	-0.04490	0.13102	-0.01807	-0.04173	-0.04016	0.00329	-0.18193
Aerial Survey	0.03256	-0.00545	0.22167	0.11458	0.05910	0.22419	0.22305	0.22211	0.23258	0.46933
ATM Survey	-1.68802	-1.80720	0.30153	-0.26164	-1.45994	0.23750	0.36707	0.35975	0.74166	0.37066
Survey Subtotal	**-1.31068**	**-1.01796**	**1.69580**	**0.77033**	**-0.63505**	**1.65931**	**1.89806**	**1.55497**	**2.21390**	**2.43203**
MexCal_S1 Lengths	399.06	403.55	425.68	398.13	399.98	423.94	427.70	427.77	425.60	399.63
MexCal_S2 Lengths	318.83	325.10	324.52	352.04	322.62	346.83	349.83	349.82	351.81	333.71
PacNW Lengths	233.86	220.46	221.66	219.09	242.19	236.21	234.71	234.70	231.71	227.98
Aerial Lengths	19.14	17.49	18.04	17.64	18.04	17.88	17.46	17.46	17.01	19.00
ATM Lengths	89.66	88.58	95.54	90.31	88.09	95.47	96.94	96.95	140.16	178.17
Lengths Subtotal	**1060.54**	**1055.17**	**1085.43**	**1077.21**	**1070.92**	**1120.33**	**1126.65**	**1126.70**	**1166.29**	**1158.47**
MexCal_S1 CondAL	267.06	268.37	270.13	268.25	269.19	270.37	281.99	281.99	281.93	279.12
MexCal_S2 CondAL	231.06	230.65	233.56	232.48	232.44	235.97	241.26	241.27	240.50	236.30
PacNW CondAL	182.41	184.82	191.81	189.11	186.36	191.72	204.24	204.20	207.53	205.05
ATM CondAL	32.17	29.57	29.20	29.01	29.34	28.97	28.82	28.82	51.11	50.43
CondAL Subtotal	**712.70**	**713.41**	**724.70**	**718.85**	**717.32**	**727.04**	**756.30**	**756.28**	**781.07**	**770.90**
Catch	2.98E-10	2.50E-08	2.50E-08	2.50E-08	2.50E-08	2.50E-08	2.50E-08	2.50E-08	2.50E-08	2.50E-08
Recruitment	11.0596	11.6086	16.1047	13.1482	11.5448	15.9554	16.5304	16.5076	17.5333	18.5644
Parm_softbounds	0.00990076	0.00937793	0.00855647	0.00910637	0.00925356	0.00855483	0.00844848	0.00844603	0.00854344	0.0085694
TOTAL	**1783.00**	**1779.18**	**1827.94**	**1809.99**	**1799.16**	**1864.99**	**1901.39**	**1901.06**	**1967.11**	**1950.37**
DERIVED QUANTITIES:	**X5_final**	**+Catch**	**+MexCal_S1_len**	**+MexCal_S2_len**	**+PacNW_len**	**+All Fshy Lengths**	**+All Fshy CondAL**	**+DEPM**	**+ATM**	**X6a**
Ln(R0)	15.6444	15.6329	15.6277	15.6524	15.6245	15.6051	15.6314	15.6313	15.6293	15.6029
SSB-Virgin	968,738	943,048	927,914	958,594	930,449	905,585	926,223	926,127	928,343	899,121
Stock Biomass -1999 peak	1,448,190	1,442,590	1,267,130	1,348,920	1,380,660	1,236,690	1,245,020	1,246,210	1,245,960	1,137,660
Stock Biomass - 2011	988,385	715,305	1,325,230	1,035,190	867,696	1,219,090	1,266,840	1,264,640	1,275,550	1,261,710
Stock Biomass - 2012		786,668	1,170,560	966,134	909,272	1,052,190	1,100,780	1,098,840	1,075,510	1,048,210

Table 8b. Likelihood components and derived quantities for the final 2011 model (X5) and preliminary update model X6b with stepwise addition of new data.

NEW DATA / PROCESS:	X5_final	X5b	+Catch	+MexCal_S1_len	+MexCal_S2_len	+PacNW_len	+All Fshy Lengths	+All Fshy CondAL	+DEPM	+ATM	X6b
Revised & New Catch											
MexCal_S1 Length Comp											
MexCal_S2 Length Comp											
PacNW Length Comp											
New Fishery CondAL Comps											
DEPM 2012 Estimate											
ATM 2012 Estimate & Comps											
Est RecDevs to End Year -2											
Est RecDevs to End Year -1											
Use 'X5_final' Var. Adj. & SigR											
Retune model (var. adj. & SigR)											
LIKELIHOOD COMPONENT:	**X5_final**	**X5b**	**+Catch**	**+MexCal_S1_len**	**+MexCal_S2_len**	**+PacNW_len**	**+All Fshy Lengths**	**+All Fshy CondAL**	**+DEPM**	**+ATM**	**X6b**
DEPM Survey	0.37279	0.35261	1.21665	0.74850	1.07435	0.59203	0.87632	0.91448	0.47895	0.60990	0.75278
TEP Survey	-0.02801	0.07469	0.72922	0.05487	-0.68357	0.18015	0.04310	0.03969	0.03989	0.11112	-0.03133
Aerial Survey	0.03256	-0.00718	-0.12661	0.06035	0.09972	0.03494	0.12927	0.11097	0.11082	0.10745	0.19856
ATM Survey	-1.68802	-1.92198	1.22180	-1.04750	2.97970	-1.66549	-0.61471	-0.69126	-0.69256	-1.62523	-1.69143
Survey Subtotal	**-1.31068**	**-1.50186**	**3.04107**	**-0.18377**	**3.47020**	**-0.85837**	**0.43397**	**0.37388**	**-0.06290**	**-0.79675**	**-0.77142**
MexCal_S1 Lengths	399.06	393.62	403.98	427.02	431.16	399.95	425.15	428.97	428.98	427.23	399.74
MexCal_S2 Lengths	318.83	324.18	321.48	326.66	353.99	322.44	348.95	352.45	352.45	354.80	329.39
PacNW Lengths	233.86	241.11	217.15	219.51	223.19	241.50	236.42	235.08	235.08	232.86	219.17
Aerial Lengths	19.14	19.21	16.54	17.56	21.10	17.95	17.57	17.10	17.10	16.64	18.95
ATM Lengths	89.66	96.79	89.11	89.47	96.64	87.88	95.89	97.45	97.45	138.44	181.47
Lengths Subtotal	**1060.54**	**1074.90**	**1048.25**	**1080.22**	**1126.08**	**1069.72**	**1123.98**	**1131.05**	**1131.06**	**1169.96**	**1148.72**
MexCal_S1 CondAL	267.06	267.17	270.17	268.11	267.22	269.20	269.75	281.33	281.33	281.31	279.23
MexCal_S2 CondAL	231.06	231.63	233.00	232.13	230.96	232.49	234.66	238.99	238.99	238.08	234.47
PacNW CondAL	182.41	181.34	182.35	187.53	174.49	185.63	188.47	199.66	199.65	202.22	199.18
ATM CondAL	32.17	32.31	29.93	29.29	28.85	29.39	29.09	28.99	28.99	52.24	51.93
CondAL Subtotal	**712.70**	**712.44**	**715.45**	**717.06**	**701.52**	**716.71**	**721.96**	**748.96**	**748.96**	**773.85**	**764.81**
Catch	2.98E-10	2.98E-10	3.26E-02	2.50E-08	2.50E-08	2.50E-08	2.50E-08	2.50E-08	2.50E-08	2.50E-08	2.50E-08
Recruitment	11.0596	10.6768	15.1873	15.8437	30.7454	11.5568	14.0284	13.9987	13.9996	14.6745	14.5614
Parm_softbounds	0.00990076	0.00993435	0.0123514	0.0091628	0.0245871	0.00943035	0.00836934	0.00821469	0.00821439	0.00886692	0.00822824
TOTAL	**1783.00**	**1796.52**	**1781.98**	**1812.95**	**1861.84**	**1797.14**	**1860.41**	**1894.39**	**1893.96**	**1957.70**	**1927.33**
DERIVED QUANTITIES:	**X5_final**	**X5b**	**+Catch**	**+MexCal_S1_len**	**+MexCal_S2_len**	**+PacNW_len**	**+All Fshy Lengths**	**+All Fshy CondAL**	**+DEPM**	**+ATM**	**X6b**
Ln(R0)	15.6444	15.6091	15.4943	15.6339	15.2715	15.6017	15.6097	15.6283	15.6283	15.651	15.6411
SSB-Virgin	968,738	935,311	820,183	943,866	627,112	910,161	913,445	928,588	928,550	955,767	944,044
Stock Biomass -1999 peak	1,448,190	1,447,670	1,306,690	1,412,360	956,403	1,396,590	1,322,590	1,347,880	1,347,950	1,390,090	1,335,880
Stock Biomass - 2011	988,385	795,841	267,982	886,071	562,574	792,391	956,506	928,411	927,958	927,077	873,786
Stock Biomass - 2012	---		164,565	664,095	429,559	694,353	751,224	716,673	716,226	690,282	635,732

Table 9. Parameters and asymptotic standard deviations for models X6e and X6h.

					X6e (Proposed Update)		X6h (Strict Update)	
Parameter	**Phase**	**Min**	**Max**	**Initial Value**	**Final Value**	**Std Dev**	**Final Value**	**Std Dev**
NatM_p_1_Fem_GP_1	-3	0.3	0.7	0.4000	0.4000	_	0.4000	_
L_at_Amin_Fem_GP_1	3	3	15	10.0000	10.9665	0.1858	11.1034	0.1818
L_at_Amax_Fem_GP_1	3	20	30	25.0000	23.2048	0.1575	23.3654	0.1807
VonBert_K_Fem_GP_1	3	0.05	0.99	0.4000	0.4535	0.0207	0.4275	0.0208
CV_young_Fem_GP_1	3	0.05	0.3	0.1400	0.1591	0.0064	0.1542	0.0062
CV_old_Fem_GP_1	3	0.01	0.1	0.0500	0.0533	0.0025	0.0528	0.0027
Wtlen_1_Fem	-3	-3	3	0.0000	0.0000	_	0.0000	_
Wtlen_2_Fem	-3	-3	5	2.9483	2.9483	_	2.9483	_
Mat50%_Fem	-3	9	19	15.8800	15.8800	_	15.8800	_
Mat_slope_Fem	-3	-20	3	-0.9046	-0.9046	_	-0.9046	_
Eggs/kg_inter_Fem	-3	0	10	1.0000	1.0000	_	1.0000	_
Eggs/kg_slope_wt_Fem	-3	-1	5	0.0000	0.0000	_	0.0000	_
SR_LN(R0)	1	3	25	16.0000	15.6435	0.1235	15.6047	0.1614
SR_Ricker	6	0.2	4	2.5000	2.7851	0.6822	3.8917	0.6127
SR_sigmaR	-3	0	2	0.8595	0.7270	_	0.8900	_
SR_R1_offset	2	-15	15	0.0000	-1.2527	0.2345	-1.6447	0.2781
Early_InitAge_6	_	_	_	_	-0.8059	0.5421	-0.9150	0.6420
Early_InitAge_5	_	_	_	_	-0.8178	0.5304	-0.8885	0.6311
Early_InitAge_4	_	_	_	_	-0.7529	0.5339	-0.8000	0.6424
Early_InitAge_3	_	_	_	_	0.2814	0.3889	0.5584	0.4096
Early_InitAge_2	_	_	_	_	0.9744	0.2711	1.2557	0.2994
Early_InitAge_1	_	_	_	_	1.6596	0.2245	2.0101	0.2614
Main_RecrDev_1993	_	_	_	_	0.0677	0.3777	-0.6822	0.3283
Main_RecrDev_1994	_	_	_	_	-0.5934	0.2749	-1.2356	0.2290
Main_RecrDev_1995	_	_	_	_	-0.0763	0.1924	-0.6186	0.1644
Main_RecrDev_1996	_	_	_	_	0.7931	0.1563	0.3176	0.1427
Main_RecrDev_1997	_	_	_	_	0.7077	0.1476	0.2265	0.1219
Main_RecrDev_1998	_	_	_	_	-0.4282	0.1695	-0.7850	0.1789
Main_RecrDev_1999	_	_	_	_	-0.2932	0.2456	-0.4841	0.2760
Main_RecrDev_2000	_	_	_	_	0.2425	0.2011	0.0344	0.2252
Main_RecrDev_2001	_	_	_	_	-1.4505	0.1896	-1.8015	0.1913
Main_RecrDev_2002	_	_	_	_	0.9937	0.1734	0.5621	0.1591
Main_RecrDev_2003	_	_	_	_	-0.2141	0.2824	-0.6974	0.2815
Main_RecrDev_2004	_	_	_	_	0.7746	0.1432	0.5619	0.1637
Main_RecrDev_2005	_	_	_	_	0.0852	0.1342	0.1905	0.1482
Main_RecrDev_2006	_	_	_	_	0.7270	0.2499	1.2794	0.2113
Main_RecrDev_2007	_	_	_	_	0.1371	0.3220	0.9953	0.2649
Main_RecrDev_2008	_	_	_	_	0.7787	0.2952	1.8684	0.2117
Main_RecrDev_2009	_	_	_	_	-0.8785	0.2954	0.2684	0.2363
Main_RecrDev_2010	_	_	_	_	-1.3731	0.3487	_	_
Q_base_4_DEPM	5	-3	3	-1.3900	-1.7934	0.2763	-1.8314	0.3230
Q_base_5_TEP	5	-3	3	-0.6900	-0.6182	0.2554	-0.4305	0.2718
Q_base_6_TEP_full	5	-3	3	-0.6900	-0.6896	4921.5600	-0.6897	4921.5300
Q_base_7_Aerial	5	-3	3	0.0000	-0.0811	0.4355	-0.3482	0.4689
Q_base_8_Acoustic	-5	-3	3	0.0000	0.0000	_	0.0000	_

Table 9 (cont'd). Parameters and asymptotic standard deviations for models X6e and X6h.

					X6e (Proposed Update)		X6h (Strict Update)	
Parameter	Phase	Min	Max	Initial Value	Final Value	Std Dev	Final Value	Std Dev
SizeSel_1P_1_MexCal_S1	4	10	28	18.0000	18.8749	0.3525	19.0318	0.3678
SizeSel_1P_2_MexCal_S1	4	-5	3	3.0000	-3.2153	1.5193	-3.2169	1.5618
SizeSel_1P_3_MexCal_S1	4	-1	9	2.5000	2.3622	0.1459	2.3816	0.1435
SizeSel_1P_4_MexCal_S1	4	-1	9	4.0000	1.1244	0.4762	1.0574	0.5039
SizeSel_1P_5_MexCal_S1	-4	-10	10	-10.0000	-10.0000	_	-10.0000	_
SizeSel_1P_6_MexCal_S1	4	-10	10	10.0000	-4.9898	4.0663	-4.7099	3.5826
SizeSel_1P_1_MexCal_S1_BLK1repl_1999	4	10	28	18.0000	16.7351	0.1344	16.8495	0.1342
SizeSel_1P_2_MexCal_S1_BLK1repl_1999	-4	-5	3	-5.0000	-5.0000	_	-5.0000	_
SizeSel_1P_3_MexCal_S1_BLK1repl_1999	4	-1	9	2.5000	2.0874	0.0809	2.1208	0.0777
SizeSel_1P_4_MexCal_S1_BLK1repl_1999	4	-1	9	4.0000	1.6027	0.1328	1.6058	0.1416
SizeSel_1P_5_MexCal_S1_BLK1repl_1999	-4	-10	10	-10.0000	-10.0000	_	-10.0000	_
SizeSel_1P_6_MexCal_S1_BLK1repl_1999	4	-10	10	10.0000	-3.5588	0.3801	-3.3025	0.3905
SizeSel_2P_1_MexCal_S2	4	10	28	18.0000	16.3789	0.2361	16.4983	0.2500
SizeSel_2P_2_MexCal_S2	-4	-5	3	-4.9000	-4.9000	_	-4.9000	_
SizeSel_2P_3_MexCal_S2	4	-1	9	2.5000	1.7717	0.1511	1.8174	0.1516
SizeSel_2P_4_MexCal_S2	4	-1	9	4.0000	2.3041	0.2638	2.3318	0.2991
SizeSel_2P_5_MexCal_S2	-4	-10	10	-10.0000	-10.0000	_	-10.0000	_
SizeSel_2P_6_MexCal_S2	4	-10	10	10.0000	-2.3217	0.6494	-2.0878	0.6879
SizeSel_2P_1_MexCal_S2_BLK1repl_1999	4	10	28	18.0000	14.9456	0.1437	15.0525	0.1514
SizeSel_2P_2_MexCal_S2_BLK1repl_1999	-4	-5	3	-5.0000	-5.0000	_	-5.0000	_
SizeSel_2P_3_MexCal_S2_BLK1repl_1999	4	-1	9	2.5000	1.5236	0.1202	1.5845	0.1224
SizeSel_2P_4_MexCal_S2_BLK1repl_1999	4	-1	9	4.0000	2.2826	0.1212	2.3061	0.1367
SizeSel_2P_5_MexCal_S2_BLK1repl_1999	-4	-10	10	-10.0000	-10.0000	_	-10.0000	_
SizeSel_2P_6_MexCal_S2_BLK1repl_1999	4	-10	10	10.0000	-3.1325	0.3077	-2.8166	0.3215
SizeSel_3P_1_PacNW	4	10	28	18.0000	19.0048	0.2102	19.3382	0.2336
SizeSel_3P_2_PacNW	4	1	16	4.0000	2.4379	0.2262	2.5497	0.2224
SizeSel_7P_1_Aerial	4	10	28	18.0000	20.6811	0.3873	20.8118	0.3725
SizeSel_7P_2_Aerial	4	-5	3	3.0000	-4.9261	2.2396	-4.9028	2.8981
SizeSel_7P_3_Aerial	4	-1	9	2.5000	0.6824	0.4689	0.7251	0.4296
SizeSel_7P_4_Aerial	4	-1	9	4.0000	0.6204	0.7442	0.5587	0.7939
SizeSel_7P_5_Aerial	-4	-10	10	-10.0000	-10.0000	_	-10.0000	_
SizeSel_7P_6_Aerial	4	-10	10	10.0000	-2.9012	1.7414	-2.7426	1.7536
SizeSel_8P_1_Acoustic	4	10	28	18.0000	22.6937	0.7723	23.6833	1.0244
SizeSel_8P_2_Acoustic	-4	-5	3	3.0000	3.0000	_	3.0000	_
SizeSel_8P_3_Acoustic	4	-1	9	2.5000	3.2065	0.2388	3.2783	0.2734
SizeSel_8P_4_Acoustic	-4	-1	9	4.0000	4.0000	_	4.0000	_
SizeSel_8P_5_Acoustic	-4	-10	10	-10.0000	-10.0000	_	-10.0000	_
SizeSel_8P_6_Acoustic	-4	-10	10	10.0000	10.0000	_	10.0000	_

Table 10. Likelihood components and variance adjustments for model X6e.

COMPONENT	-log(L)	MexCal_S1	MexCal_S2	PacNW	DEPM	TEP	Aerial	ATM
Catch	2.50E-08	1.81E-15	1.89E-15	2.50E-08	---	---	---	---
Survey	0.32633	---	---	---	0.76879	-0.03804	1.20566	-1.61008
Length comp	1154.580	399.335	329.262	219.131	---	---	25.245	181.611
Age comp	765.245	279.312	234.644	199.385	---	---	---	51.904
Recruitment	14.431							
Parm softbounds	0.00890186							
TOTAL	1934.59							

INPUT VARIANCE ADJUSTMENTS	MexCal_S1	MexCal_S2	PacNW	DEPM	TEP	Aerial	Acoustic
Index_extra_CV	0.0000	0.0000	0.0000	0.4045	0.3480	0.3495	0.2219
effN_mult_Lencomp	1.8610	1.7230	0.6028	1.0000	1.0000	1.0000	3.1979
effN_mult_Agecomp	0.8000	0.8000	0.2500	1.0000	1.0000	1.0000	0.2500

Table 11. Derived SSB (mt) and recruits (year-class abundance, billions of age-0 fish) for model X6e. SSB estimates are calculated at the beginning of Season 2 of each model year, e.g. the 2012 value is SSB January 2013. Recruits are age-0 fish calculated at the beginning of each model year (July).

Model year	SSB (mt)	SSB Std Dev	Year class abundance (billions)	Recruits Std Dev
Virgin	945,899	119,452	6.222	0.768
1993	388,245	78,100	1.778	0.485
1994	551,312	102,844	11.511	1.611
1995	711,856	125,516	5.047	0.820
1996	791,590	133,290	6.813	1.017
1997	763,310	129,065	14.289	1.845
1998	874,376	135,624	13.749	1.556
1999	1,039,870	148,053	3.647	0.525
2000	996,883	142,069	3.050	0.423
2001	810,236	120,420	5.669	0.607
2002	632,173	99,976	1.469	0.289
2003	488,308	83,379	22.302	2.359
2004	651,419	99,112	7.863	1.054
2005	837,694	122,477	17.443	1.894
2006	1,010,840	139,967	6.505	0.931
2007	1,047,250	146,350	8.956	1.232
2008	974,298	142,150	4.621	0.836
2009	857,618	134,408	10.123	1.687
2010	785,170	135,020	2.396	0.568
2011	667,141	133,182	1.655	0.494
2012	435,351	118,835	---	---

Table 12. Pacific sardine biomass and population numbers-at-age (1,000s) by model year and semester for model X6e.

		BIOMASS (mt)			POPULATION NUMBERS-AT-AGE (1,000s of fish)										
Model year	Sem	Total (0+)	Age 1+	SSB	0 (R)	1	2	3	4	5	6	7	8	9	10+
VIRG	1	1,197,300	1,135,810	---	6,221,630	4,170,480	2,795,560	1,873,920	1,256,130	842,006	564,414	378,338	253,607	169,998	345,648
VIRG	2	1,175,590	1,067,760	945,899	5,093,840	3,414,500	2,288,810	1,534,240	1,028,430	689,376	462,103	309,757	207,636	139,183	282,993
INIT	1	342,122	324,550	---	1,777,790	1,191,690	798,814	535,461	358,930	240,598	161,278	108,108	72,467	48,576	98,767
INIT	2	335,917	305,106	270,285	1,455,530	975,674	654,014	438,398	293,867	196,985	132,043	88,511	59,331	39,771	80,863
1993	1	585,273	507,320	---	7,886,320	5,286,360	1,847,640	640,715	157,944	102,650	72,044	108,108	72,467	48,576	98,767
1993	2	649,205	512,551	388,245	6,455,680	4,251,030	1,438,680	497,427	124,287	81,810	57,884	87,263	58,648	39,373	80,176
1994	1	805,540	691,760	---	11,510,900	5,248,140	3,376,470	1,146,740	400,403	100,634	66,431	47,068	71,009	47,743	97,356
1994	2	888,287	688,818	551,312	9,423,140	4,241,270	2,665,770	903,431	318,545	80,802	53,652	38,142	57,652	38,805	79,217
1995	1	965,141	915,256	---	5,046,750	7,574,760	3,210,230	2,036,240	707,862	253,413	64,758	43,155	30,737	46,506	95,298
1995	2	994,010	906,558	711,856	4,131,320	6,105,730	2,516,260	1,591,940	559,922	202,676	52,158	34,898	24,912	37,743	77,443
1996	1	1,044,380	977,035	---	6,812,670	3,346,110	4,773,170	1,977,700	1,270,090	450,735	163,866	42,260	28,306	20,219	93,540
1996	2	1,027,940	909,888	791,590	5,576,760	2,689,010	3,709,840	1,532,430	997,993	358,875	131,569	34,094	22,899	16,382	75,910
1997	1	1,140,160	998,922	---	14,289,100	4,522,420	2,113,290	2,929,390	1,226,160	804,884	290,551	106,721	27,682	18,602	75,016
1997	2	1,120,450	872,910	763,310	11,693,800	3,536,260	1,521,680	2,093,410	907,014	615,088	226,684	84,255	22,002	14,843	60,110
1998	1	1,269,970	1,134,060	---	13,749,400	9,421,060	2,702,300	1,172,180	1,649,030	724,087	494,240	182,726	68,027	17,780	60,630
1998	2	1,330,240	1,092,000	874,376	11,254,600	7,538,010	2,074,490	896,197	1,282,470	572,318	394,696	146,787	54,831	14,359	49,071
1999	1	1,369,360	1,333,310	---	3,647,320	9,044,510	5,698,750	1,582,850	701,665	1,019,690	458,479	317,349	118,245	44,215	51,206
1999	2	1,347,510	1,284,360	1,039,870	2,983,330	7,098,220	4,399,130	1,251,550	564,673	826,816	372,860	258,407	96,339	36,035	41,744
2000	1	1,276,440	1,246,290	---	3,049,780	2,327,520	5,233,750	3,393,010	996,149	454,997	669,278	302,381	209,743	78,230	63,183
2000	2	1,154,980	1,102,200	996,883	2,493,340	1,786,080	3,897,410	2,602,560	781,648	360,503	532,289	240,868	167,196	62,384	50,400
2001	1	1,088,790	1,032,760	---	5,669,170	1,930,530	1,295,020	2,974,520	2,058,460	626,875	290,613	430,000	194,769	135,263	91,278
2001	2	964,916	866,902	810,236	4,630,320	1,418,600	905,815	2,188,520	1,574,230	487,386	227,406	337,380	153,006	106,326	71,786
2002	1	883,049	868,532	---	1,468,610	3,515,830	985,731	674,357	1,709,410	1,252,740	390,544	182,737	271,460	123,192	143,475
2002	2	733,949	708,590	632,173	1,197,970	2,439,090	631,992	464,897	1,246,670	935,826	294,482	138,324	205,850	93,501	108,968
2003	1	854,528	634,081	---	22,302,200	900,511	1,658,940	465,507	362,030	992,159	750,821	237,048	111,515	166,083	163,453
2003	2	885,642	500,300	488,308	18,203,900	642,464	1,099,520	323,721	261,889	729,878	555,918	175,978	82,886	123,518	121,618
2004	1	1,054,710	976,986	---	7,863,300	14,440,400	490,752	863,086	258,919	210,968	589,511	449,486	142,356	67,066	198,388
2004	2	1,076,280	940,223	651,419	6,427,430	10,955,900	350,264	613,480	184,674	150,684	421,193	321,155	101,709	47,915	141,729
2005	1	1,280,190	1,107,780	---	17,442,500	5,156,830	8,581,710	279,366	495,472	149,873	122,507	342,680	261,377	82,791	154,393
2005	2	1,305,540	1,003,630	837,694	14,262,800	3,980,280	6,293,550	203,051	359,839	108,802	88,903	248,620	189,602	60,050	111,973
2006	1	1,430,280	1,365,980	---	6,504,580	11,411,200	3,099,710	5,008,030	164,028	292,401	88,605	72,465	202,733	154,640	140,329
2006	2	1,393,330	1,280,750	1,010,840	5,318,320	8,782,450	2,291,220	3,741,190	123,907	221,924	67,366	55,131	154,284	117,700	106,819
2007	1	1,445,390	1,356,860	---	8,956,330	4,233,280	6,764,060	1,811,910	3,013,730	100,538	180,554	54,868	44,926	125,757	183,043
2007	2	1,349,220	1,194,230	1,047,250	7,321,700	3,233,880	4,950,250	1,346,650	2,272,820	76,293	137,331	41,772	34,216	95,797	139,457
2008	1	1,332,440	1,286,760	---	4,621,300	5,757,390	2,425,720	3,856,420	1,077,220	1,837,000	61,901	111,602	33,970	27,836	191,446
2008	2	1,199,830	1,119,900	974,298	3,775,980	4,303,520	1,728,230	2,839,430	814,645	1,405,150	47,558	85,896	26,167	21,451	147,580
2009	1	1,206,240	1,106,180	---	10,123,300	2,953,330	3,190,680	1,337,480	2,264,330	657,306	1,138,730	38,609	69,792	21,270	137,452
2009	2	1,118,950	943,793	857,618	8,274,510	2,241,660	2,315,750	990,319	1,706,750	499,220	867,340	29,442	53,247	16,232	104,919
2010	1	1,100,900	1,077,220	---	2,395,640	6,518,600	1,687,770	1,806,380	791,770	1,377,710	404,413	703,646	23,901	43,241	98,420
2010	2	976,323	934,882	785,170	1,957,700	4,897,010	1,200,640	1,307,350	582,851	1,021,520	300,662	523,677	17,796	32,203	73,313
2011	1	914,513	898,150	---	1,655,440	1,542,840	3,690,930	937,893	1,047,110	471,421	829,238	244,432	426,031	14,483	85,900
2011	2	759,325	730,713	667,141	1,351,640	1,115,670	2,500,570	664,808	769,969	352,111	623,112	184,128	321,285	10,928	64,852
2012	1	758,096	659,539	---	9,970,800	1,032,190	784,295	1,868,970	518,380	610,221	280,735	498,016	147,327	257,218	60,705
2012	2	626,521	454,683	435,351	8,117,810	655,552	431,552	1,110,970	329,138	398,477	185,295	330,138	97,855	171,010	40,399

Table 13. Pacific sardine harvest control rules for the 2013 management year based on stock biomass estimated in model X6e.

Harvest Formula Parameters	Value			
BIOMASS (ages 1+, mt)	659,539			
P^* (probability of overfishing)	0.45	0.40	0.30	0.20
$BUFFER_{P^*}$ (Sigma=0.36)	0.95577	0.91283	0.82797	0.73861
F_{MSY} (stochastic, SST-independent)	0.18			
FRACTION	0.15			
CUTOFF (mt)	150,000			
DISTRIBUTION (U.S.)	0.87			

Amendment 13 Harvest Formulas	MT
OFL = BIOMASS * F_{MSY} * DISTRIBUTION	103,284
$ABC_{0.45}$ = BIOMASS * $BUFFER_{0.45}$ * F_{MSY} * DISTRIBUTION	98,716
$ABC_{0.40}$ = BIOMASS * $BUFFER_{0.40}$ * F_{MSY} * DISTRIBUTION	94,281
$ABC_{0.30}$ = BIOMASS * $BUFFER_{0.30}$ * F_{MSY} * DISTRIBUTION	85,515
$ABC_{0.20}$ = BIOMASS * $BUFFER_{0.20}$ * F_{MSY} * DISTRIBUTION	76,287
HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION	66,495

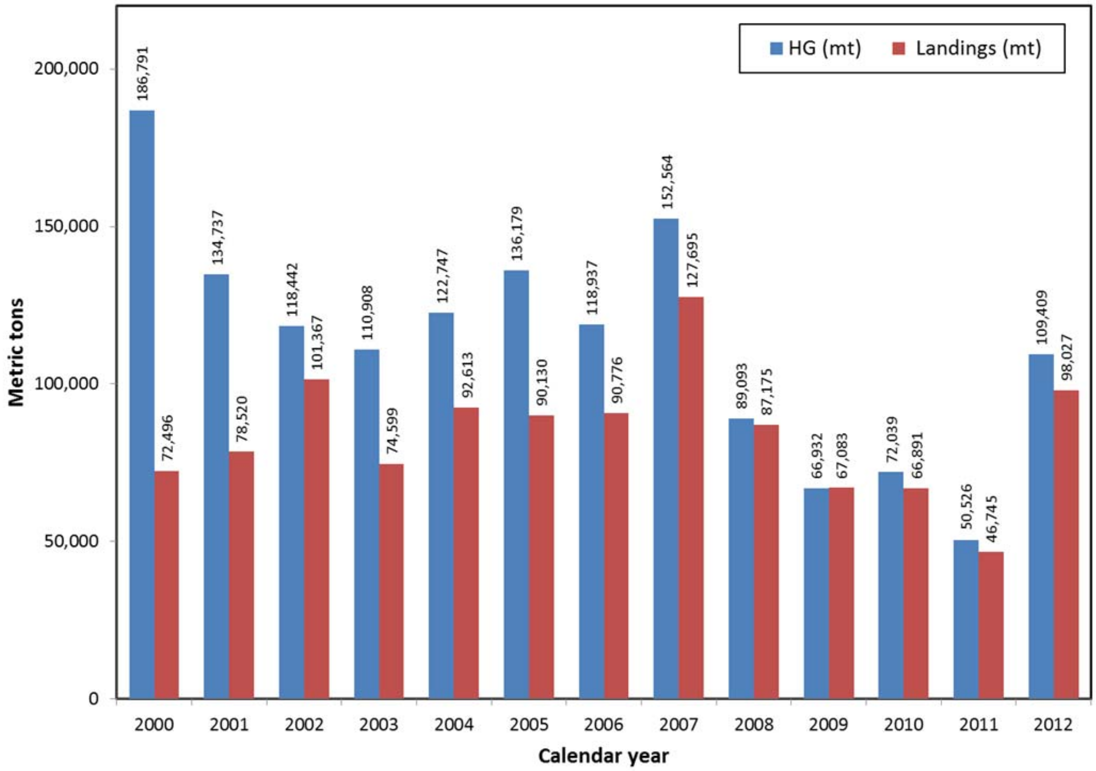

Figure 1a. U.S. harvest guidelines and landings since calendar year 2000.

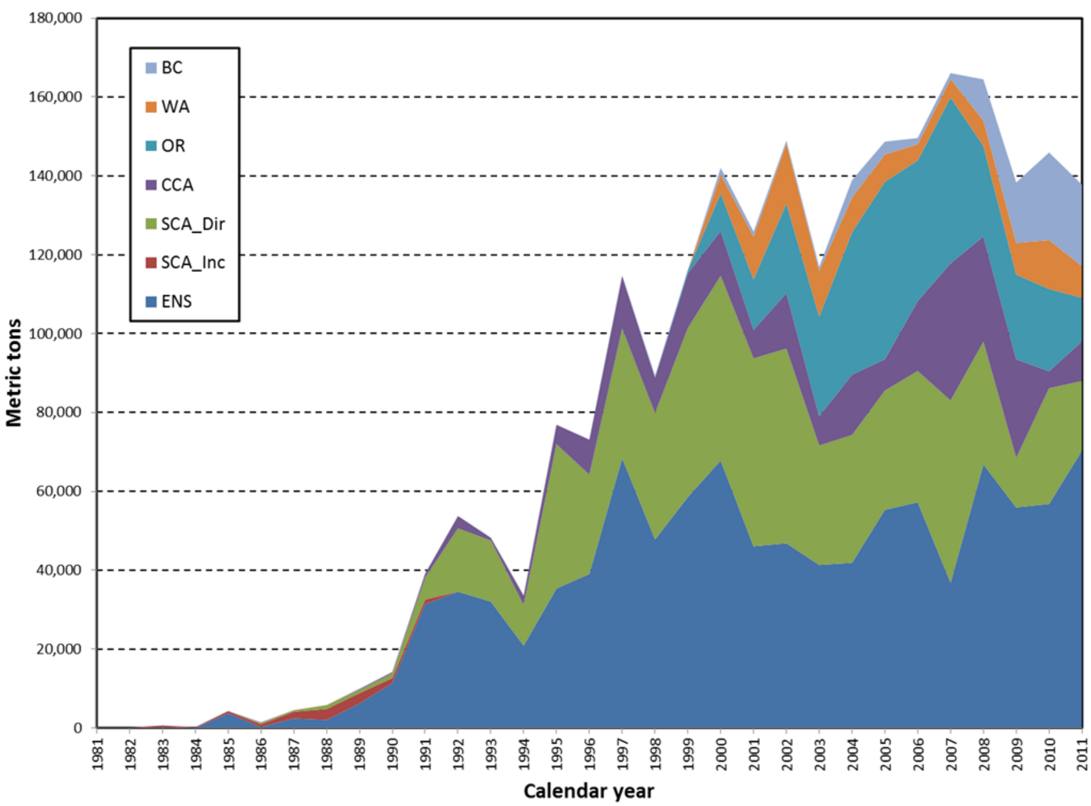

Figure 1b. Pacific sardine landings (mt) by major fishing region and calendar year.

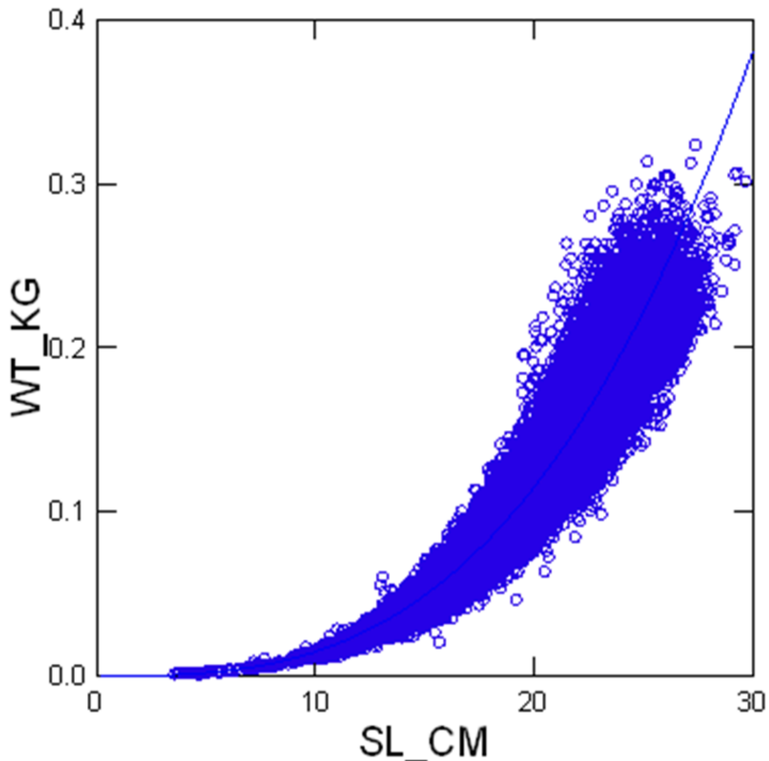

Figure 2a. Weight-at-length regression from fishery samples as applied in the base model, where: a = 1.68384E-05 and b = 2.94825 (n=155,814, R^2 = 0.928).

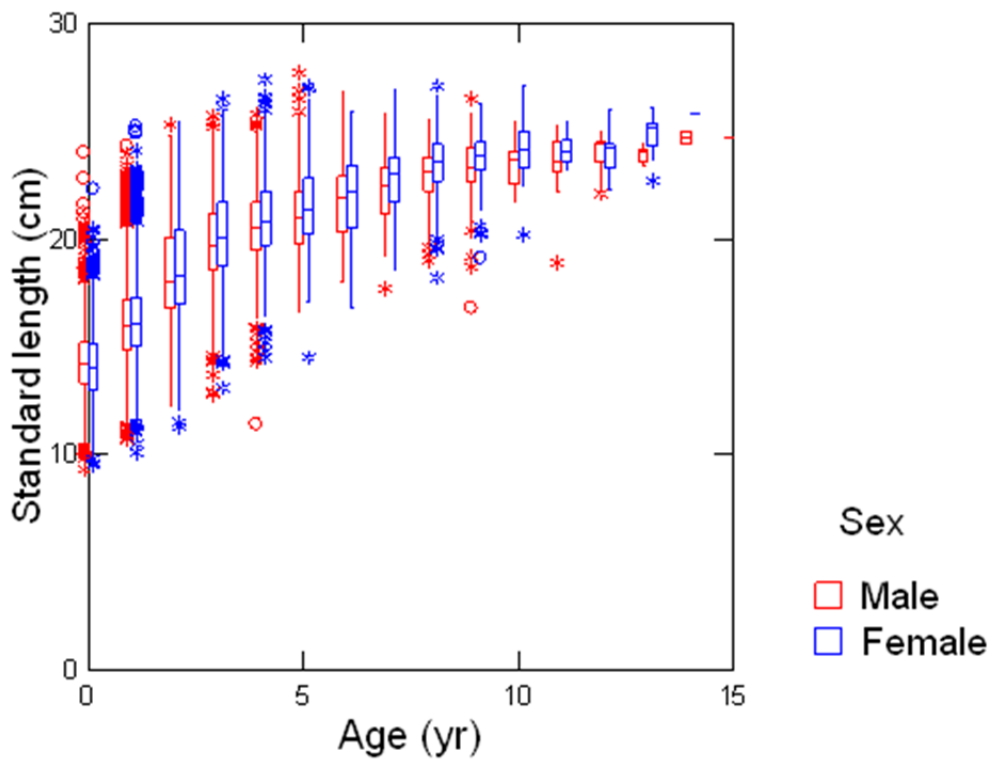

Figure 2b. Length-at-age by sex from fishery samples. Box symbols indicate median and quartile ranges for the raw data. The SS model is based on pooled sexes.

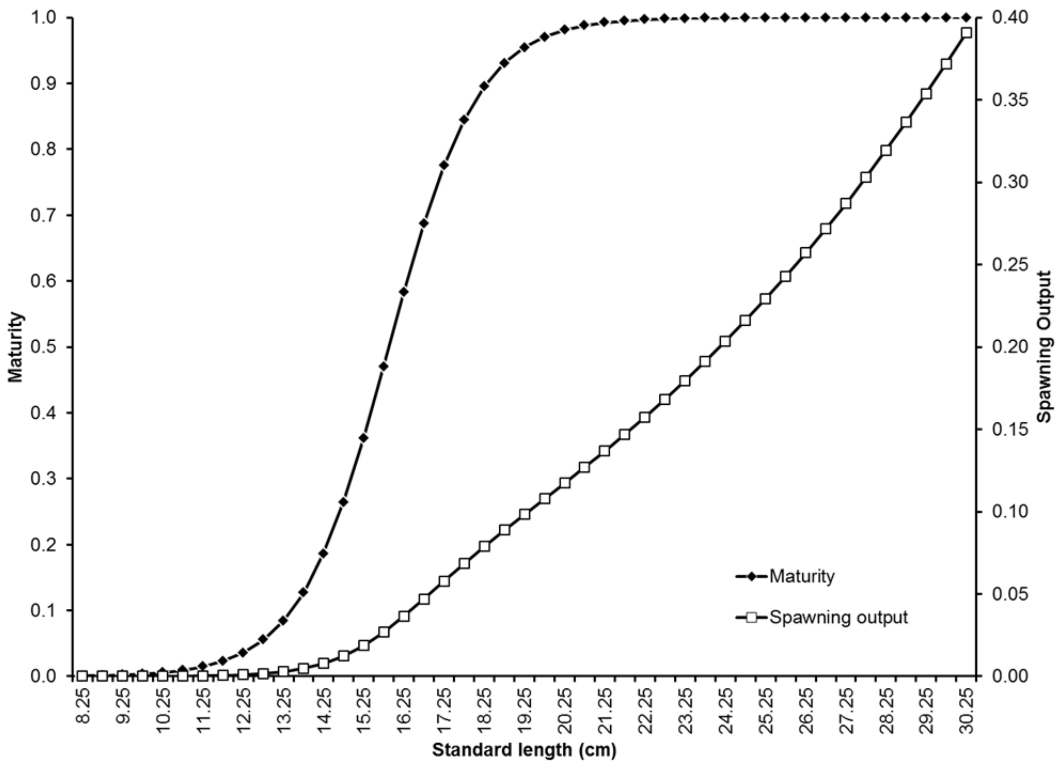

Figure 2c. Maturity (L_{50} = 15.88 cm) and spawning output as a function of length.

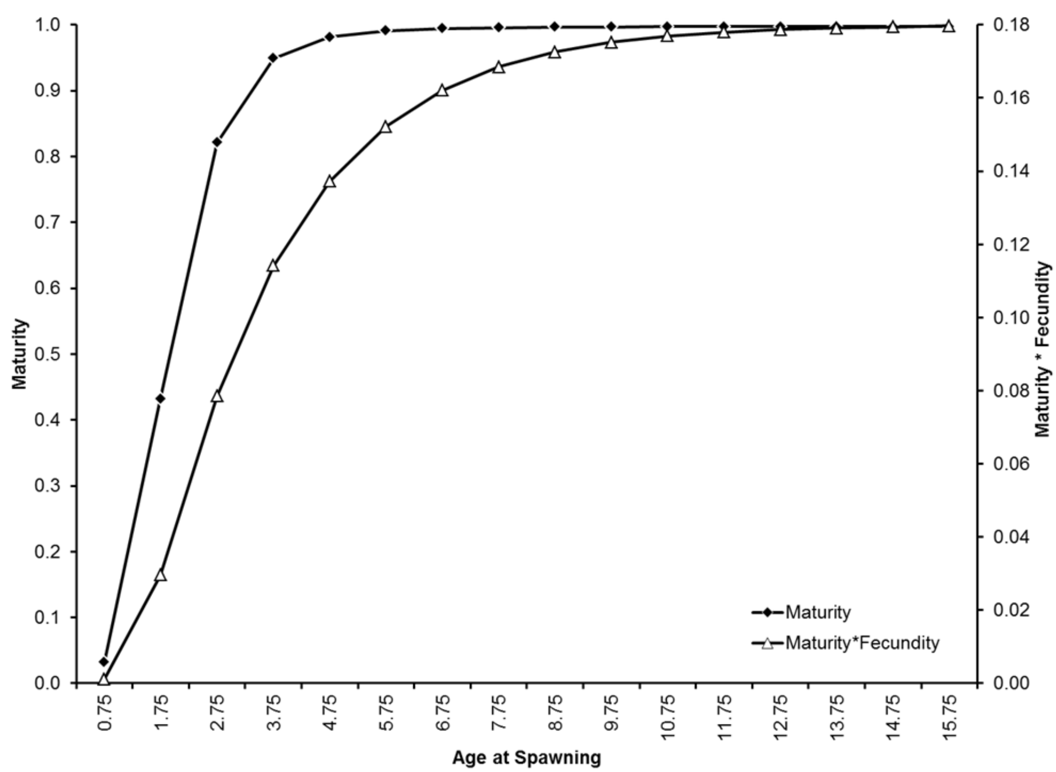

Figure 2d. Maturity and fecundity as a function of age, as derived from model X6e.

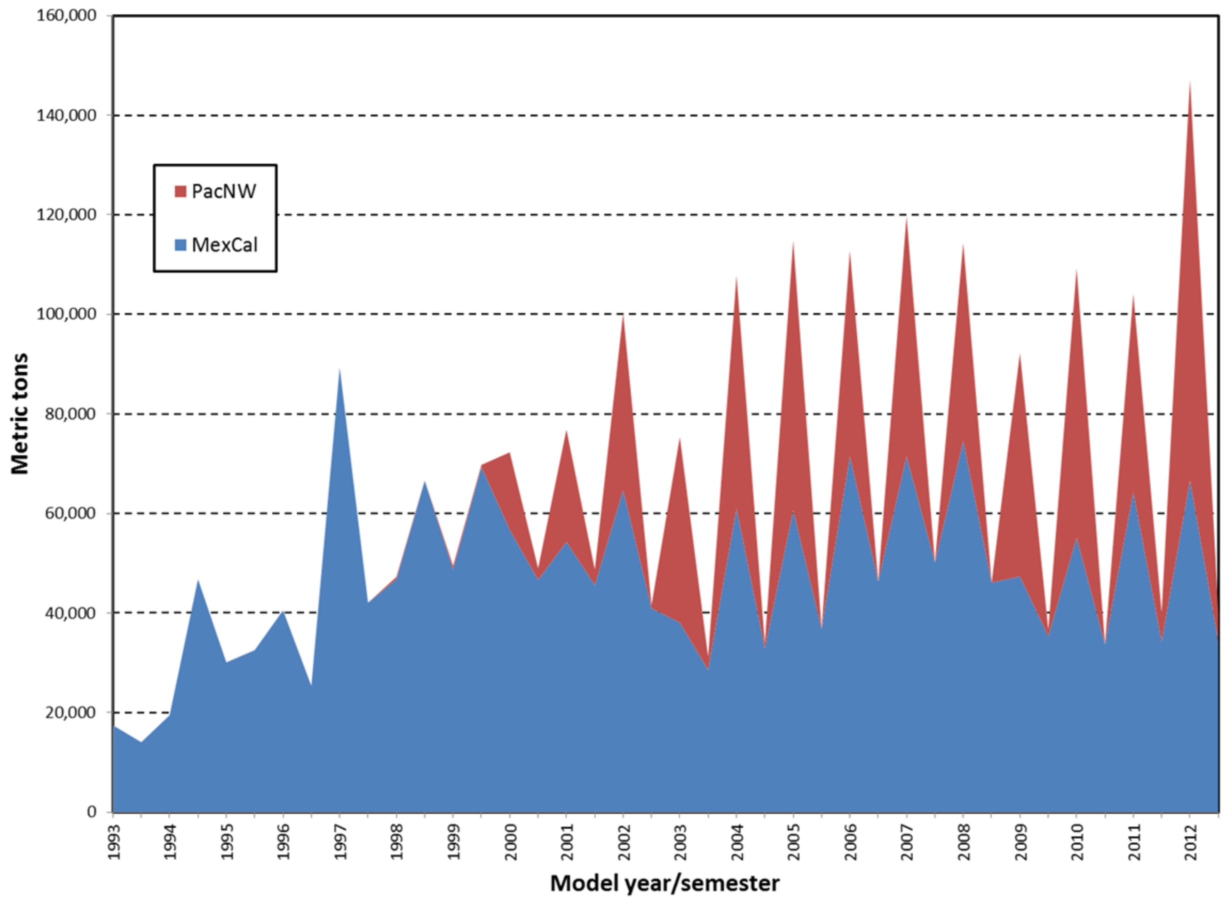

Figure 3. Pacific sardine landings (mt) by fishery, model year and semester as used in SS.

