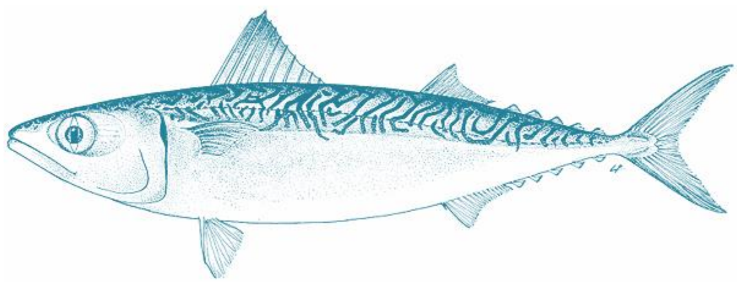
PACIFIC MACKEREL (*Scomber japonicus*) STOCK ASSESSMENT FOR USA MANAGEMENT IN THE 2015-16 FISHING YEAR



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PREFACE

A Pacific mackerel stock assessment is conducted every two years to provide management advice in support of the Pacific Fishery Management Council (PFMC) process, which ultimately establishes a harvest guideline (HG or quota) for the Pacific mackerel fishery that operates off the USA Pacific coast. The HG for Pacific mackerel applies to a fishing/management season that spans from July 1st and ends on June 30th of the subsequent year (henceforth, presented as a 'fishing year'). For example, in this report, both two-year (2014-15) and single-year (2014) references refer to the same fishing year that spanned from July 1, 2014 to June 30, 2015. The primary purpose of the assessment is to provide an estimate of current abundance (in biomass), which is used in a harvest control rule for setting HGs. For details regarding this harvest control rules applicable to this species, see Amendment 8 of the Coastal Pelagic Species (CPS) Fishery Management Plan (FMP), section 4.0 (PFMC 1998). Also, for additional harvest stipulations and estimated quantities that have been recently adopted for management of the small pelagic fisheries, such as overfishing limits, acceptable biological catches, etc., see the CPS FMP-Amendment 13 (PFMC 2011). The last full stock assessment, review, and management advice for this species occurred in 2011 (Crone et al. 2011; STAR 2011a), with a HG serving for two fishing years. In April 2013 and 2014, catch-based projection assessments were conducted and used to determine the HG for the upcoming fishing year (Crone 2013; Crone and Hill 2014). The stock assessment report presented here was reviewed in April 2015 for purposes of advising management for two consecutive fishing years, 2015-16 and 2016-17 (STAR 2015). In 2017, a catch-based projection assessment is to be conducted for management for the following two consecutive fishing years, 2017-18 and 2018-19, with a full assessment scheduled for 2019.

This report is based on the most recent stock assessment review (STAR), which was held from April 27-29, 2015 at the Southwest Fisheries Science Center (SWFSC/NOAA/NMFS) in La Jolla, CA to evaluate the ongoing Pacific mackerel stock assessments that are used to provide management guidance on a systematic basis following PFMC procedures (PFMC 2014a). The first draft of the assessment report was distributed prior to the review meeting in April, which highlighted candidate models for consideration that addressed five primary areas related to both the quality of data and parameterizations included in the assessment, particularly, in the context of meeting the overriding goal to provide an estimate of current abundance annually for management purposes. An important area of discussion during the review was determination of the utility of fishery-independent data from a newly-implemented acoustic-trawl (AT) survey conducted by (SWFSC) in formal assessments of the stock. Given conclusions from the STAR panel regarding the adequacy (representativeness) of information from the AT survey for informing abundance estimation in the assessment at this time, data from this survey were not included in the model H3 proposed by the stock assessment team (STAT). Rather, noting unresolved areas and lack of consensus regarding a final model (STAR 2015), the STAT selected model H3 as the most objective configuration for advising management in the short-term, given: 1) it represented an updated configuration that closely resembled the previously accepted model (XA) for management in 2011; 2) was a plausible configuration ('state of nature'), with reasonable fits to input time series; 3) was stable in diagnostic-related perturbations; 4) was consistent with external information concerning stock availability to the fisheries, including results that reflected historically low estimates of recent stock biomass as indicated in the AT survey index of abundance time series, recent history of unrealized quotas by the USA commercial fishery, and limited catches reported in Mexico; and finally, 5) resulted in generally similar derived quantities useful to management as analogous models that included the AT survey data. Following the CPS terms of reference, this report focuses on data and parameterizations included in model H3, and presents summary information for the candidate models also reviewed.

It is important to note that the STAR panel concluded the AT survey potentially represents the most objective information available for monitoring the inherently variable abundance of this species on a systematic basis. However, recommendations from the review found that the utility of these data for informing management at this time is limited due to assumptions regarding the extensive range of the stock related to the spatial boundaries of the survey, i.e., uncertainty surrounding the variable portion of the stock biomass in the area surveyed and determination of appropriate bounds for survey catchability for this species. Further, the STAT concurred with the STAR panel that further modeling investigations would benefit future development of an AT-based assessment that provides justifiable estimates of catchability (both inside and outside the model), includes plausible/supported biological assumptions and internal consistency among data sources used in the model, and generates robust results for management. Important areas of general consensus, unresolved sample/modeling uncertainties, and recommendations for future research are presented in the Model selection and evaluation, Unresolved problems and major uncertainties, and Research and Data Needs sections below. Finally, although model H3 did not include AT survey data, baseline information and related displays associated with candidate models that did incorporate these fishery-independent data are presented in the final assessment report here for purposes of more fully documenting relevant work conducted prior and during the review in April 2015.

EXECUTIVE SUMMARY

Stock

The full range of Pacific mackerel in the northeastern Pacific Ocean is from southeastern Alaska to Banderas Bay (Puerto Vallarta), Mexico, including the Gulf of California (Figure 1). The majority of the fish are typically distributed from Monterey Bay, California to Cabo San Lucas, Baja California Sur, being most abundant south of Point Conception, California. Although stock structure of this species off the Pacific coast of North America is not known definitively, it is generally hypothesized that three spawning aggregations exist currently: one in the Gulf of California; one in the vicinity of Cabo San Lucas; and one along the Pacific coast north of Punta Abreojos, Baja California Sur, extending north to waters off southern California, and even further off the Pacific Northwest, depending on oceanographic conditions. The latter sub-stock is harvested by fishermen in the USA and Baja California, Mexico, and is the population addressed in this assessment.

Catches

Pacific mackerel are primarily landed by commercial purse-seine vessels operating along the USA Pacific coast (California ports primarily, but also Oregon and Washington in more recent years), as well as off Baja California by a fleet based in Mexico (Figure ES-1 and Table ES-1). A minor recreational fishery, including commercial passenger fishing vessel (CPFV), small private boat, pier, beach, etc. has traditionally operated in California waters, but has contributed <5% to the total annual landings of Pacific mackerel in most years (Table ES-1). Catch time series from 1983 to 2014 were used in this assessment, based on landings from both commercial (USA and Mexico) and recreational (USA) fisheries. Landings were combined into a single fishery in model H3.

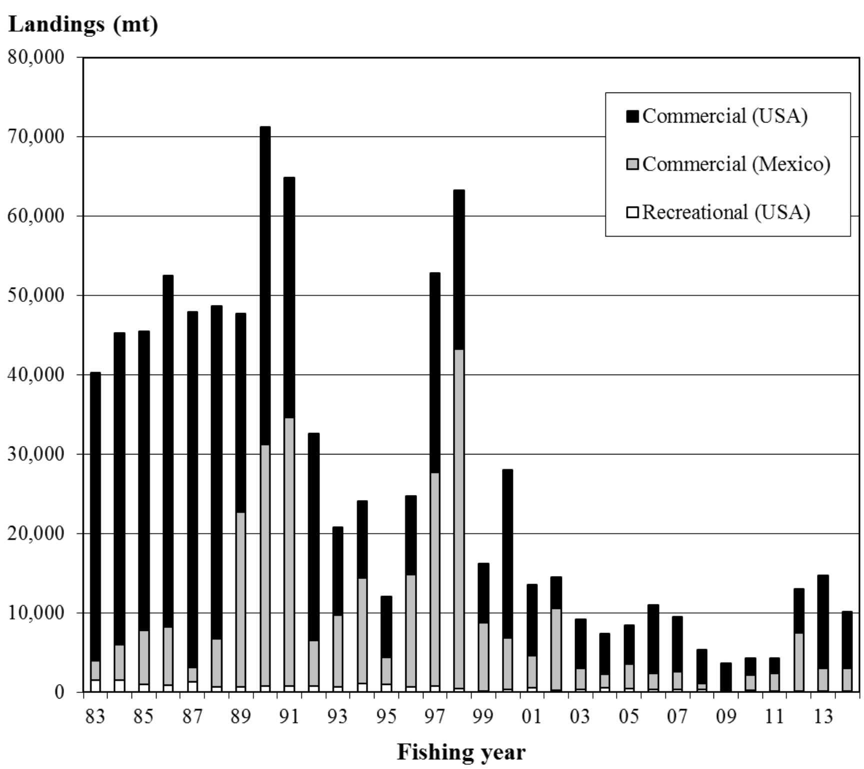

Figure ES-1. Landings of Pacific mackerel by fishery (1983-14). Model H3 is based on a single, combined fishery (see total estimates in Table ES-1).