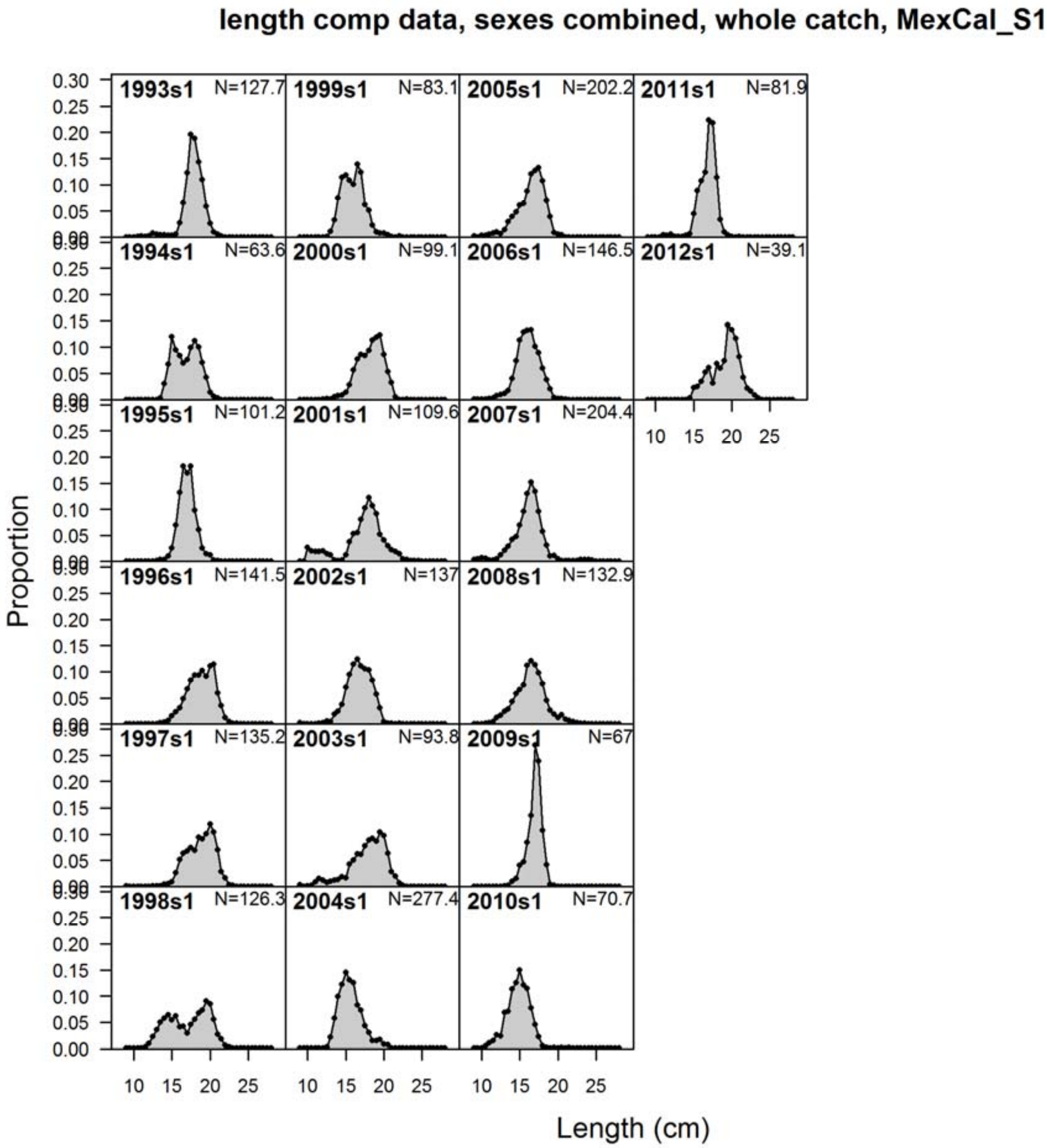

Figure 4a. Length-composition and effective sample size data for the MexCal_S1 fishery.

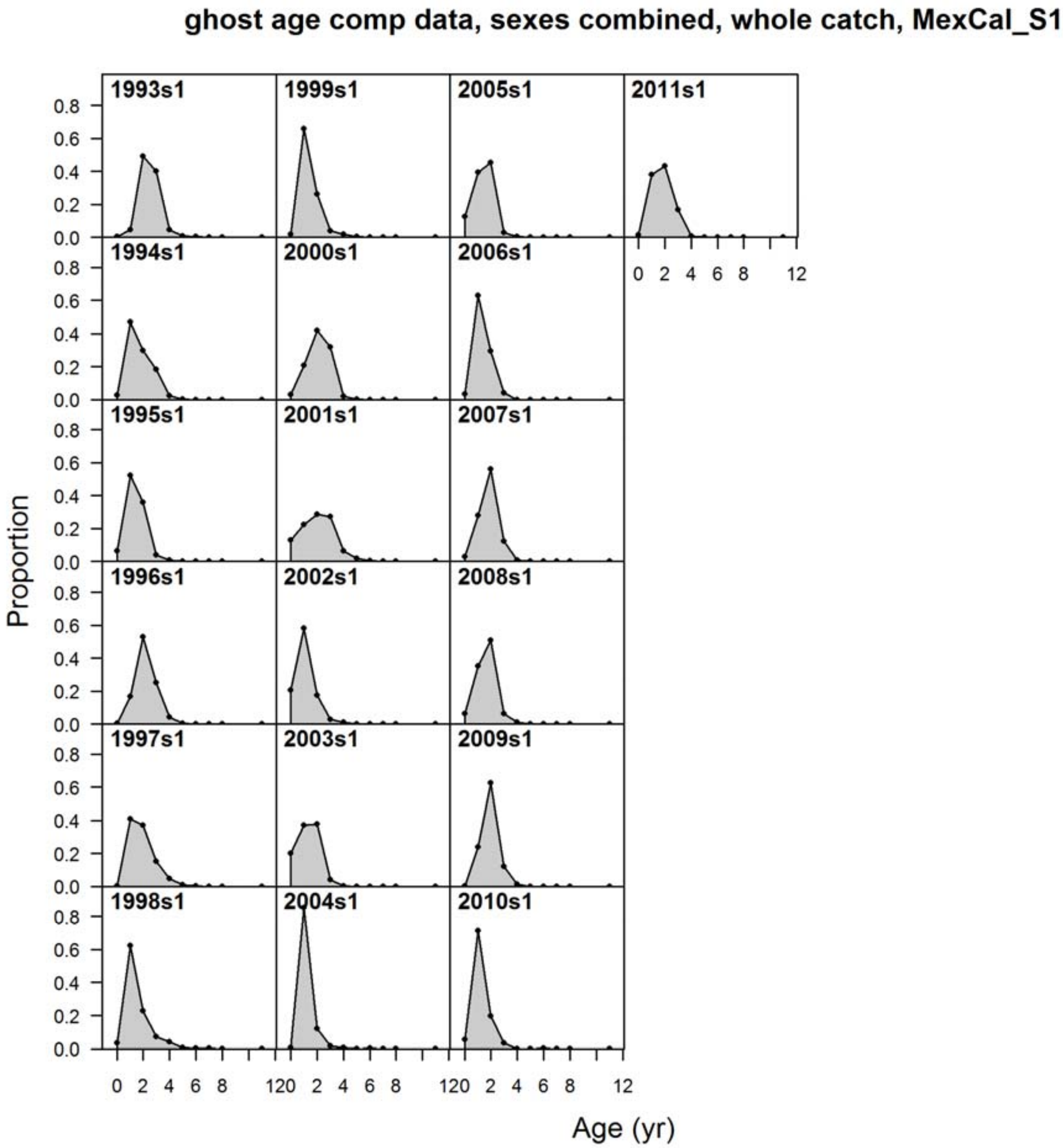

Figure 4b. Implied age-composition data for the MexCal-S1 fishery.

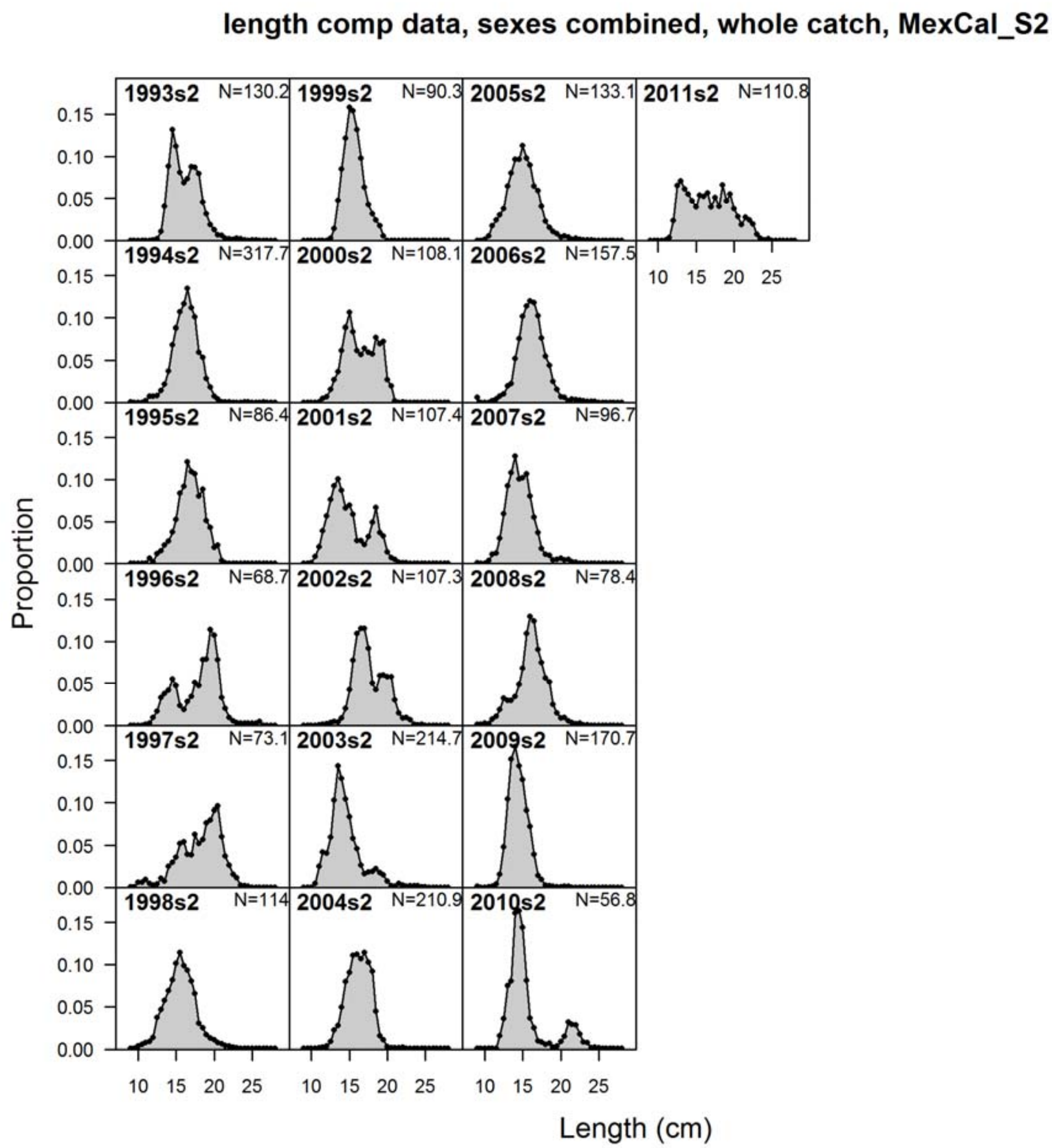

Figure 5a. Length-composition data and effective sample size for the MexCal_S2 fishery.

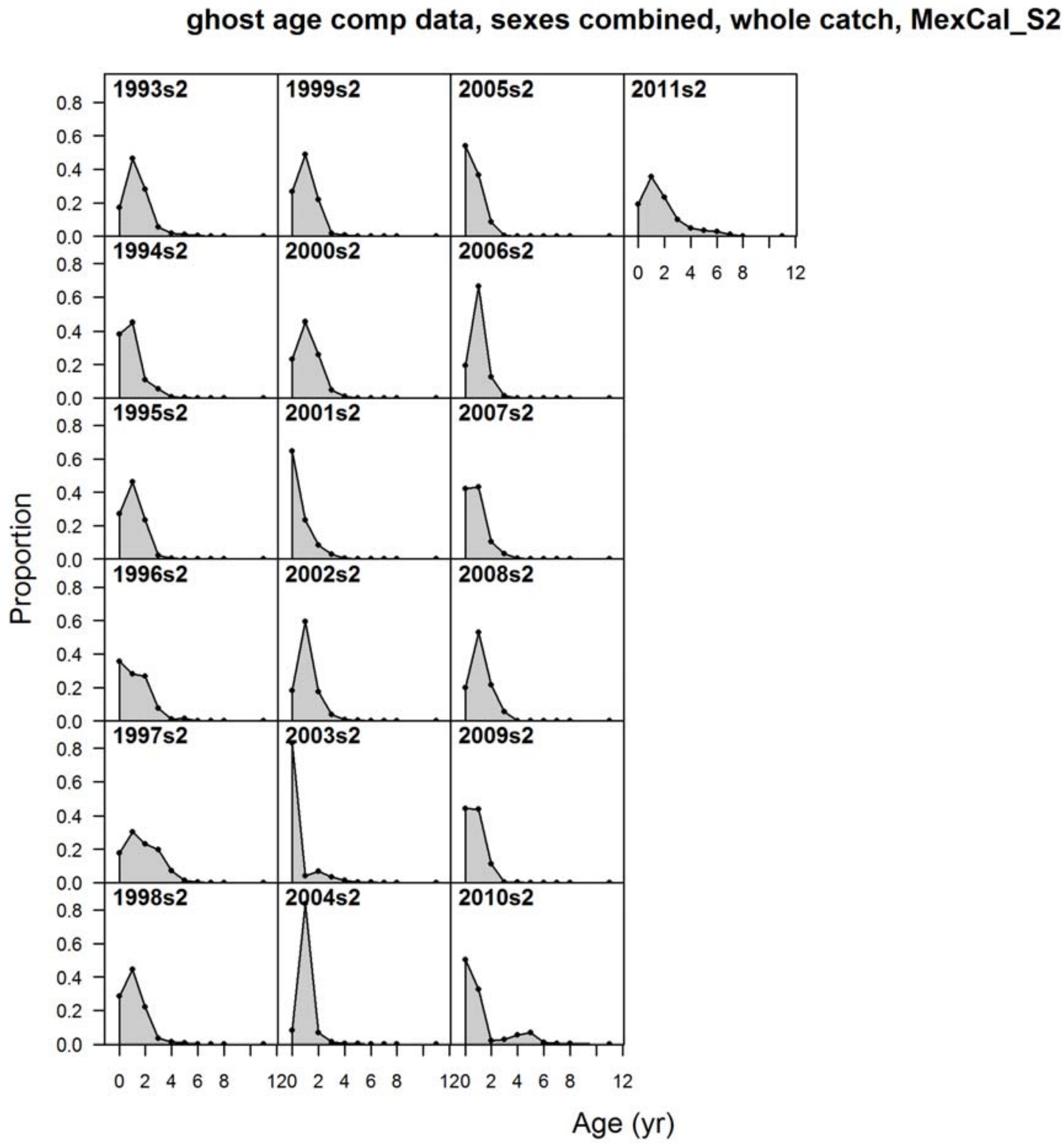

Figure 5b. Implied age-composition data for the MexCal_S2 fishery.

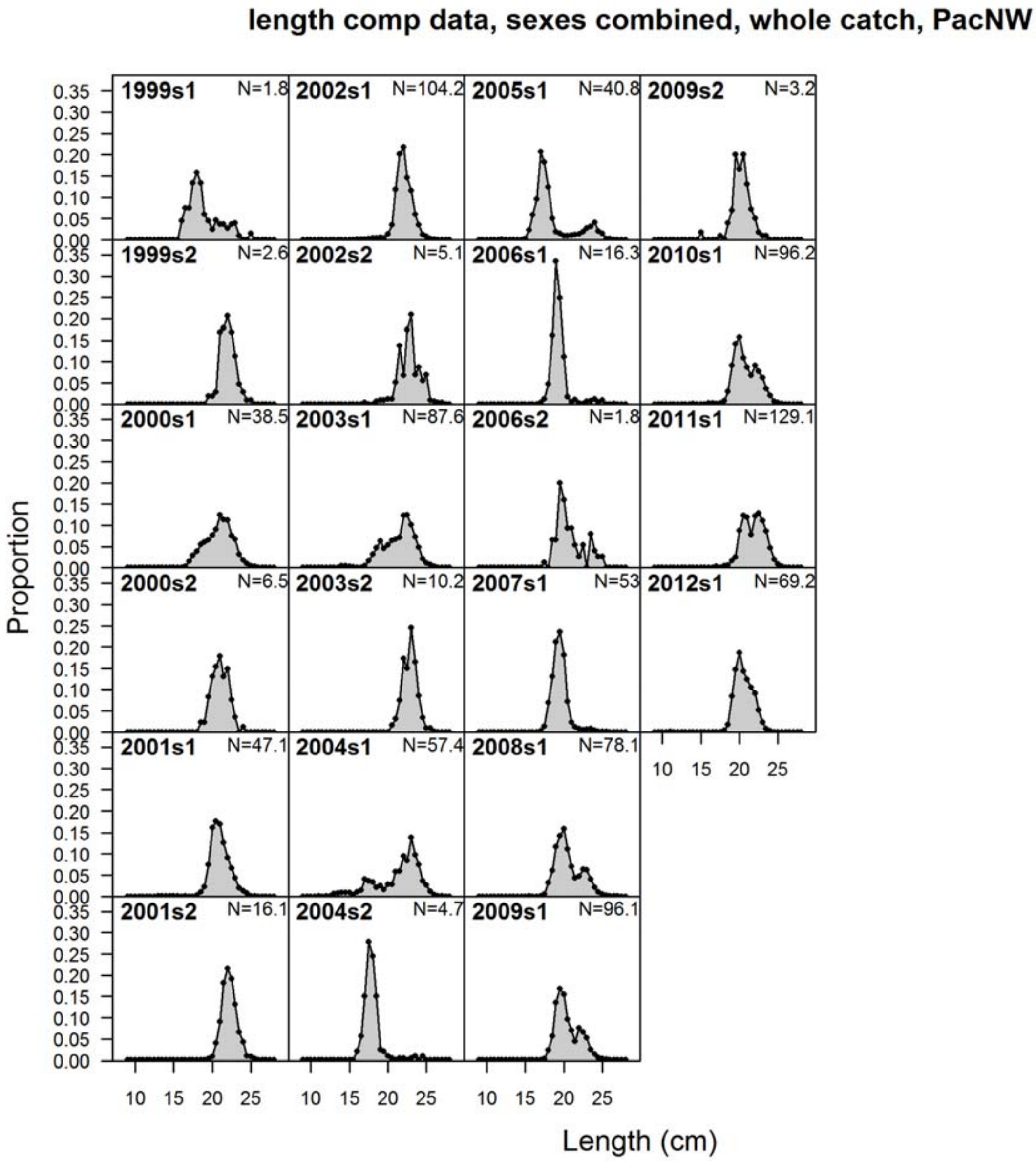

Figure 6a. Length-composition and effective sample size data for the PacNW fishery.

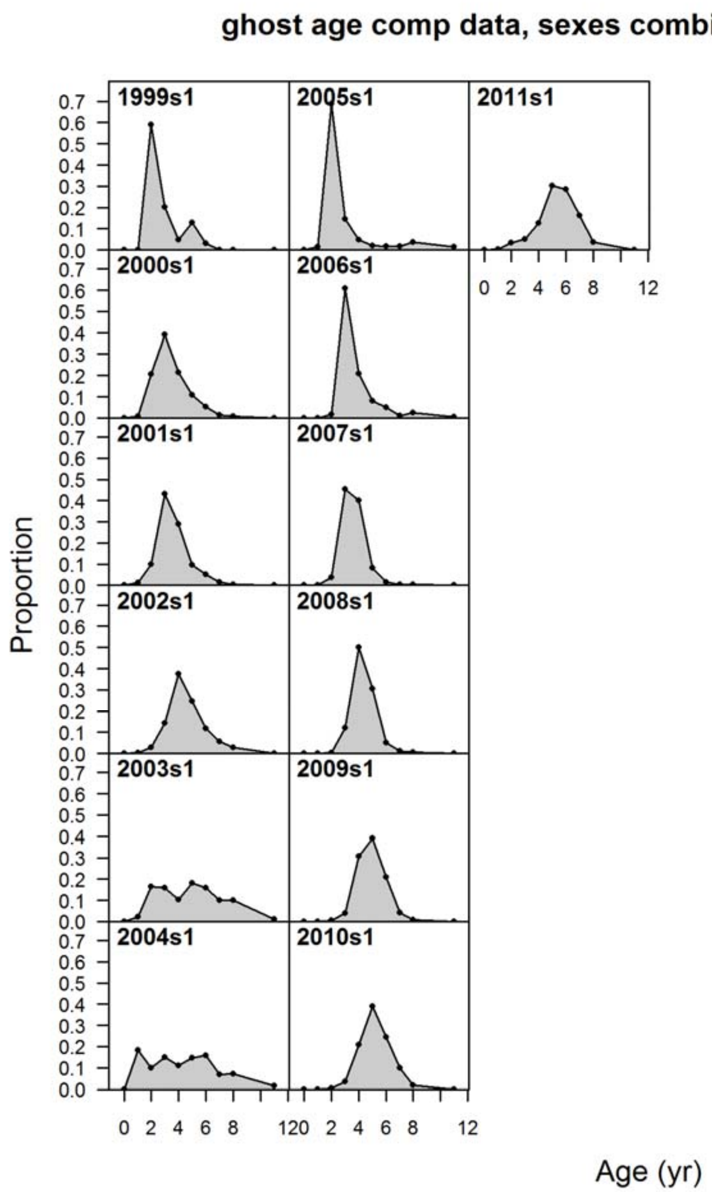

Figure 6b. Implied age-composition data for the PacNW fishery.

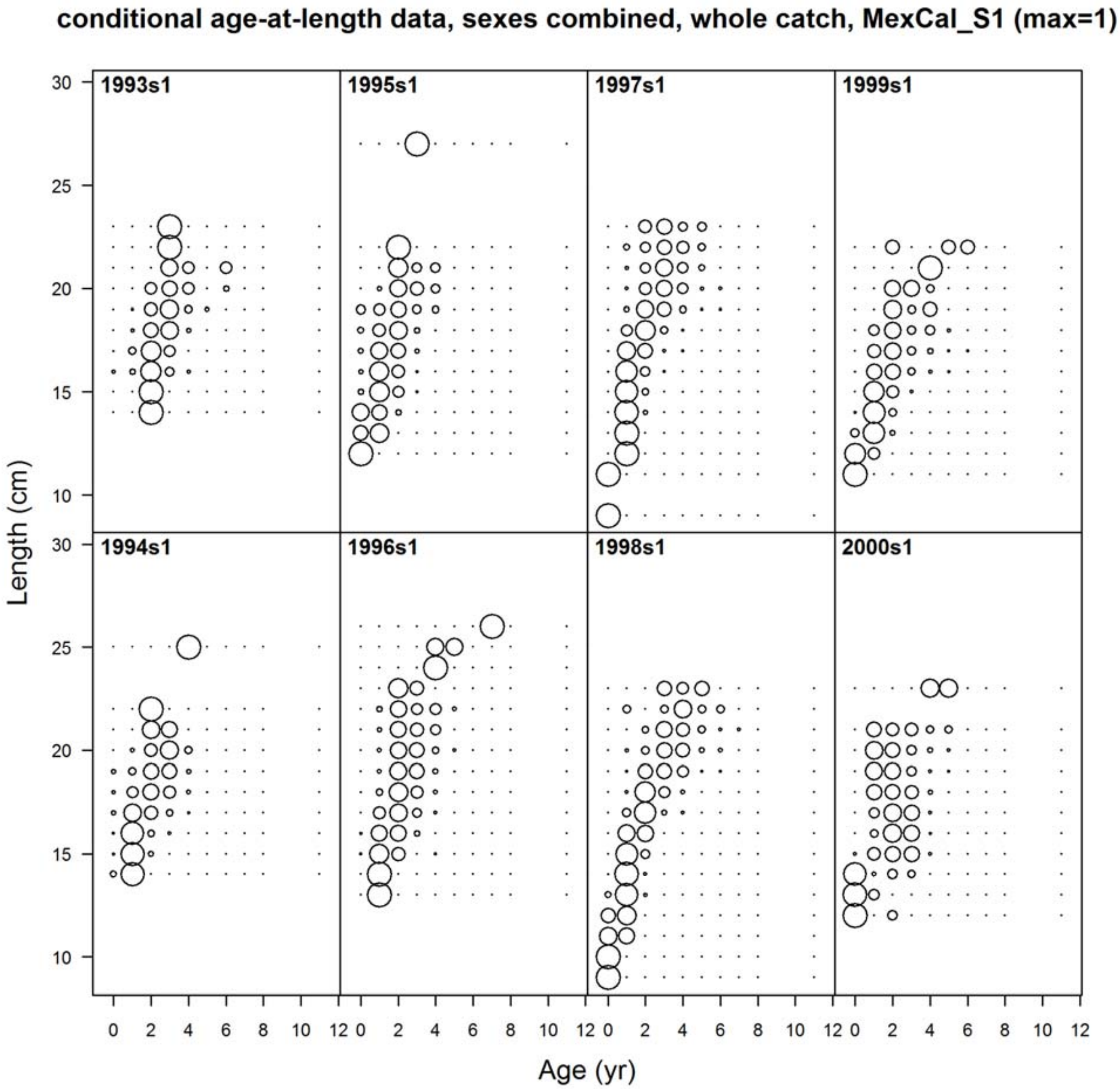

Figure 7. Conditional age-at-length data for the MexCal_S1 fishery, 1993-2000.

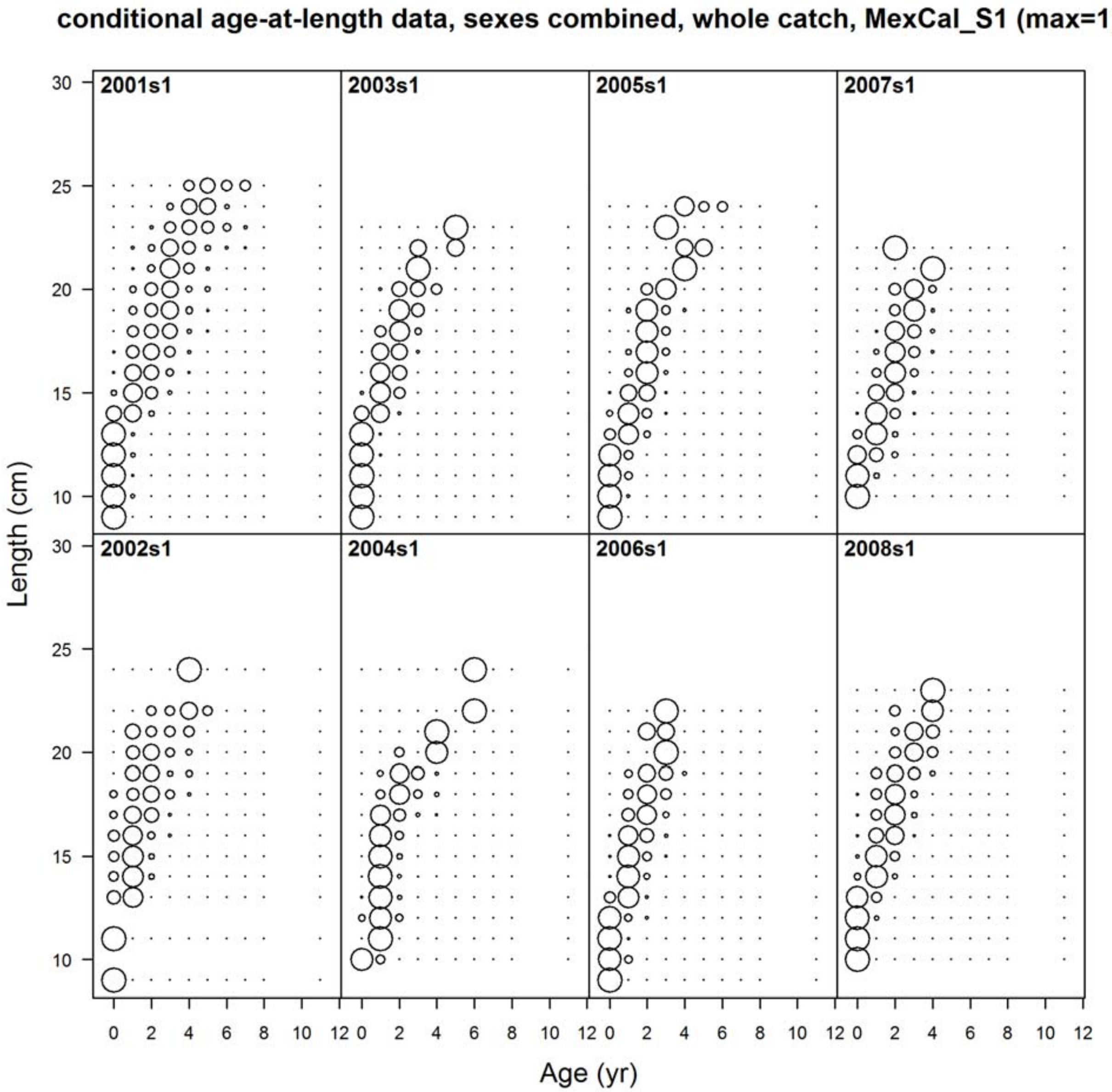

Figure 7 (cont'd). Conditional age-at-length data for the MexCal_S1 fishery, 2001-2008.

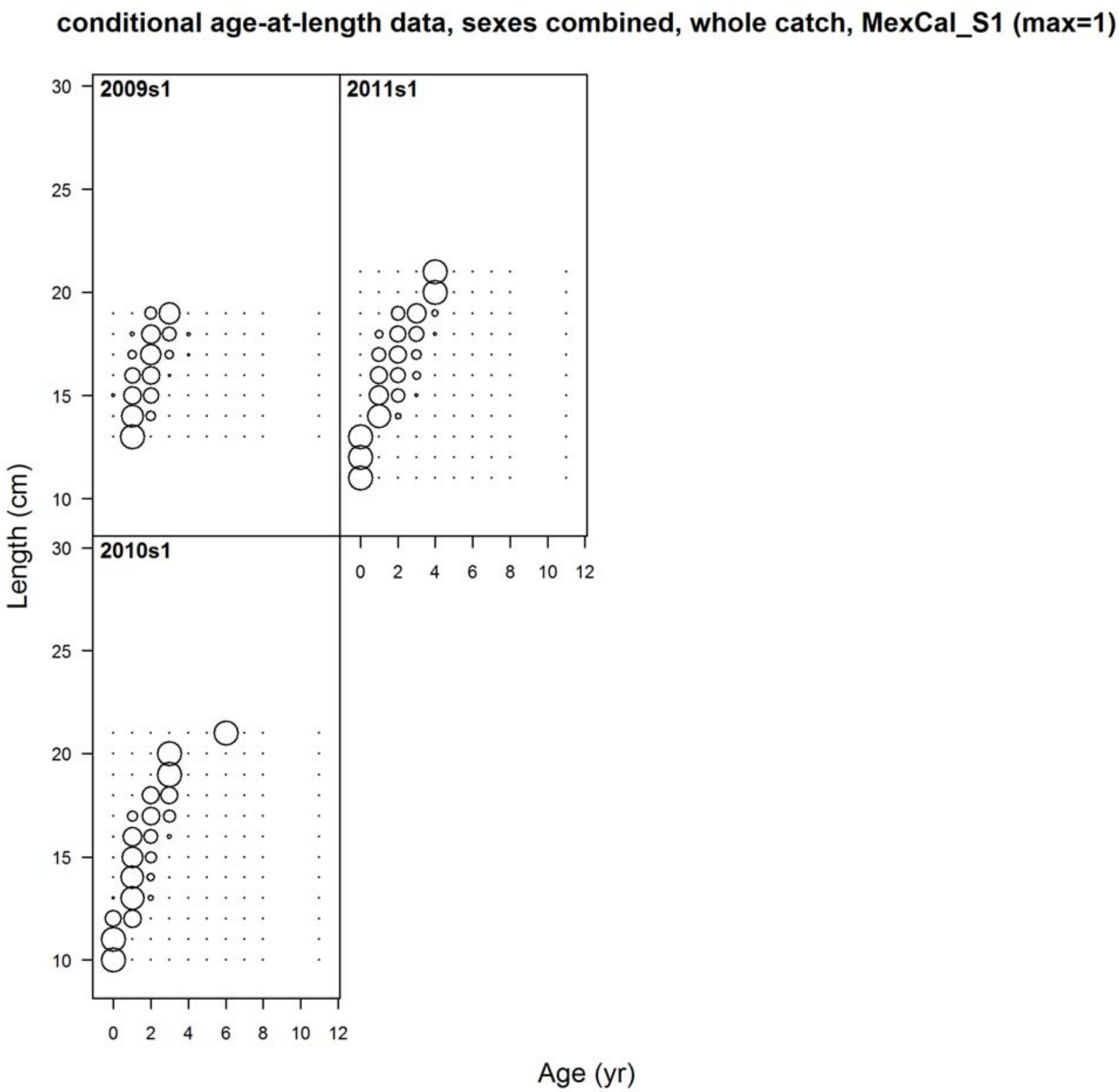

Figure 7 (cont'd). Conditional age-at-length data for the MexCal_S1 fishery, 2009-2011.

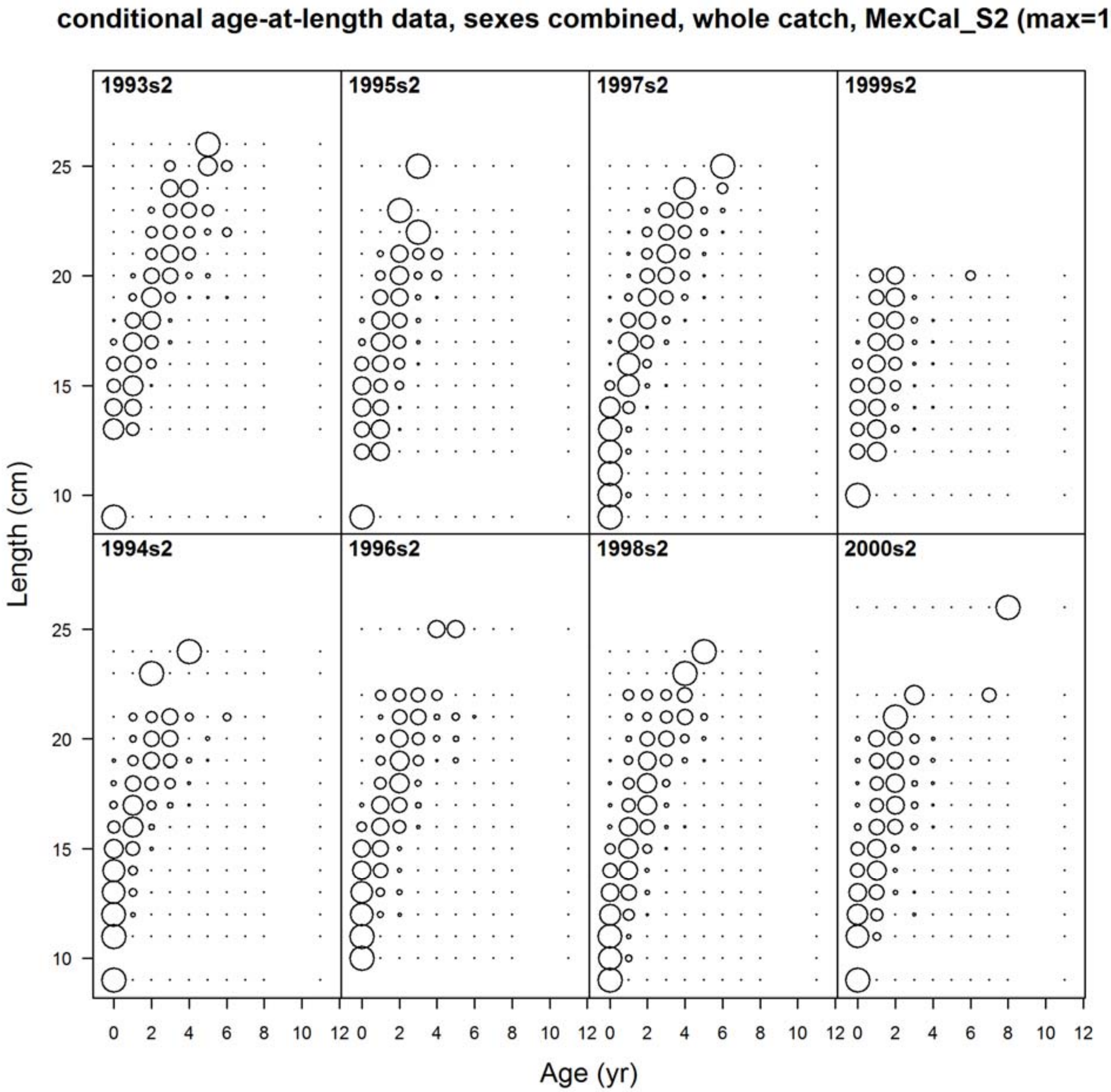

Figure 8. Conditional age-at-length data for the MexCal_S2 fishery, 1993-2000.

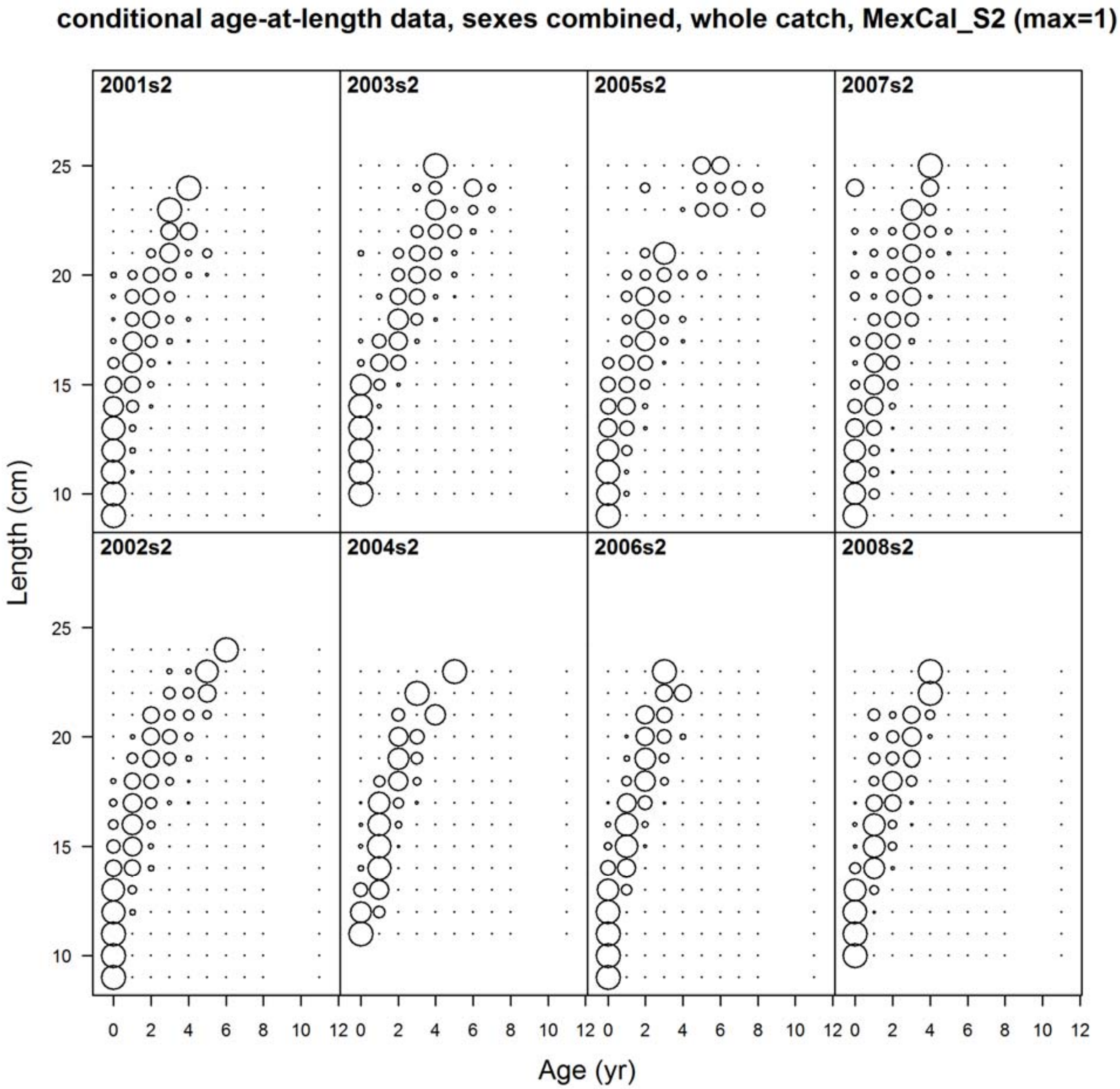

Figure 8 (cont'd). Conditional age-at-length data for the MexCal_S2 fishery, 2001-2008.

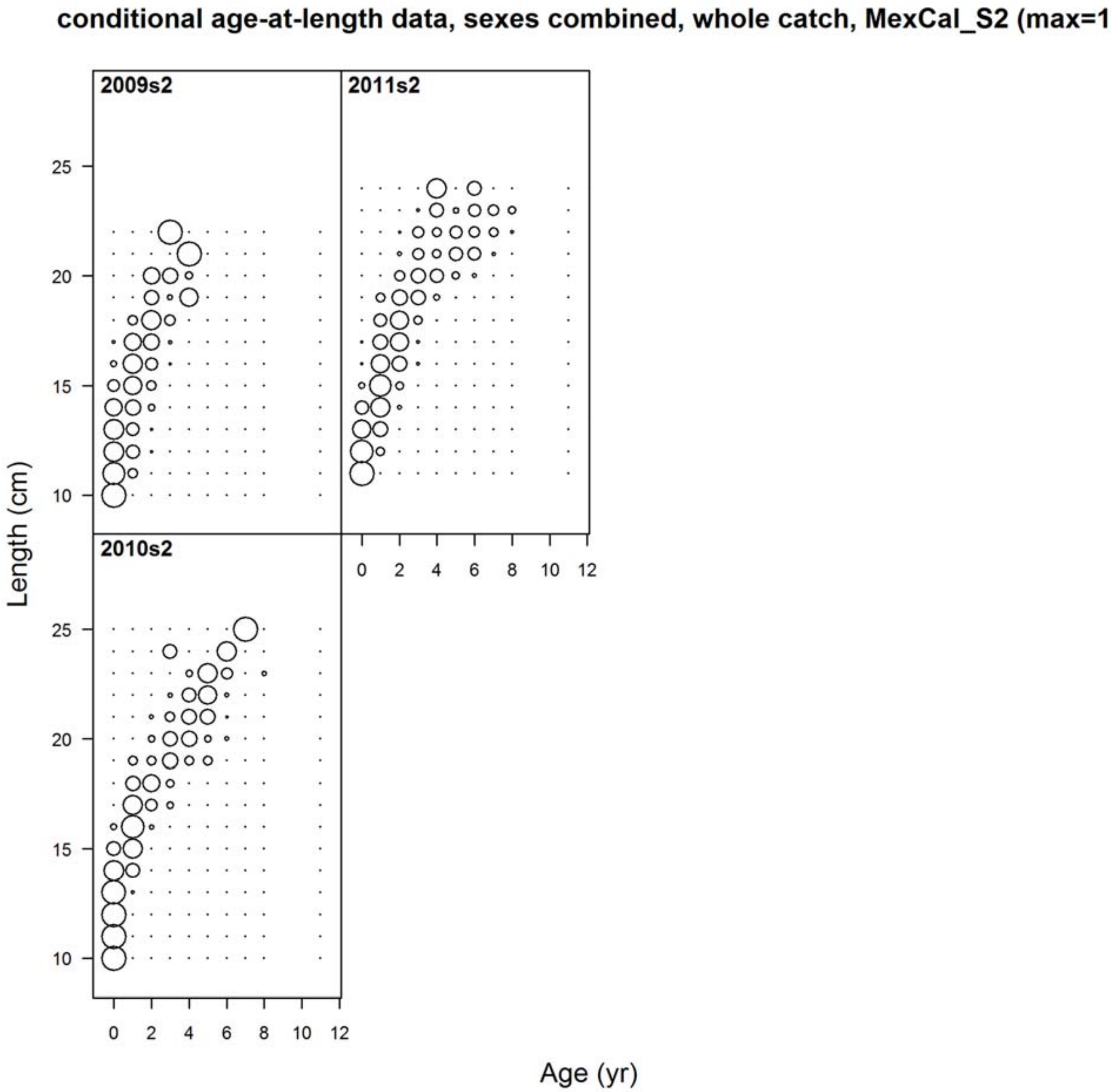

Figure 8 (cont'd). Conditional age-at-length data for the MexCal_S2 fishery, 2009-2011.

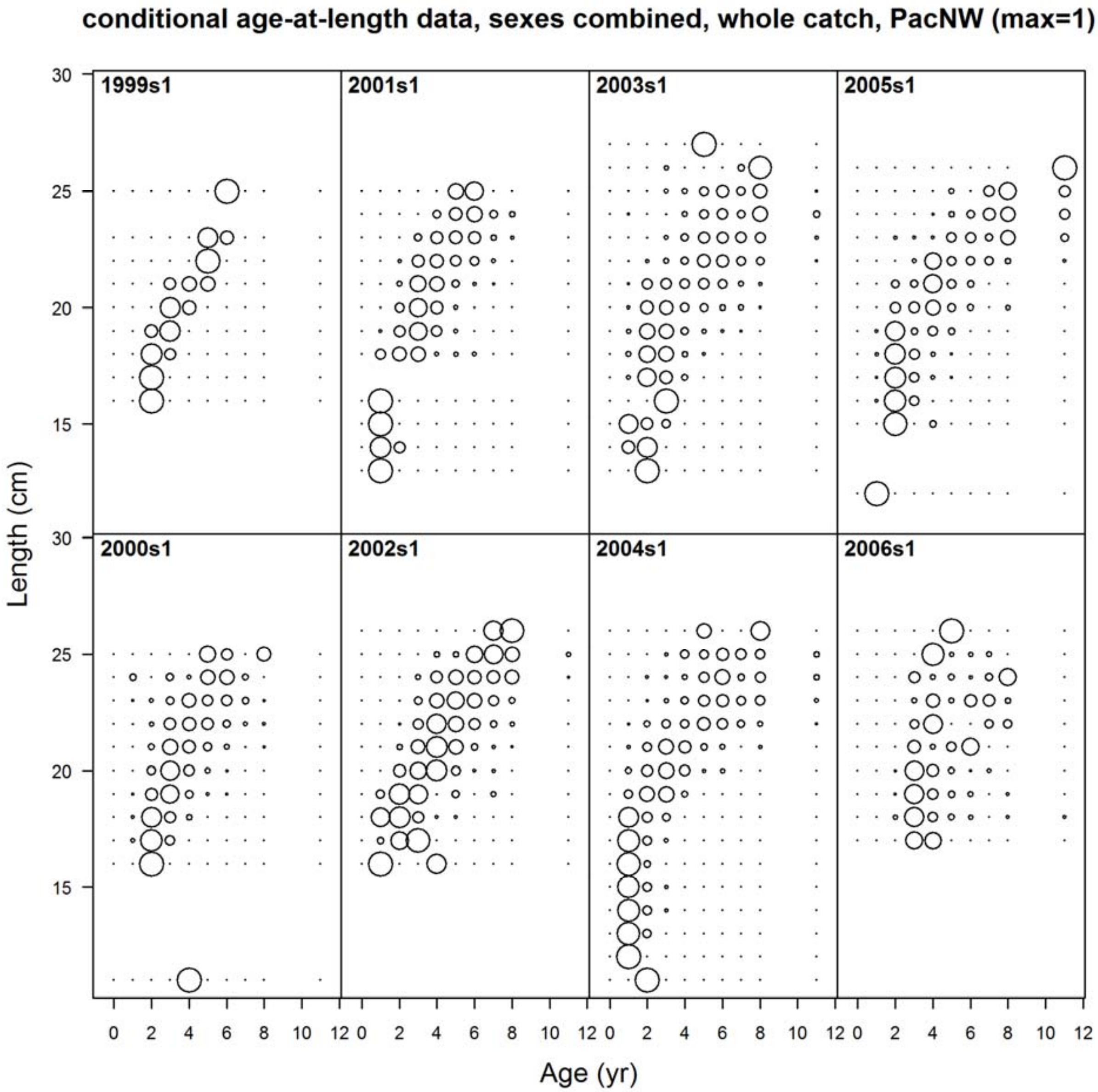

Figure 9. Conditional age-at-length data for the PacNW fishery, 1999-2006.

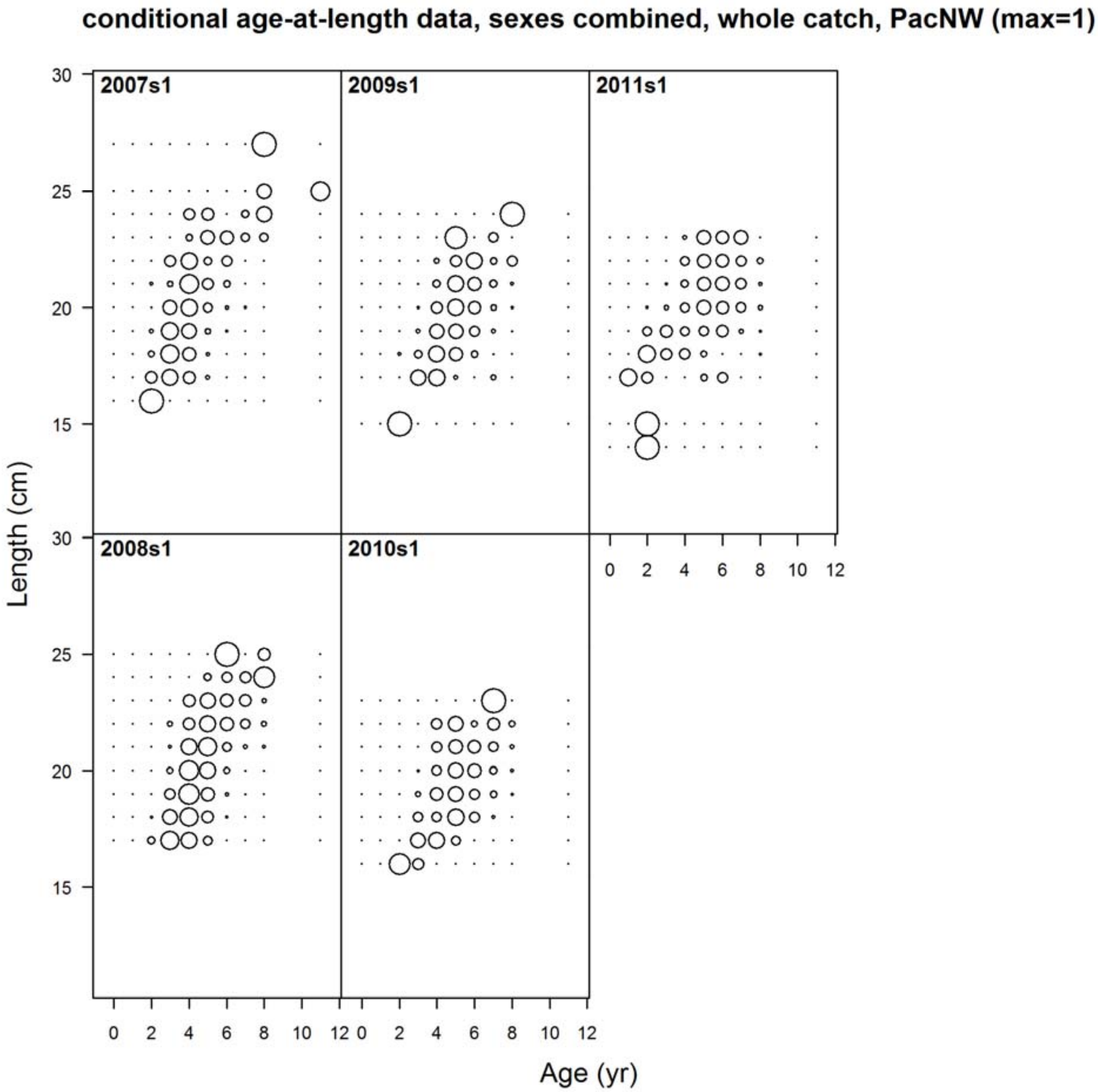

Figure 9 (cont'd). Conditional age-at-length data for the PacNW fishery, 2007-2011.

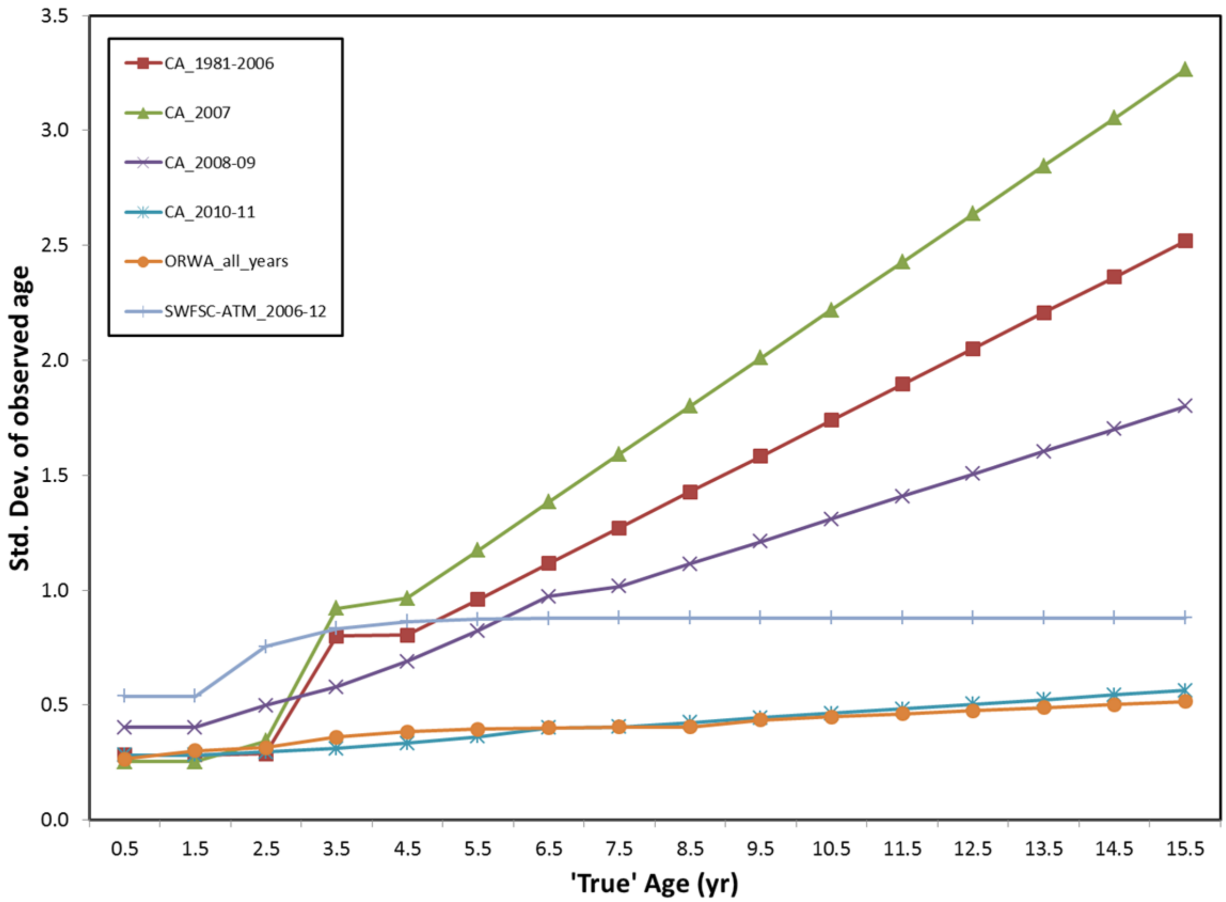

Figure 10. Laboratory- and year-specific ageing errors.

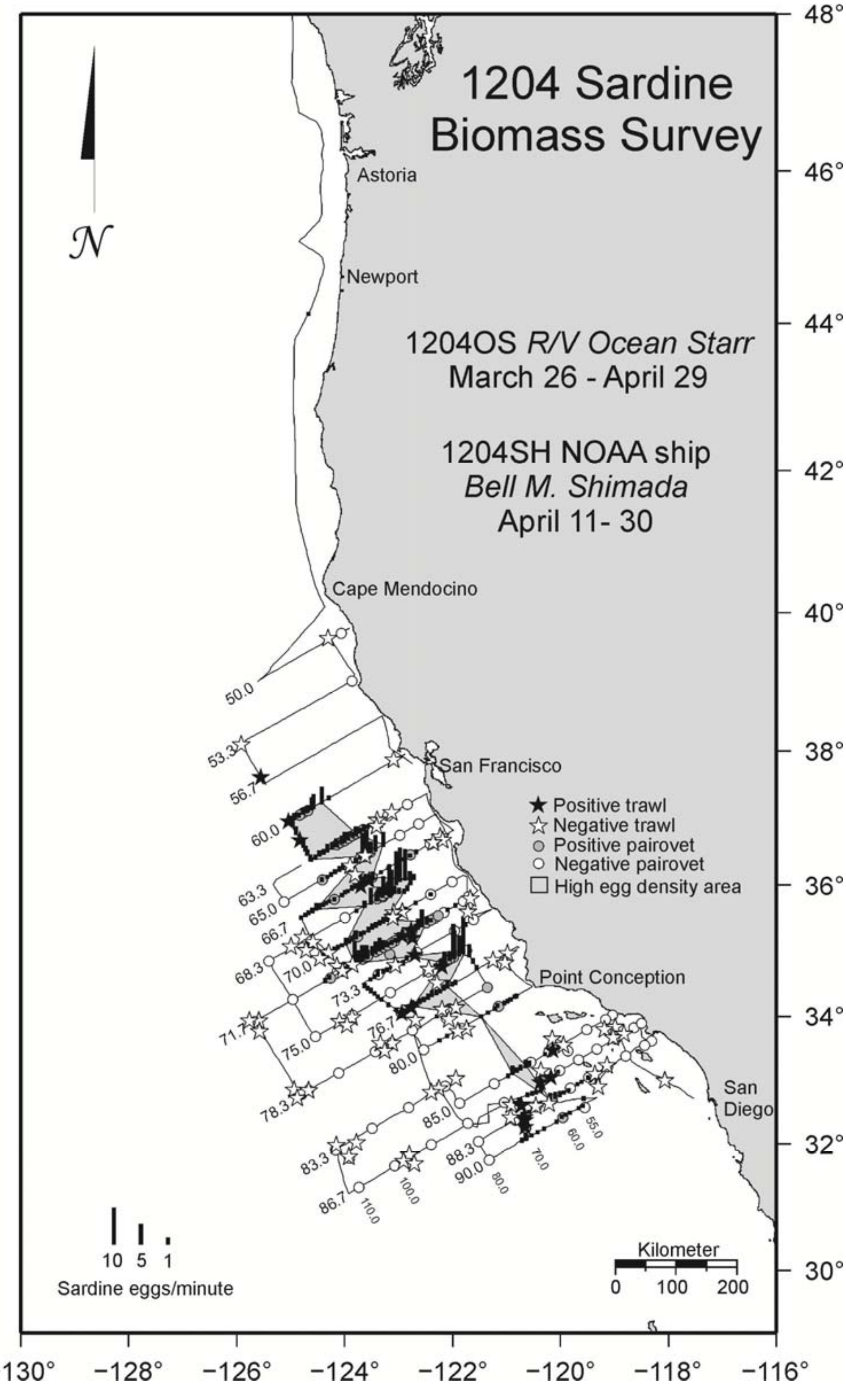

Figure 11a. Distribution of CUFES and pairovet ichthyoplankton collections and adult trawl samples from the SWFSC 1204 sardine survey, conducted onboard the R/V Ocean Starr and NOAA ship Bell M. Shimada during spring of 2012. Standard sampling area for the DEPM index is displayed on the following page.

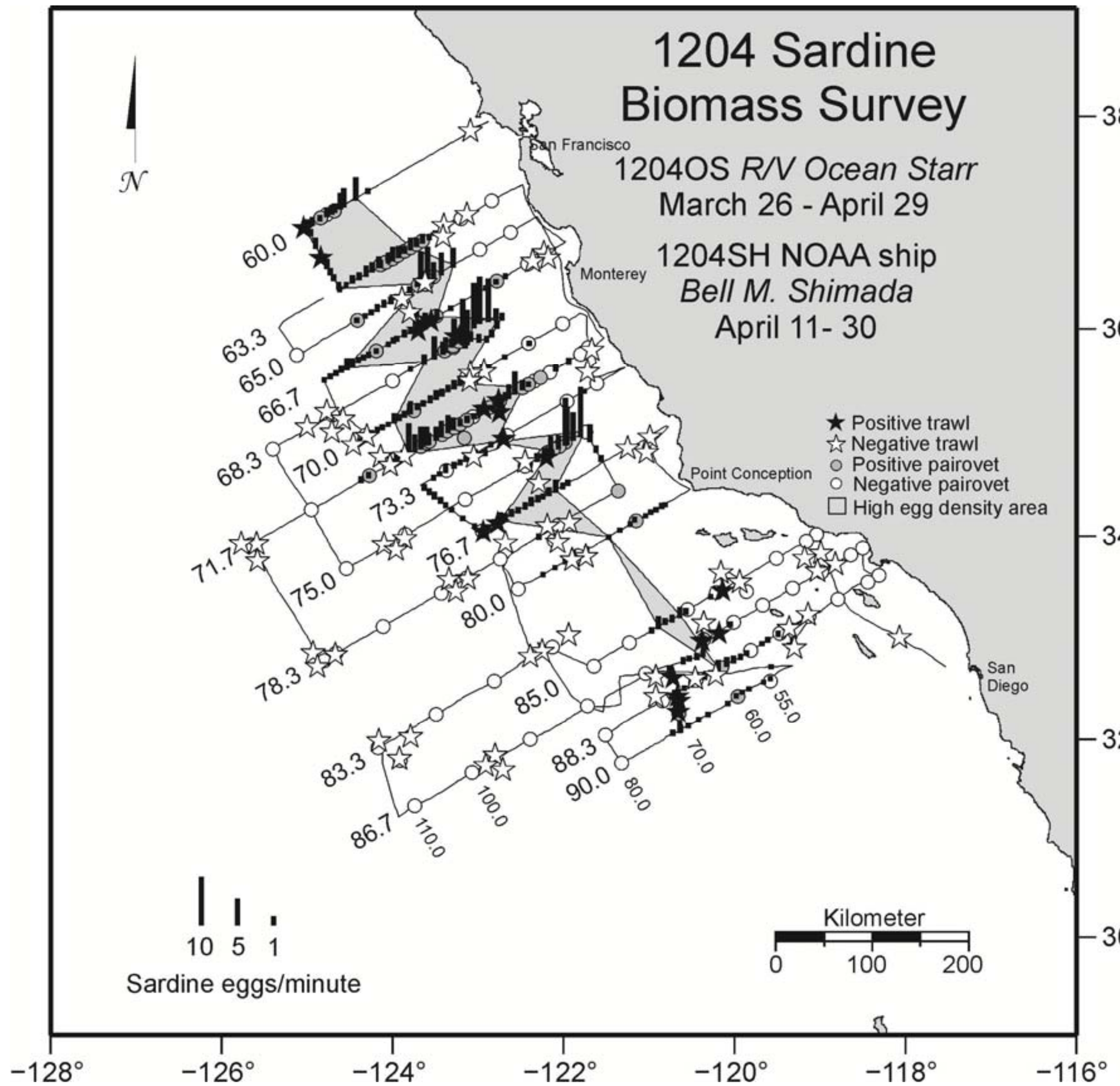

Figure 11b. Distribution of CUFES and pairovet ichthyoplankton collections and adult trawl samples from the SWFSC 1204 sardine survey in the standard sampling area for the DEPM index, conducted onboard the R/V Ocean Starr and NOAA ship Bell M. Shimada during spring of 2012.

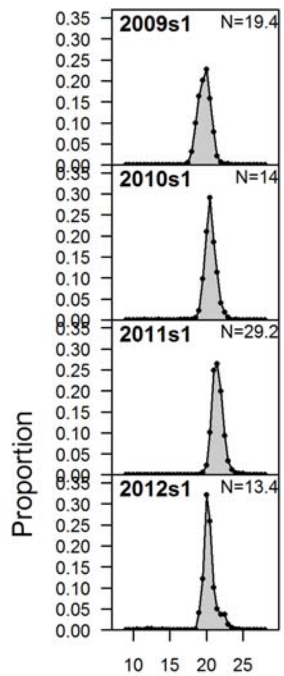

Figure 12. Length-composition data (SL-cm) for the aerial survey.

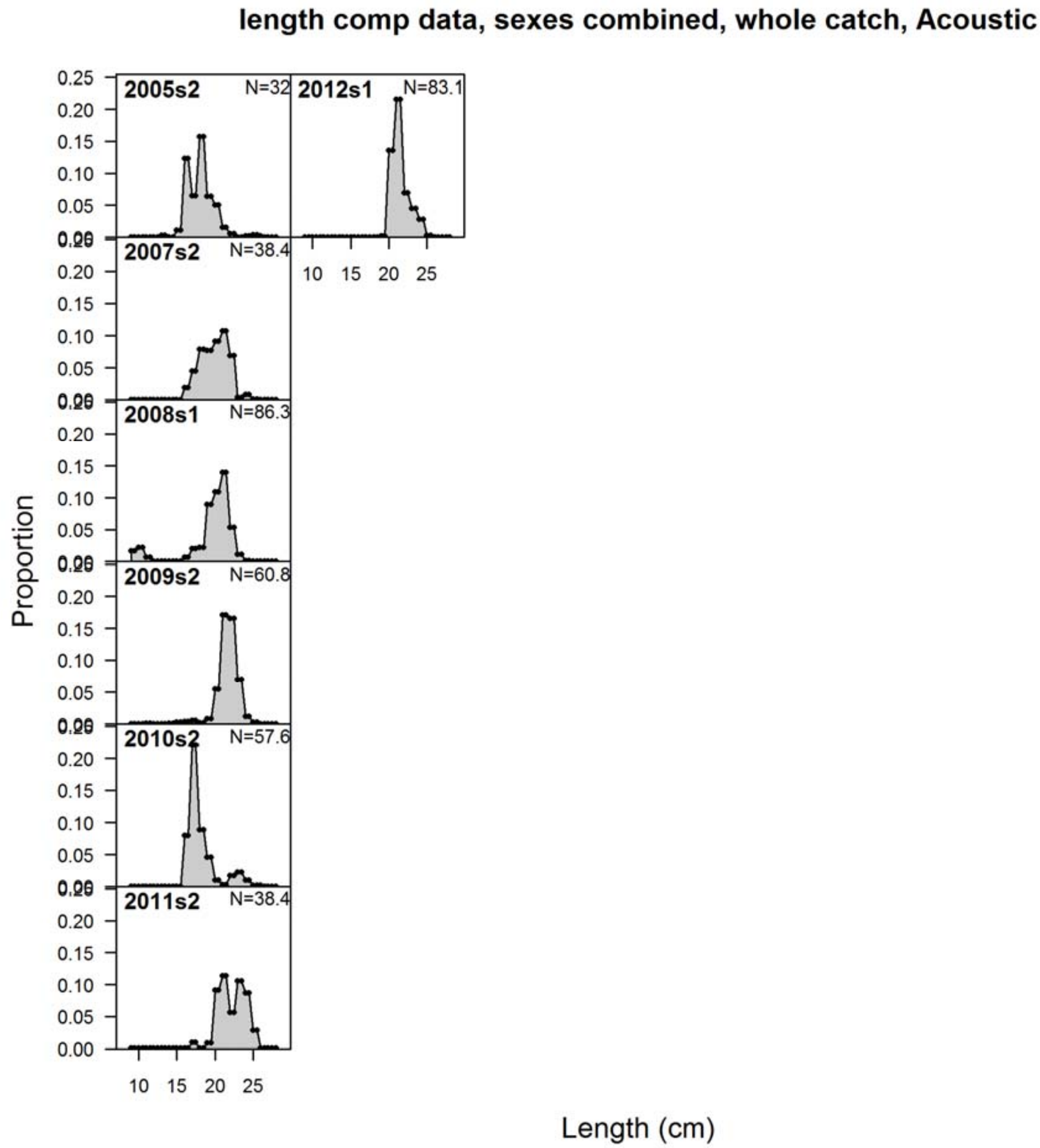

Figure 13a. Length-composition data (1-cm resolution) for the acoustic survey, 2005-2012.

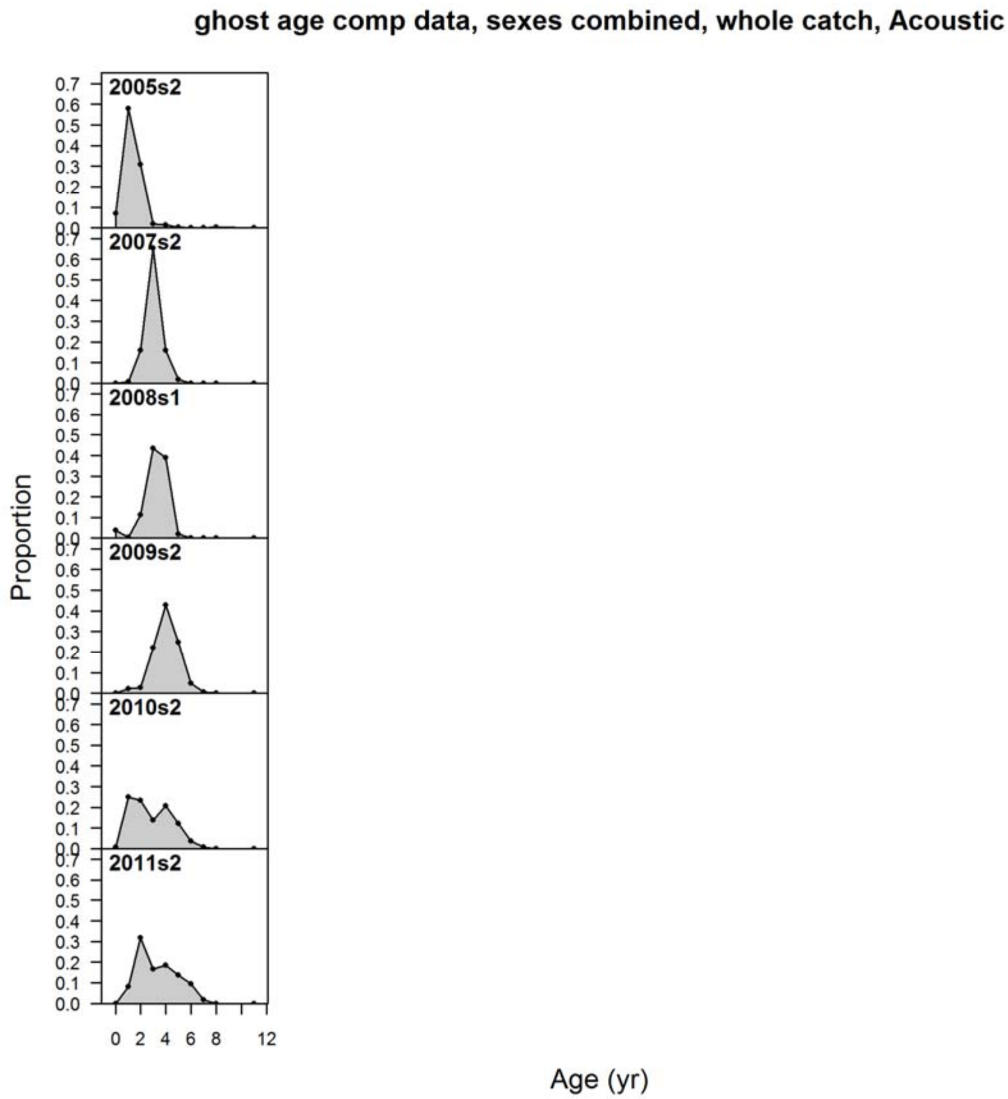

Figure 13b. . Implied age-composition data for the acoustic survey, 2005-2011.

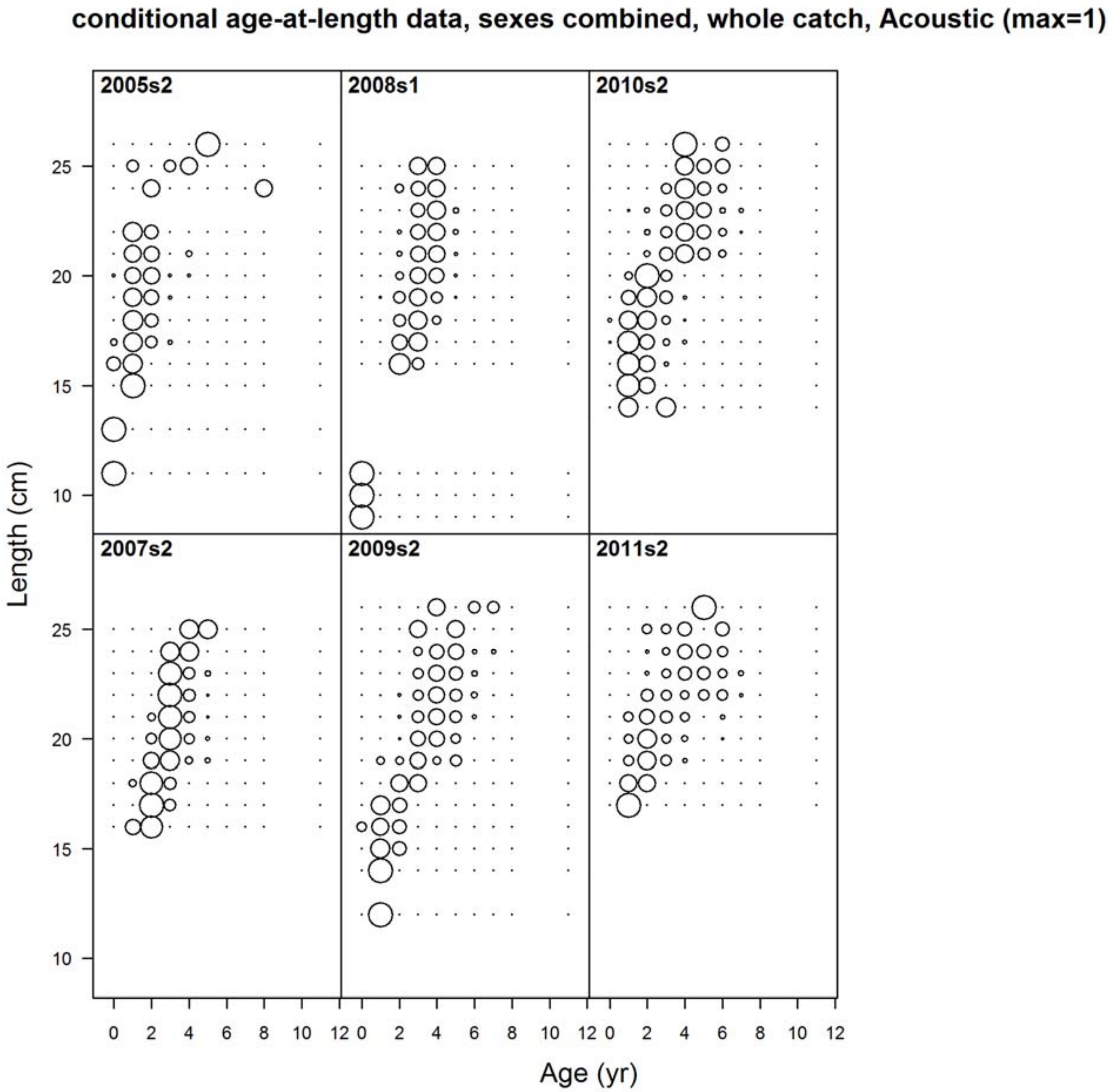

Figure 14. Conditional age-at-length data for the Acoustic-trawl survey, 2005-2011.

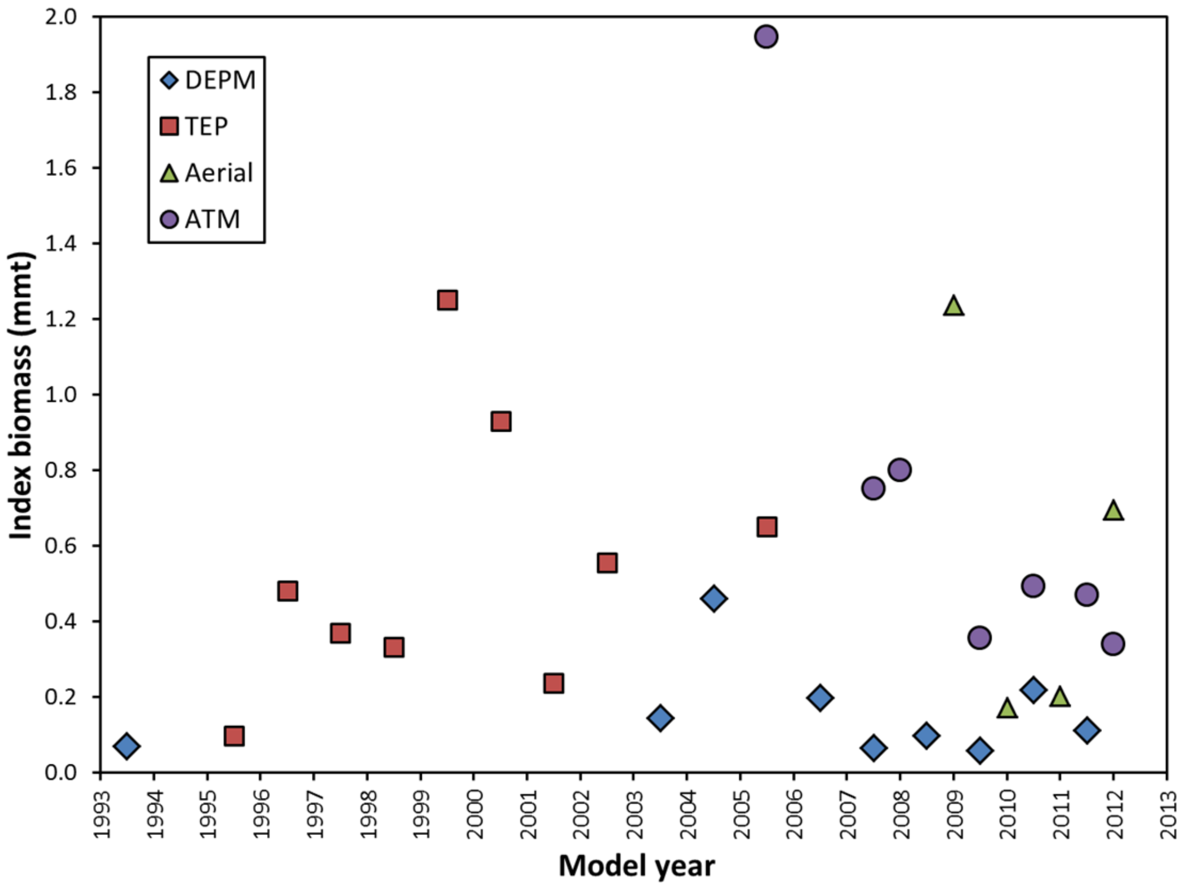

Figure 15. Survey indices of relative abundance (original values). TEP is modeled as total SSB, and DEPM as female SSB.

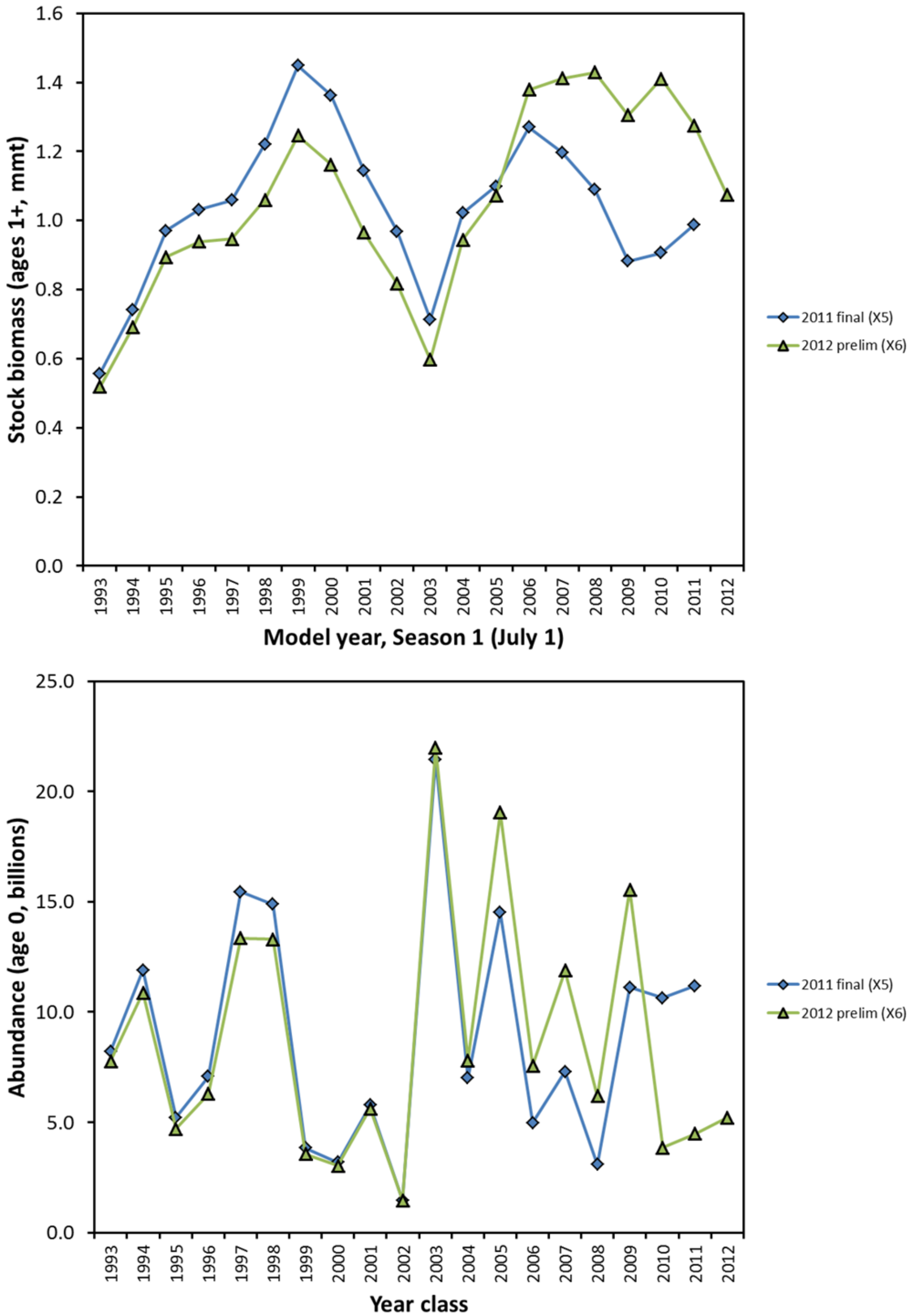

Figure 16. Stock biomass and recruitment for the final 2011 model (X5) and preliminary 2012 update model (X6).

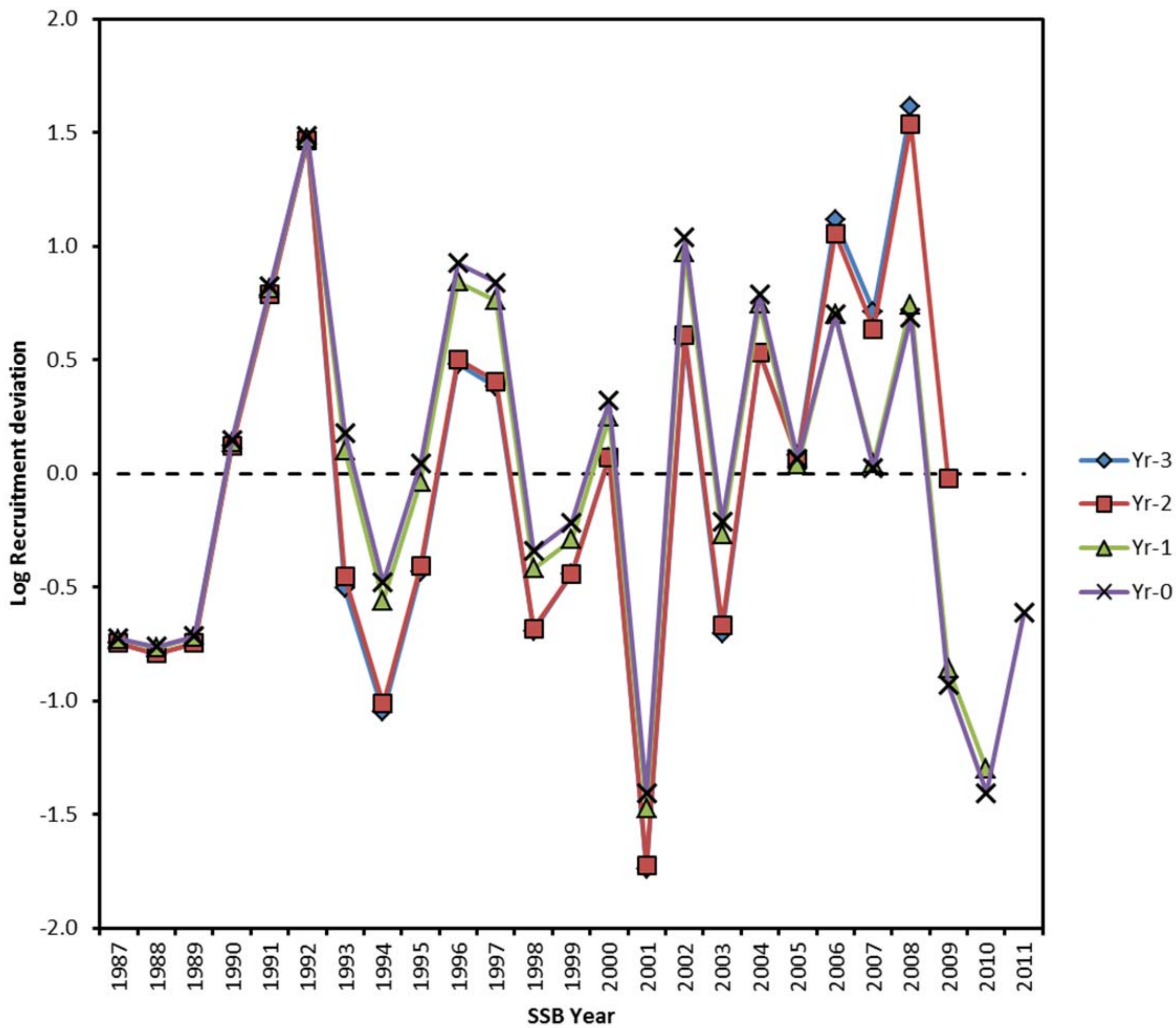

Figure 17. Profile on the last year for estimated recruitment deviations (end year -0, -1, -2, and -3) for preliminary model X6.

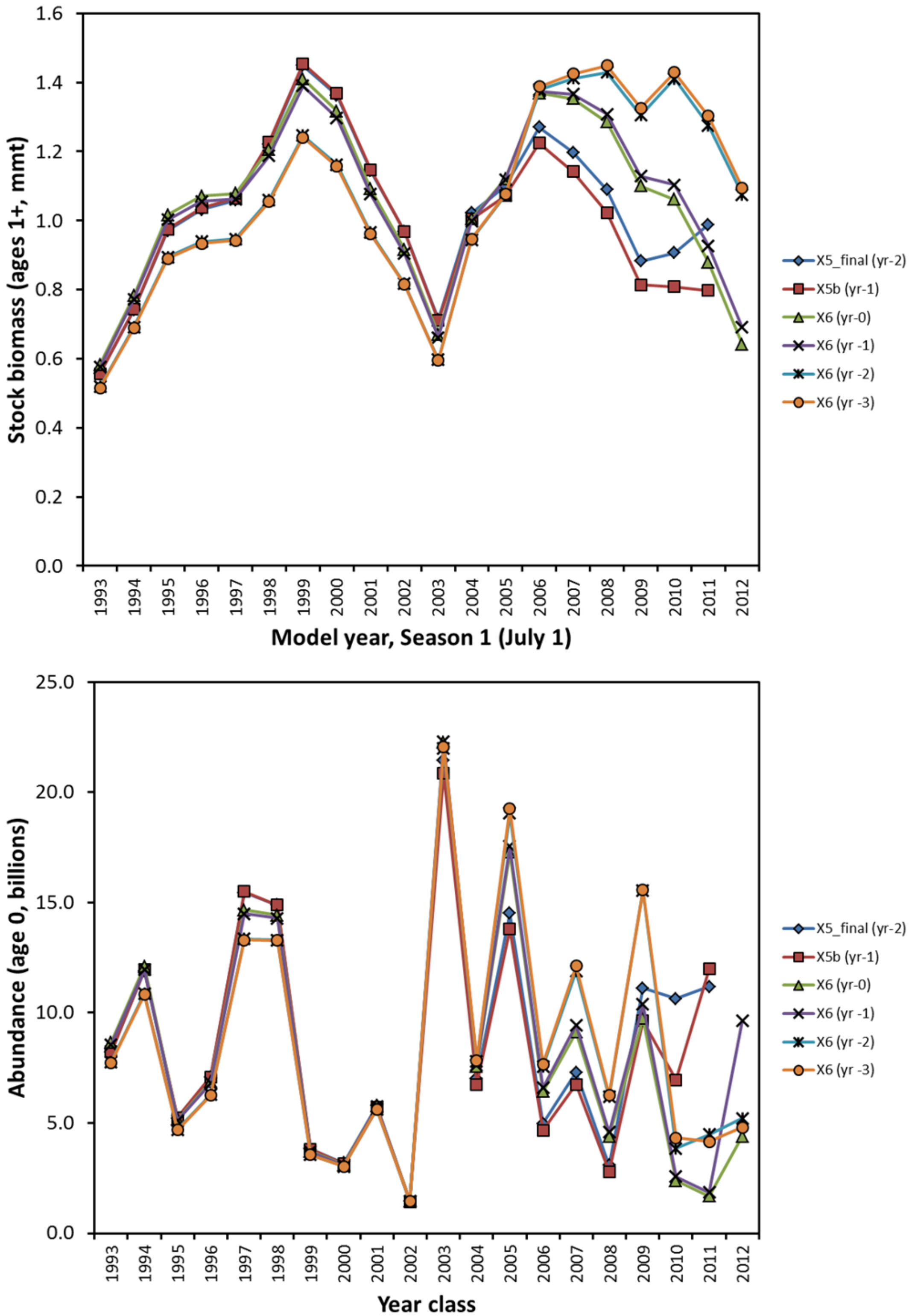

Figure 18. Stock biomass and recruitment for profile on the last year for estimated recruitment deviations (end year -0, -1, -2, and -3) for preliminary model X6.

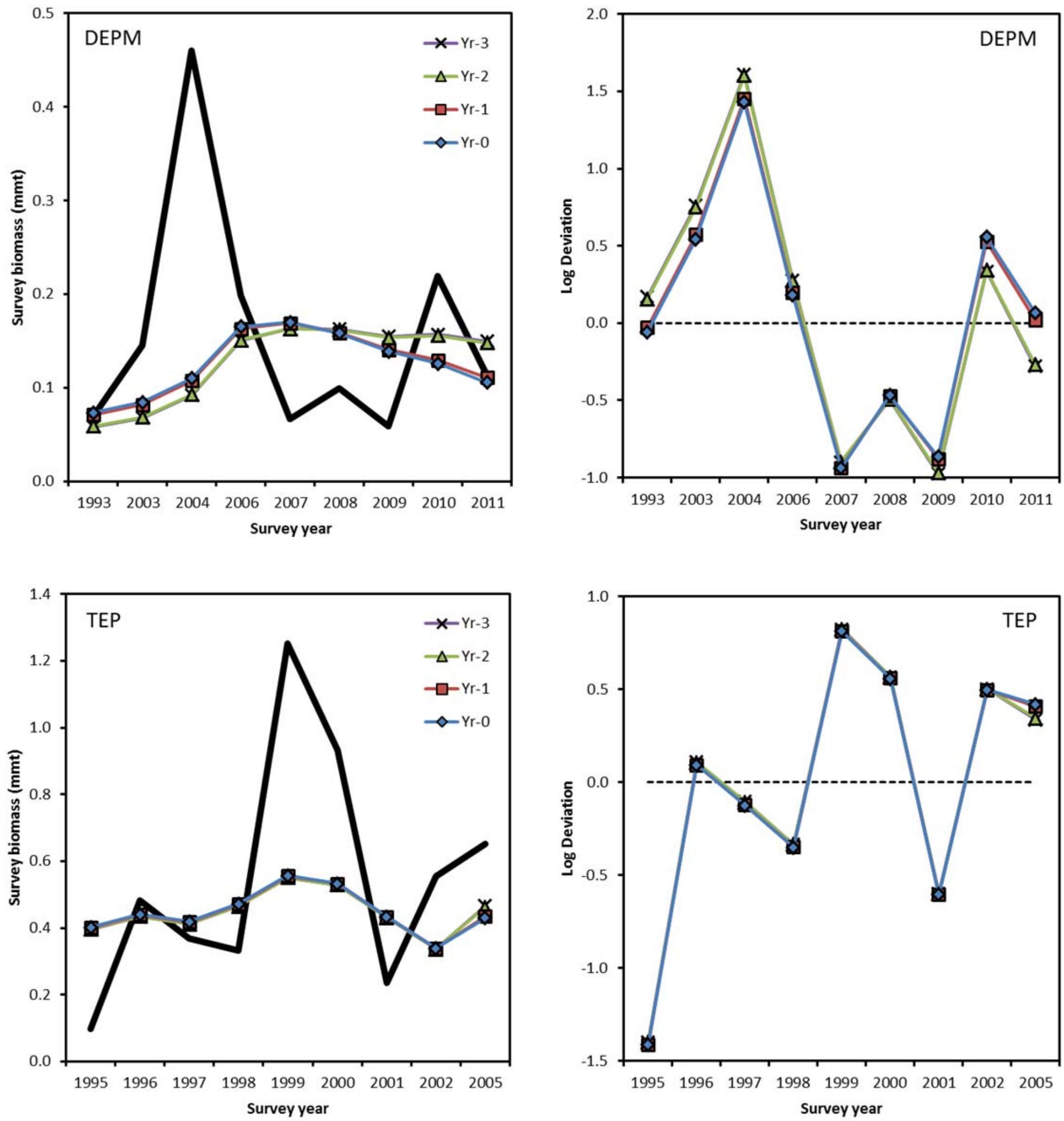

Figure 19. Preliminary model X6 fits to DEPM and TEP surveys for a profile on the last year for estimated recruitment deviations (end year -0, -1, -2, and -3).