Table ES-1. Landings (mt) of Pacific mackerel by fishery (1983-14). Recreational fishery proportion of total landings is also presented. Model H3 is based on a single, combined fishery (see total estimates).

	Commercial				Recreational		Recreational
Fishing year	**MX**	**CA**	**OR**	**WA**	**CA**	**Total**	**Proportion**
2004	1,711.4	5,011.8	110.4	23.7	544.0	7,401.3	0.07
2005	3,084.9	4,572.1	314.3	22.3	412.0	8,405.5	0.05
2006	1,986.1	7,870.2	669.4	41.8	372.0	10,939.5	0.03
2007	2,218.4	6,208.4	697.8	37.5	310.4	9,472.5	0.03
2008	803.1	4,203.9	57.6	9.0	280.3	5,353.9	0.05
2009	49.4	3,278.7	54.4	4.9	268.6	3,656.0	0.07
2010	1,916.7	2,047.0	47.8	1.6	216.6	4,229.7	0.05
2011	2,232.0	1,665.2	201.9	83.0	127.0	4,309.0	0.03
2012	7,390.0	3,201.5	1,587.8	693.4	100.2	12,972.9	0.01
2013	2,825.2	11,165.3	437.9	178.5	139.9	14,746.9	0.01
2014	2,825.0	5,445.5	1,172.3	544.8	136.4	10,124.0	0.01
Avg. (2004-14)	2,458.4	4,970.0	486.5	149.1	264.3	8,328.3	0.04

Data and assessment

Historically, various age-structured population dynamics models have been used to assess the status of Pacific mackerel off the USA Pacific coast, which were generally based on fishery landings, length/age compositions, and relative indices of abundance from fisheries and/or research surveys. The last full stock assessment of Pacific mackerel was completed in 2011 for USA management in the 2011-12 fishing year (Crone et al. 2011). All candidate model scenarios (configurations) presented in this assessment report were based on an age-structured modeling framework (Stock Synthesis) and age-based selectivity using both age data (commercial fishery) and depending on the configuration, length data from either the CPFV fleet alone (e.g., model H3) or including acoustic-trawl survey length data as well. Primary sources of sample data included in model H3 follow: catch time series (see Catches above); age compositions from the commercial fishery operating out of California (1983-14); and an index of abundance from the CPFV fleet (1983-14), with associated length compositions (1992-14). Note that some candidate models also included length composition (2005-13) and index of abundance time series from the acoustic-trawl (AT) survey (2005-2013). Model H3 closely resembled model XA (model from last full assessment conducted in 2011), including updated data/time series and generally similar assumptions and parameterizations.

Spawning stock biomass and recruitment

Recruitment was modeled using the Beverton-Holt (B-H) stock-recruitment relationship in all candidate models, with fixed recruitment variance ($\sigma_R = 0.75$) and estimated steepness ($h = 0.48$, model H3). Virgin recruitment (R_0) for model H3 was estimated to be roughly 0.54 billion age-0 fish, based on a virgin (female) spawning stock biomass estimate of approximately 78,425 mt. Since the mid-1980s, SSB has continually declined, remaining consistently low over the last decade (Table ES-2, Figure ES-2). Periods of high recruitment success were last observed in the mid-1980s and mid-1990s (1-2.7 billion fish), followed by very low recruitment success from the mid-1990s to 2012, with somewhat higher levels estimated most recently, noting that estimates are highly uncertain (Figure ES-3, Table ES-2).

Table ES-2. Estimated stock biomass (*B* in mt, age 1+ fish), recruitment (*R* in 1,000s, age-0 fish), spawning stock biomass (male and female *SSB*), and fishing mortality (*F*) time series for Pacific mackerel based on model H3 (2004-14).