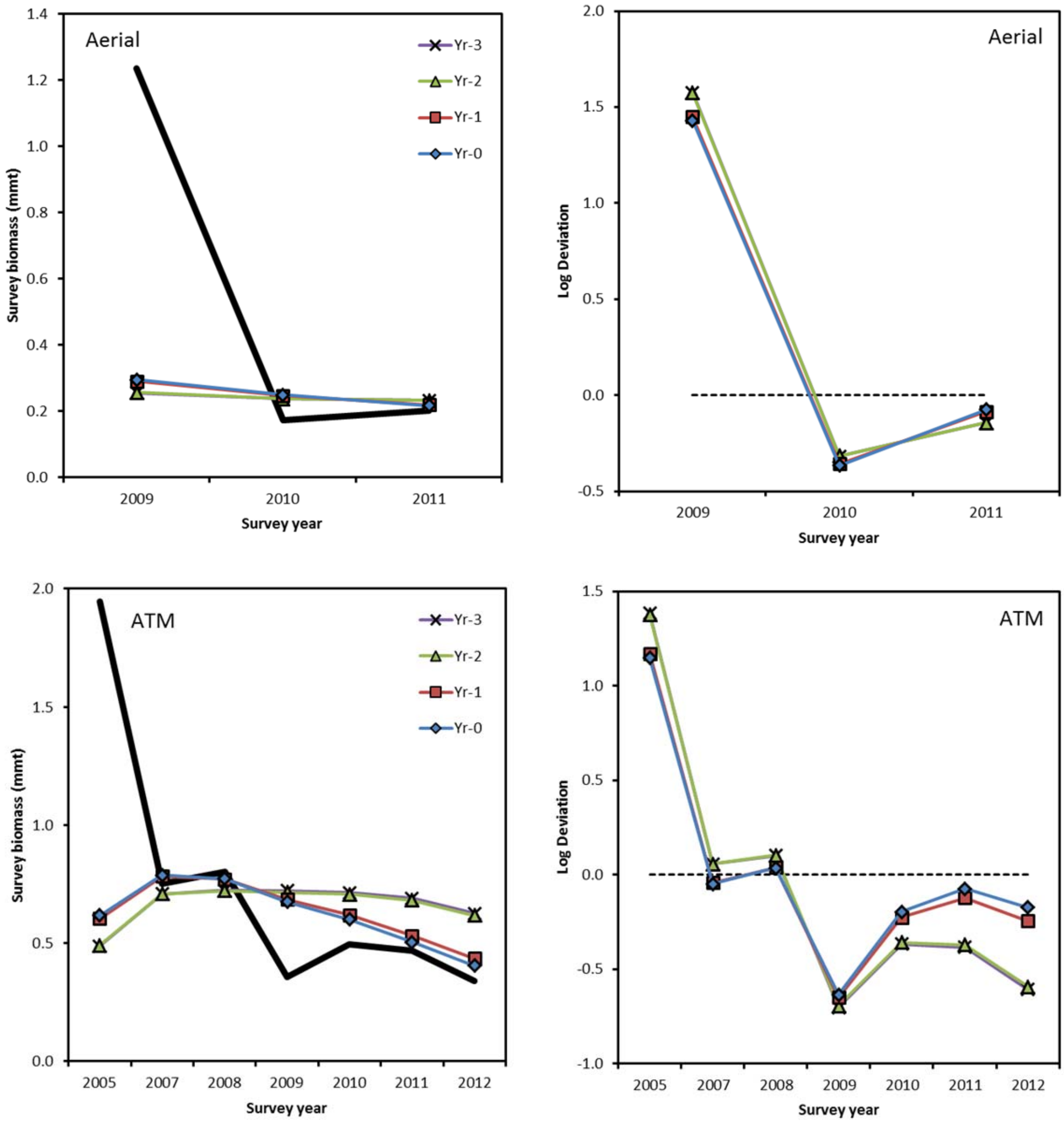

Figure 19 (cont'd). Preliminary model X6 fits to Aerial and ATM surveys for a profile on the last year for estimated recruitment deviations (end year -0, -1, -2, and -3).

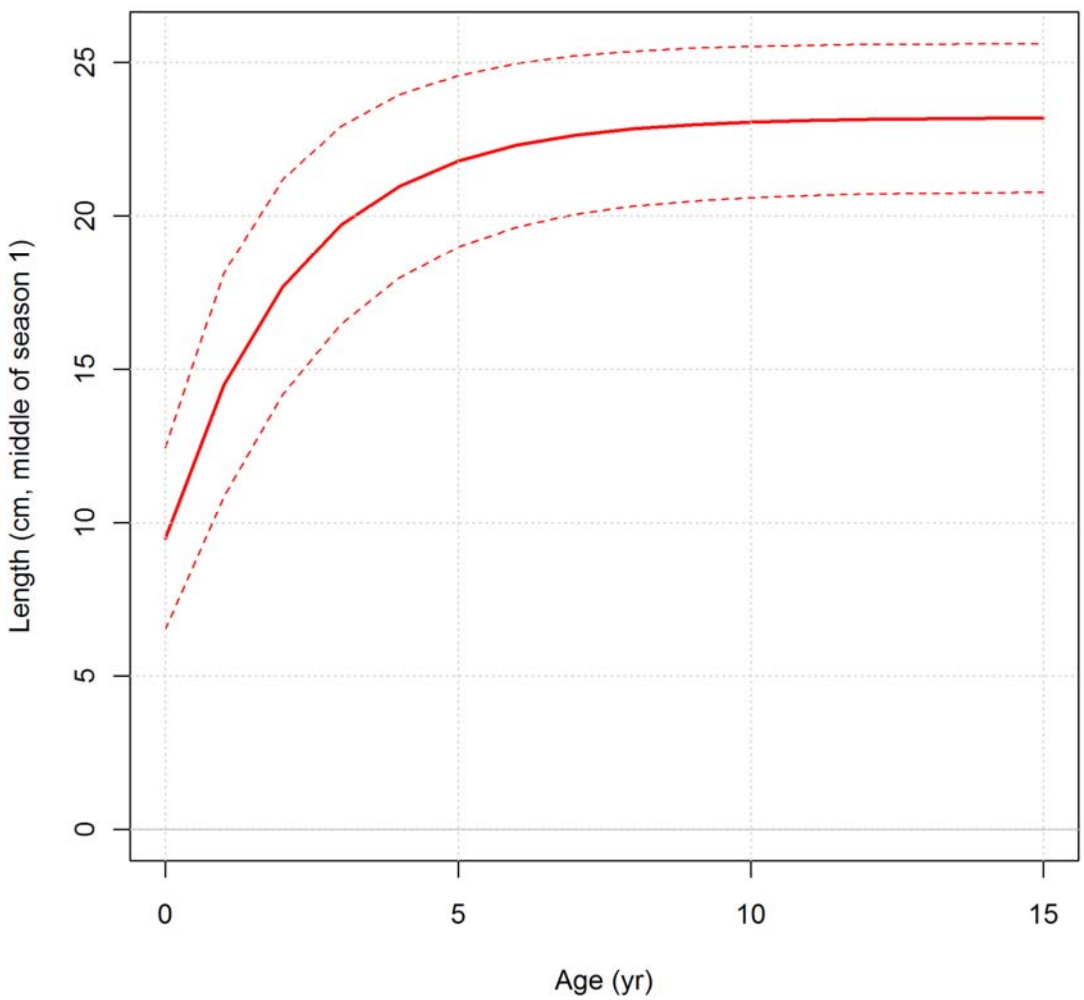

Figure 20. Length-at-age as estimated in model X6b ($L_{0.5yr}$ = 11.0, L_{∞} = 23.2, K = 0.454).

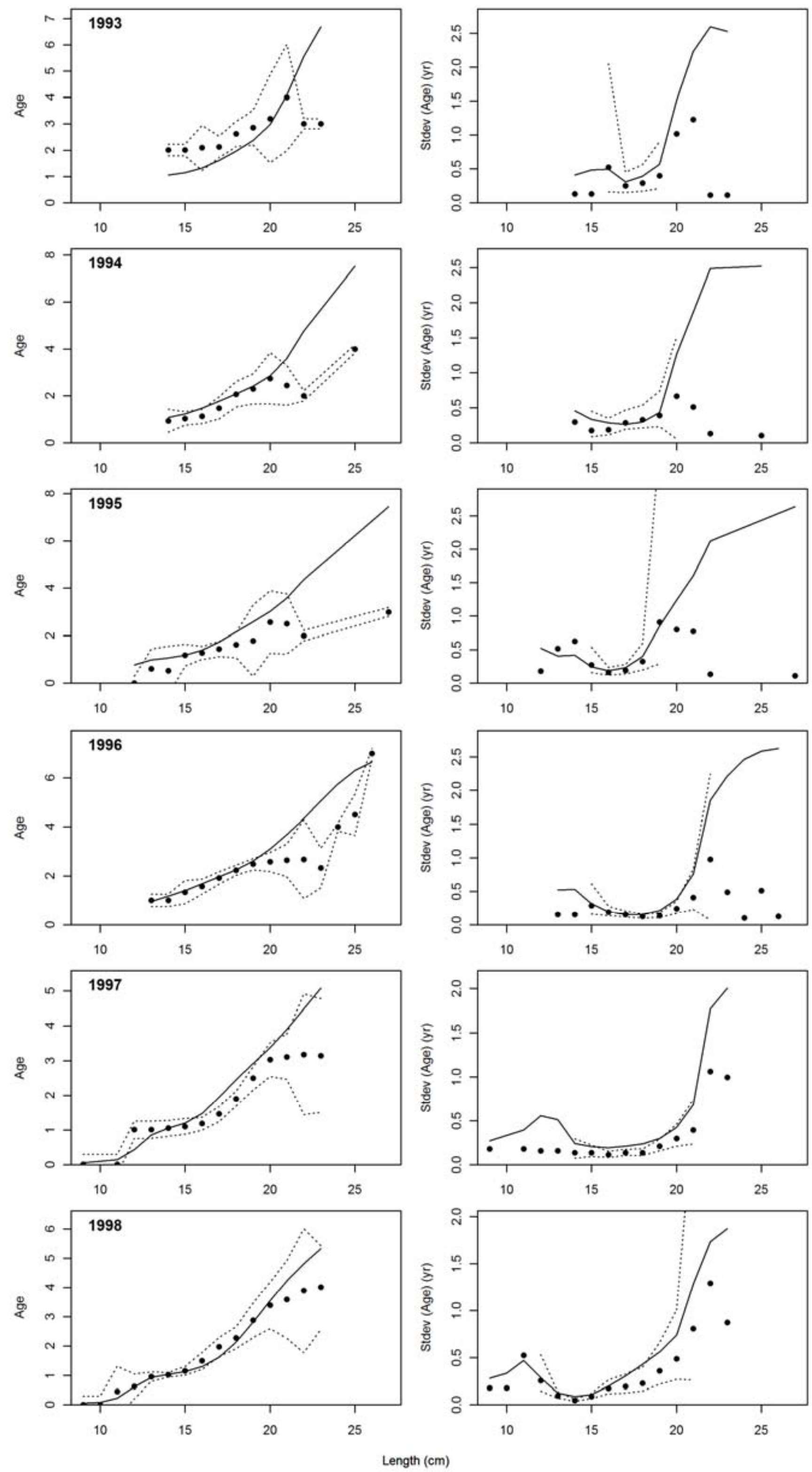

Figure 21. Model X6e fit to conditional age-at-length data, MexCal_S1, 1993-1998.

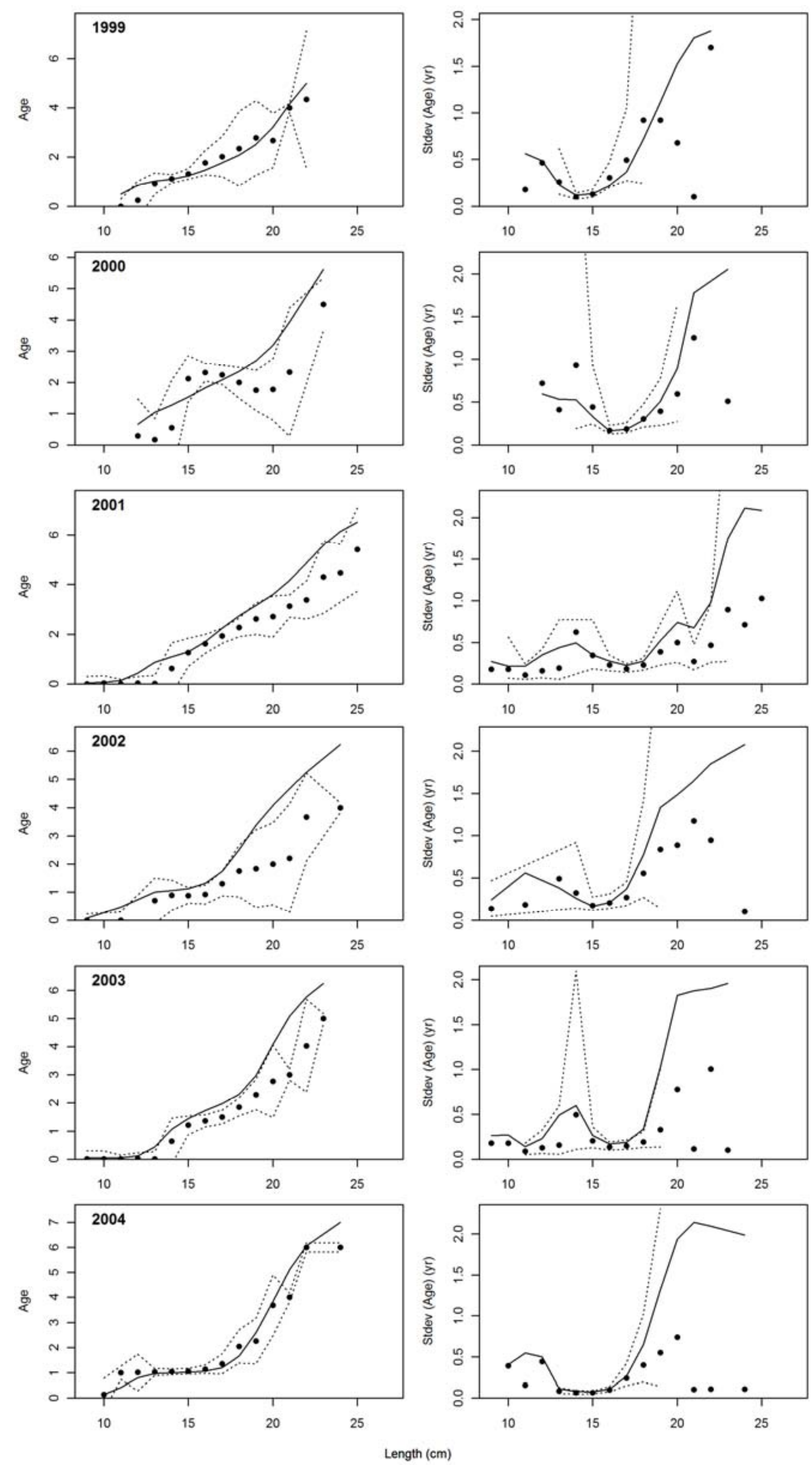

Figure 21 (cont'd). Model X6e fit to conditional age-at-length data, MexCal_S1, 1999-2004.

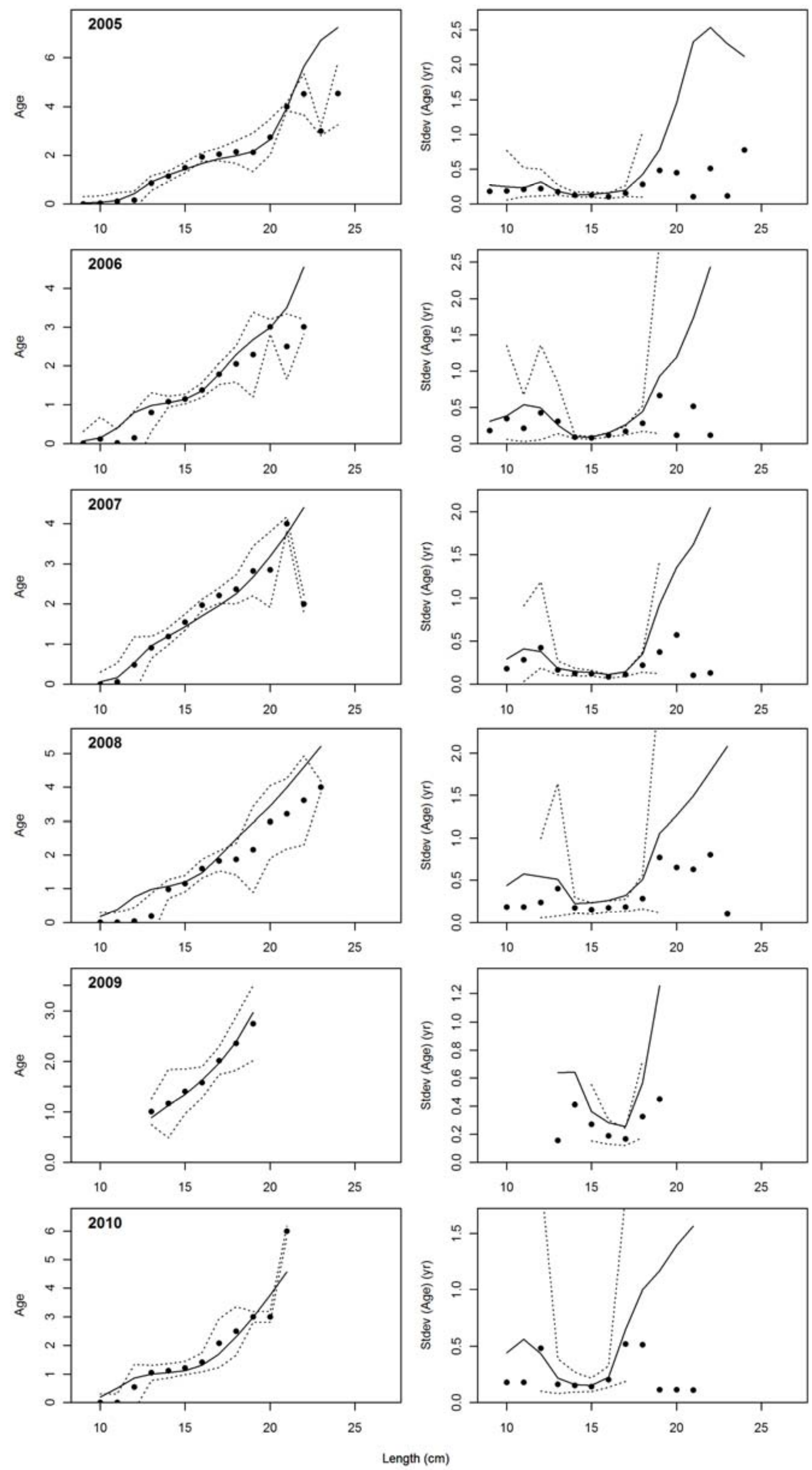

Figure 21 (cont'd). Model X6e fit to conditional age-at-length data, MexCal_S1, 2005-2010.

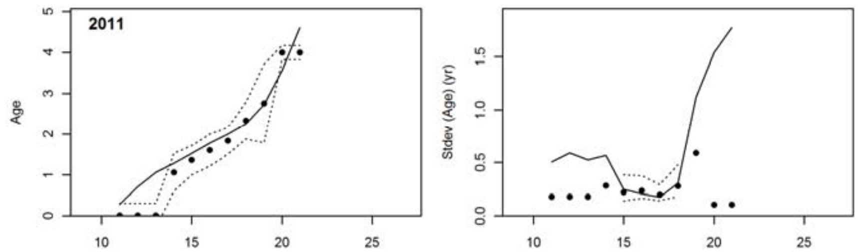

Figure 21 (cont'd). Model X6e fit to conditional age-at-length data, MexCal_S1, 2011.

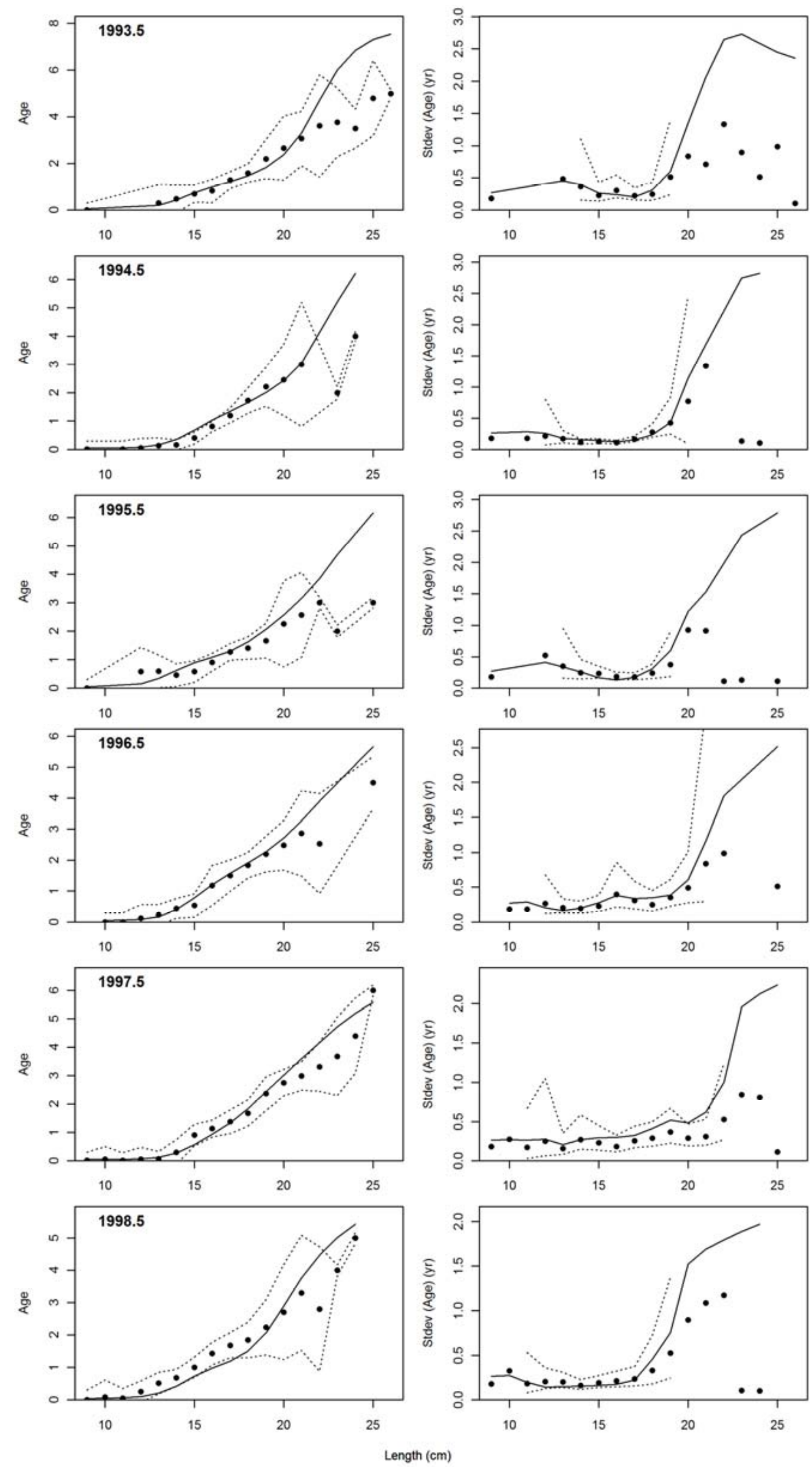

Figure 22. Model X6e fit to conditional age-at-length data, MexCal_S2, 1993-1998.

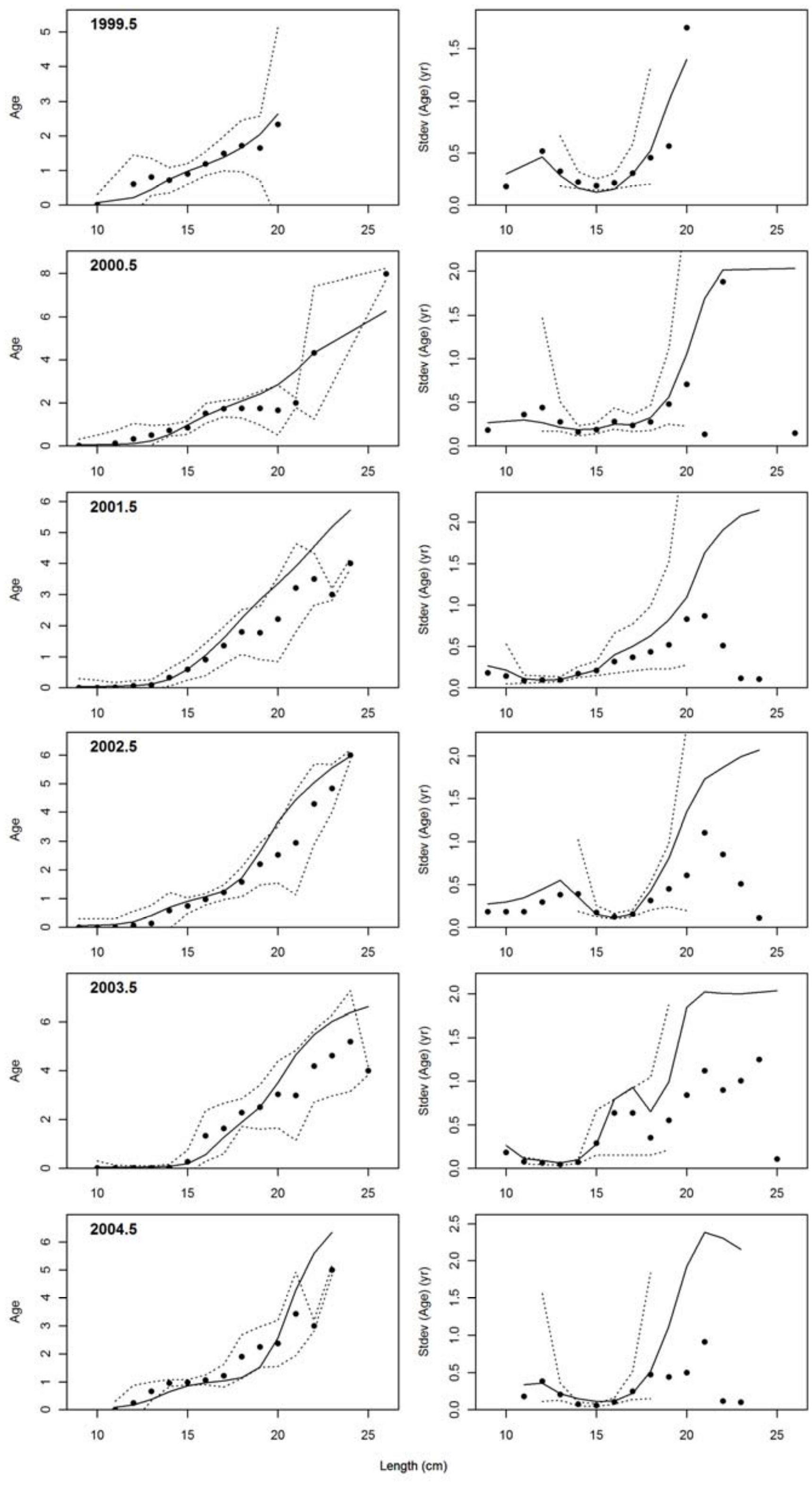

Figure 22 (cont'd). Model X6e fit to conditional age-at-length data, MexCal_S2, 1999-2004.

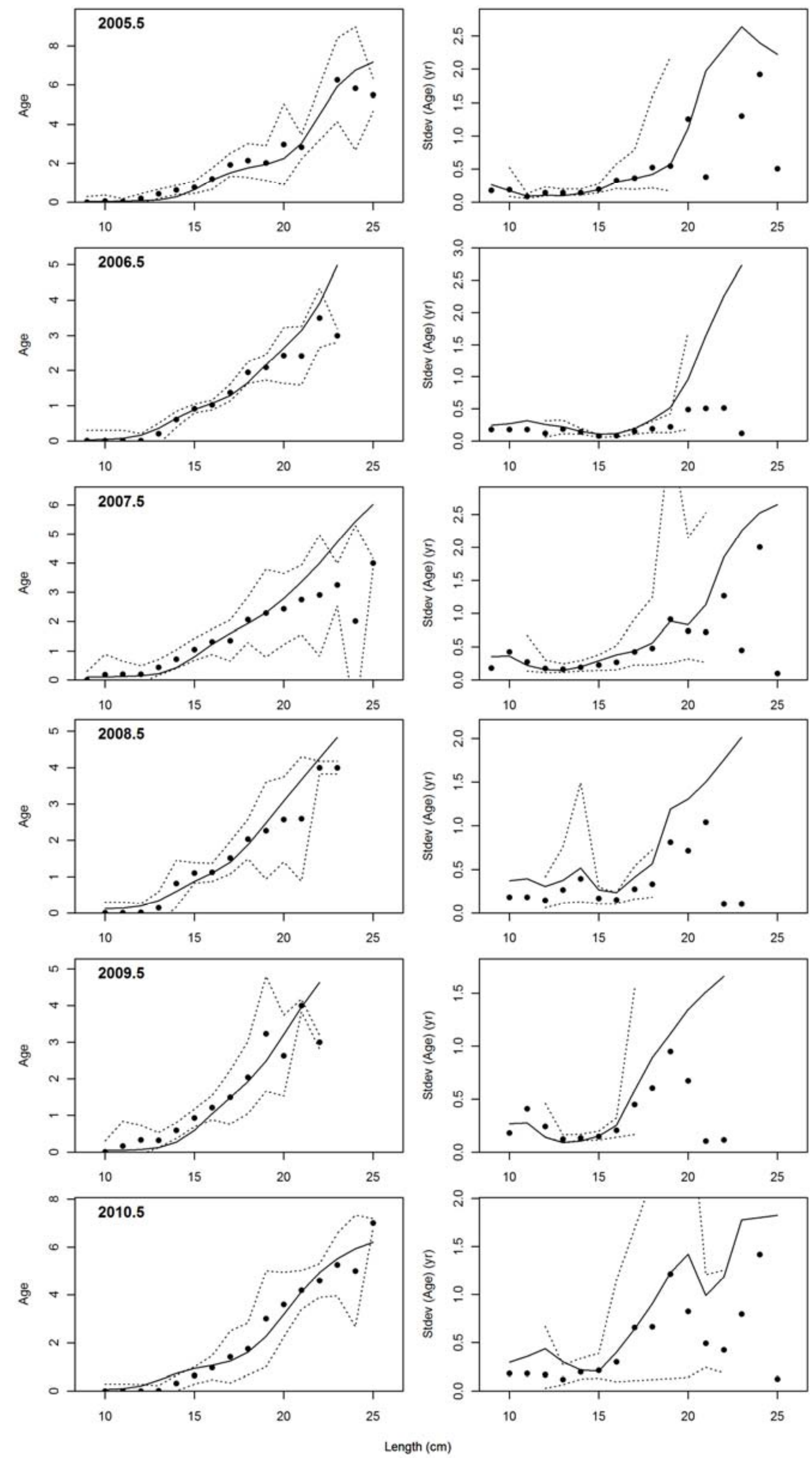

Figure 22 (cont'd). Model X6e fit to conditional age-at-length data, MexCal_S2, 2005-2010.

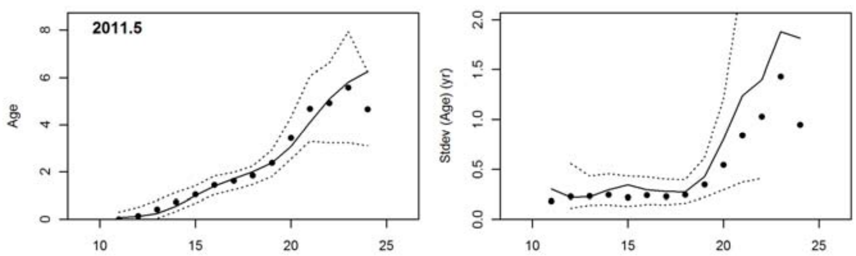

Figure 22 (cont'd). Model X6e fit to conditional age-at-length data, MexCal_S2, 2011.

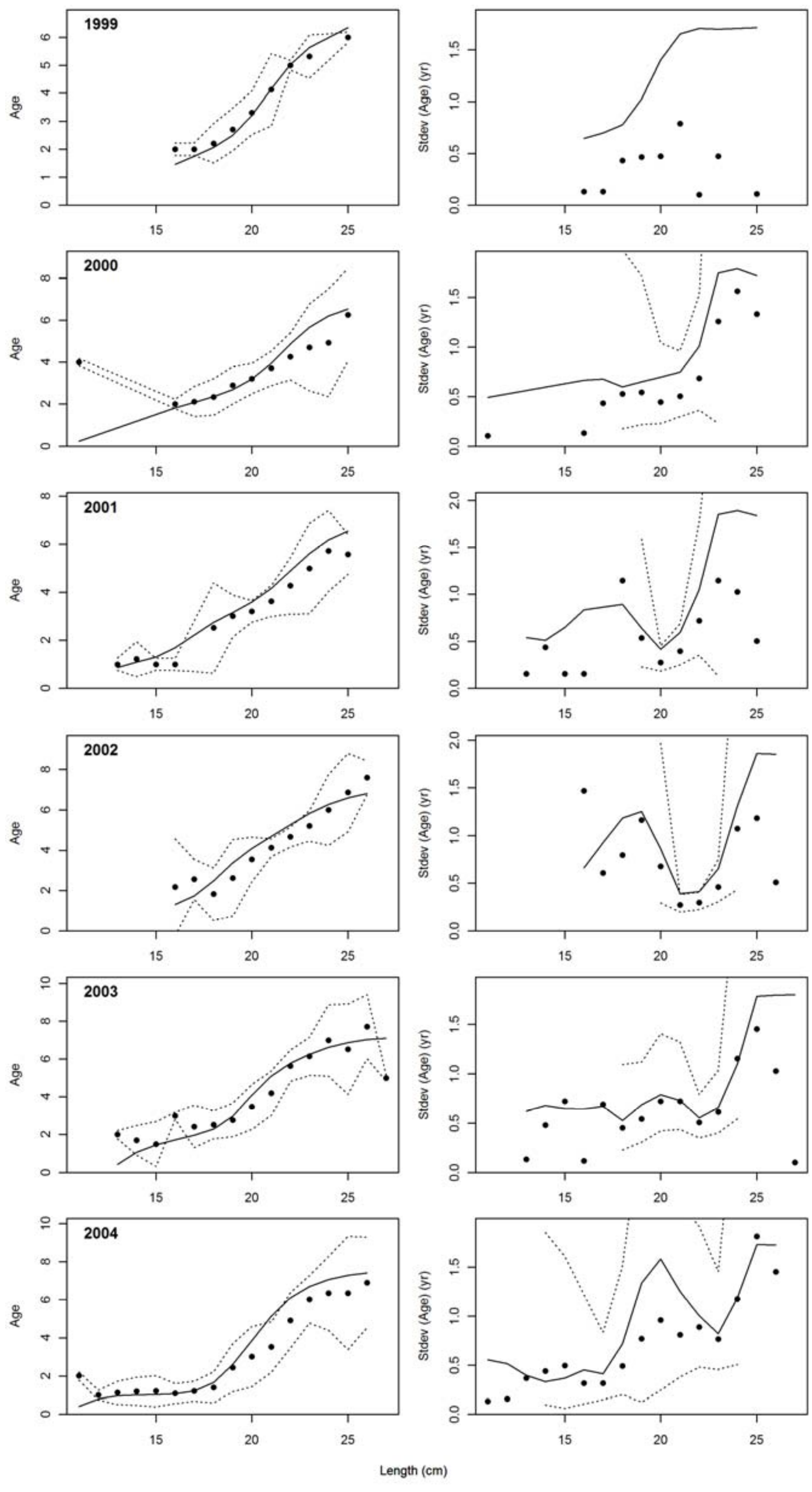

Figure 23. Model X6e fit to conditional age-at-length data, PacNW, 1999-2004.

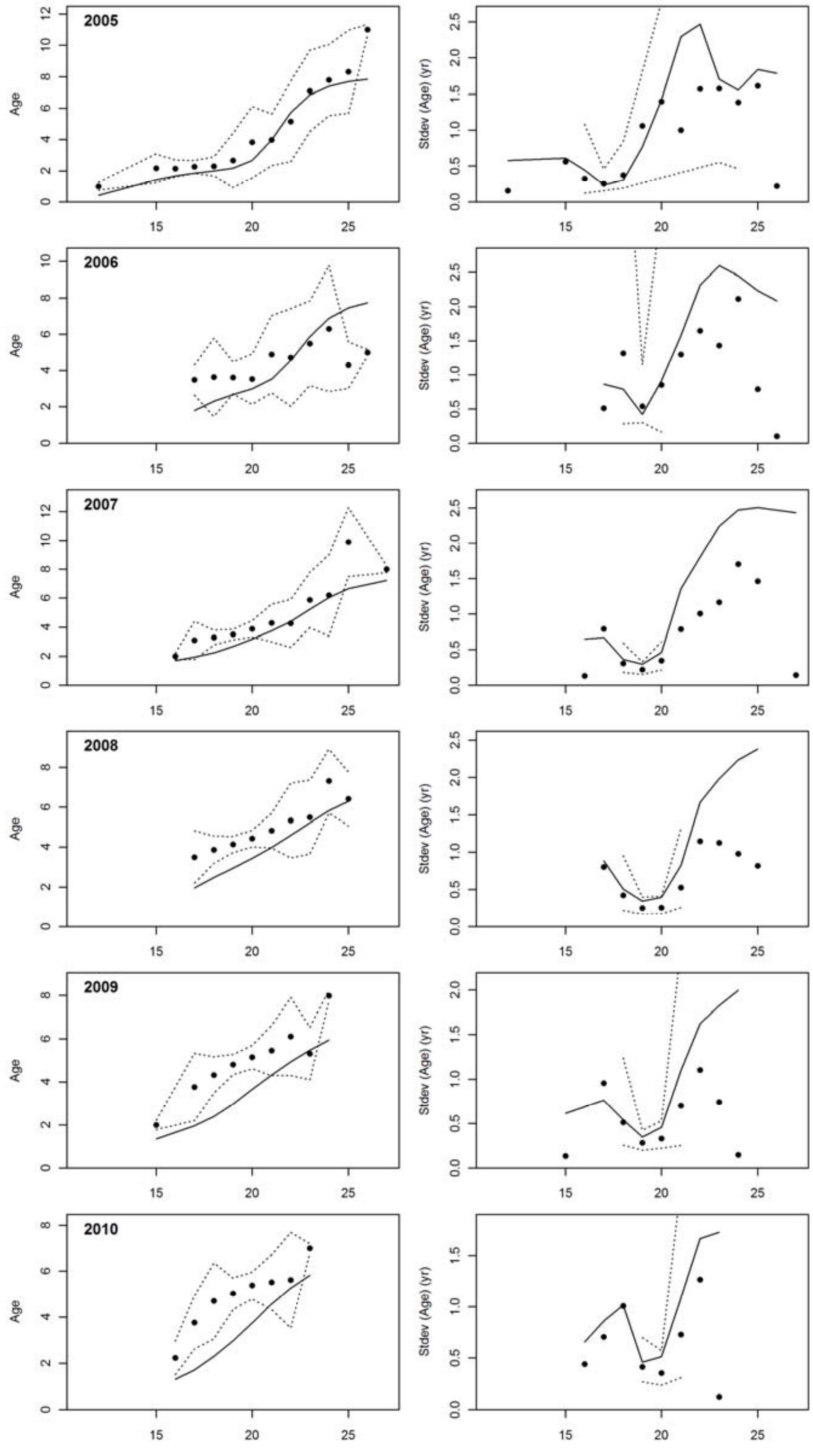

Figure 23 (cont'd). Model X6e fit to conditional age-at-length data, PacNW, 2005-2010.

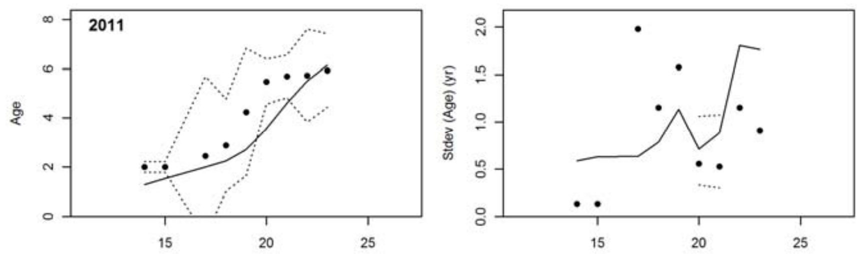

Figure 23 (cont'd). Model X6e fit to conditional age-at-length data, PacNW, 2011.

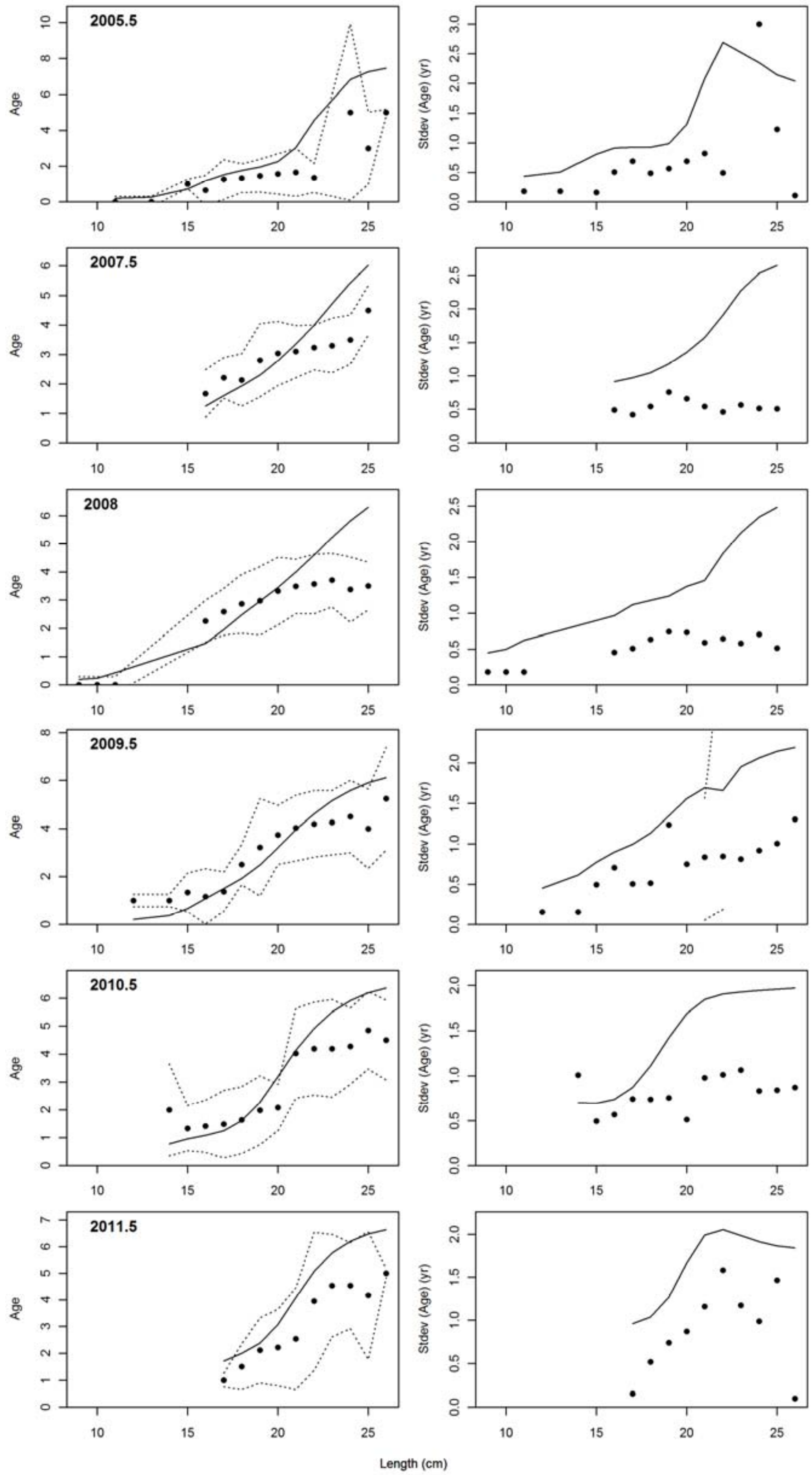

Figure 24. Model X6e fit to conditional age-at-length data, Acoustic survey, 2005-2011.

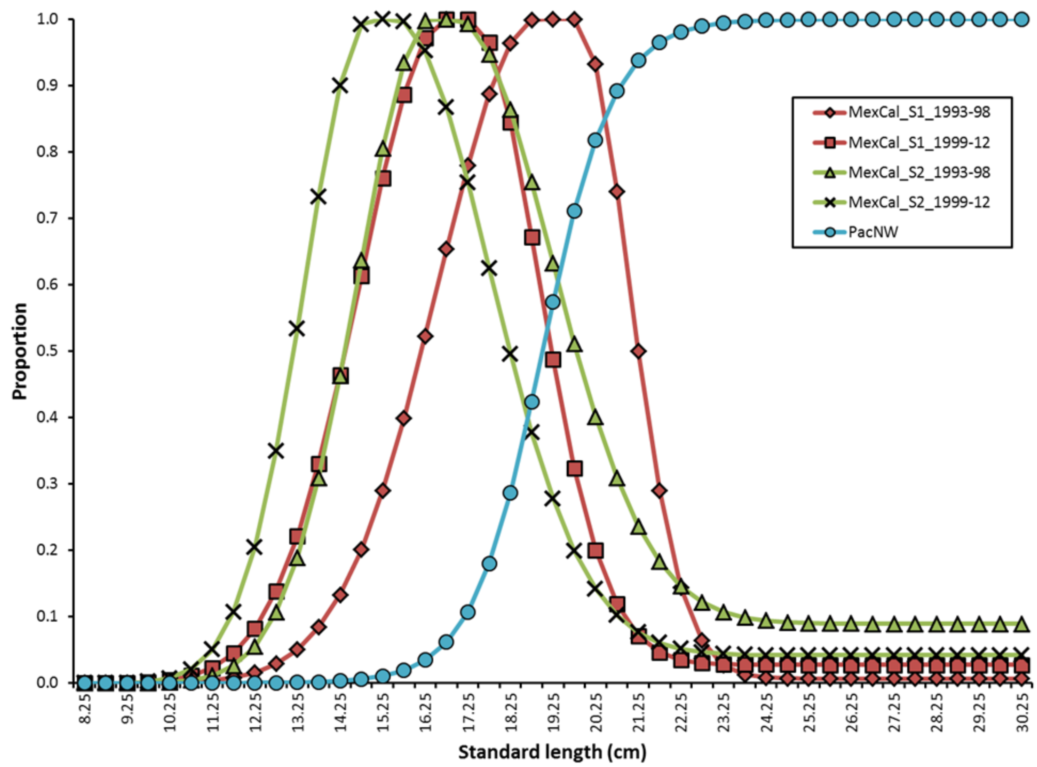

Figure 25a. Fishery length selectivities estimated in model X6e.

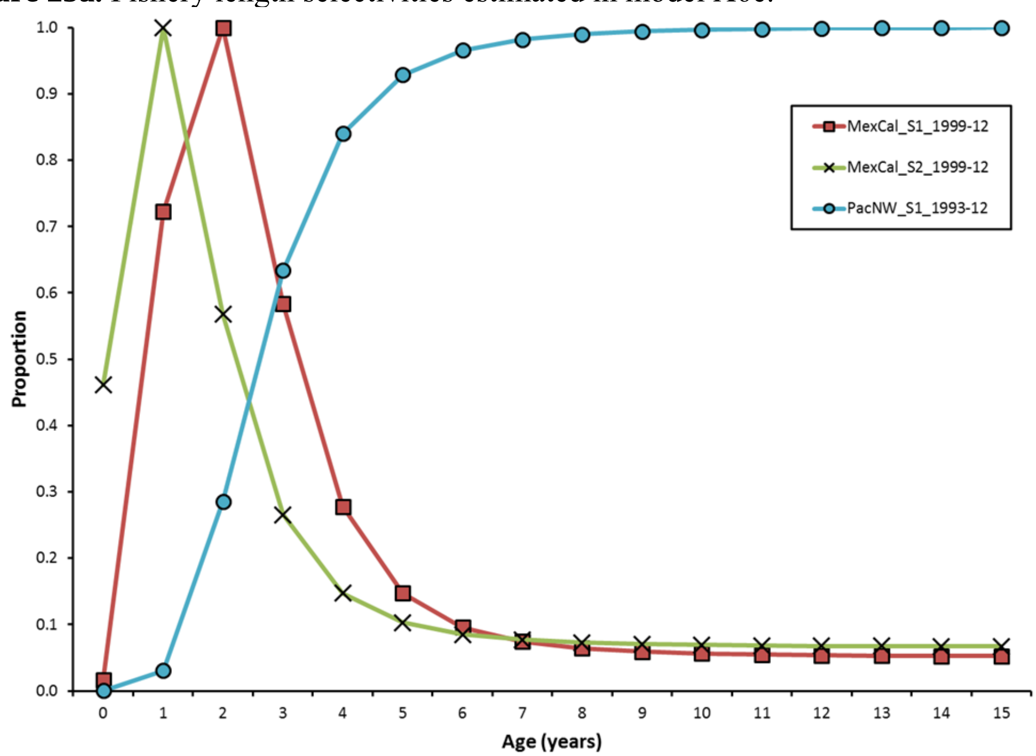

Figure 25b. Terminal period fishery age selectivities implied by the product of length selectivity and the ALK.

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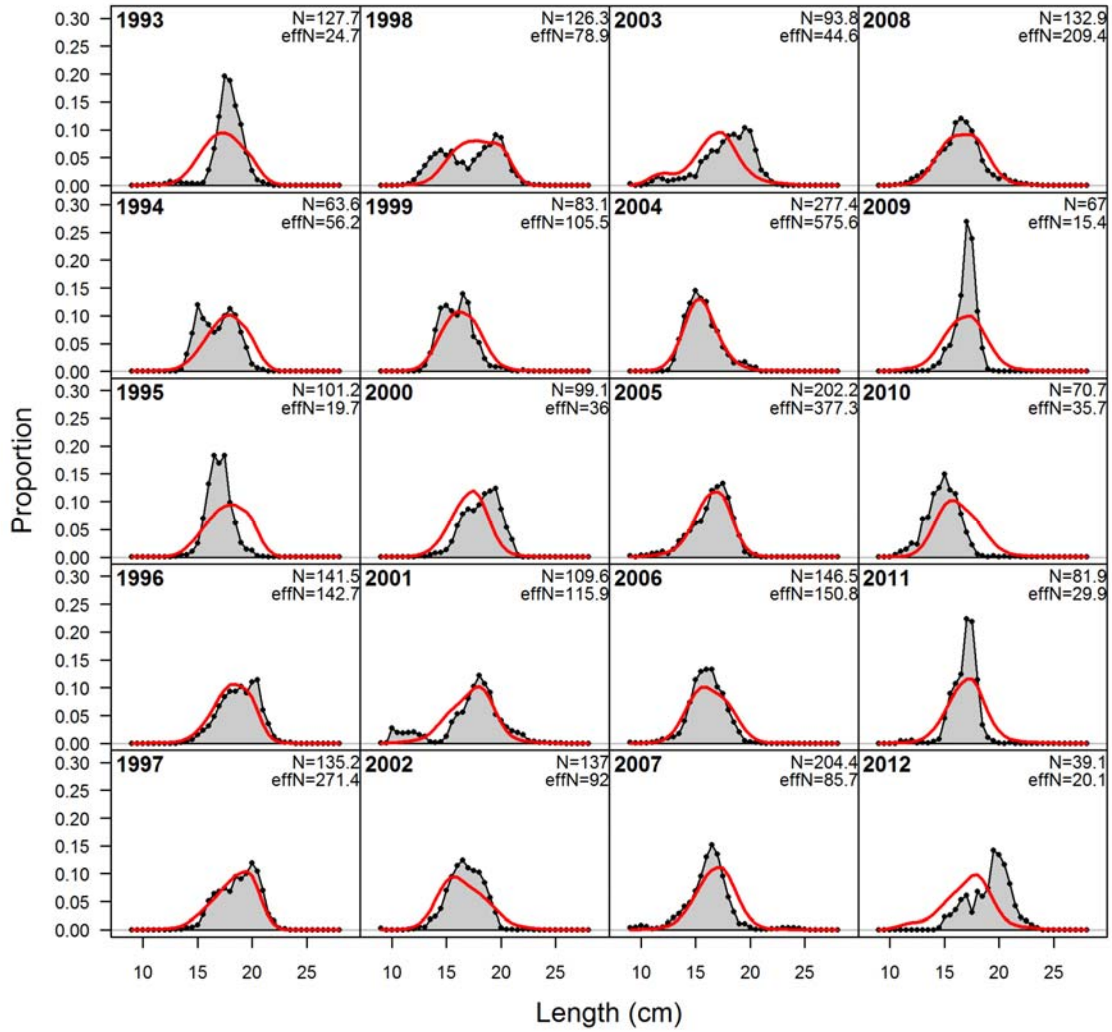

Figure 26a. Model X6e fits to MexCal_S1 length-frequency data (Season 1).

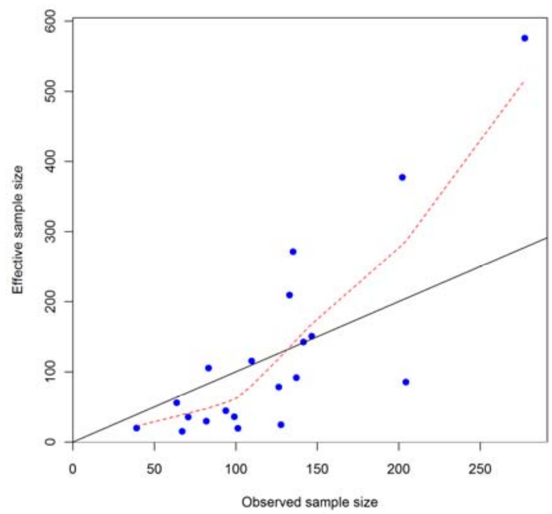

Figure 26b. Observed and effective sample sizes for MexCal_S1 length-frequencies.

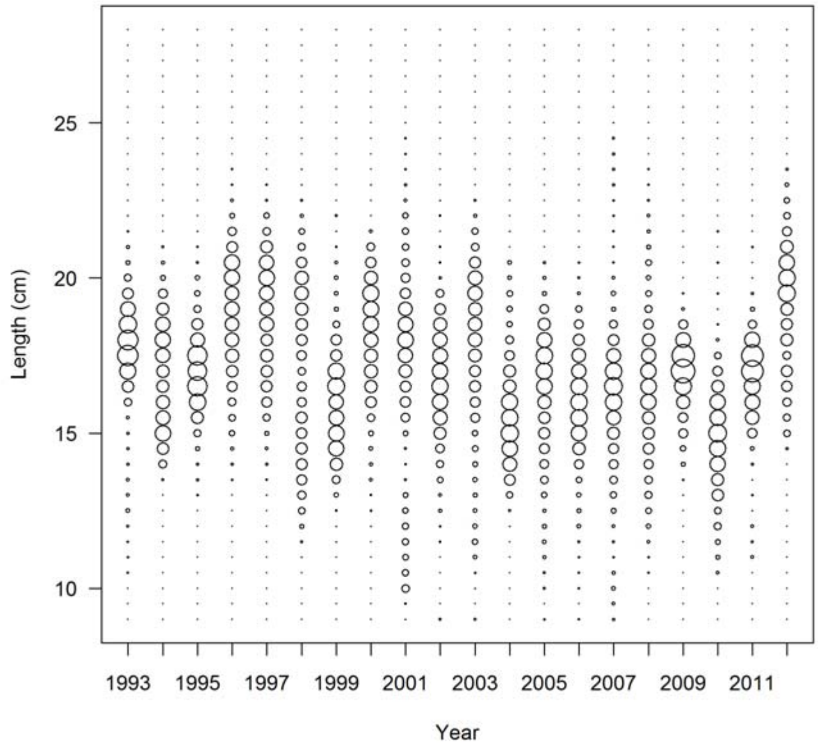

Figure 26c. Bubble plot of MexCal_S1 length-frequency data (Season 1).

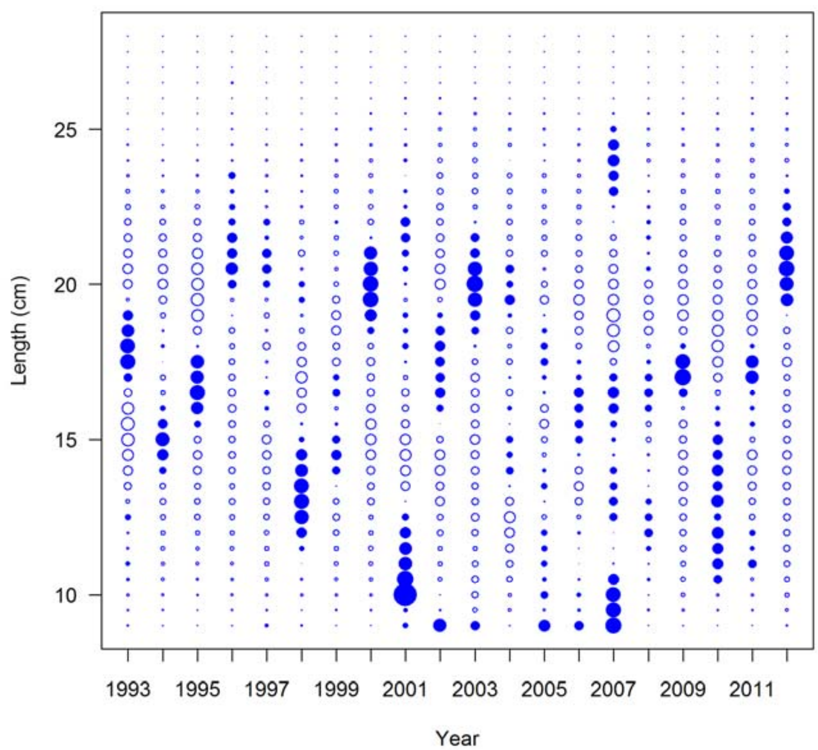

Figure 26d. Pearson residuals (max=9.01) for model X6b fit to MexCal_S1 length-frequencies.

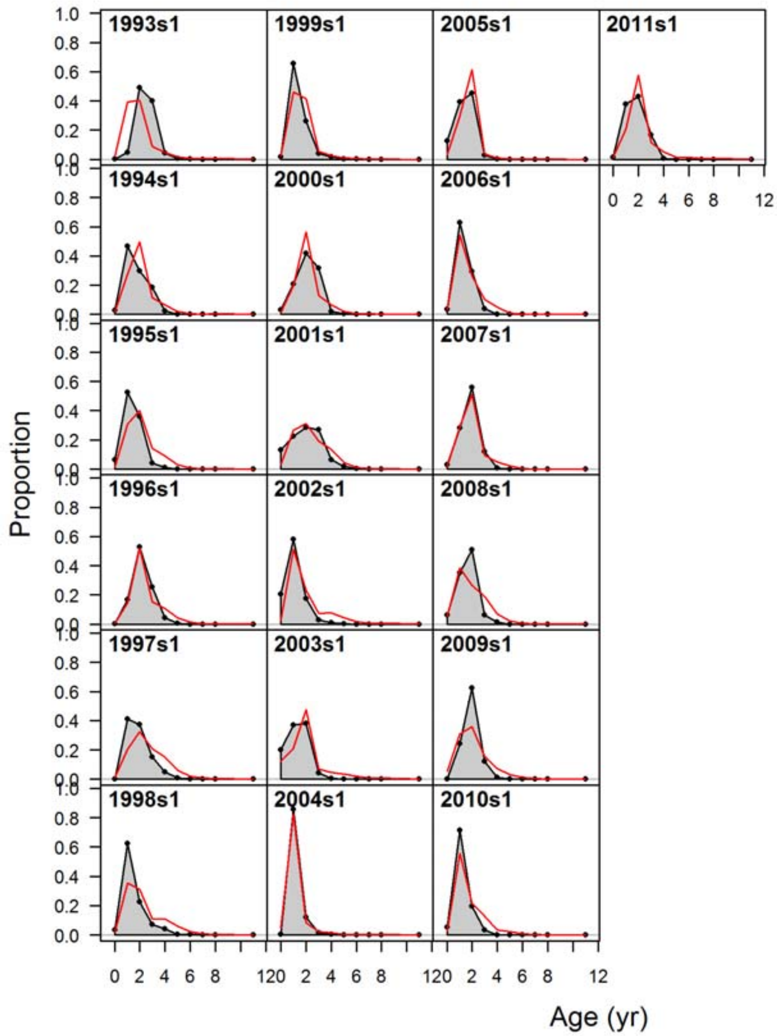

Figure 27a. Model X6e fits to MexCal_S1 implied age-frequency data (Season 1).

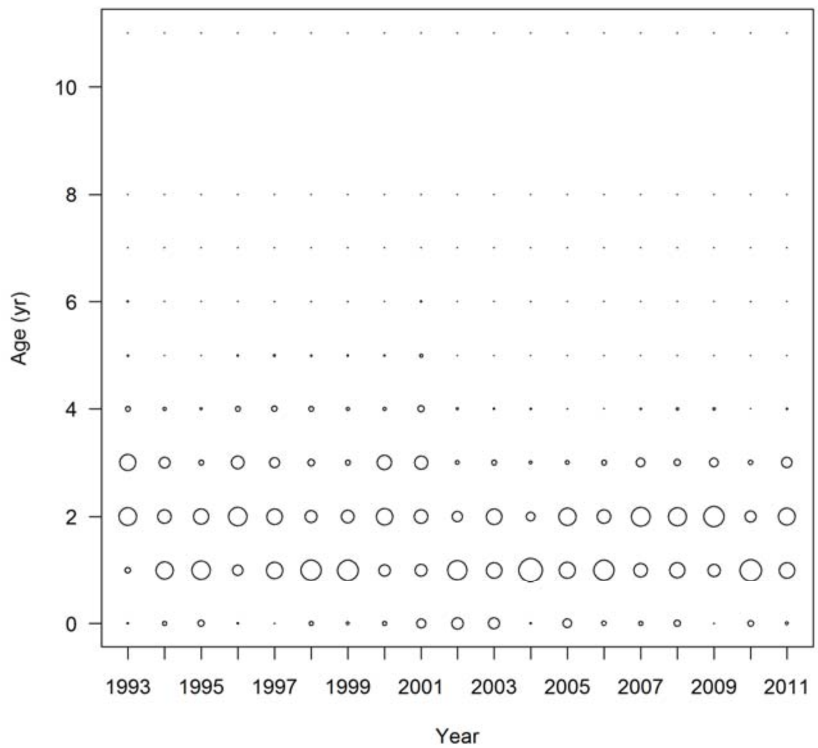

Figure 27b. Bubble plot of MexCal_S1 implied age-frequency data (Season 1).

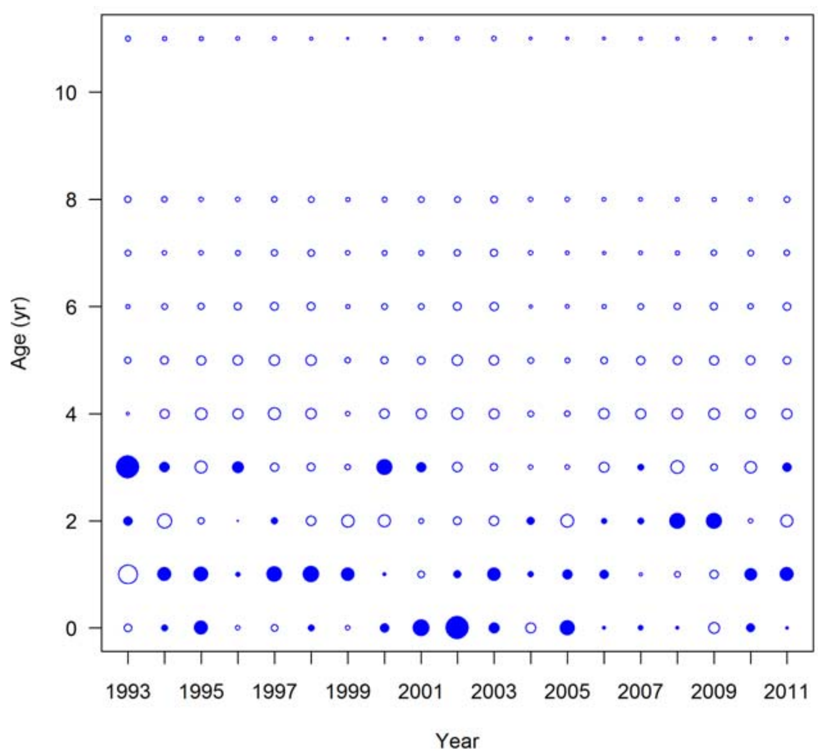

Figure 27c. Pearson residuals (max=1.12) for model X6e fit to MexCal_S1 implied age-frequencies.

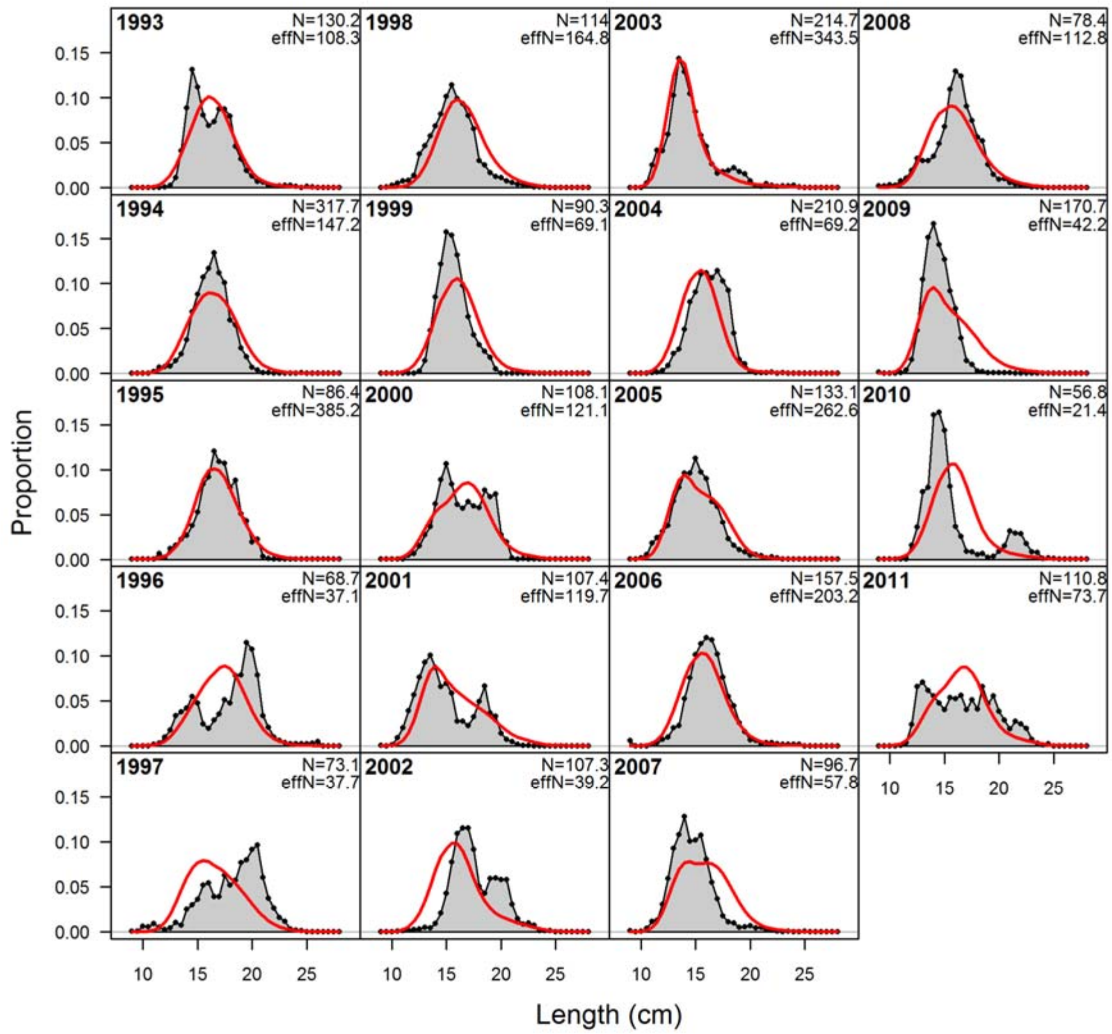

Figure 28a. Model X6e fits to MexCal_S2 length-frequency data (Season 2).

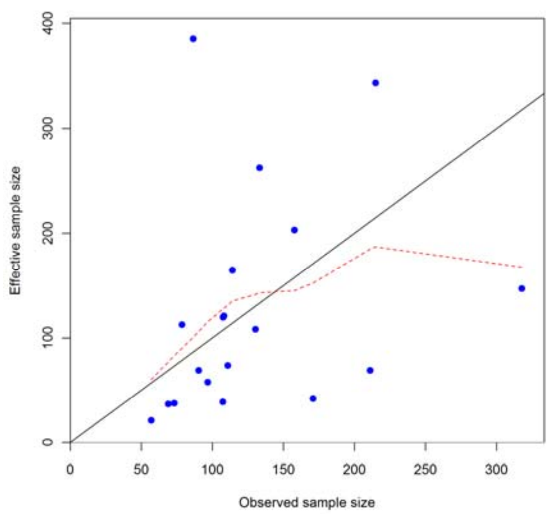

Figure 28b. Observed and effective sample sizes for MexCal_S2 fishery length-frequencies (X6e).

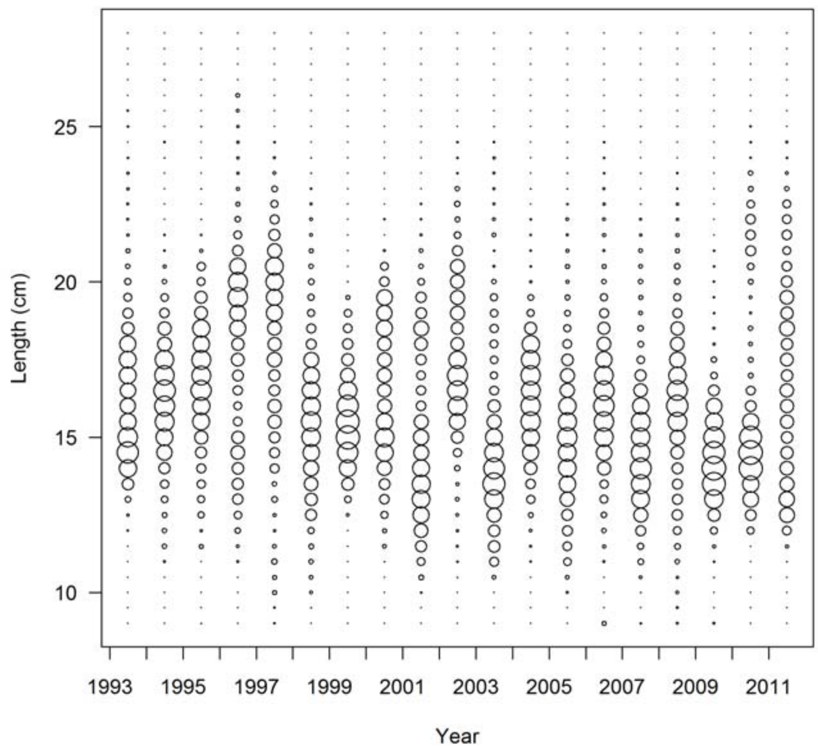

Figure 28c. Bubble plot of MexCal_S2 length-frequency data (Season 2).

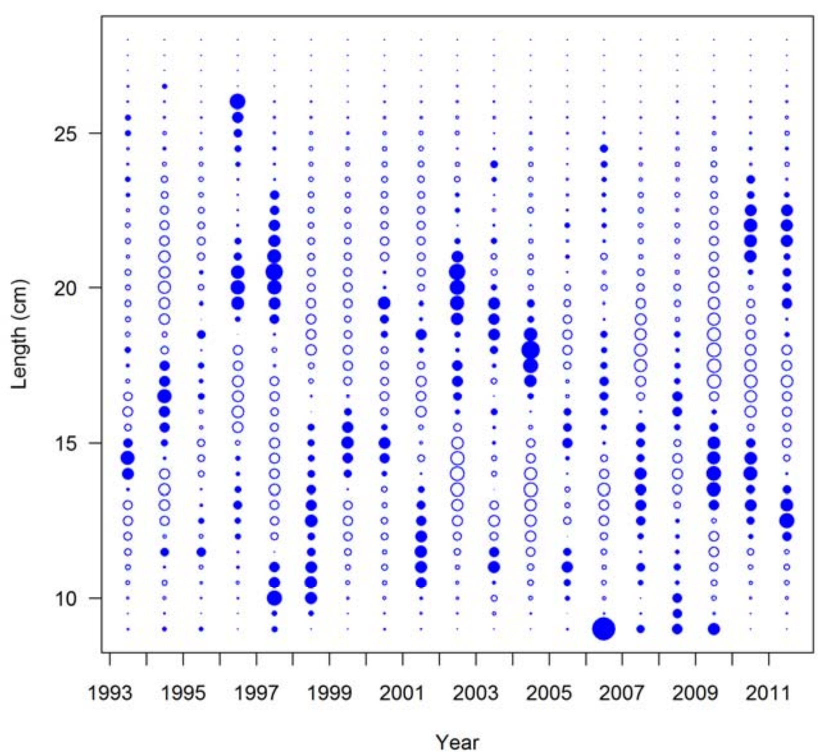

Figure 28d. Pearson residuals (max=7.28) for fit to MexCal_S2 length-frequency data.

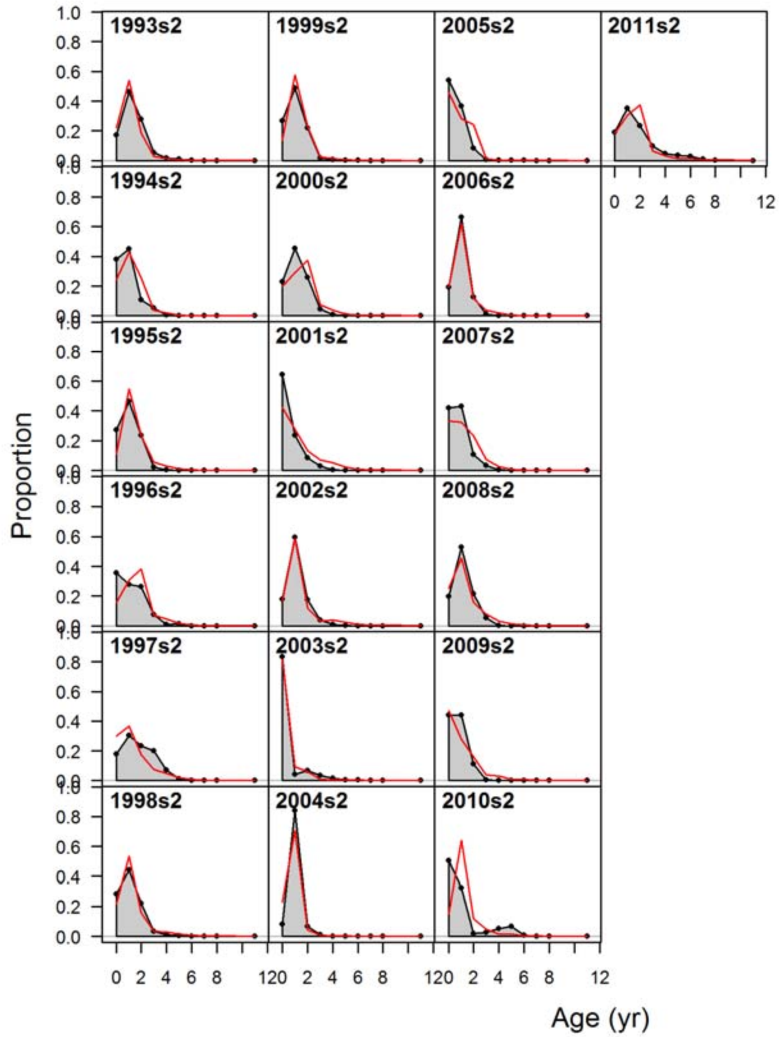

Figure 29a. Model X6e fits to MexCal_S2 implied age-frequency data (Season 2).

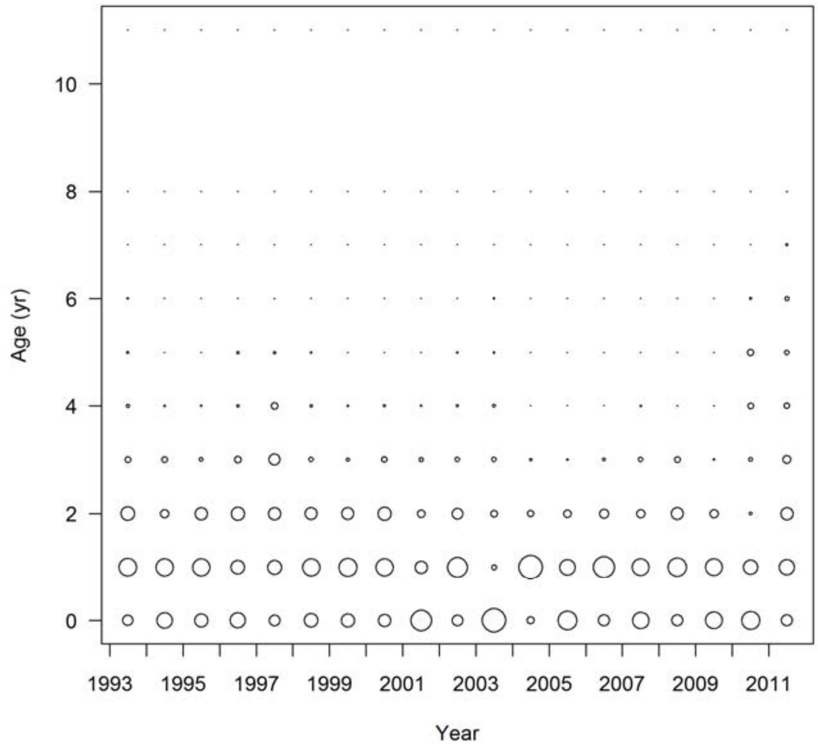

Figure 29b. Bubble plot of MexCal_S2 implied age-frequency data (Season 2).

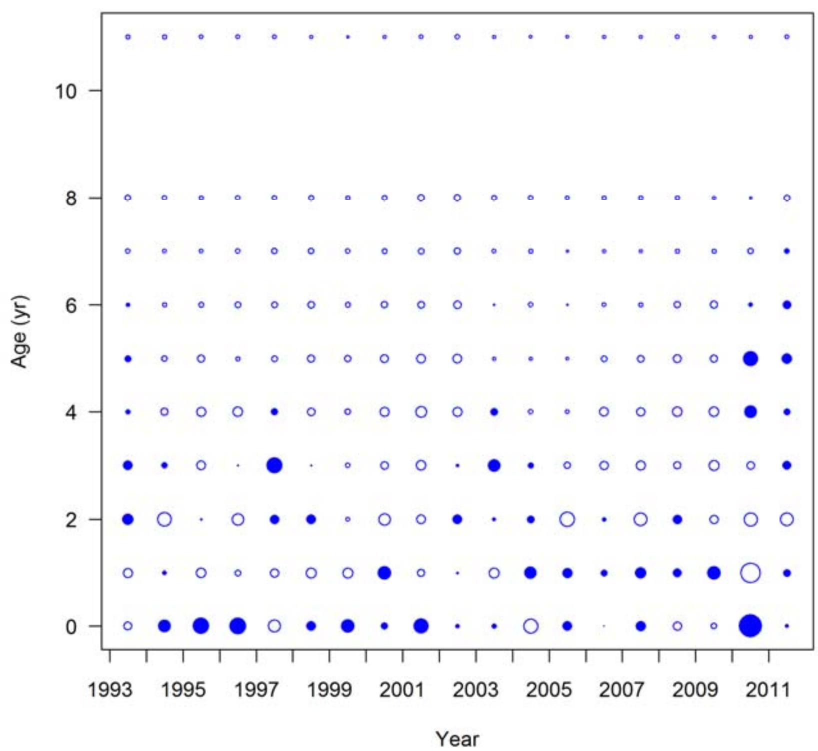

Figure 29c. Pearson residuals (max=0.99) for model X6e fit to MexCal_S2 implied age-frequency data.

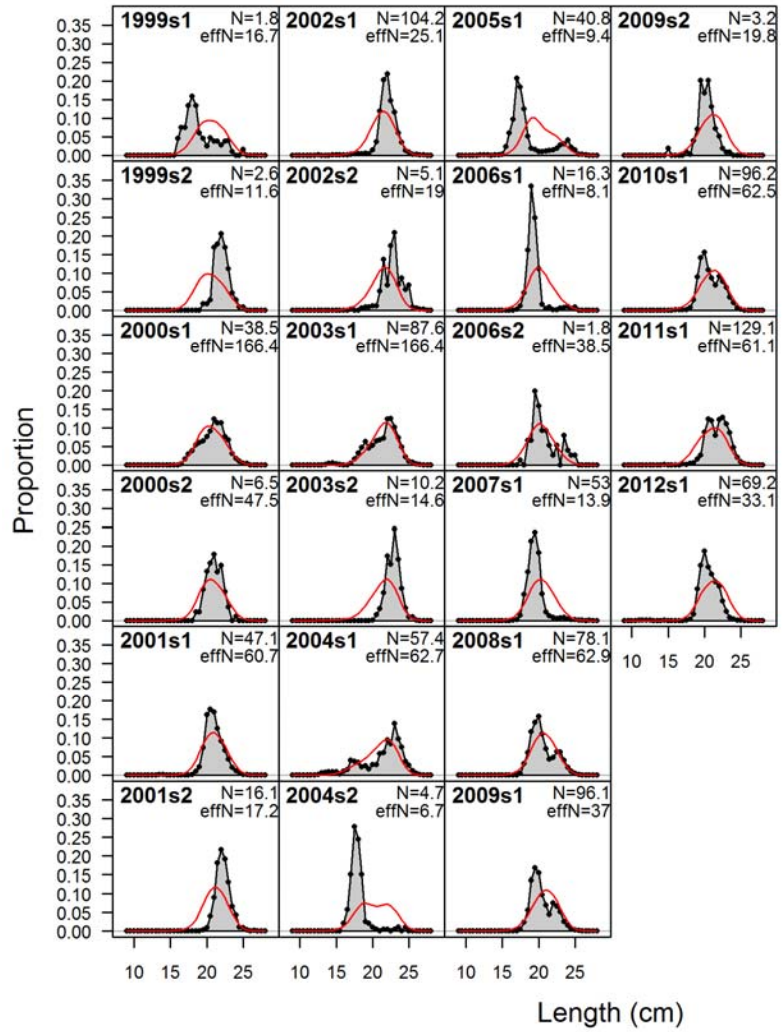

Figure 30a. Model X6e fits to PacNW length-frequency data.

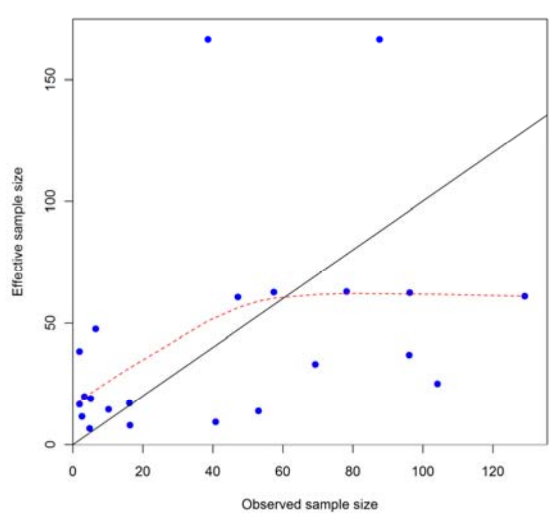

Figure 30b. Observed & effective sample sizes for PacNW fishery length-comps (X6e).

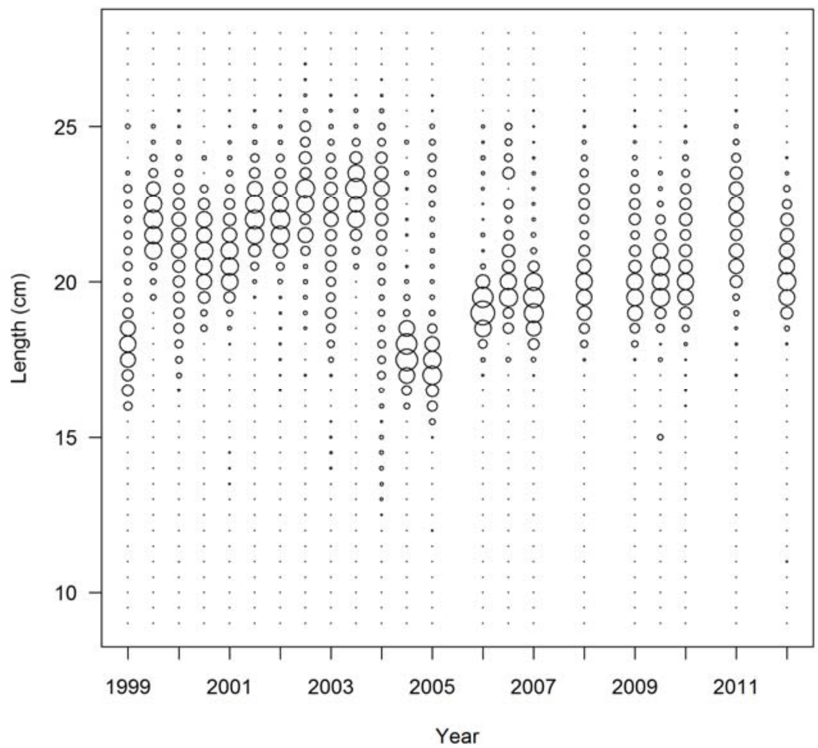

Figure 30c. Bubble plot of PacNW length-frequency data.

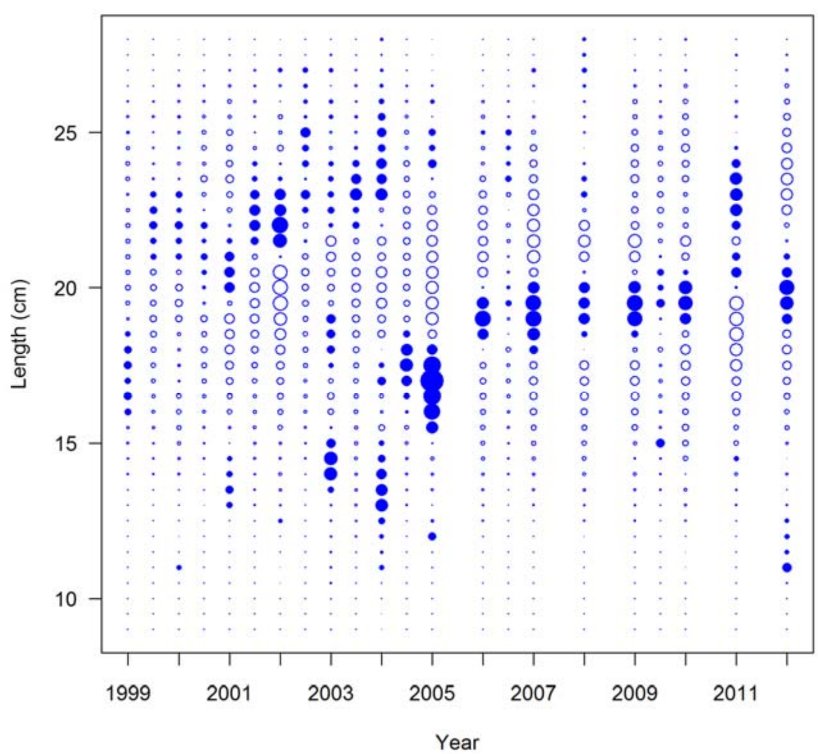

Figure 30d. Pearson residuals (max=6.78) for model X6b fit to PacNW length-frequency data.

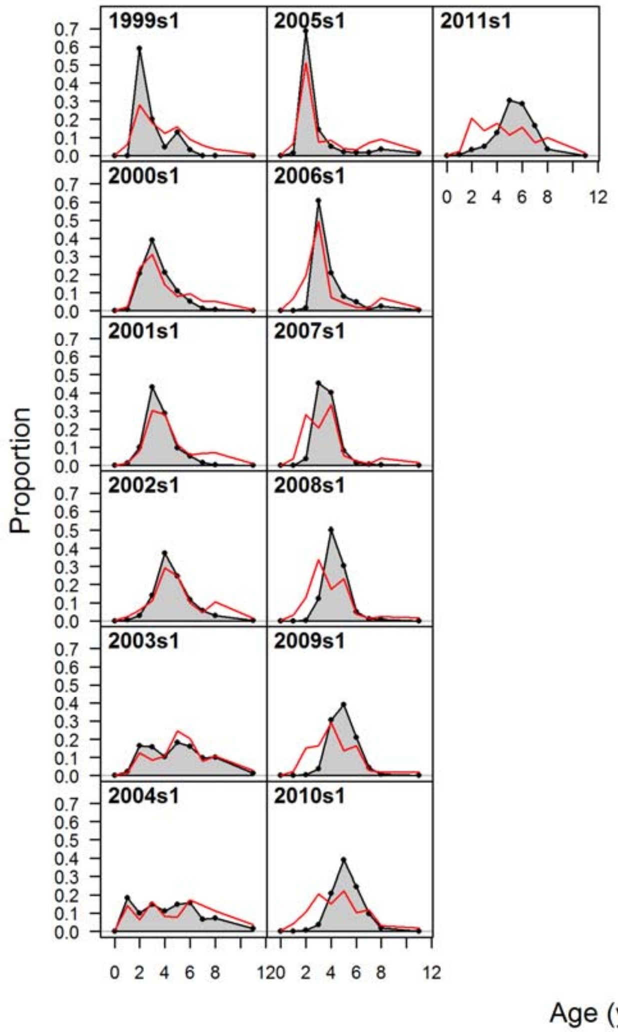

Figure 31a. Model X6e fits to implied age-frequency data for the PacNW fishery.

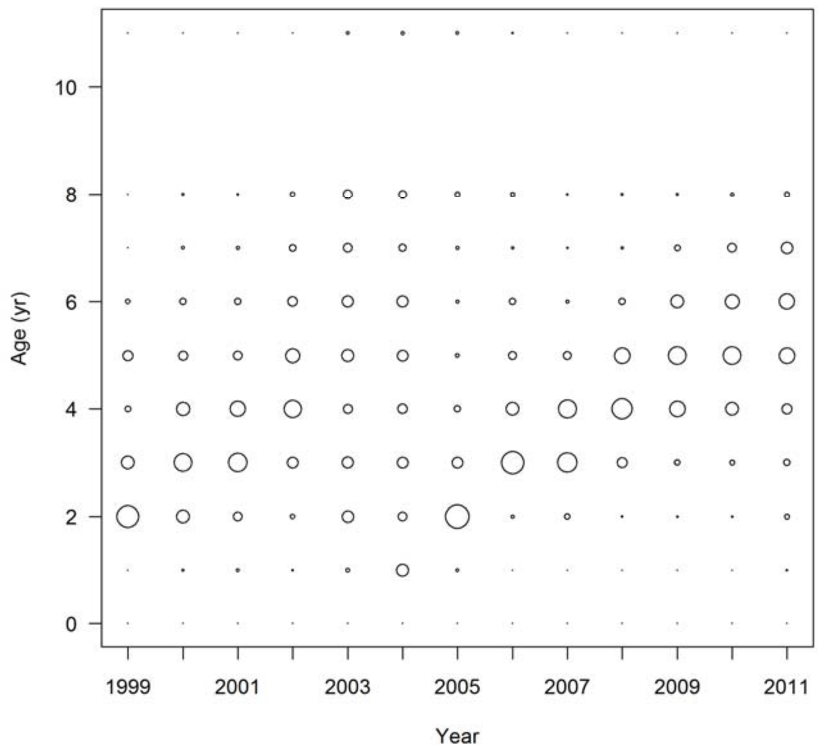

Figure 31b. Bubble plot of PacNW implied age-frequency data.

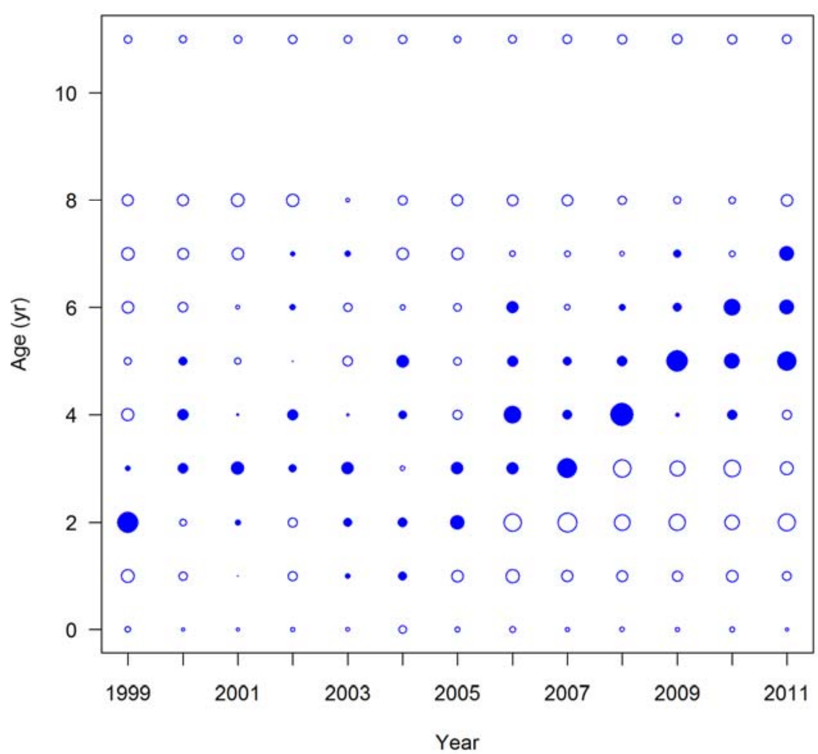

Figure 31c. Pearson residuals (max=0.86) for fit to PacNW implied age-frequency data.

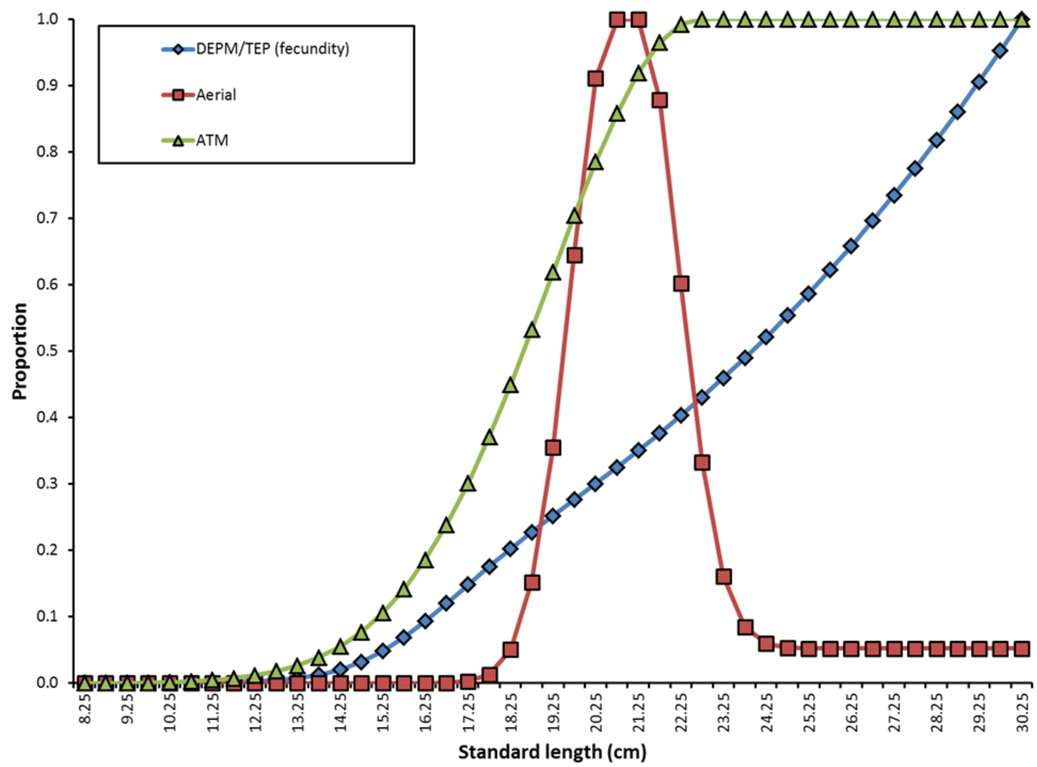

Figure 32a. Survey length selectivities estimated by model X6e.