Fishing year	*B (mt)*	*R* (1,000s of fish)	*SSB* (mt)	*F* (yr^{-1})
2004	31,714	179,264	12,948	0.21
2005	38,649	314,605	13,108	0.18
2006	58,056	221,319	16,139	0.17
2007	67,254	160,740	21,364	0.14
2008	68,392	125,712	26,957	0.08
2009	66,763	54,106	31,632	0.06
2010	57,925	158,783	33,506	0.07
2011	57,122	263,888	31,247	0.07
2012	69,164	225,612	29,970	0.18
2013	71,723	499,332	28,474	0.18
2014	97,395	387,989	30,807	0.09
2015	120,435	300,935	40,777	0.18
2016	118,968	327,350	47,178	0.18
Avg. 2004-16	71,043	247,664	28,008	0.14

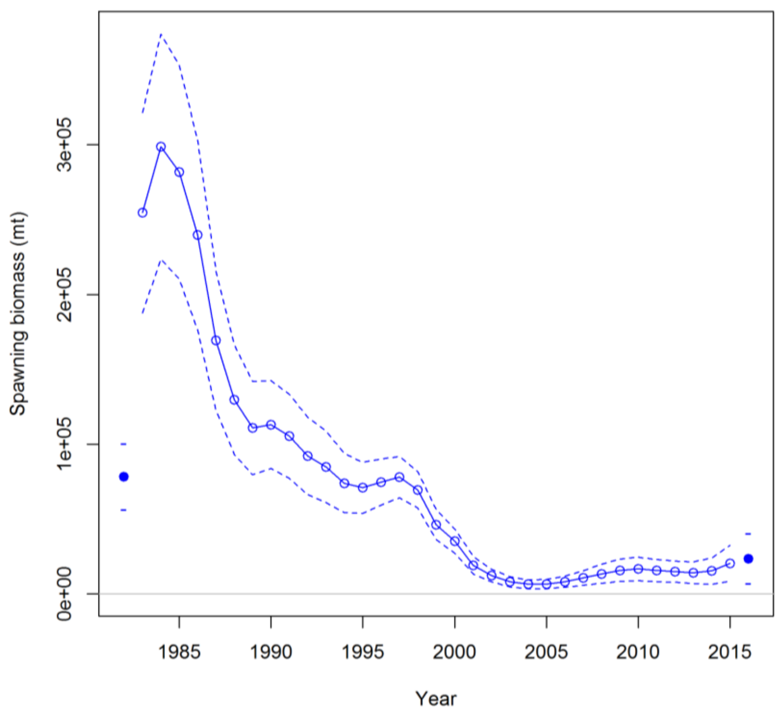

Figure ES-2. Estimated spawning stock biomass (female SSB) time series and 95% confidence intervals for Pacific mackerel for model H3. Solid dots reflect estimate of virgin (female) SSB and forecasted (female) SSB in July 2016.

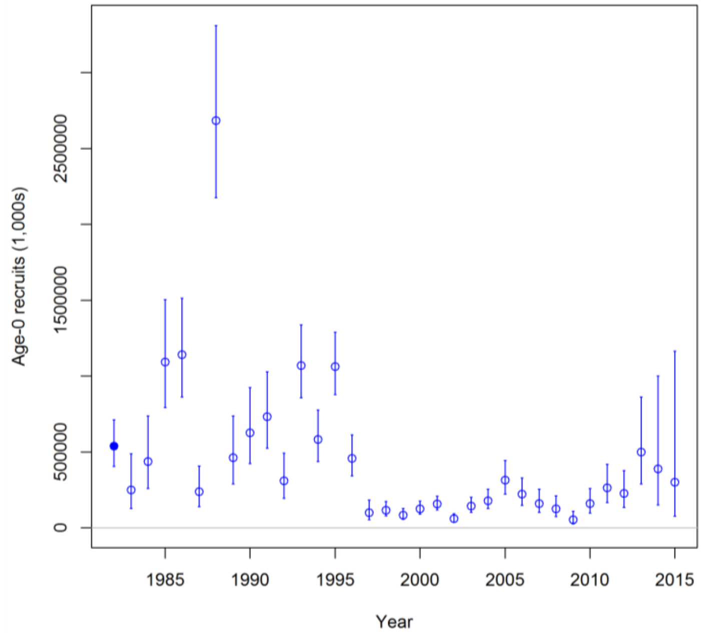

Figure ES-3. Estimated recruitment (1,000s of age-0 fish) time series and 95% confidence intervals for Pacific mackerel for model H3. Solid dots reflects estimate of virgin recruitment.