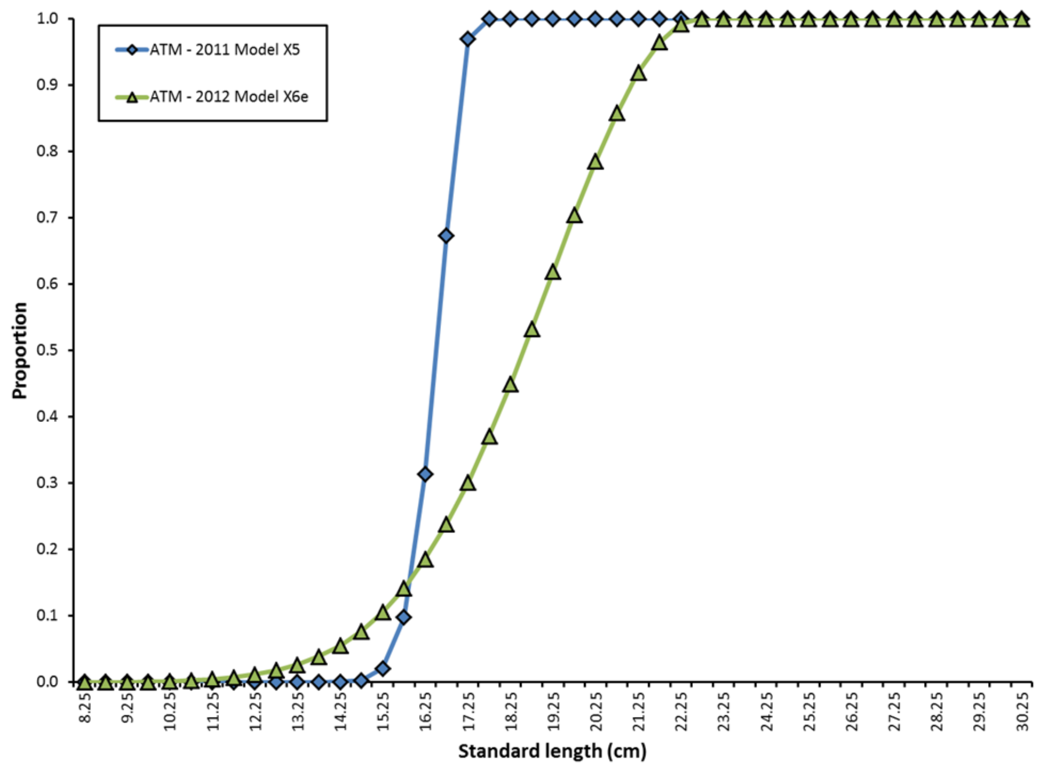

Figure 32b. ATM length selectivity estimated by 2011 model X5 and 2012 model X6e.

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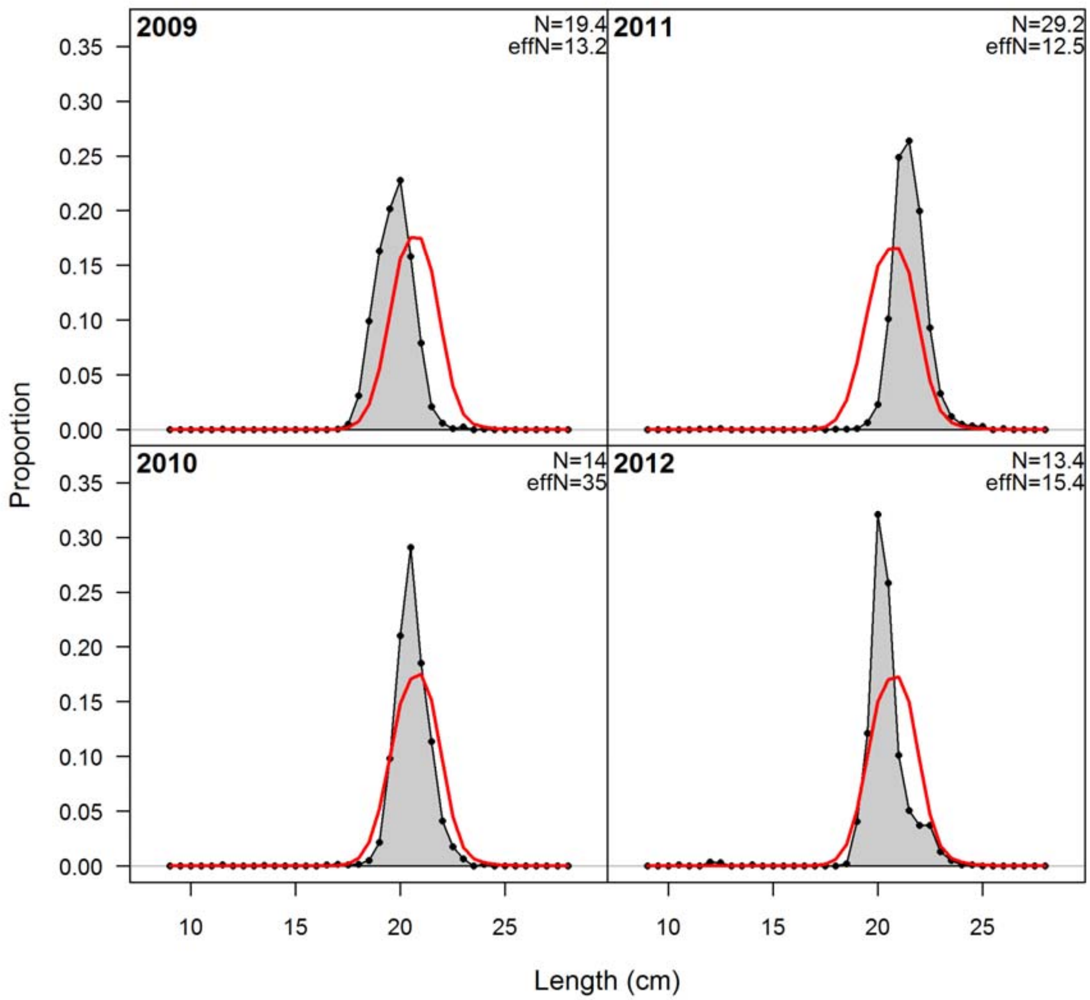


Figure 33a. Model X6e fits to Aerial survey length-frequency data.

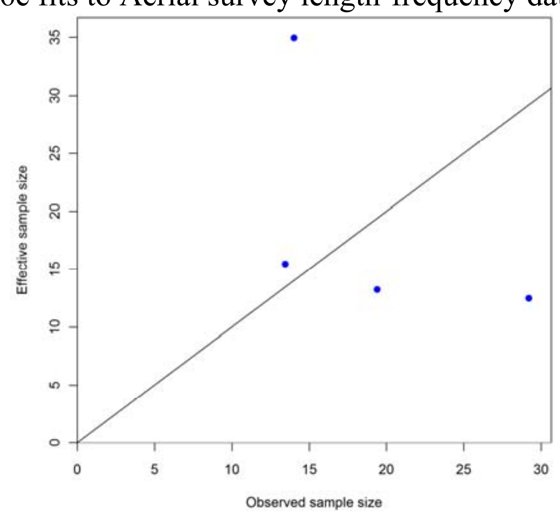


Figure 33b. Observed and effective sample sizes for Aerial survey fishery length-frequency data.

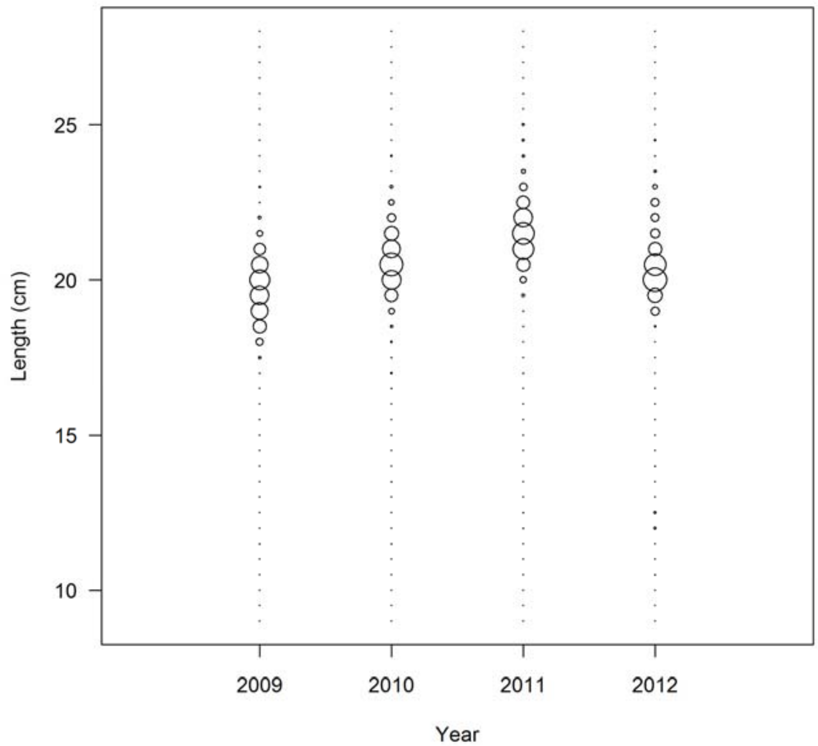


Figure 33c. Bubble plot of Aerial survey length-frequency data.

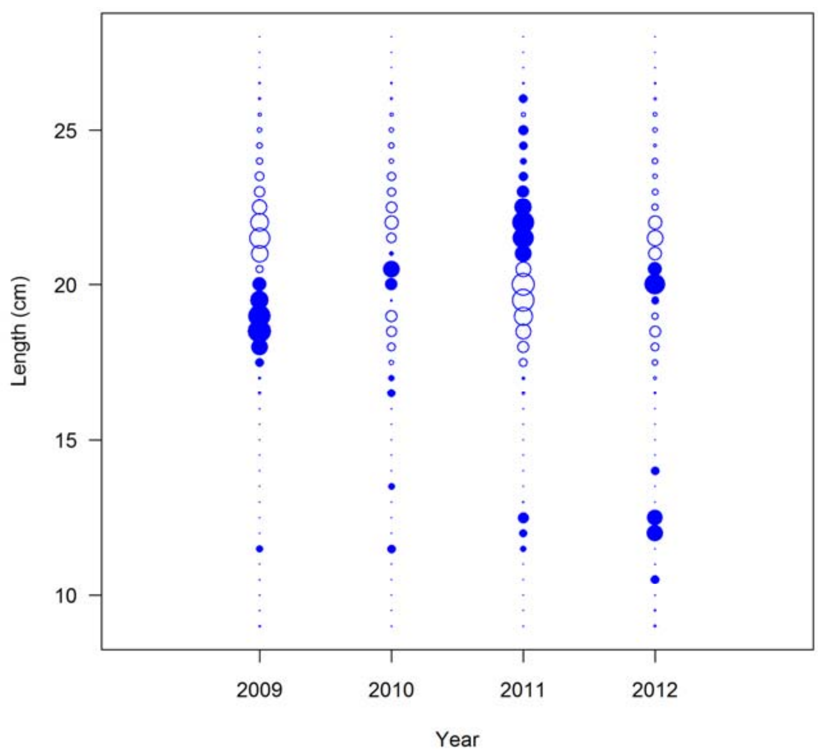


Figure 33d. Pearson residuals (max=2.25) for fit to Aerial survey length-frequency data.

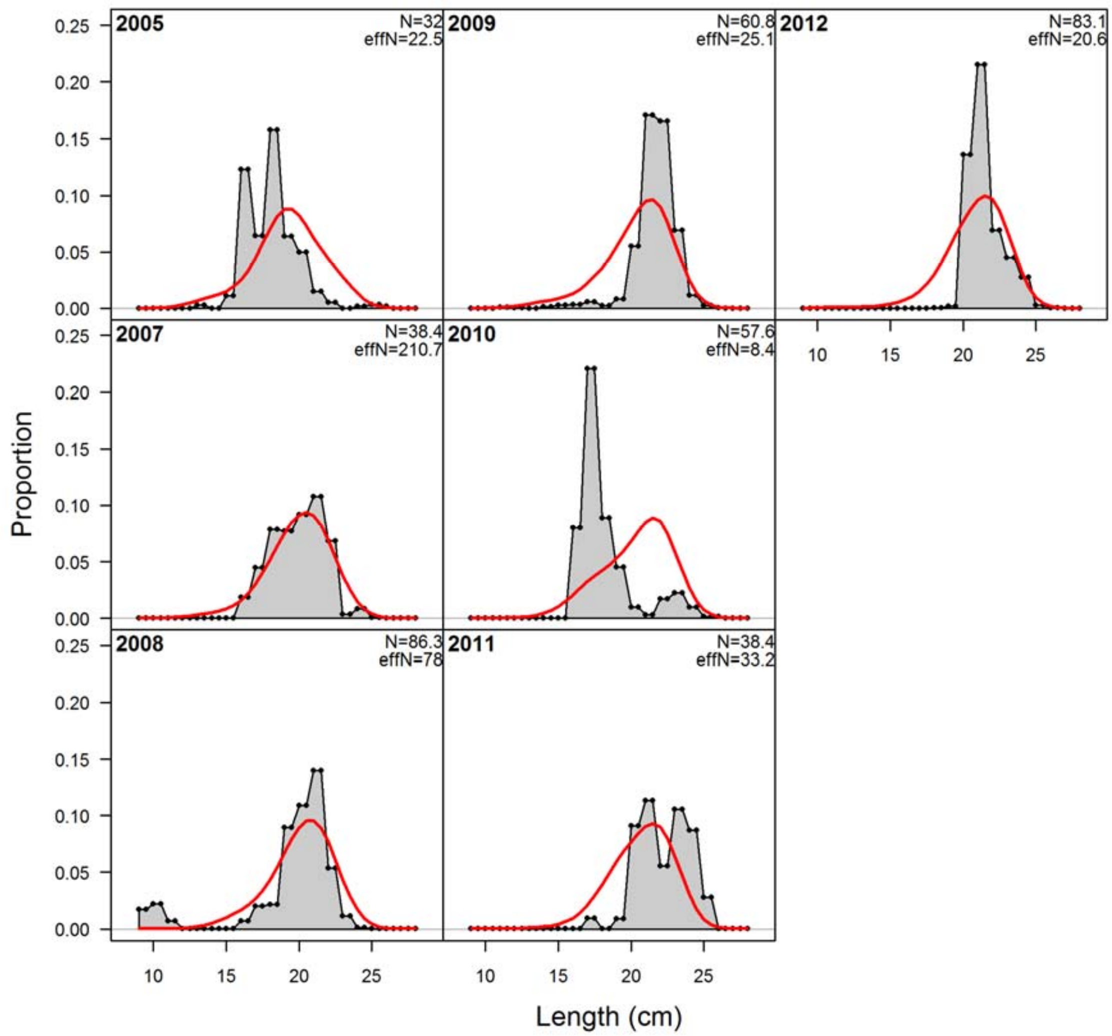


Figure 34a. Model X6e fits to Acoustic survey length-frequency data.

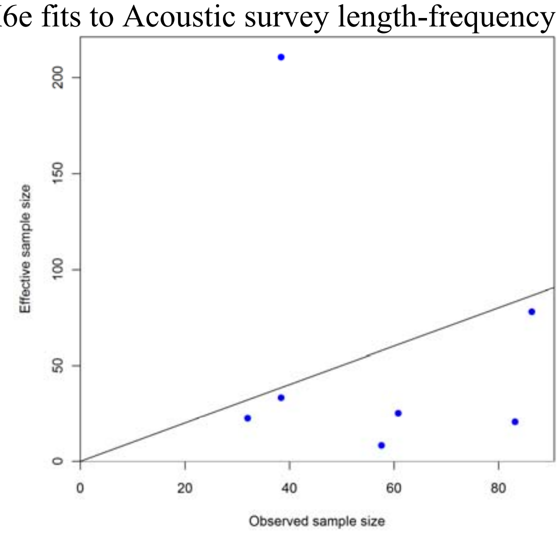


Figure 34b. Observed and effective sample sizes for Acoustic survey fishery length data.

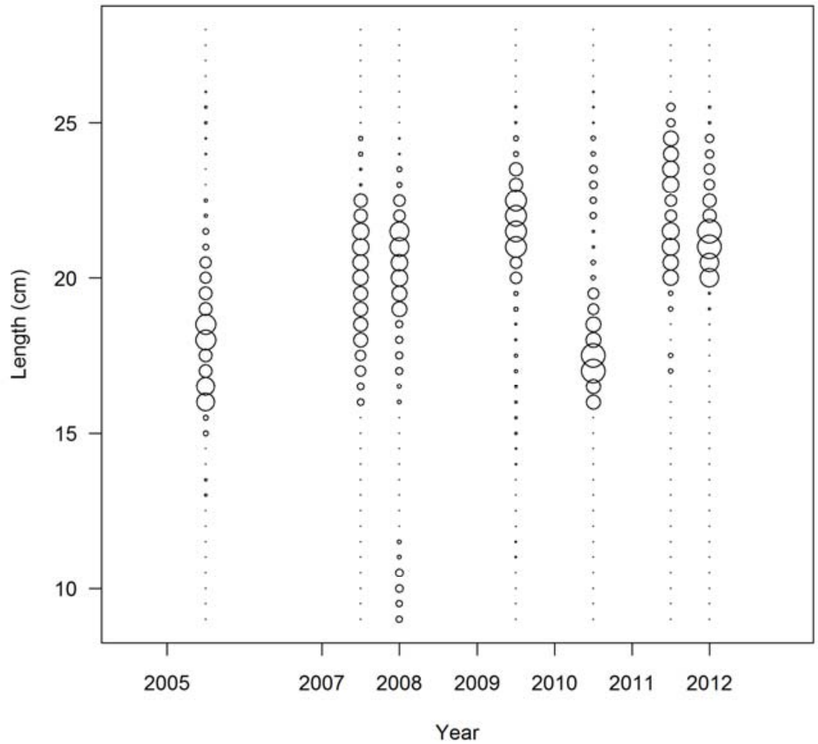


Figure 34c. Bubble plot of Acoustic survey length-frequency data.

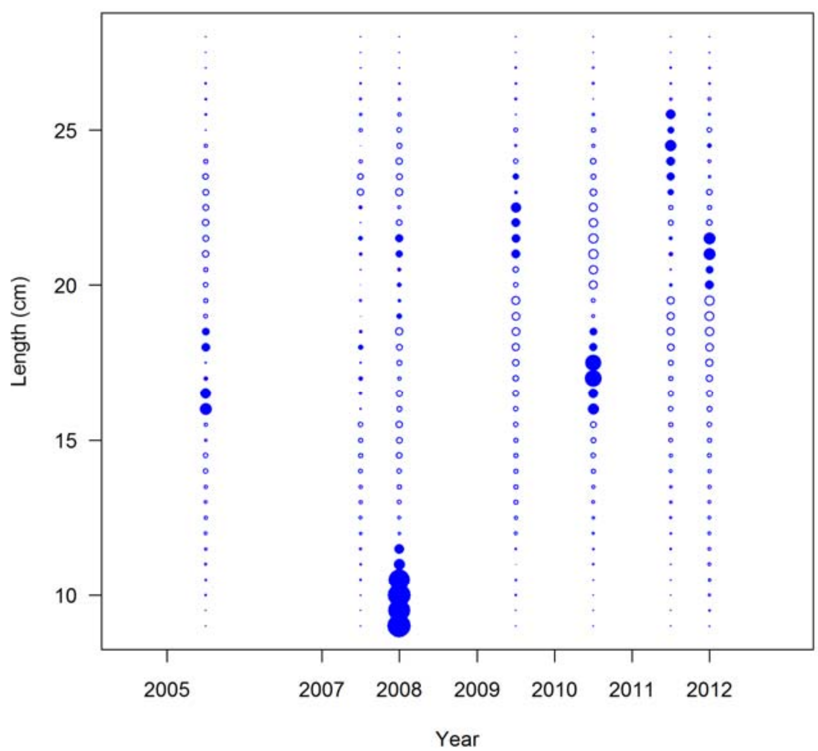


Figure 34d. Pearson residuals (max=14.78) for fit to Acoustic survey length-frequency data.

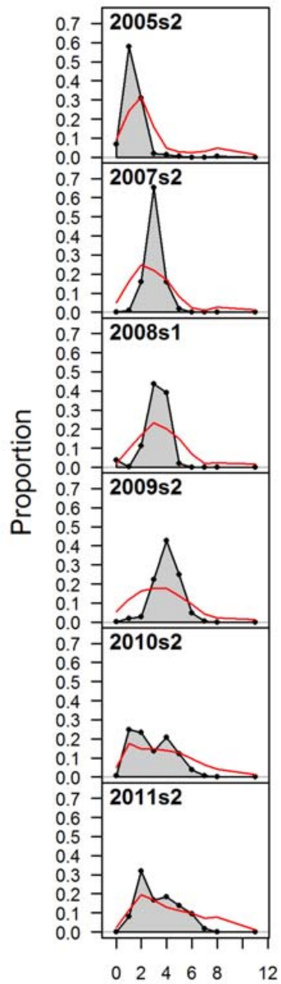


Figure 35a. Base model fits to Acoustic survey implied age-frequency data.

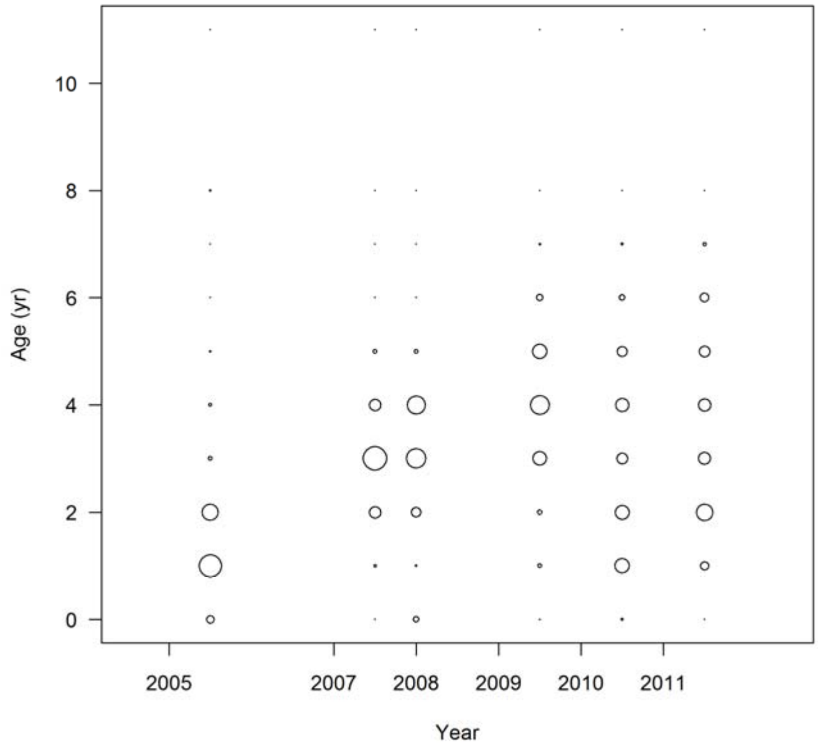


Figure 35b. Bubble plot of Acoustic survey implied age-frequency data.

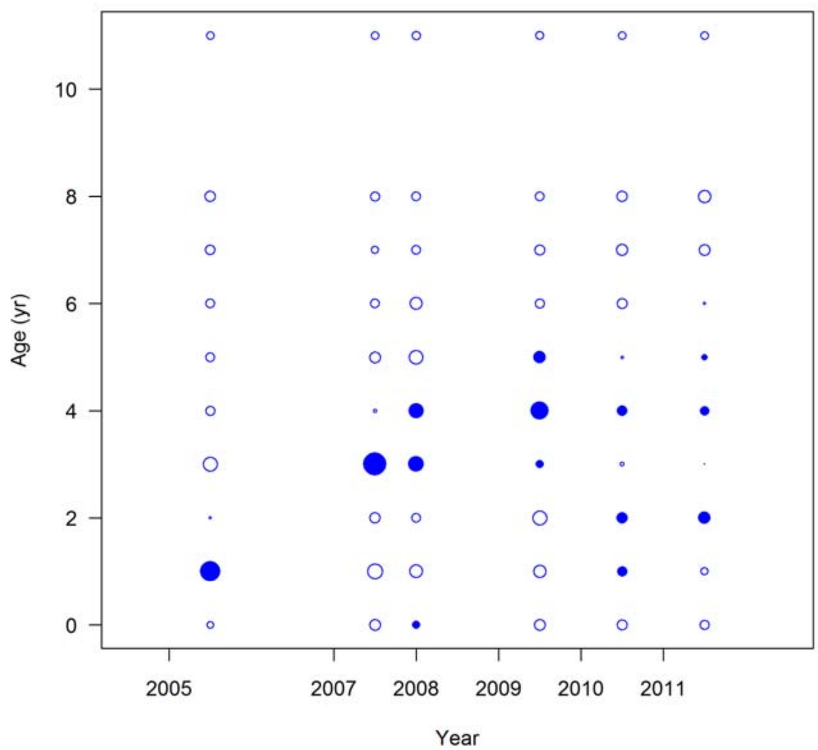


Figure 35c. Pearson residuals (max=1.05) for fit to Acoustic survey implied age-frequency data.

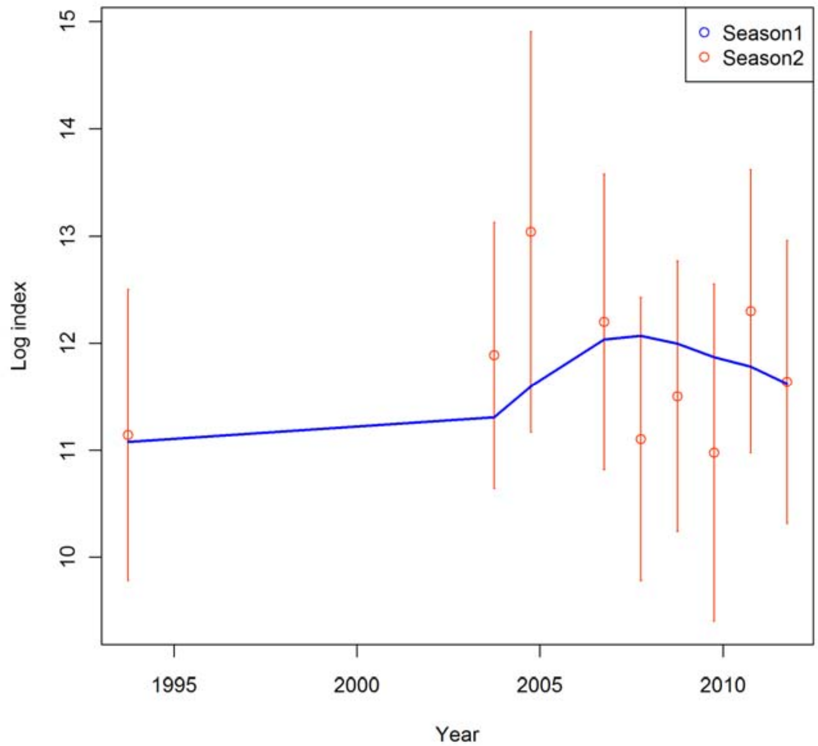


Figure 36a. Model X6e fit to the Daily Egg Production Method (DEPM) series of female SSB (q=0.166).

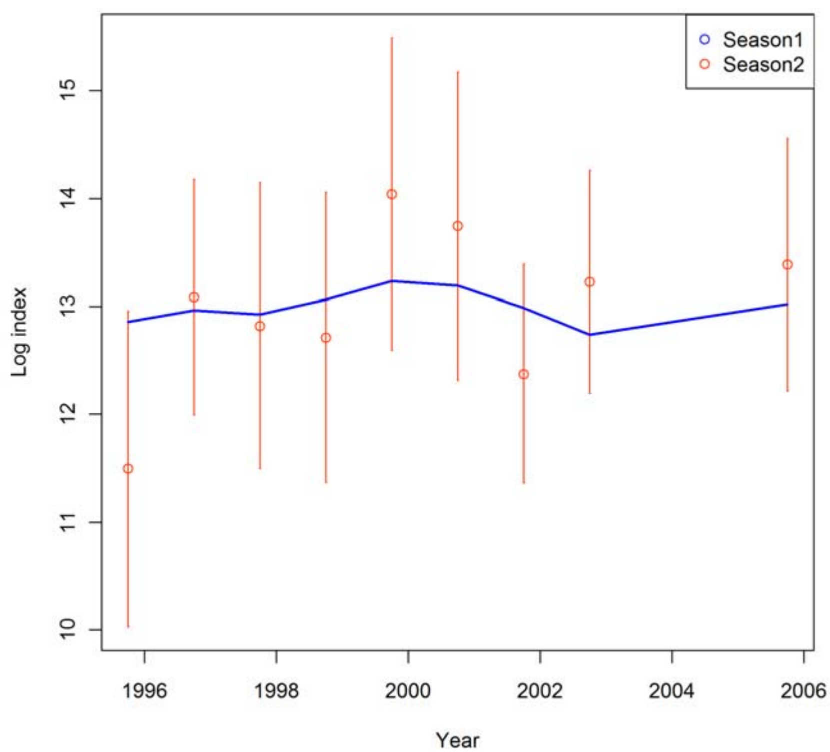


Figure 36b. Model X6e fit to the Total Egg Production (TEP) series of total SSB (q=0.539).

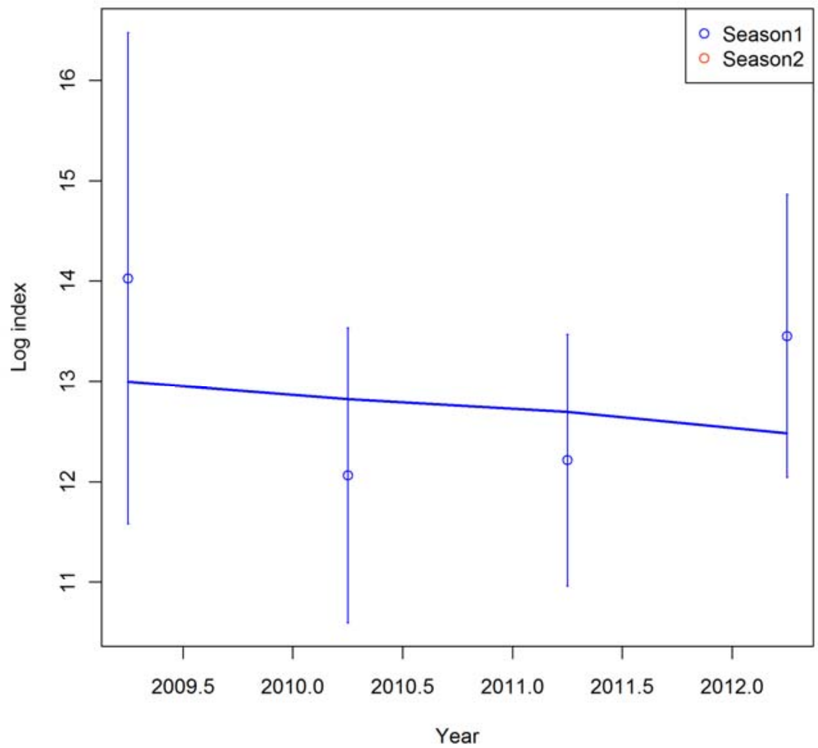


Figure 36c. Model X6e fit to Aerial survey estimates of biomass (q = 0.922).

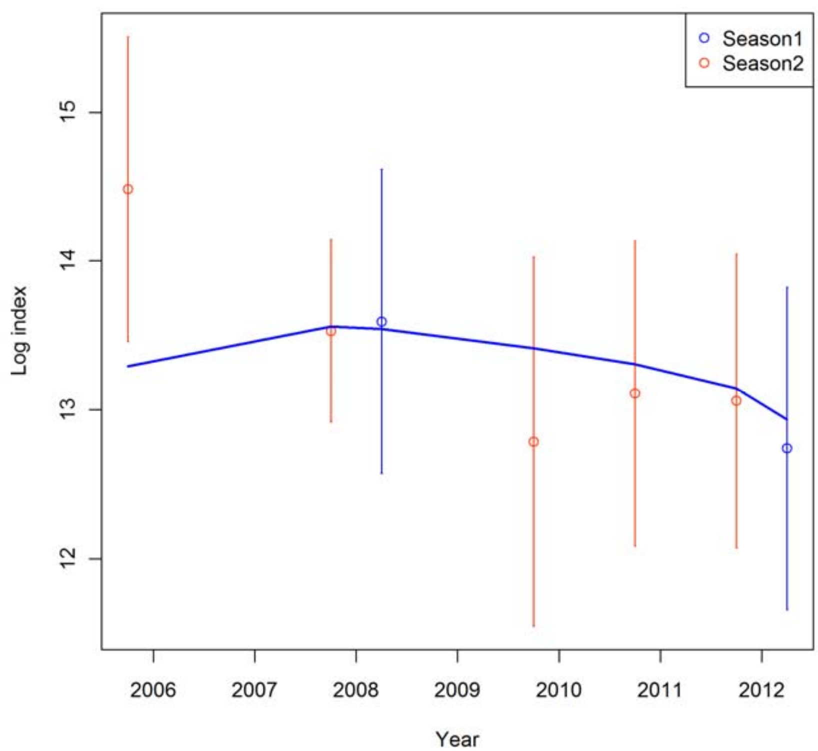


Figure 36d. Model X6e fit to the Acoustic survey biomass series (q = 1; fixed).

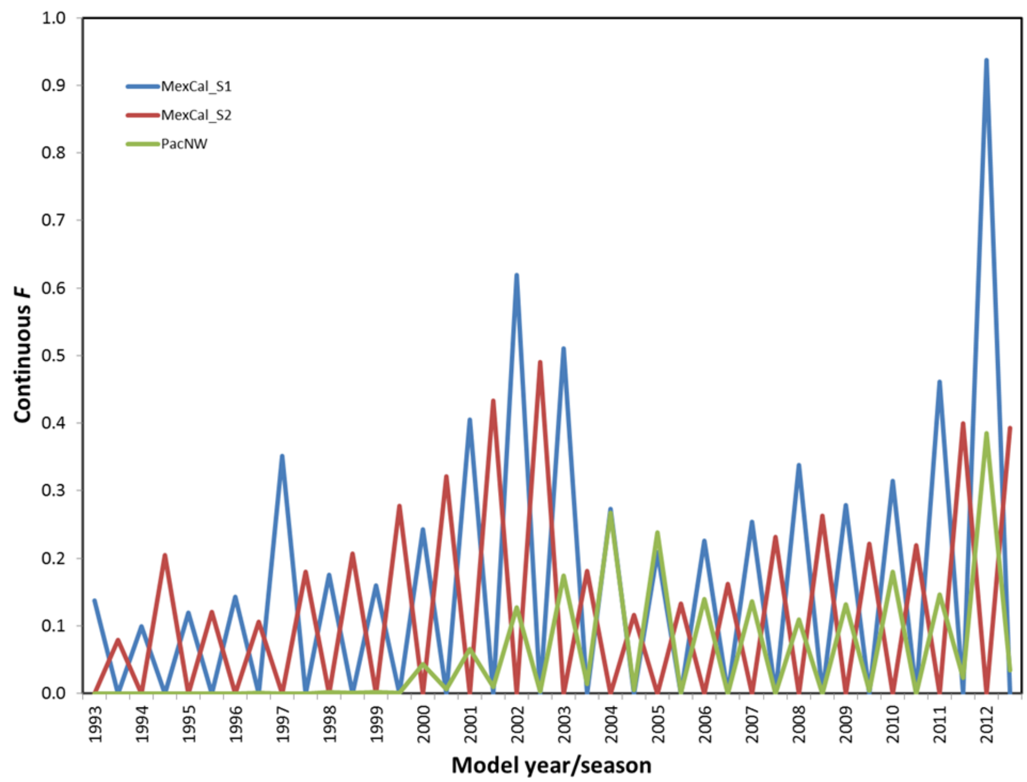


Figure 37a. Model X6e fishing mortality rate (continuous *F*; SS method 3) by fishery.

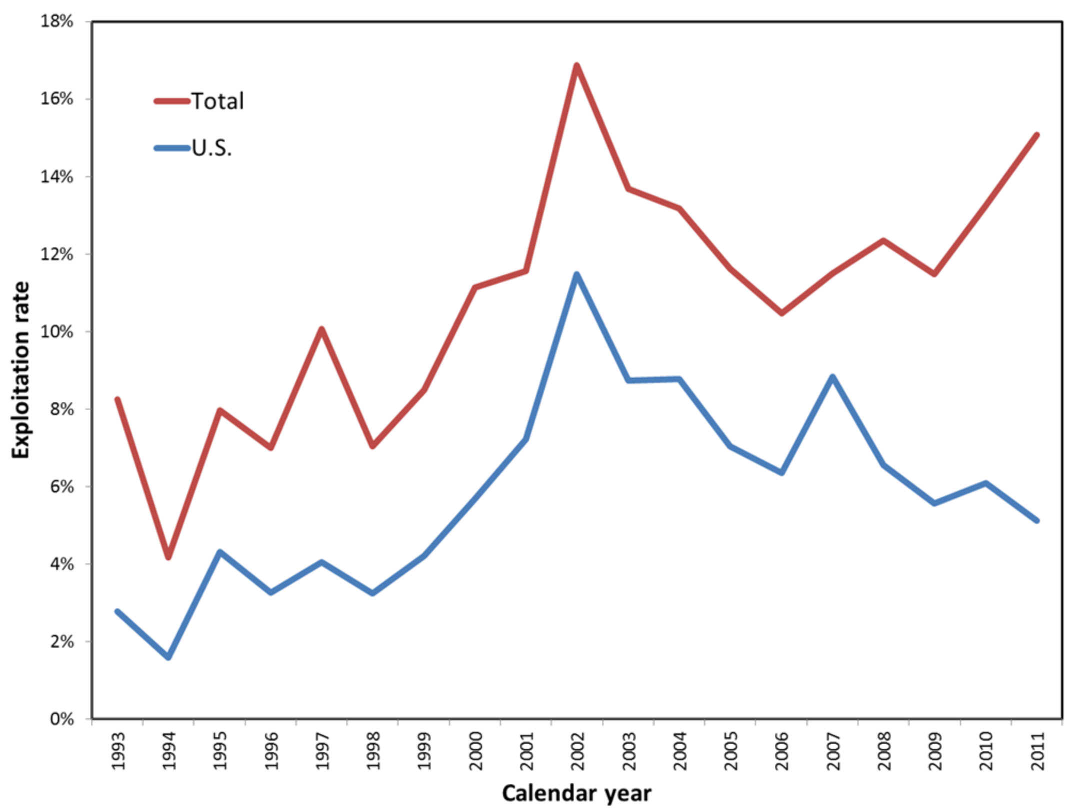


Figure 37b. Exploitation rate (CY landings / July total biomass) for model X6e.

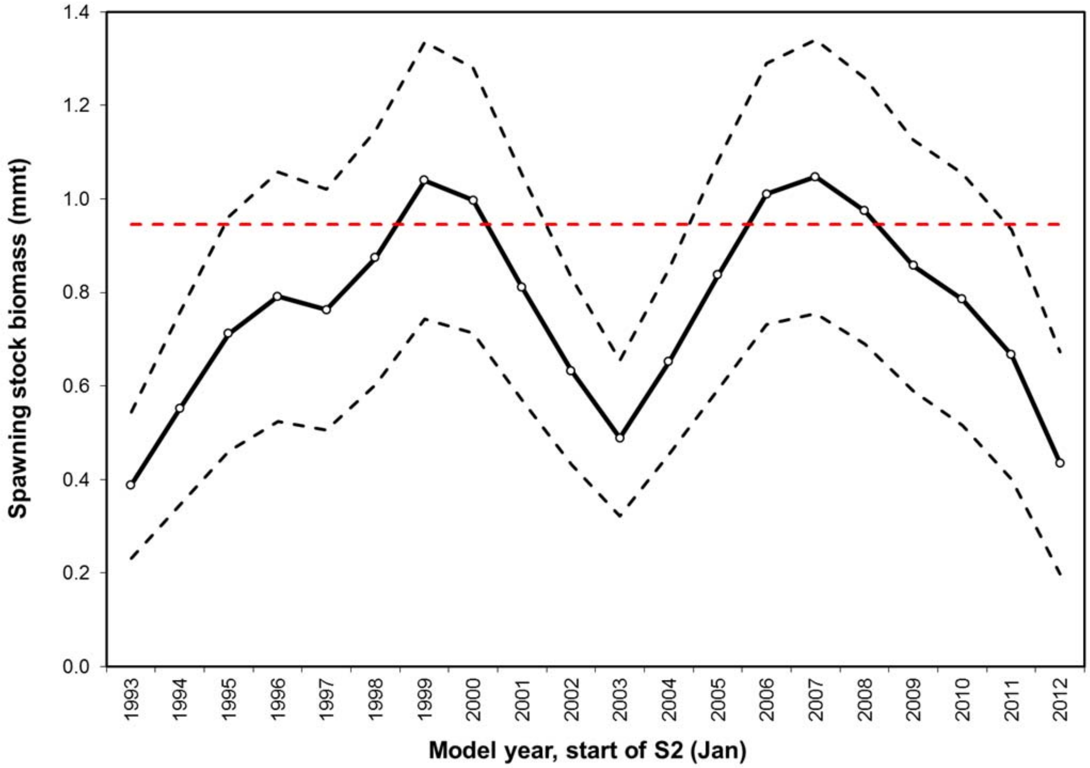


Figure 38a. Model X6e SSB with ~95% confidence intervals. Red line is SSB-zero.

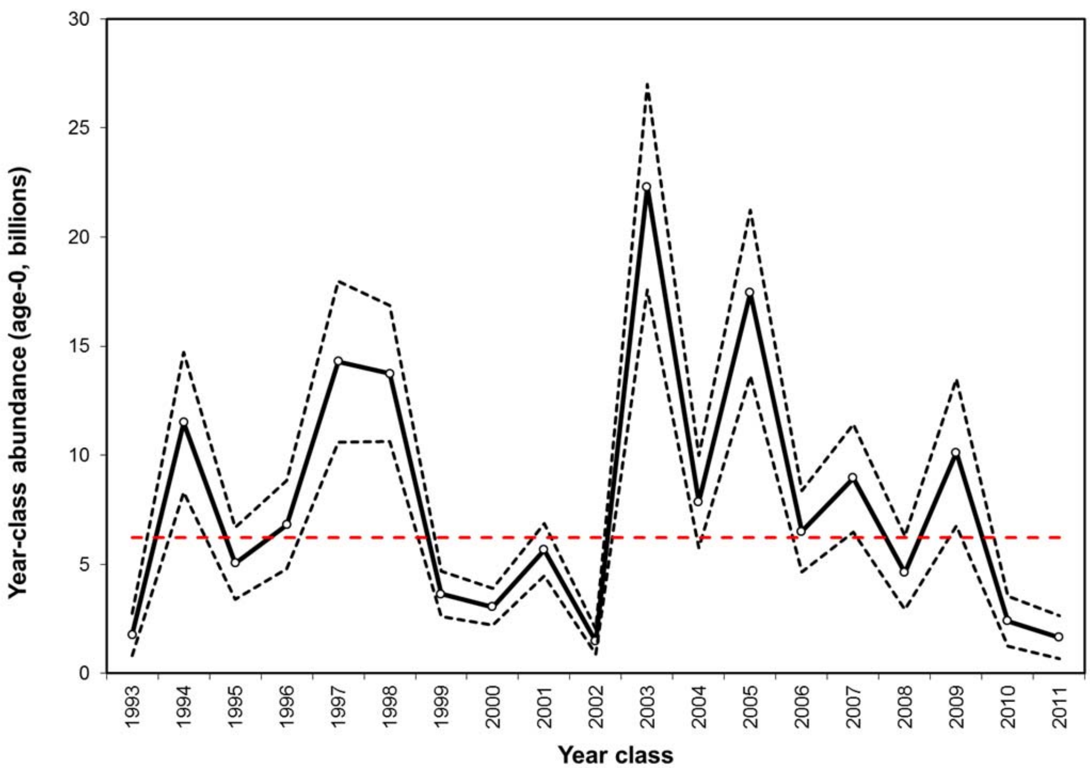


Figure 38b. Model X6e year-class abundance with ~95% confidence intervals. Red line is R-zero.

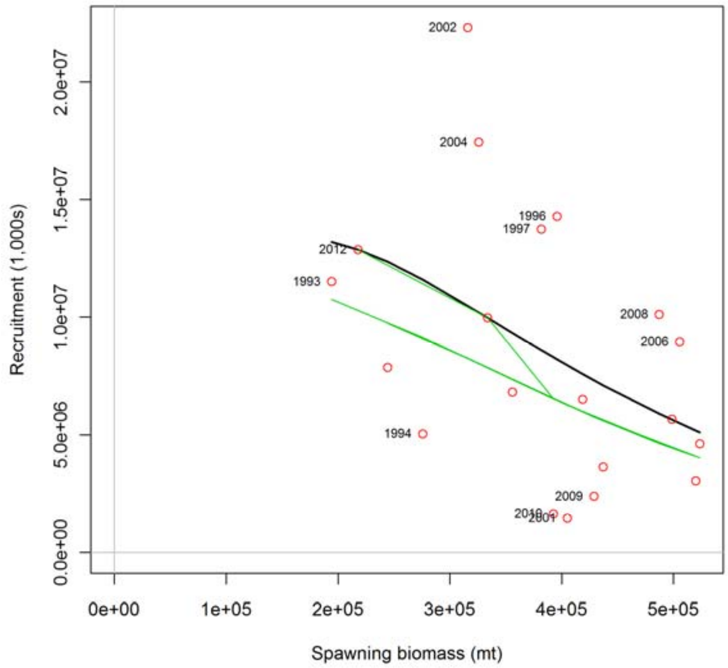


Figure 39a. Spawner-recruitment relationship for model X6b, showing Ricker function fit with bias correction. Steepness (h) = 2.785, R_0 = 6.22 billion age-0 fish, and σ_R = 0.727. Year labels indicate year of spawning season (S2) prior to recruitment season in the following S1, e.g. label '2002' is the SSB that produced the 2003 year-class.

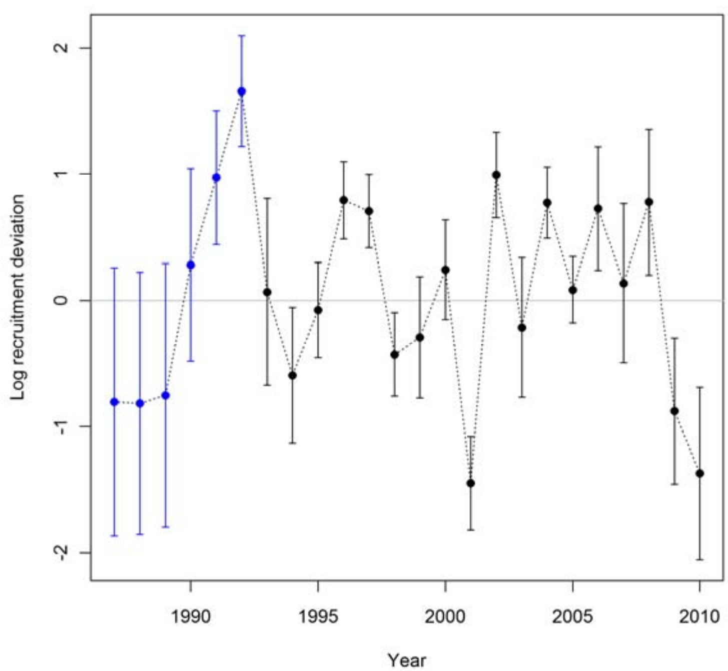


Figure 39b. Recruitment deviations and standard errors estimated in model X6e (σ_R = 0.727). Year labels represent year of SSB producing the subsequent year class.

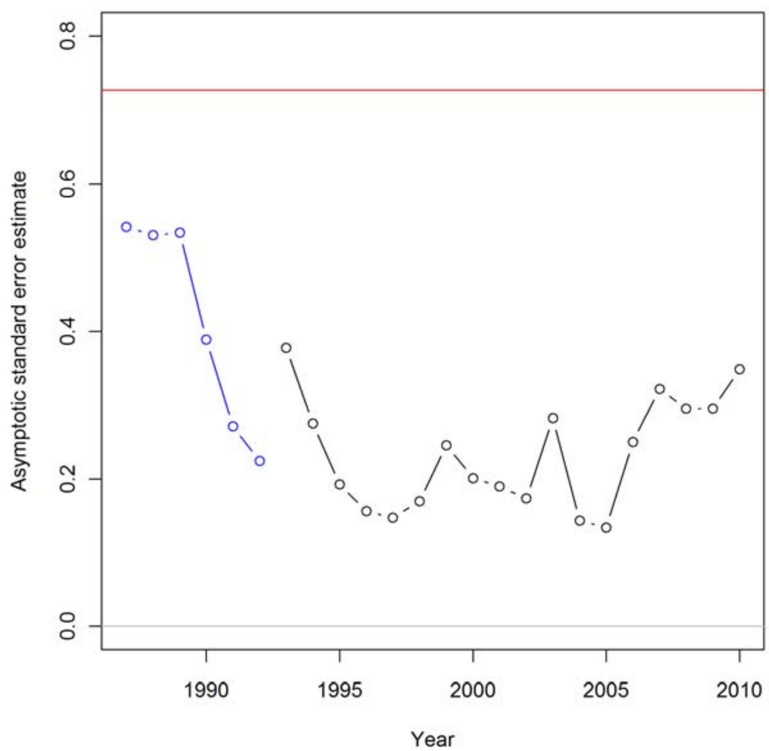


Figure 39c. Asymptotic standard errors for estimated recruitment deviations in model X6e.

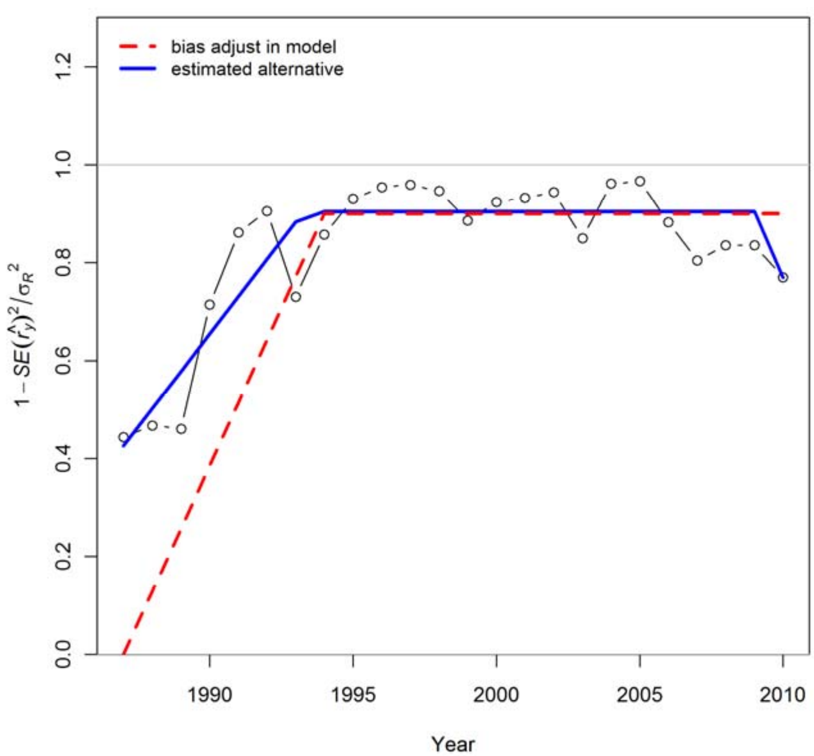


Figure 39d. S-R bias adjustment ramp applied in the model X6e.

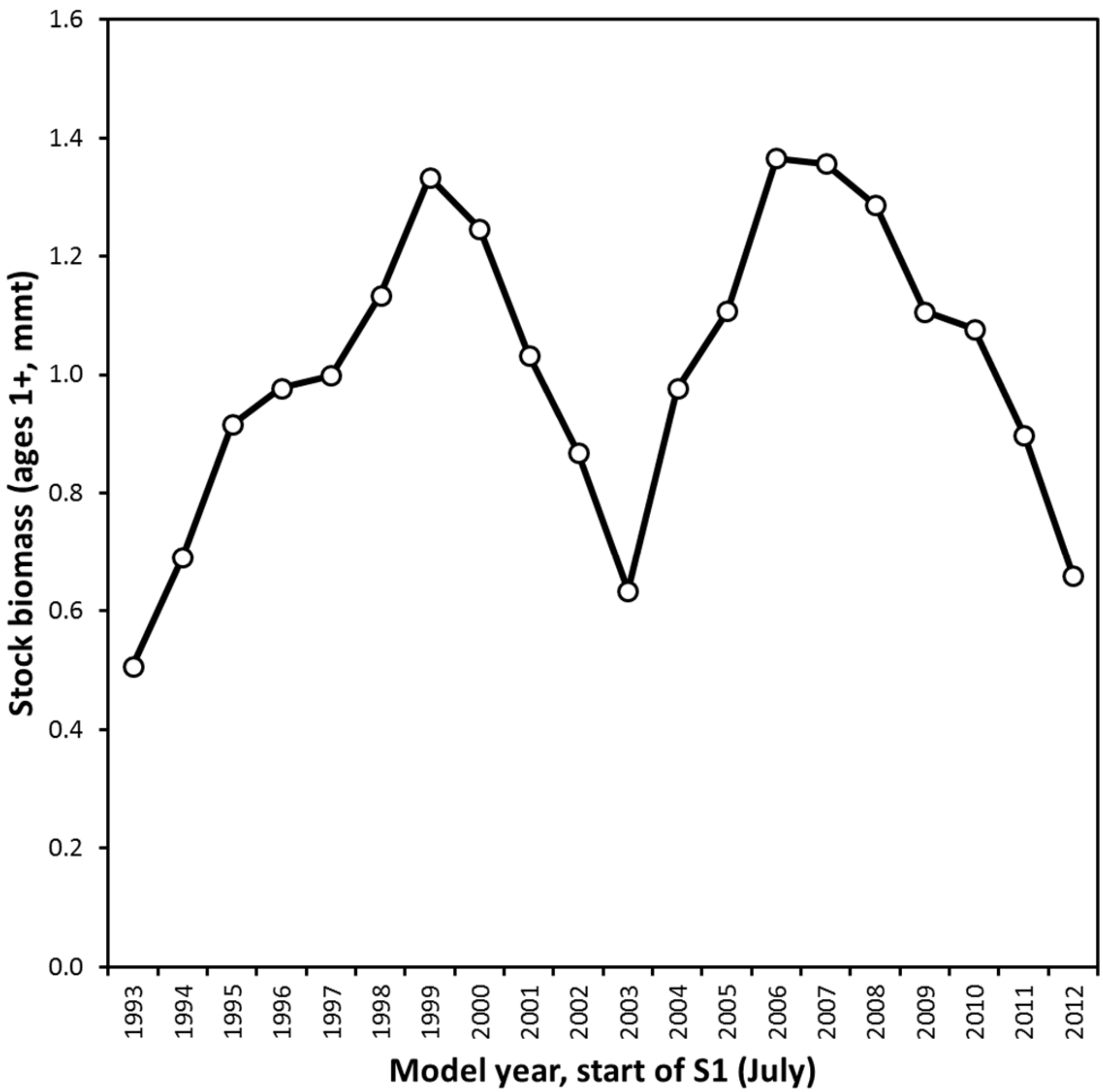


Figure 40. Model X6e stock biomass (ages 1+) used for annual management measures. Stock biomass was estimated to be 659,539 mt on July 1, 2012.

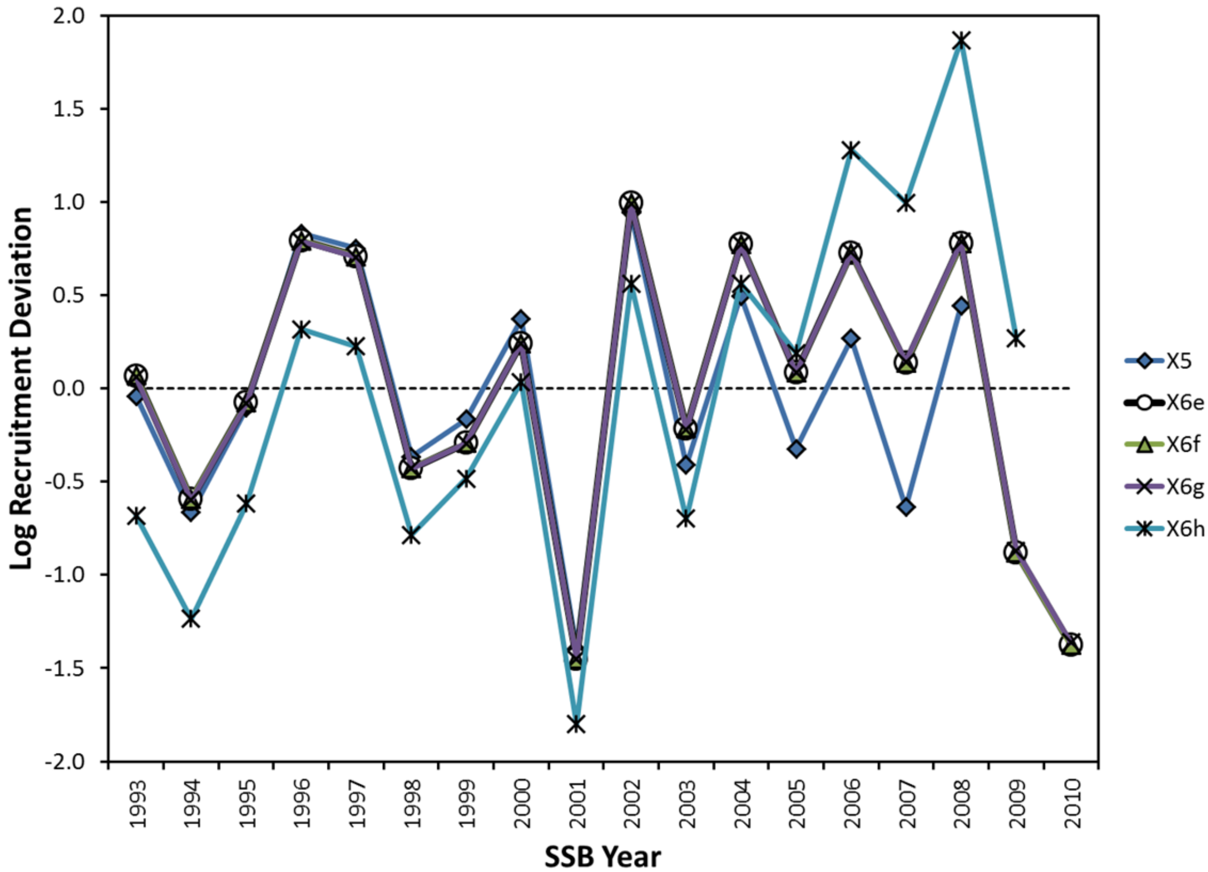
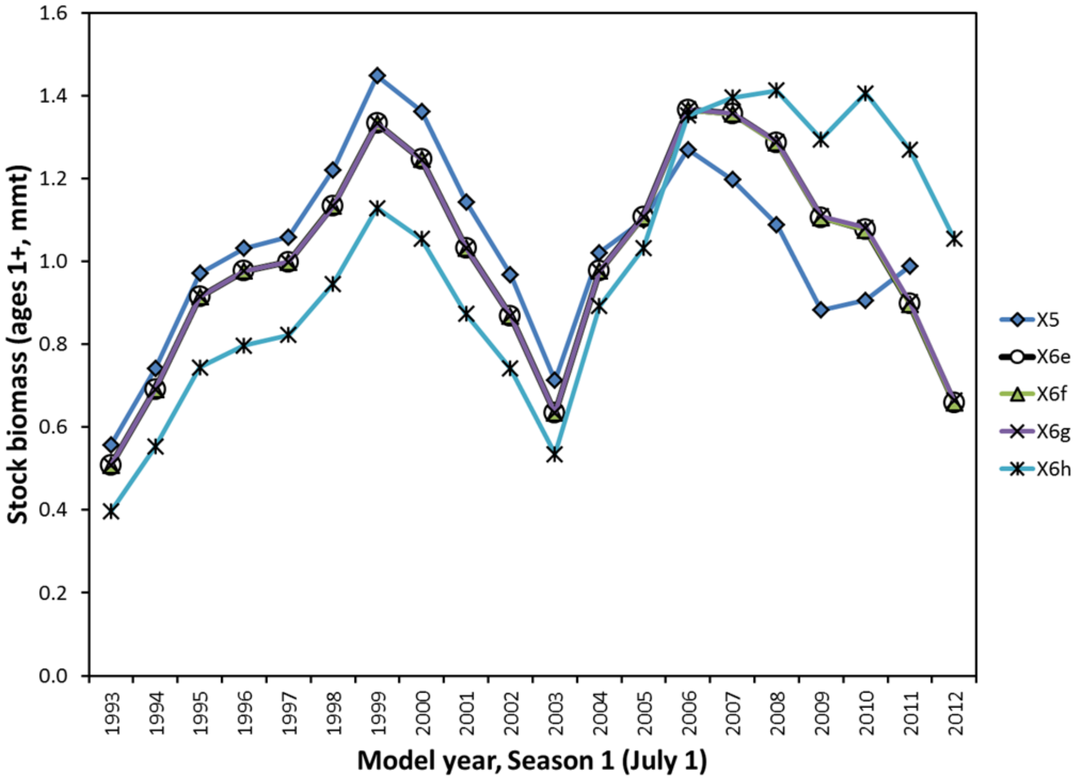


Figure 41. Estimated recruitment deviations from models X5, and X6e-h.



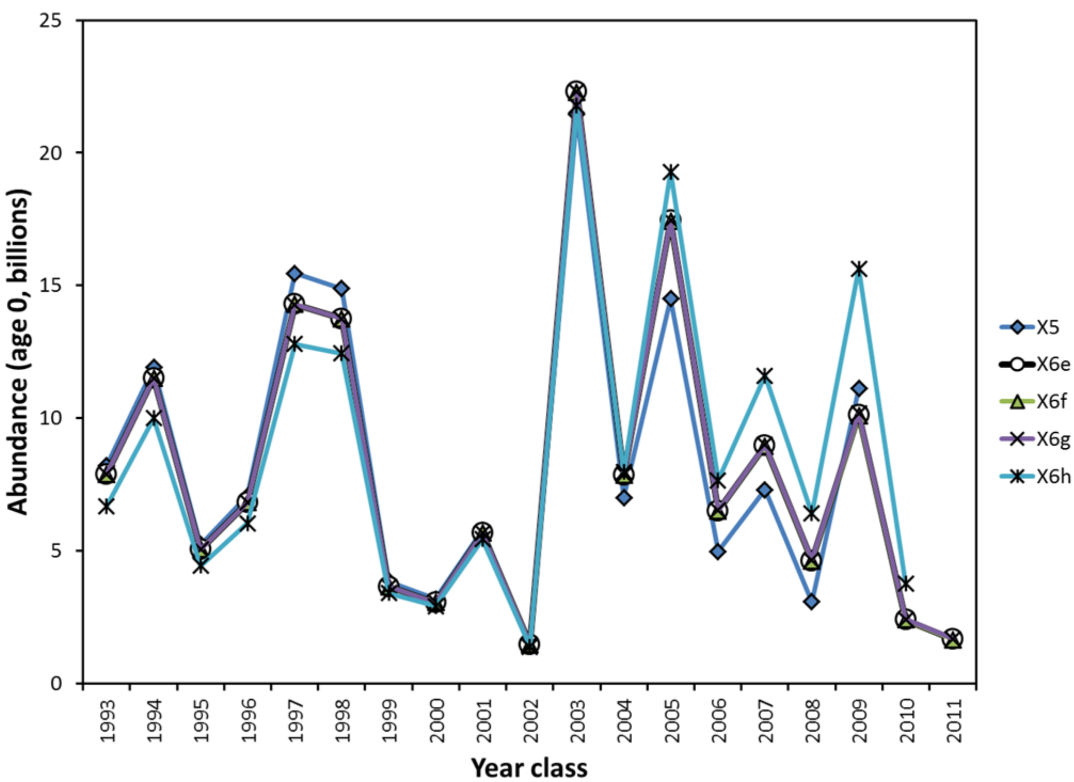


Figure 42. Stock biomass (upper) and recruitment (lower) for models X5 and X6e-h.

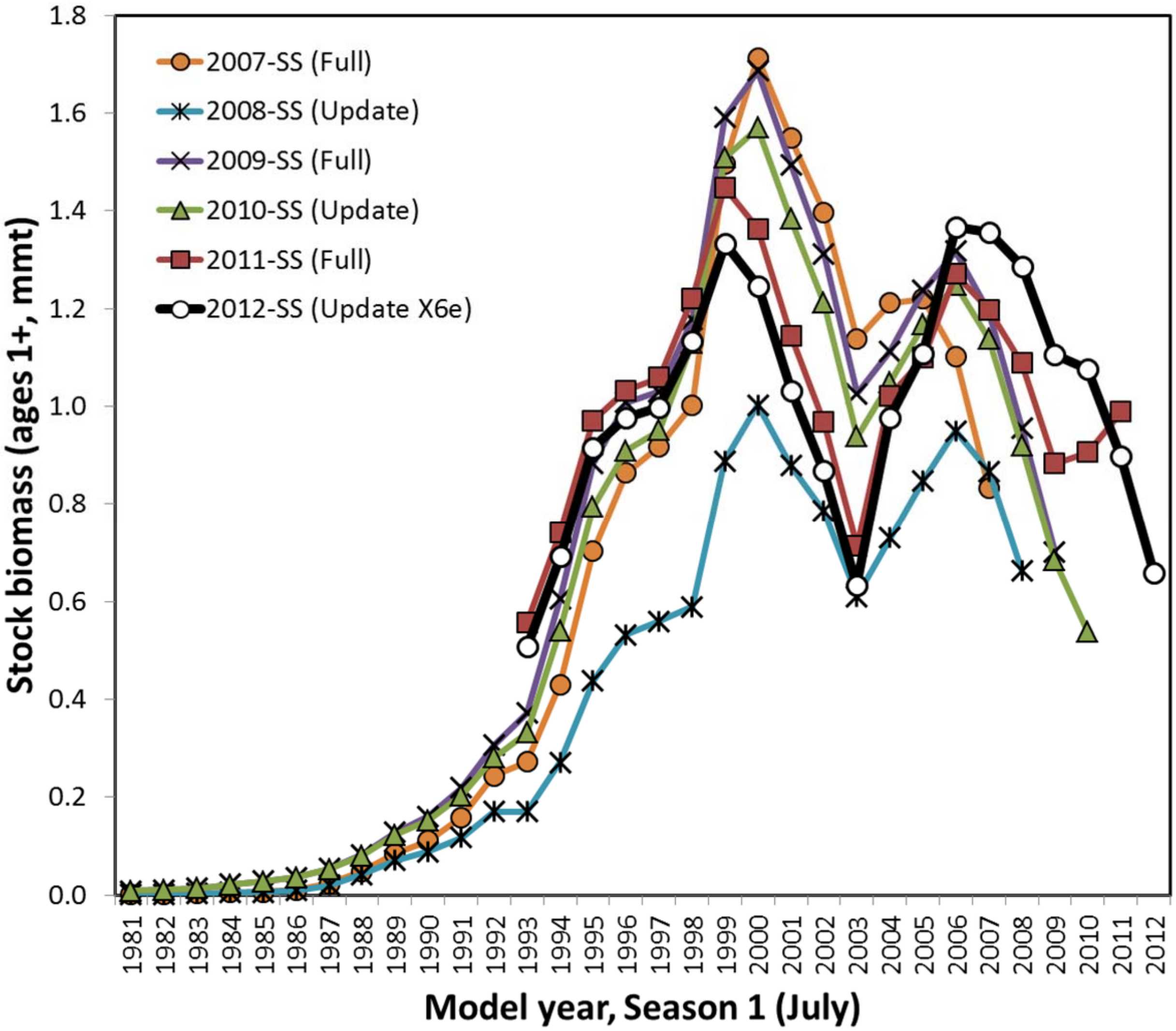


Figure 43a. Pacific sardine stock biomass (ages 1+) from the base model compared to range of models from the past five assessments.

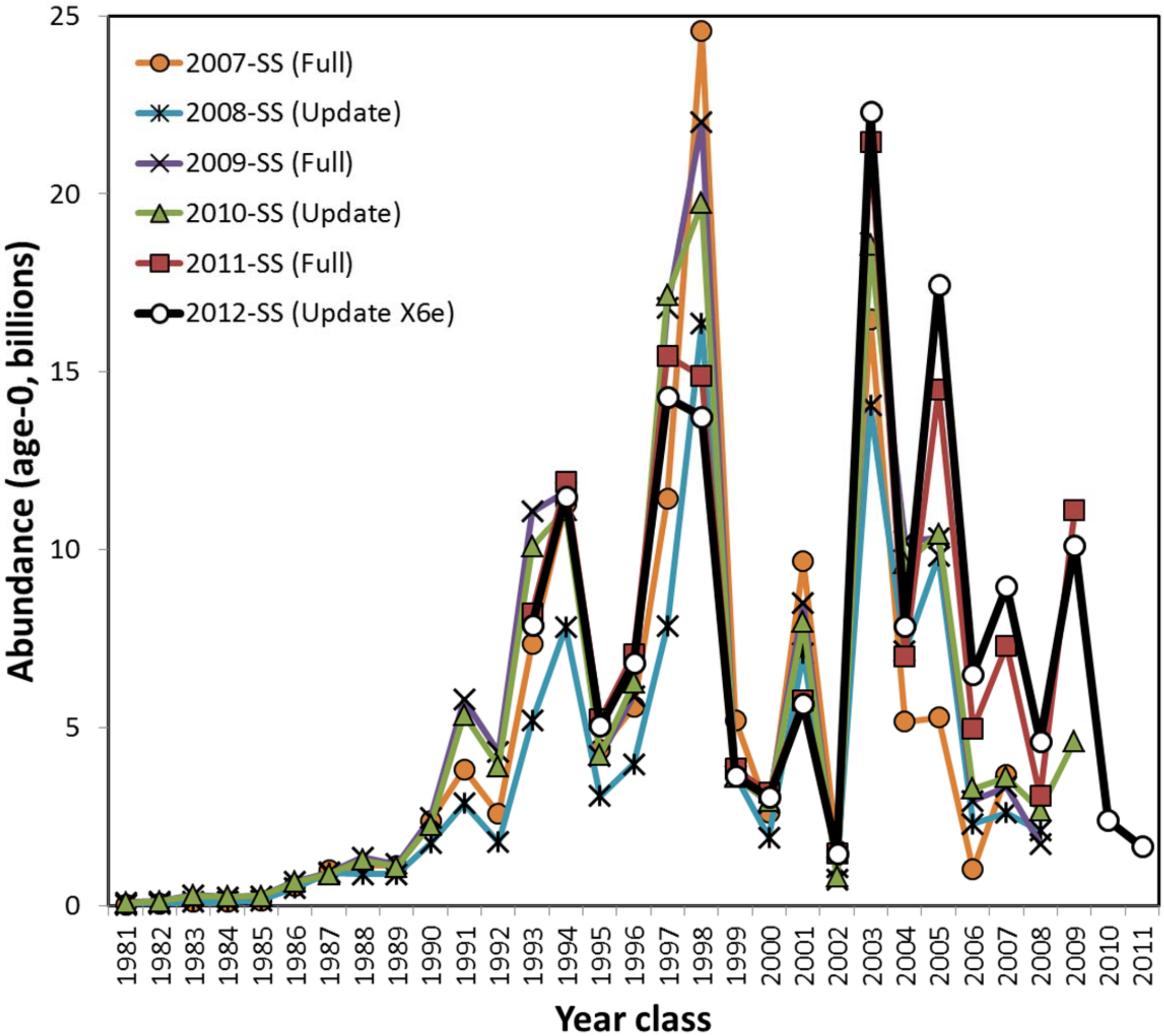


Figure 43b. Pacific sardine recruit (age-0) abundance from the base model compared to range of models from the past four assessments.

APPENDICES

Appendix A. Acoustic-trawl estimates of sardine biomass off California during spring 2012.

Appendix B. Acoustic-trawl estimates of sardine biomass off the west coasts of the United States of America and Canada during summer 2012.

Appendix C. PFMC scientific peer reviews and advisory body reports.

Appendix A

Acoustic-trawl estimates of sardine biomass off California during spring 2012

Juan Zwolinski, David A. Demer, Beverly J. Macewicz,

George R. Cutter Jr., Kyle A. Byers, Josiah S. Renfree, and Thomas S. Sessions

This report summarizes results from the spring 2012 acoustic-trawl method (ATM) survey off central and southern California (**Fig. 1**). The survey was conducted from NOAA FSV *Bell M. Shimada* and chartered FV *Ocean Starr*. A cruise report and a manuscript including details of the ATM, these results, and the biomass estimates of other coastal pelagic fish species (CPS) are being finalized.

The ATM survey totaled 2 248 n.mi. of trackline spanning over 51 327 n.mi.^{2} and the expected distribution of the northern stock of Pacific sardine (**Fig. 1**). During daylight, from sunrise to sunset, multifrequency echosounders were used to sample acoustic backscatter from CPS. During nighttime, surface trawls were used to identify the proportions of CPS and their lengths. Due to their temporal-spatial proximity, data from trawl catches conducted each night were combined into clusters. Day and night, a continuous underway fish egg sampler (CUFES) was used to sample CPS eggs within 5 m of the sea-surface. Overall, only 14 catch clusters included CPS, and these clusters included a median of only 17 sardine.

Post-survey strata were defined with considerations to the sampling intensity, the presence of CPS in the echosounder and net samples, and the existence and abundance of sardine eggs in the CUFES samples (**Fig. 1**). The coastal region and the far offshore oceanic transects had no sardine (**Fig. 2**). The remaining offshore survey area was split into four strata (south-, mid-, central-, and north-offshore) for biomass estimations (**Table 1**). Within these stratum, the sparse trawl data were necessarily used to apportion the CPS backscatter to species (**Figs. 1 & 2**) and the sardine backscatter to length classes (**Figs. 3-5**).

The central-offshore stratum contained the largest concentration of CPS backscatter; trawl clusters with sardine; CUFES samples with sardine eggs (**Figs. 1 & 2**); about half of the area; and about 85% of the sardine (~0.421 million metric tons (Mt)). However, the CPS backscatter within this stratum was apportioned to species and sardine lengths based on nine trawl clusters that contained a total of only 175 sardine (**Table 1**), and, due to their proximity to high backscatter, mostly on only three clusters containing 37 fish (**Fig. 2**). The four strata (**Table 1**) contained a total sardine biomass of 0.470 Mt ($CI_{95\%}$ = [0.224; 0.750]; CV = 28.6%). The sardine abundance was comprised mostly of sardine with modal values of standard lengths (SL) at ~ 21 and 23 cm, corresponding to the putative 2009 cohort (**Table 2**).

Table 1. Sardine biomass by stratum for the spring 2012 survey.

Stratum		Transect		Trawls		Sardine		
Name	**Area (n.mi.)**	**Number**	**Distance (n.mi.)**	**CPS clusters**	**Number of sardine**	**Biomass (1000 tons)**	**95% confidence interval (1000 tons)**	***CV***
North-offshore	10283	3	236	1	61	31.63	0 - 68.91	95.6
Central-offshore	24846	12	1169	9	175	420.46	178.90 - 702.24	31.1
Mid-offshore[1]	4444	0	0	0	0	2.87	0.00 - 4.70	38.4
South-offshore	11754	4	609	4	261	14.52	9.41 - 19.65	20.5
Total	**51327**	**19**	**2248**	**14**	**497**	**469.48**	**223.83 - 749.56**	**28.6**

[1] The mean biomass density for the mid-offshore stratum was estimated from the densities of the bordering transects (i.e., the nearest transects from the central-offshore and south-offshore strata).

Table 2. Sardine abundance versus standard length for the spring 2012 survey using all positive sardine clusters, and sequentially removing clusters 12, 15, and 34 (see **Fig. 2**).

	Abundance			
Standard length (cm)	**All clusters (number);**	**No cluster 12 (number);**	**No cluster 15 (number);**	**No cluster 34 (number);**
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	63 911 373	0	63 911 373	65 641 845
18	0	0	0	0
19	57 833 499	103 898 256	104 630 872	57 833 499
20	602 555 207	630 934 637	594 249 915	612 144 909
21	750 656 682	871 142 584	780 843 471	643 559 792
22	369 584 592	397 825 774	412 229 319	210 278 827
23	700 811 155	555 210 916	726 845 298	709 986 816
24	576 472 913	448 673 208	415 317 565	528 773 022
25	185 021 711	167 175 095	231 819 084	90 717 682
26	407 022	407 022	407 022	407 022
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
30	0	0	0	0

Figure 1. Acoustic backscatter from coastal pelagic fish species (CPS; left), proportions of CPS in trawl clusters (middle), and sardine egg densities from the continuous underway fish-egg sampler (CUFES).

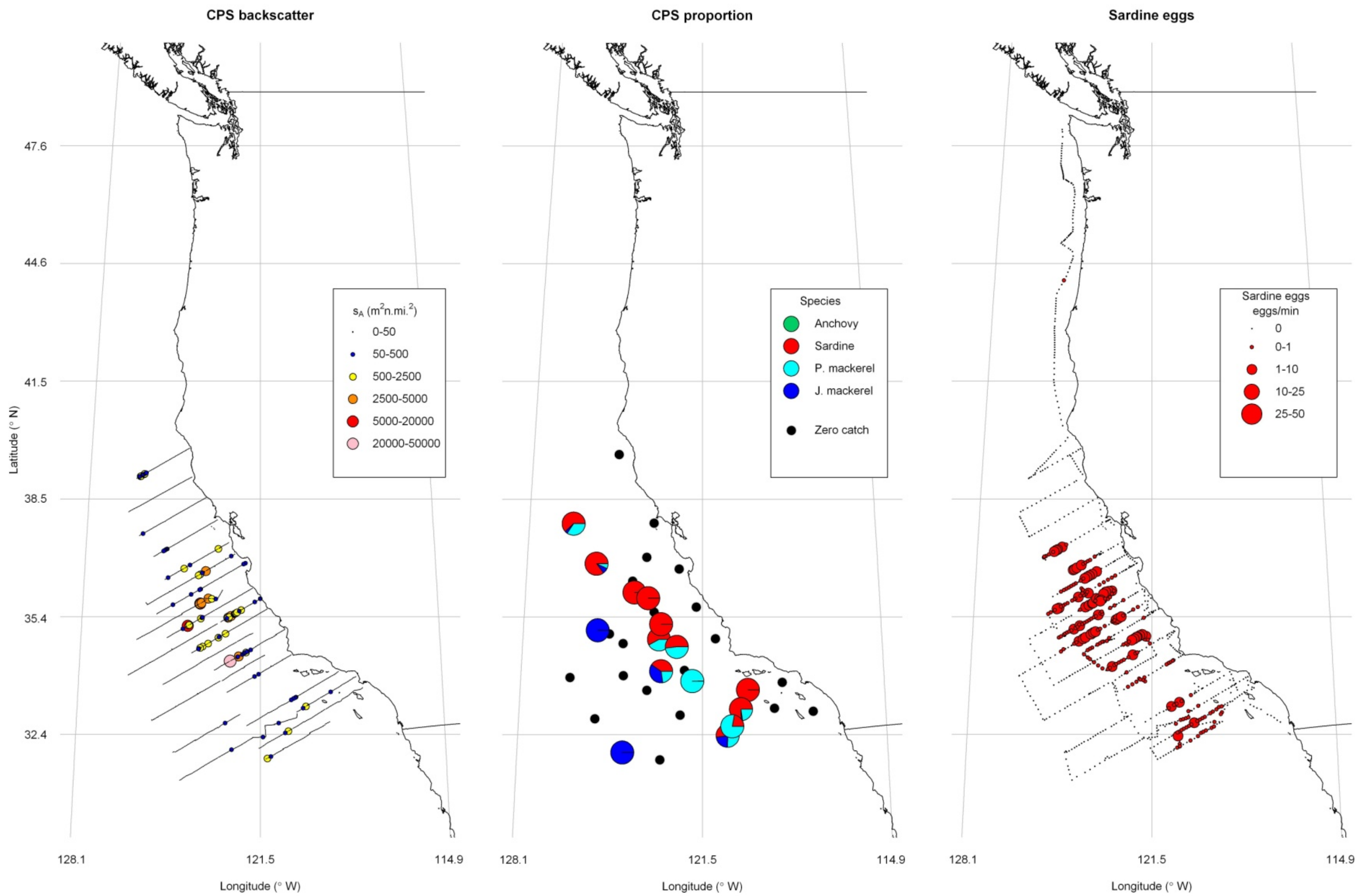


Figure 2. Sardine biomass densities versus stratum (**Table 1**) estimated using the acoustic-trawl method (ATM). The positions of trawl clusters containing sardine are indicated (numbers). Distributions of the density-weighted sardine lengths are shown in **Fig. 4**.

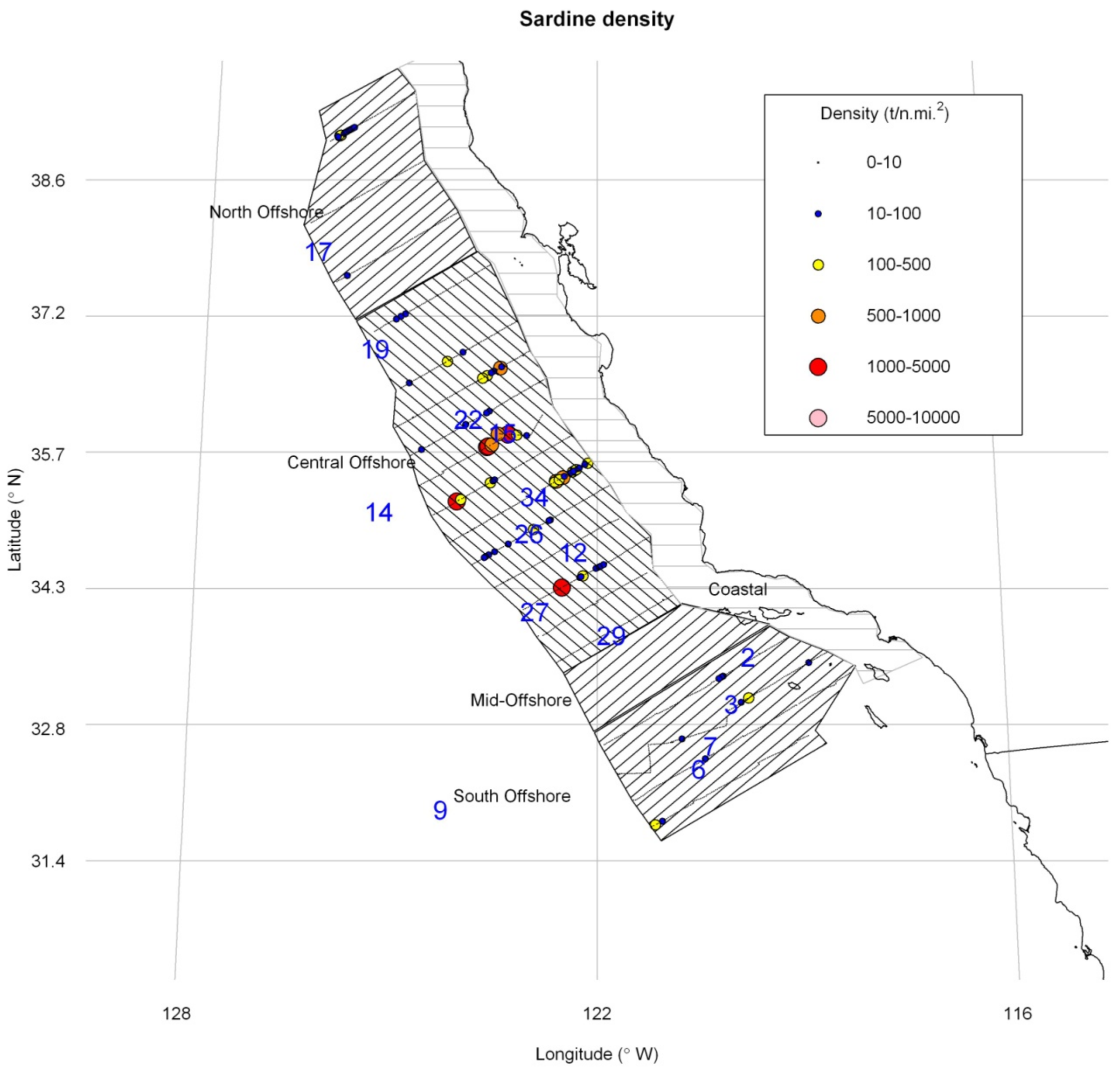


Figure 3. Distributions of sardine lengths versus trawl cluster, the total number of sardine caught in each cluster, and the proportions of the sardine abundances within each respective stratum represented by these data. The locations of the trawl clusters are shown in **Fig. 2**.

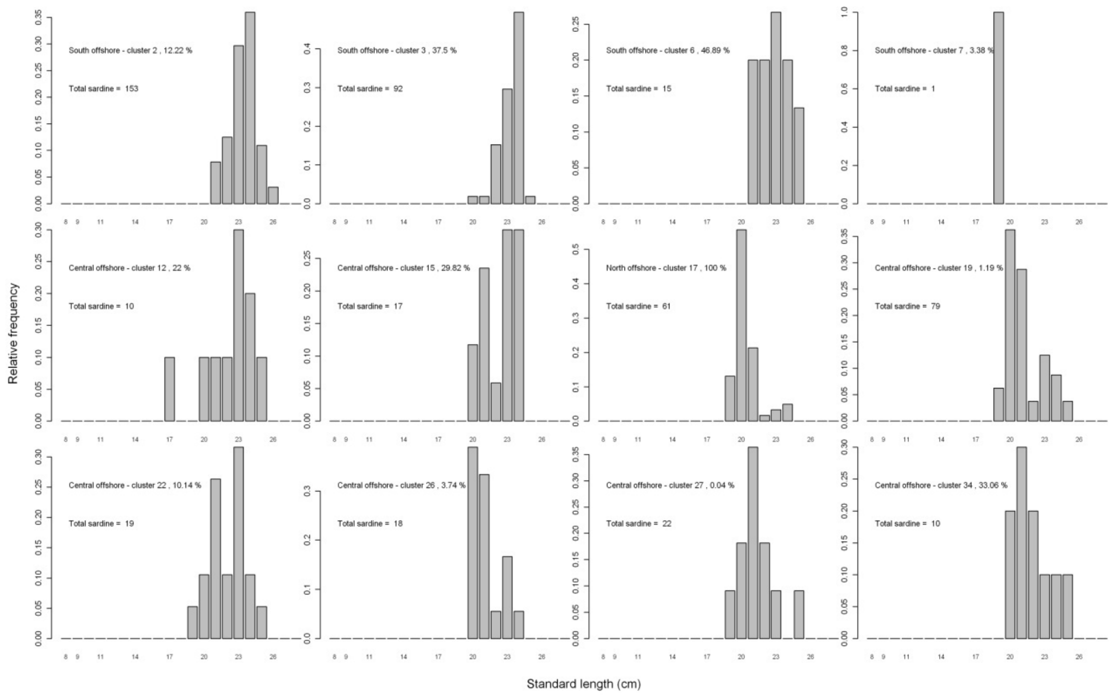


Figure 4. Sardine abundance versus standard length and stratum for the spring 2012 survey.

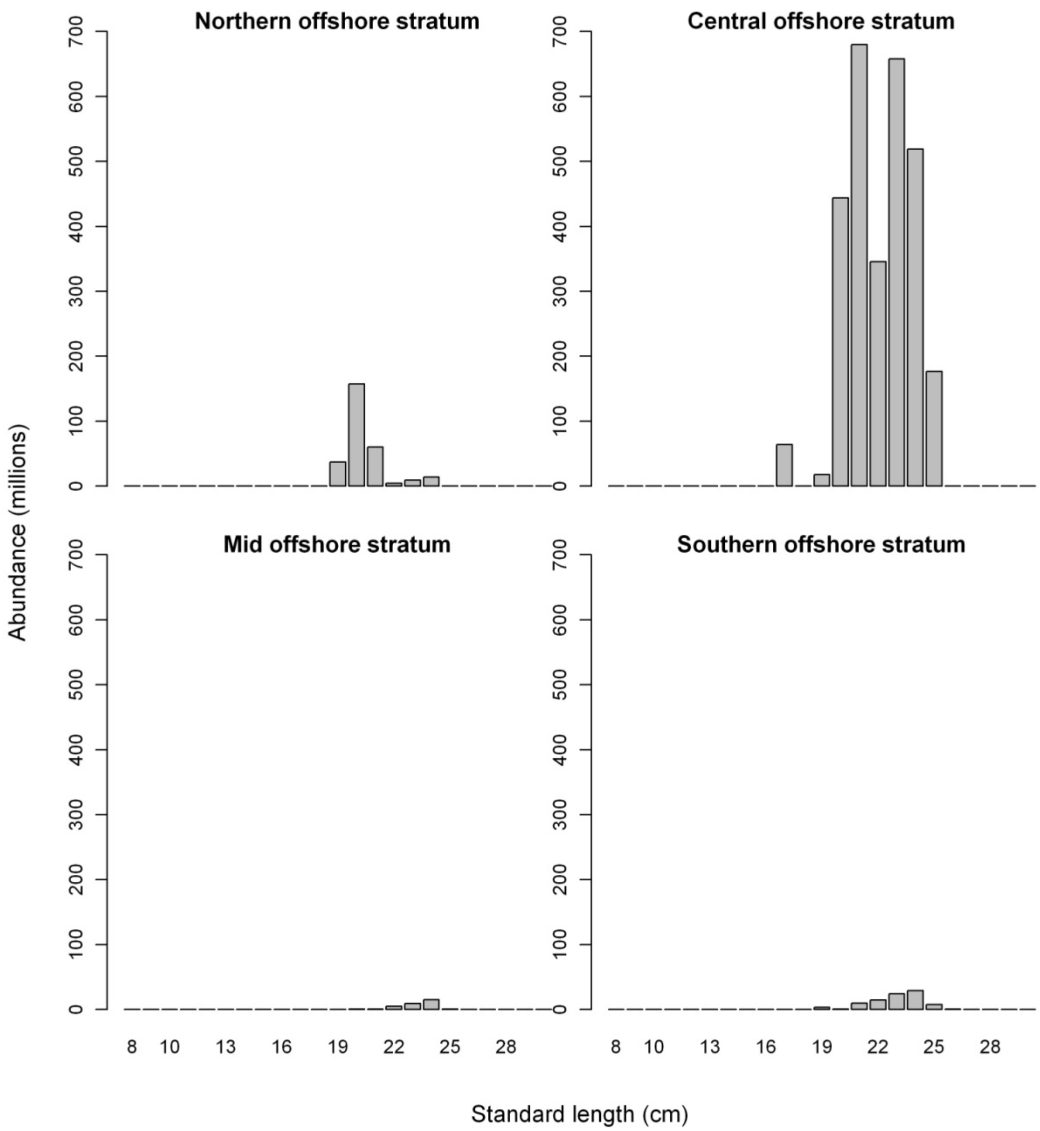
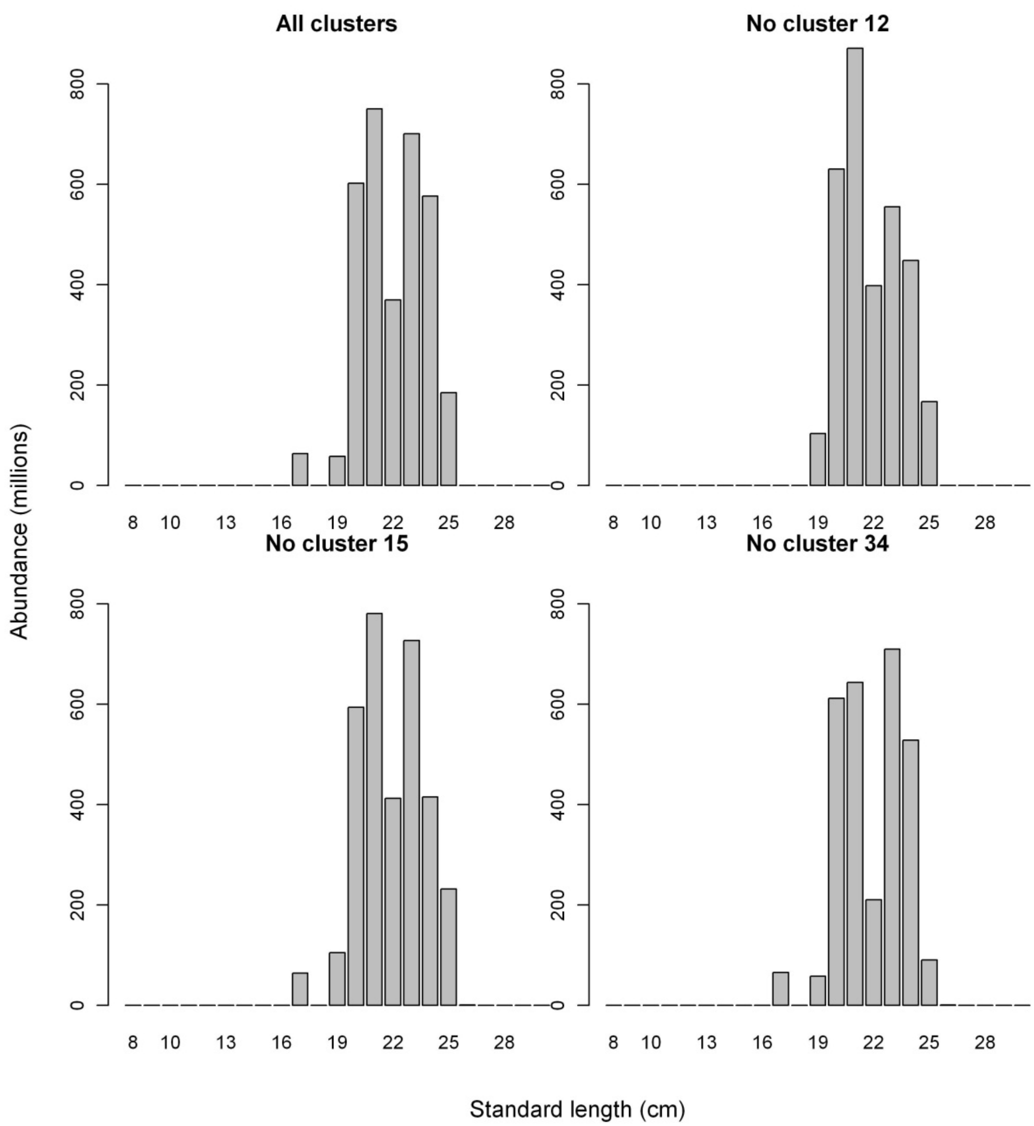


Figure 5. Sardine abundance versus standard length for the entire spring 2012 survey using all trawl clusters and sequentially removing clusters 12, 15 or 34 (**Figs. 2 & 3**) The data are provided in **Table 2**. This distribution and its bimodality are largely dependent on the catch locations and standard lengths of only 37 fish from the central stratum caught in those three clusters.