Stock biomass

Estimated stock biomass (mt, age 1+ fish) of Pacific mackerel is used for setting management specifications on an annual basis. Similar to estimated SSB, estimates of stock biomass have continually declined since the mid-1980s, remaining at low levels since 2004, with some increase noted in the last few years (Table ES-2, Figure ES-4). Past and present assessments of this stock indicate that since at least the late 1990s, abundance has remained at historically low levels (<150,000 mt).

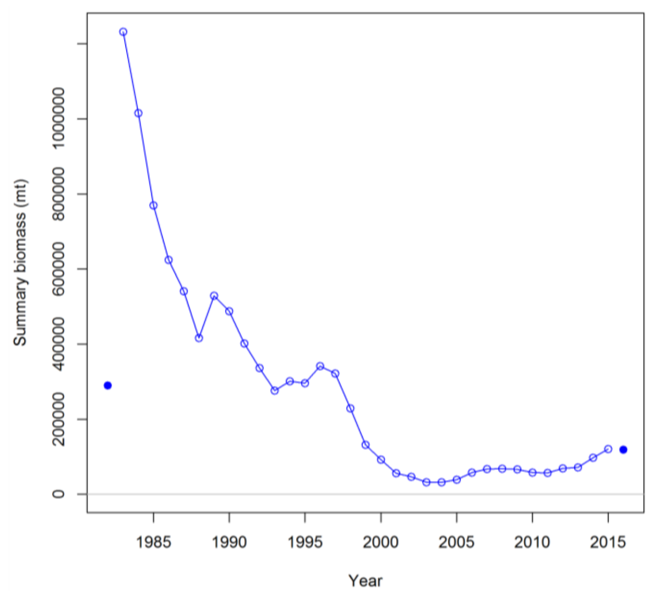

Figure ES-4. Estimated stock biomass (age 1+ fish, mt) time series for Pacific mackerel for model H3. Solid dots reflect estimate of virgin stock biomass and forecasted stock biomass in July 2016.

Exploitation status

Estimated rates of instantaneous fishing mortality (*F*, yr^{-1}) for this stock have fluctuated over time, from <0.1 to nearly 0.4 observed from the late 1990s to early 2000s. Recent estimates of fishing intensity indicate *F* has been generally <0.2 over the last decade (Table ES-2). Exploitation rate (annual catch/mid-year total biomass) time series closely follow the estimated *Fs* over time, with annual removal rates (including Mexico catches) reaching roughly 25-35% from the late 1990s to mid-2000s and <5 to 20% over the last decade (Figure ES-5).