Appendix B

Acoustic-trawl estimates of sardine biomass off the west coasts of the United States of America and Canada during summer 2012

Juan Zwolinski, David A. Demer, Beverly J. Macewicz,

George R. Cutter Jr., Kyle A. Byers, Josiah S. Renfree, and Thomas S. Sessions

This report summarizes acoustic-trawl method (ATM) estimates of the sardine distribution and abundance from the summer 2012 survey (SaKe 2012) off the west coasts of the USA and Vancouver Island, Canada (**Fig. 1**). The survey was conducted from NOAA FSV *Bell M. Shimada*. A cruise report and a manuscript including details of the ATM, these results, and the biomass estimates of other coastal pelagic fish species (CPS) are being finalized.

The ATM survey totaled 3632 n.mi. of trackline spanning over 39 614 n.mi.^{2} and the expected distribution of the northern stock of Pacific sardine (**Fig. 1**). During daylight, from sunrise to sunset, multi-frequency echosounders were used to sample acoustic backscatter from CPS. During nighttime, surface trawls were used to identify the proportions of CPS and their lengths. Due to their temporal-spatial proximity, data from trawl catches conducted each night were combined into clusters. Overall, 31 catch clusters included CPS and these clusters included an average catch of 274 sardine (median = 7).

For biomass estimation, the survey area was split into three strata, each having relatively homogeneous species composition and density (Fig. 1; **Table 1**). The Oregon-California stratum contained the largest concentration of CPS backscatter and trawl clusters with sardine (**Figs. 1 & 2**). Sardine were concentrated north of San Francisco, off northern California and southern Oregon (**Fig. 2**).

The three strata (**Table 1**) contained a total sardine biomass of 0.341 Mt ($CI_{95\%}$ = [0.188; 0.688]; CV = 33.4%). The sardine abundance was comprised mostly of sardine with modal standard length (SL) ~ 21 cm, corresponding to the putative 2009 cohort (**Table 2**).

Table 1. Sardine biomass by stratum for the summer 2012 survey.

Stratum		Transect		Trawls		Sardine		
Name	**Area (n.mi.)**	**Number**	**Distance (n.mi.)**	**CPS clusters (number)**	**Sardine (number)**	**Biomass (1000 tons)**	**95% confidence interval (1000 tons)**	***CV* (%)**
Vancouver Island	7370	15	698	8	1051	18.675	2.661 - 54.017	61.9
Washington-Oregon	10 832	20	915	9	3516	13.335	3.918 - 27.559	42.9
Oregon-California	17 295	39	1614	14	3920	308.821	150.872 - 650.235	37.3
Central California	4169	11	390	0	0	0	NA	NA
Total	**39 666**	**85**	**3632**	**31**	**8487**	**340.8311**	**187.666 - 687.523**	**33.4**

Table 2. Sardine abundance versus standard length for the summer 2012 survey using all positive sardine clusters (see **Fig. 2**).

Standard length (cm)	**All clusters (number);**
8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	0
18	1906030
19	10394493
20	732568840
21	1160073971
22	372313768
23	243284246
24	148308909
25	15833336
26	1290773
27	0
28	0
29	0
30	0

Figure 1. Acoustic backscatter from coastal pelagic fish species (CPS; left); and proportions of CPS in trawl clusters (right).

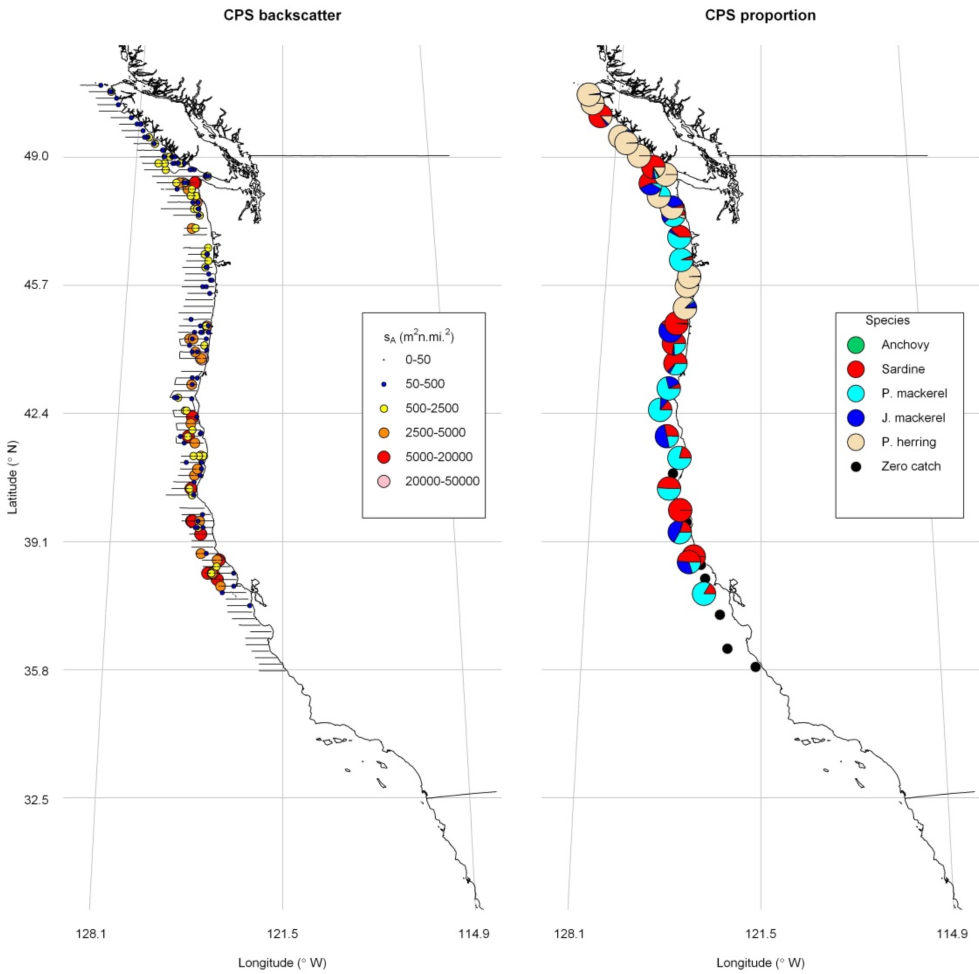


Figure 2. Sardine biomass densities versus stratum (**Table 1**) estimated using the acoustic-trawl method (ATM).

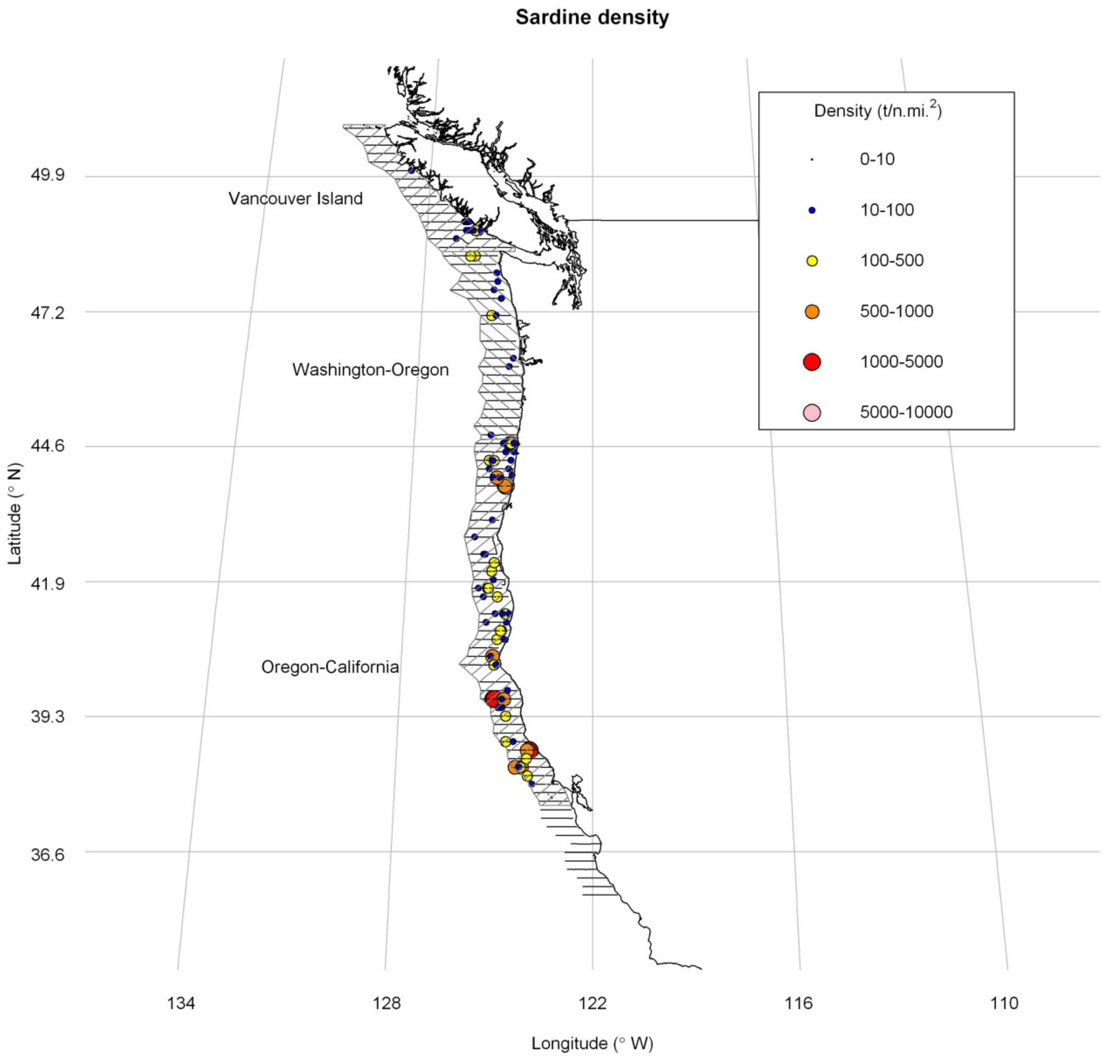
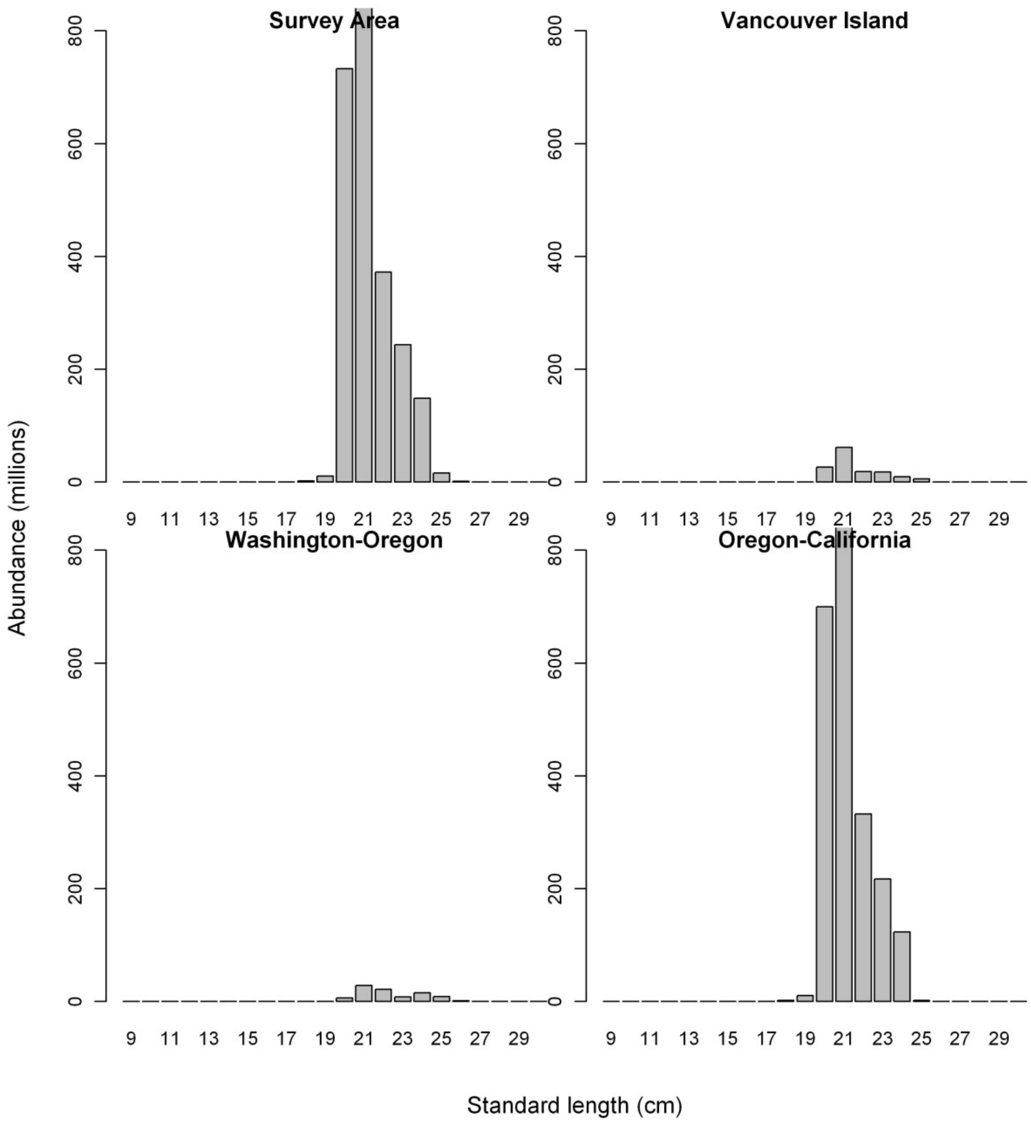


Figure 3. Sardine abundance versus standard length for the summer 2012 survey (SaKe 2012). Data for the entire survey are provided in **table 2**.



Appendix C

PFMC scientific peer reviews and advisory body reports.

Pacific Sardine
Update Assessment Meeting Report

NOAA / Southwest Fisheries Science Center
La Jolla, California
October 2-3, 2012

Review Panel (Scientific and Statistical Committee (SSC)) Members
Owen Hamel (Chair), Northwest Fisheries Science Center (NWFSC)
Ray Conser, Southwest Fisheries Science Center (SWFSC)

Pacific Fishery Management Council (Council) Representatives
Kirk Lynn, Coastal Pelagic Species Management Team (CPSMT)
Diane Pleschner-Steele, Coastal Pelagic Species Advisory Subpanel (CPSAS)
Kerry Griffin, Council Staff

Pacific Sardine Stock Assessment Team
Kevin Hill, NOAA /SWFSC
Paul Crone, NOAA /SWFSC

Acoustic-Trawl Survey Team
David Demer, NOAA/SWFSC
Juan Zwolinski, NOAA/SWFSC

Aerial Survey Team
Tom Jagielo, Tom Jagielo Consulting
Ryan Howe, Northwest Sardine Survey (NWSS)
Jerry Thon, NWSS

Daily Egg Production Model Team
Nancy Lo, NOAA /SWFSC

Overview

The Pacific Sardine (Update) Stock Assessment Review convened at the Southwest Fisheries Science Center, La Jolla, CA laboratory on October 2-3, 2012 to review a draft update assessment by the Stock Assessment Team (STAT) for Pacific Sardine. Introductions were made (see list of attendees, Appendix 1), the agenda was adopted, and Kerry Griffin reviewed the Terms of Reference (TOR) for CPS assessments with respect to how the Panel would be conducted. A draft assessment document and background materials were provided to the Panel in advance of the meeting on a SWFSC FTP site.

Kevin Hill presented the assessment methodology and the results from a draft assessment utilizing the Stock Synthesis Assessment Tool, Version 3.21d (SS3) to the Panel. The draft assessment update included new and updated data, including updated final landings for model years 2010 and 2011, estimated landings for model year 2012, and updated and new length and conditional age-at-length compositions. Also included were a new Daily Egg Production Method (DEPM) survey point and new spring and summer acoustic-trawl survey points. The 2012 Pacific Northwest Aerial survey point was not included in the draft assessment update due to its late arrival and the low number of valid point sets. The base model ("X6b") in the draft assessment update also contained one minor change in the model parameterization from the 2011 assessment. Recruitment deviations were estimated through the year prior to the model year (t-1), rather than through the year two years prior (t-2) as was done in the 2011 assessment.

David Demer, Nancy Lo, and Tom Jagielo presented methods and results for the acoustic-trawl, Daily Egg Production Method (DEPM), and aerial surveys, respectively. The 2012 aerial survey was only able to conduct 14 valid point (trawl) sets (given their strict guidelines for valid point sets) and these all occurred beginning shortly after the aerial transects were completed, rather than concurrently as in previous years.

The review and explorations of the data and model focused on evaluating the proposed change in the number of years with estimated recruitment deviations and whether and how to include the aerial survey index estimate for 2012.

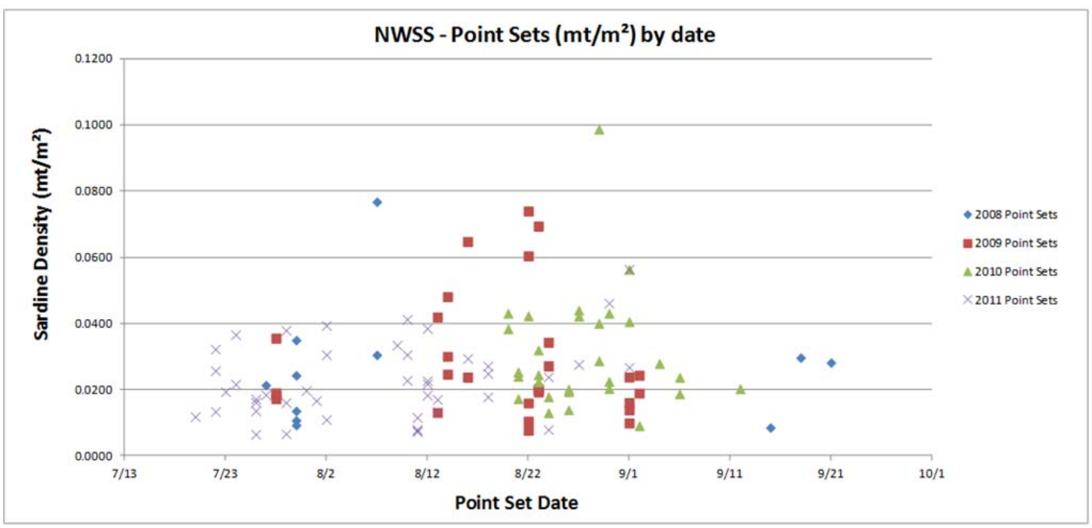
The Review Panel thanked the STAT and the Aerial Survey team for their work and willingness to respond to Panel requests, and the staff at the SWFSC La Jolla laboratory for their support and provisioning during the meeting.

Requests for Additional Analyses

A. For the aerial survey, pool the point sets over all years to estimate one surface area-density relationship. Then use this new relationship to re-estimate the complete time series of biomass estimates. **Rationale**: Pooling over years may be useful for handling the small number of usable point sets in 2012 (n=14). However, this would be a change in practice from previous years and it would be useful to evaluate the effect of such pooling more generally. **Results**: A comparison of the pooled (first set of rows) and the yearly (second set of rows) sardine biomass estimates and CVs is shown in the table below. The pooled estimates were standardized in terms of the area included and thus, were not directly comparable to the yearly estimates for 2009 and 2010. In particular, the 2009 estimate was difficult to compare between the methods (or to other years for the annual estimates), because the range of the survey was much broader. Still, generally, it appears that the pooling process does not bias estimates in either direction, i.e., in some years, the pooled estimate was less than the year-based estimate, while in other years, it was greater. The Aerial Survey team indicated that all yearly estimates will be revisited before the next full assessment, in efforts to standardize and improve methods across years.

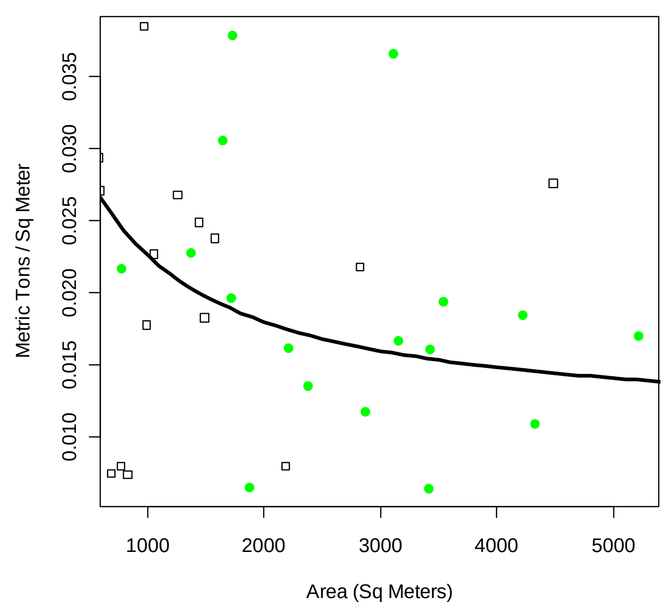
	2009	2010	2011	2012
Biomass (mt) - All Point Sets (n = 123)	826,868	141,586	261,957	696,251
CV	1.74	0.42	0.27	0.38
Biomass (mt) - Yearly Point Sets	1,236,911	173,390	201,888	906,680
n	28	24	35	14
CV	0.90	0.42	0.30	0.45

B. As time allows, evaluate the effect of lack of overlap in the timing of the aerial survey transects and the point sets in 2012 – perhaps by simulating a similar lack of overlap for years prior to 2012. This is a lower priority request given the sparseness of these data. **Rationale**: The transect data and the point set data were used jointly to estimate sardine biomass. The only year without coincident sampling was 2012 and thus, it would be useful to evaluate the effect. **Results**: Preliminary analysis (see below) indicated that there was a broad distribution of point sets throughout the sampling period in 2011 and these data may be amenable to further analysis. See follow-up Request D below.



C. Modify the stock-recruitment (S-R) bias adjustment ramp so that 2009 is the last year with no adjustment (cf. Figure 35c in the draft assessment document). In this case, 2010 would then fall on the ramp that goes to zero in 2011, and then re-tune. **Rationale**: Not estimating the recruitment deviations in the last two years (2010-11) – as done in the last full stock assessment – gave unexpectedly large differences in scale and trend from the last assessment. An alternative run (X6b) with only the final year not estimated was more reasonable, but the decision as to how many recruitment deviations should be estimated at the end of the time series is a somewhat subjective exercise in formal assessments. The S-R bias adjustment ramp approach may provide an objective middle ground. **Results**: Age 1+ biomass and recruitment estimates were quite similar to Run X6b (both scale and trend). However, the likelihood was only marginally greater, indicating that this approach had fully allowed for an adequate increase in variance of the 2010 recruitment deviation. A modification to Stock Synthesis may be needed to fully explore this approach for handling recruitment deviations near the end of the time series by reducing the applied σ-R, as well as bias adjustment for those years.

D. For the aerial survey, split the 2011 data into two parts (July 20 - August 10 and August 11 - September 1). Then for each period, plot the surface area-density data and fit curves, as appropriate. **Rationale**: The results from Request B, above, indicated that there was a broad distribution of point sets throughout the sampling period in 2011 (more so than other years), as well as about a week- long gap between the periods in early August, making it the most promising year to examine possible early- and late-season effects. **Results**: All of the 2011 point sets are shown in the figure below. Although the data were limited, no differences were apparent in the point sets done early in the season and those done late in the season. As such, lack of overlap in transect and point set sampling in 2012 does not appear to be a major issue.



Green dots = 2011 “early”; Black squares = 2011 “late”.

E. Re-run X6b adding the 2012 aerial survey (pooled point-sets estimate); use size compositions from the 2012 point sets and subsequently re-tune the model. **Rationale**: This is the candidate base case. The Panel would like to review all results and diagnostics including the final tuned model. **Results**: Age 1+ biomass and recruitment estimates were quite similar to Run X6b (both scale and trend). Fits to the indices and other diagnostics appeared to be reasonable. Re-tuning the model increased the variance estimates for the surveys slightly, but had little effect on age 1+ biomass, recruitment estimates, or diagnostics.

F. Re-run X6b adding the 2012 aerial survey (year-based estimate); use size compositions from the point sets. **Rationale**: This is a sensitivity run to evaluate the effect of incorporating the year-based estimate into the model (as had been done in previous years). **Results**: Age 1+ biomass and recruitment estimates were quite similar to Run X6b (both scale and trend). Fits to the indices and other diagnostics appeared to be reasonable.

G. Re-run X6b adding the full time series of pooled aerial survey estimates (2009-2012); use size compositions from the point sets. **Rationale**: This is a sensitivity run to evaluate the effect of using pooled estimates for all years. **Results**: This run will be included in the final assessment document.

H. Re-run X6a adding the 2012 aerial survey (year-based estimate). **Rationale**: This is a sensitivity run and it will provide (for the record) the results of a strict assessment update. **Results**: This run will be included in the final assessment document.

Issues raised by the CPSMT and CPSAS representatives during the meeting

a) CPSMT issues

The CPSMT representative commends the STAT and Panel for their preparation and review of the latest sardine stock assessment update incorporating new fishery and survey data. The CPSMT representative also recognizes the work of all the survey teams and agencies for their efforts in providing data for this assessment.

There appear to be discrepancies between survey and fishery data with regard to the timing and location of sardine occurrence. Summer fisheries in the Pacific Northwest encounter sardine in unmixed schools during the day, while the acoustic survey found relatively few sardine north of southern Oregon, typically in mixed assemblages at night. Sardine is sampled by the acoustic survey in offshore areas off California but not in nearshore areas (up to 1 or 2 miles off shore) which account for significant fishery landings. The CPSMT representative supports addressing these discrepancies with concurrent sampling by fishery seasons and geography, as well as by sampling in nearshore areas with vessels suited to that habitat. The timing of surveys relative to fishery prosecution may also affect survey results and this should also be considered.

The CPSMT representative supports the use of pooled point set data from recent years in this assessment as a result of the small sample size and non-synchronous timing of the 2012 point set data with the transect data. It may be worthwhile to look into the variability of the surface area-biomass relationship to confirm the validity of this approach for this and other aerial surveys in calculating biomass estimates. In addition, catchability (q) has been cited as a varying factor in this survey, leading to imprecise and perhaps inaccurate biomass estimates; the CPSMT representative agrees with the suggestion of a methods review for this survey in the near future.

b) CPSAS issues

The CPSAS representative commends the SSC subcommittee and STAT for their work to include as much flexibility as possible into this stock assessment update in an attempt to resolve tension in the model between biological data and survey data, and between the surveys themselves.

Previous Panels, the CPS Advisory Bodies, and the SSC have remarked that additional development was needed in the areas of surveys in order to enrich the data sources that fuel the model. A similar comment is appropriate this year, as the model appears to be struggling to fit survey data vs. biological composition data from the fishery.

Both aerial and acoustic surveys roughly overlapped the same time period in WA and northern OR, yet recorded widely different quantitative values for sardine biomass.

The 2012 aerial survey estimated a biomass of 906,680 mt for the Pacific Northwest, although the 2012 aerial survey was unique: a relatively small sample size and short lag between transects and point sets. The increase in biomass was attributed to good viewing conditions in 2012 for the one transect set that was completed, illustrating the year-to-year variability in catchability in this survey method.

In contrast, Table 1, Appendix B of the 2012 preliminary sardine stock assessment document displays the biomass estimated from acoustic trawl (ATM) measurements by stratum for the summer 2012 survey. The ATM biomass estimate for Washington-Oregon (13,335 mt) is far lower than actual landings made in the fishery during the summer fishing period (the fishery attained the July 1-Sep. 14 allocation and closed on August 22. OR-WA landings for the period totaled 48,653 mt through August 27.

Variability is apparent in all the indices employed to measure sardine abundance. Survey timing is critical, and each survey measures only a spot in time. Also critically important is the weighting attributed to various model components, i.e., surveys. The acoustic surveys are assigned a catchability coefficient (q) of 1, assuming that this survey method 'sees' the entire biomass. However, the CPSAS representative and industry are concerned that acoustic methods miss the upper 10 meters of the water column, as the vessel avoidance issue has not been resolved satisfactorily. Nor do acoustic surveys capture the full extent of the nearshore area, i.e., the beach, where sardines are known to congregate in California.

Two different states of nature seem to exist in this stock assessment update. The general trend in DEPM and acoustic surveys appear to be telling the same story, indicating a decline in biomass, but the aerial survey contradicts this, and the fishery is seeing length compositions that are not included in the surveys. This assessment update has highlighted the conflict in both scale and trend.

Sardine variability and dynamic swings in abundance are well documented over time. The CPSAS representative, on behalf of the CPSAS and industry, appreciates efforts of the STAT and SWFSC to acknowledge these problems and work to resolve them in future surveys and stock assessments, although this update is unable to make substantial changes to resolve the conflicts this year as stipulated in the *Terms of Reference for the Groundfish and CPS Stock Assessment and Review Process for 2013-2014*. Thus, management measures for 2013 will continue the trend to down-weight the biomass estimate. However, this will ensure a sustainable resource that is in no danger of overfishing.

Research recommendations (in addition to those in the 2011 STAR panel report)

1. Consider the spatial-temporal relationship of acoustic and aerial surveys and fishery catches to compare estimates of biomass from stratified areas of the coast between surveys, and to evaluate effect of the timing of fishing on the biomass observed by the surveys in any year. This could take the form of a spatial population model operating on a short time-step (daily or weekly).
2. Consider a Beverton-Holt or other S-R relationship in place of the Ricker model to investigate if such a change will stabilize the model relative to the number of recent years of recruitments estimated, while providing a biologically realistic relationship.
3. Consider placing a smaller σ_R (as well as bias correction) on the final recruitment estimated to reflect the reduced amount of information available for estimating that recruitment (this will likely require a change in the SS3 platform).
4. Consider the changes within and between years in targeting in considering the proper treatment of fishery selectivities and blocks and proper weighting of these data.
5. Conduct a methodology review on how to compare and best utilize data from the acoustic and aerial surveys in the sardine stock assessment. Among other possible issues, the review should consider if and how to improve their combined use in the assessment and consider incorporating the aerial survey as a minimum estimate (most easily done with a change in SS3, but doable with a prior on *q* for this survey).
6. Consider the proper weighting of both fishery and survey biological data vs. survey time series data. Consider downweighting biological compositions and emphasizing particular survey time series in future sensitivity analyses, e.g., see Francis (2011).

References

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences. 68(6): 1124-1138.

Appendix A. List of attendees

Name	Affiliation
Owen Hamel	Panel Chair (NWFSC)
Ray Conser	Panel member (SWFSC)
Diane Pleschner-Steele	CPSAS adviser
Kirk Lynn	CPSMT adviser
Kevin Hill	STAT lead (SWFSC)
Chelsea Protasio	CDFG
Emmanis Dorval	SWFSC
Jenny McDaniel	SWFSC
Paul Crone	STAT (SWFSC)
Ben Enticknap	Oceana
Juan Zwolinski	SWFSC
David Demer	SWFSC
Kevin Piner	SWFSC
Mike Okoniewski	Pacific Seafood
Dale Sweetnam	SWFSC
Nancy Lo	SWFSC
Cisco Werner	SWFSC
Bev Macewicz	SWFSC
Kristen Koch	SWFSC
Erin Reed	SWFSC
Kyle Byers	SWFSC
Jerry Thon	NWSS
Ryan Howe	NWSS
Russ Vetter	SWFSC
Ed Weber	SWFSC
Tim Sippel	SWFSC
Eric Lynn	SWFSC

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON THE PACIFIC SARDINE STOCK ASSESSMENT AND MANAGEMENT FOR 2013, INCLUDING PRELIMINARY EFP PROPOSALS AND TRIBAL SET-ASIDE

The Scientific and Statistical Committee (SSC) reviewed the 2012 update assessment of the northern subpopulation of Pacific sardine. Dr. Kevin Hill from the Southwest Fisheries Science Center (SWFSC) presented an overview of the assessment and discussed new data in the assessment, including the 2012 acoustic trawl (ATM), egg production (DEPM) and aerial surveys. The aerial survey used a slightly different methodology than used previously, with biomass estimates in the model derived from point sets pooled across years, with length data from 2012. The SWFSC conducted a spring DEPM survey and both spring (in California) and summer (from San Diego into Canada) ATM surveys. The estimate of spawning stock biomass in 2012 from the update assessment was 50 percent lower than the previous estimate for 2011, but higher than those for years 2008-10.

Several issues regarding the surveys were raised. The summer ATM survey found that trawls in the northern area had highly mixed species composition. There was a discrepancy between the biomass estimate in the northern (WA/OR) portion of the ATM survey area and the fishery landings (as well as the aerial survey estimate). Vessel avoidance and the acoustic transducer on the survey vessel missing fish on the surface were raised as possible explanations for this discrepancy. The aerial survey used the one complete set of transects (Set B) for school number and surface area estimates, while the point sets were taken after completion of the transacts rather than concurrently. More problematically, only 14 acceptable point sets were conducted, and they were not spatially representative of the sardine schools photographed during the transects. Given this lack of spatial coverage of the point sets, and the highly mixed Coastal Pelagic Species found in the ATM trawls in the same area as many of the photographed schools, there are potential species composition problems with the estimates derived from the aerial photographs. However, the composition of photographed schools and ATM trawls are not directly relatable, as the former are taken during the day and the latter at night when CPS are dispersed.

Dr. Owen Hamel of the SSC presented a report of the review panel that was convened to review the update assessment. The panel endorsed a change to the model that involved the use of recruitment deviations estimated through end year-1 and rather than end year-2, as it provided better fit to the data, and recommended that a base model (X6e) that incorporated this change be used for management in 2013.

The SSC notes that the current Harvest Control Rule uses the biomass estimate on July 1, 2012 to determine an overfishing limit and harvest guideline for the 2013 calendar year, thereby ignoring any change in biomass from July 1 to December 31, 2012. This could be consequential for this assessment, given the declining trend in abundance. The SSC suggests that future evaluations of the harvest control rule consider basing the OFL and HG on the biomass at the start of the fishing year, as is the case for other Council-managed fisheries. The SSC again emphasizes that there is little time between when data are provided to the Stock Assessment

Team (STAT) and the deadline for assessment completion, which raises multiple challenges for completing the assessment and conducting a review. This problem could be addressed by changing the start of the fishing year.

The SSC endorses the update assessment (model x6E) as the best available science for management in 2013 and further endorses the OFL=103,284 mt, and the sigma value of 0.36. The SSC notes that the relationship between temperature and stock productivity has not yet been clarified; using a constant F_{MSY} proxy was recommended in November 2011 as an interim measure only. Re-evaluation of the science used in the Harvest Control Rule parameters should be of highest priority for next year's assessment (see SSC statement F.4).

Dr. André Punt of the SSC provided an overview of the Methodology Review Panel that reviewed possible use of the Vancouver Island swept area trawl survey in management. This trawl survey has been conducted by the Department of Fisheries and Oceans (Canada) since 2002, but there have been serious issues of consistency in and adequacy of survey methodology. The 2010 survey was the first that was sufficiently close to the recommendations of the Methodology Review Panel to be appropriate for use in management. When several additional years of standardized data collection have occurred, the survey should be evaluated by the STAT and a STAR panel for use in assessment and management. The SSC further noted that coordination with US surveys could potentially increase the value of the Canadian survey. The SSC endorses the report and emphasizes that a time series derived from several more years of standardized survey methodology is necessary before the survey may be useful for management.

The SSC noted that a letter of intent to apply for an exempted fishing permit to continue the Northwest aerial sardine survey in 2013 was submitted. The survey has consistently failed to achieve adequate point sets to meet objectives specified in the sampling plan. While this might be partially addressed by scheduling changes, the SSC recommends a formal review of the survey methodology, following up on the issues raised in the 2007 STAR panel.

PFMC
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COASTAL PELAGIC SPECIES MANAGEMENT TEAM REPORT ON PACIFIC SARDINE STOCK ASSESSMENT AND MANAGEMENT FOR 2013

The Coastal Pelagic Species Management Team (CPSMT), the Coastal Pelagic Species Advisory Panel (CPSAS) and the Scientific and Statistical Committee (SSC) jointly received a presentation from Dr. Kevin Hill concerning the Pacific sardine stock assessment conducted in 2012. The CPSMT recommends that the Pacific Fishery Management Council (Council) adopt the update assessment (model X6e) for management of the 2013 sardine fishery (Agenda Item G.3.b, Supplemental Assessment Report 2). Based upon the 659,539 metric tons (mt) age 1+ biomass estimate from this assessment, the harvest control rule produces a harvest guideline (HG) of 66,495 mt (Table 1 below). The 2012 biomass estimate represents a 33 percent decrease from the full stock assessment previously adopted by the Council in November, 2011. The CPSMT notes the 2012 results of the Daily Egg Production Index and the hydroacoustic trawl surveys contributed to the decrease in the biomass estimate.

Harvest Specifications for 2013

Table 1 (below) contains the resulting overfishing limit and a range of acceptable biological catch values based on various P* (probability of overfishing) values. The CPSMT recommends that the annual catch limit equal the ABC resulting from the Council's P* choice, and that the HG/annual catch target be set equal to 66,495 mt. Considering the results of the full stock assessment conducted in 2011, the Council chose a P* of 0.40 for the 2012 fishery.

The Quinault Indian Nation (Agenda Item G.3.a, Attachment 1) requests 9,000 mt of Pacific sardine for their participation in the 2013 fishery, the same as requested for 2012. The CPSMT notes that 6,000 mt of the 2012 set-aside for the Quinault Indian Nation was not used and was released to the third fishing period. Acknowledging that a set-aside for the Quinault Indian Nation has yet to be determined, the CPSMT presents a preliminary allocation scheme for the 2013 fishery (Table 2 below) that incorporates a set-aside of 9,000 mt.

The Northwest Sardine Industry LLC has notified the Council (Agenda Item G.3.a, Attachment 2) it intends to request an exempted fishing permit (EFP) for 3,000 mt, the same as approved in 2012. Recognizing the Council will determine whether to approve the EFP at a future meeting, CPSMT recommends setting aside 3,000 mt for the Northwest sardine industry EFP, and this is reflected in Table 2.

Further, the CPSMT recommends any EFP set-aside not included in an EFP, as well as any EFP fish allocated but not utilized, should be re-allocated to the third period directed fishery. Finally, the CPSMT recommends that the incidental catch for CPS fisheries in each of the three allocation periods should be set to 1,000 mt (Table 2) and that the incidental landing allowance for CPS fisheries be no more than 40 percent Pacific sardine by weight.

Based on the values in Table 1, the CPSMT recommends adoption of the allocation scheme in Table 2.

Table 1. Pacific sardine harvest formula parameters for 2013.

Harvest Formula Parameters	Value			
BIOMASS (ages 1+, mt)	659,539			
P* (probability of overfishing)	0.45	0.40	0.30	0.20
BUFFER_{P*} (Sigma=0.36)	0.95577	0.91283	0.82797	0.73861
F_{MSY}	0.18			
FRACTION	0.15			
CUTOFF (mt)	150,000			
DISTRIBUTION (U.S.)	0.87			

Harvest Formulas	MT
OFL = BIOMASS * F_{MSY} * DISTRIBUTION	103,284
$\text{ABC}_{0.45}$ = BIOMASS * $\text{BUFFER}_{0.45}$ * F_{MSY} * DISTRIBUTION	98,716
$\text{ABC}_{0.40}$ = BIOMASS * $\text{BUFFER}_{0.40}$ * F_{MSY} * DISTRIBUTION	94,281
$\text{ABC}_{0.30}$ = BIOMASS * $\text{BUFFER}_{0.30}$ * F_{MSY} * DISTRIBUTION	85,515
$\text{ABC}_{0.20}$ = BIOMASS * $\text{BUFFER}_{0.20}$ * F_{MSY} * DISTRIBUTION	76,287
HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION	66,495

Table 2. Preliminary allocation scheme for 2013 Pacific Sardine ACT

HG = 66,495 mt; Tribal set-aside = 9,000 mt; potential EFP set-aside = 3,000 mt
Adjusted HG = 54,495 mt

	Jan 1- Jun 30	Jul 1- Sep 14	Sep 15 – Dec 31	Total
Seasonal Allocation (mt)	19,073 (35%)	21,798 (40%)	13,624 (25%)	54,495
Incidental Set-Aside (mt)	1,000	1,000	1,000	3,000
Adjusted (Directed) Allocation (mt)	18,073	20,798	12,624	51,495

Recommendations for future actions

In regards to the industry-sponsored aerial survey in 2012, the CPSMT commends the EFP applicants for their efforts. The CPSMT understands that the duration of the fishing periods, weather and other logistical limitations precluded completing the survey as designed, resulting in relatively few data points useful in the stock assessment. However, while nearly the entire set-aside was utilized, a substantial portion was not used to achieve the scientific goals of the EFP. If approved for 2013, the CPSMT encourages the EFP applicants to improve utilization of the set-aside to achieve science goals.

A methodology review of the Canadian West Coast Vancouver Island Swept Area Trawl Survey was completed in 2012 (Agenda Item G.3.a, Attachment 5). The CPSMT supports the continuation of the West Coast Vancouver Island trawl sardine survey (WCVI), and that it be conducted as recommended in the review report. The panel considered the last two years of the survey (2010-2011) as the best data and stated the necessity of at least four years of data using the latest survey design and methods before including in a stock assessment. The CPSMT recommends the stock assessment team evaluate the time series when it comprises at least four estimates, at which time it could be included in a future stock assessment.

PFMC
11/04/12

COASTAL PELAGIC ADVISORY SUBPANEL REPORT ON PACIFIC SARDINE STOCK ASSESSMENT AND MANAGEMENT FOR 2013, INCLUDING PRELIMINARY EFP PROPOSALS AND TRIBAL SET-ASIDE

West Coast Vancouver Island Survey

The Coastal Pelagic Species Advisory Subpanel (CPSAS) recommends that the Council approve West Coast Vancouver Island (WCVI) Survey for use in future stock assessments, as appropriate. The subpanel further encourages continuation of the WCVI survey using the 2011/2012 methodology.

Exempted Fishing Permit Notice of Intent

The CPSAS unanimously supports an Exempted Fishing Permit (EFP) set aside of 3,000 mt for Pacific Northwest industry-supported research, to be deducted from the harvest guideline (HG) before it is allocated to fishing periods. The CPSAS would also like to recommend that any EFP set aside not utilized be re-allocated to the third period directed fishery.

Pacific Sardine Management for 2013

The CPSAS participated in a joint meeting with the CPSMT and the Scientific and Statistical Committee (SSC) where Dr. Kevin Hill presented the 2012 sardine stock assessment for use in the 2013 fishery. We thank the Stock Assessment Team for the enormous amount of work that went into completing this stock assessment update.

The CPSAS highlights the inconsistencies between the acoustic trawl methodology (ATM), the aerial survey, and the Pacific Northwest landings data. Although the aerial and acoustic surveys in Washington and northern Oregon were conducted generally in the same time and area, each recorded widely different quantitative values for sardine biomass. The 2012 aerial survey estimated a biomass of 906,680 mt for the Pacific Northwest.

In contrast, the biomass estimated from the acoustic trawl survey for Washington-Oregon was estimated to be only 13,335 mt. This estimate is significantly lower than actual landings (48,653 mt) made in the fishery during the summer fishing period. Given this discrepancy, the CPSAS questions whether the acoustic trawl data accurately assesses the full biomass. Possible deficiencies in the current acoustic trawl methodology include inability to survey the nearshore biomass, issues of vessel avoidance, and the placement of transducers, which appears to miss sardines in the upper 10 meters of the water column.

Of additional concern, is the fact that the acoustic surveys are currently assigned a catchability coefficient (q) of 1, which assumes this survey method ‘sees’ the entire biomass in the transects. The subpanel recommends the use of side-scanning sonar in these surveys, to further study vessel avoidance and number of sardine schools in proximity to the research vessel. In the absence of this option, we recommend sonar equipped fishing vessels to accompany the research vessel.

Sardine variability and dynamic swings in abundance are well documented over time. We appreciate the efforts of the stock assessment team (STAT) and Southwest Fisheries Science Center (SWFSC) to acknowledge these problems and work to resolve them in future surveys and stock assessments. Although this update is unable to make substantial changes to resolve the conflicts this year, as stipulated in the *Terms of Reference*, we are concerned that present survey methods do not accurately estimate the existing sardine biomass.

Based on the update assessment (model X6e) for management of the 2013 sardine fishery (Agenda Item G.3.b, Supplemental Assessment Report 2) the age 1+ biomass estimate from this assessment is 659,539 mt. The harvest control rule produces a harvest guideline (HG) of 66,495 mt, with allocation to continue as in 2012 and as appears below in the supplemental CPSMT Report, Table 2, with the exception noted below.

The CPSAS recommends that the incidental landing allowance in other CPS fisheries in 2013 be raised to no more than 40 percent Pacific sardine by weight, to account for the possibility of mixed-fish catches in the Pacific mackerel fishery, particularly in summer months. The CPSAS recommends that if the directed seasonal allocation and set-asides are reached, the retention of Pacific sardine be prohibited for the remainder of that sardine season.

Table 2. Preliminary allocation scheme for 2013 Pacific Sardine ACT

HG = 66,495 mt; Tribal Set-aside = 9,000 mt; Potential EFP set-aside = 3,000 mt
Adjusted HG = 54,495 mt

	Jan 1- Jun 30	Jul 1- Sep 14	Sep 15 – Dec 31	Total
Seasonal Allocation (mt)	19,073 (35%)	21,798 (40%)	13,624 (25%)	54,495
Incidental Set-Aside (mt)	1,000	1,000	1,000	3,000
Adjusted (Directed) Allocation (mt)	18,073	20,798	12,624	51,495

The CPSAS commends the effective in-season actions taken by the National Marine Fisheries Service (NMFS) to deal with surpluses or shortages in the directed and incidental seasonal allocations.

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11/04/12

RECENT TECHNICAL MEMORANDUMS

SWFSC Technical Memorandums are accessible online at the SWFSC web site (http://swfsc.noaa.gov). Copies are also available form the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 (http://www.ntis.gov). Recent issues of NOAA Technical Memorandums from the NMFS Southwest Fisheries Science Center are listed below:

NOAA-TM-NMFS-SWFSC-491 Sacramento River winter Chinook cohort reconstruction: analysis of ocean fishery impacts.
M.R. O'FARRELL, M.S. MOHR, A.M. GROVER, and W.H. SATTERTHWAITE
(August 2012)

492 Ichthyoplankton and station data for surface (Manta) and oblique (Bongo) plankton tows for California Cooperative Oceanic Fisheries Investigations Cruises and California Current Ecosystem Survey in 2009.
A.R. THOMPSON, W. WATSON, and S.M. MANION
(July 2012)

493 A description of the tuna-porpoise observer data collected by the U.S. National Marine Fisheries Service 1971 to 1990.
A.R. JACKSON
(November 2012)

494 California Coastal Chinook salmon: status, data, and feasibility of alternative fishery management strategies.
M.R. O'FARRELL, W.H. SATTERTHWAITE, and B.C. SPENCE
(November 2012)

495 Cruise report for the Vaquita Expedition 2008 conducted aboard NOAA Ship *David Starr Jordan*, *R/V Koipai YÚ-XÁ*, and the *Vaquita Express.*
A HENRY, B. TAYLOR, L. ROJAS-BRACHO, S. RANKIN, A. JARAMILLO-LEGORETTA, T. AKAMATSU, J. BARLOW, T. GERRODETTE, C. HALL, A. JACKSON, J. REDFERN, R. SWIFT, and N. TREGENZA
(September 2012

496 2003 Survey of rockfishes in the Southern California Bight using the collaborative optical-acoustic survey technique.
D.A. DEMER, editor and list on page 5.
(October 2012)

497 2004 Survey of rockfishes in the Southern California Bight using the collaborative optical-acoustic survey technique.
D.A. DEMER, editor and list on page 4.
(October 2012)

498 2004 Survey of rockfishes in the Southern California Bight using the collaborative optical-acoustic survey technique.
D.A. DEMER, editor and list on page 6.
(October 2012)

499 Predictive modeling of cetacean densities in the California Current Ecosystem based on summer/fall ship surveys in 1991-2008.
E.A. BECKER, K.A. FORNEY, M.C. FERGUSON, J. BARLOW and J.V. REDFERN
(October 2012)

500 Marine mammal and seabird bycatch in California gillnet fisheries in 2011.
J.V. CARRETTA and L. ENRIQUEZ
(December 2012)