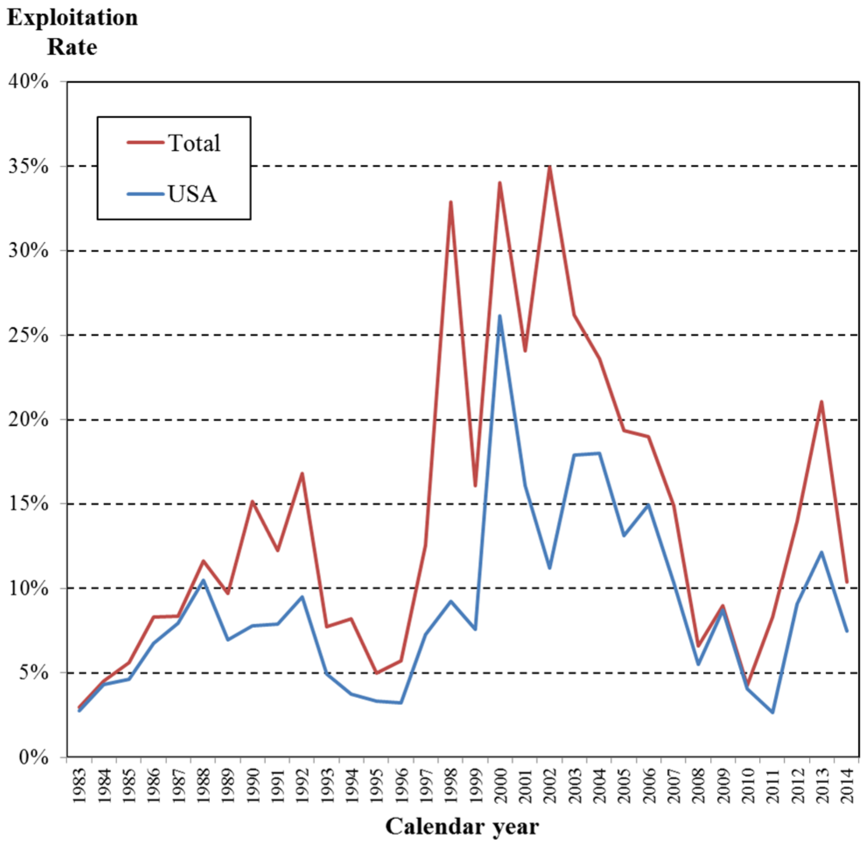

Figure ES-5. Estimated exploitation rate (catch/estimated stock biomass) time series (USA and total) for Pacific mackerel for model H3. Note that the reference year is the calendar not fishing year in this display.

Ecosystem considerations

Readers should consult PFMC (2014b, 2015) for information regarding environmental processes generally hypothesized to influence small pelagic finfish species, such as Pacific mackerel, that inhabit the California Current Ecosystem and broader northeastern Pacific Ocean. Also, see references included in AT survey index of abundance and Appendix A below.

Harvest control rules

The following harvest control rule results are applicable to model H3. Since 2000, the Pacific mackerel stock has been managed under a Federal Management Plan (FMP) harvest policy, stipulating that an optimum yield for this species should be set according to the following harvest control rule:

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

where Harvest is the harvest guideline (HG), Biomass is age 1+ stock biomass (mt) in the respective fishing year (120,435 mt in July 2015 and 118,968 mt in July 2016), Cutoff (18,200 mt) is the lowest level of estimated biomass above which harvest is allowed, E_{MSY} (30%, also referred to as Fraction) is the proportion of biomass above the Cutoff that can be harvested by fisheries, and Distribution (70%) is the average proportion of total Biomass (ages 1+) assumed in USA waters (PFMC 1998). Harvest stipulations under the federal FMP are applied to a July-June fishing year. The HG estimate based on model H3 for July 2015 was 21,469 mt (Table ES-3a) and 21,161 mt for July 2016 (Table ES-3b). Note that the forecasted HG for 2016 was based on the assumption that the HG for 2015 (21,469 mt) would be fully utilized, with predicted recruitment (i.e., 2015 year-class) for the forecast period estimated directly from the stock-recruitment relationship (see STAR 2015). Landings and associated HGs since 2004 are presented in Figure ES-6. Finally, additional harvest control rule statistics recently required for USA Pacific coast fisheries (PFMC 2011) are also included in Table ES-3 for overfishing limits, as well as a range of acceptable biological catches and limits (ABCs and ACLs) based on different probability levels of overfishing using ‘P-star’ and associated ABC ‘buffer’ calculations.

Table ES-3. Pacific mackerel harvest control rules for model H3: a) for 2015-16 management year based on estimated stock biomass in July 2015; and b) for 2016-17 management year based on estimated stock biomass in July 2016.

a)

Harvest Control Rule Formulas									
OFL = BIOMASS * E_{MSY} * DISTRIBUTION									
$ABC_{P\text{-}star}$ = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION									
HG = (BIOMASS - CUTOFF) * E_{MSY} * DISTRIBUTION									
Harvest Formula Parameters									
BIOMASS (ages 1+, mt)	120,435								
P-star	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
ABC $Buffer_{Tier\ 1}$	0.9558	0.9128	0.8705	0.8280	0.7844	0.7386	0.6886	0.6304	0.5531
ABC $Buffer_{Tier\ 2}$	0.9135	0.8333	0.7577	0.6855	0.6153	0.5455	0.4741	0.3974	0.3060
E_{MSY}	0.30								
CUTOFF (mt)	18,200								
DISTRIBUTION (U.S.)	0.70								
Harvest Control Rule Values (mt)									
OFL =	25,291								
$ABC_{Tier\ 1}$ =	24,173	23,087	22,016	20,940	19,839	18,681	17,415	15,944	13,990
$ABC_{Tier\ 2}$ =	23,104	21,074	19,164	17,338	15,562	13,798	11,992	10,052	7,738
HG =	21,469								

b)

Harvest Control Rule Formulas									
OFL = BIOMASS * E_{MSY} * DISTRIBUTION									
$ABC_{P\text{-}star}$ = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION									
HG = (BIOMASS - CUTOFF) * E_{MSY} * DISTRIBUTION									
Harvest Formula Parameters									
BIOMASS (ages 1+, mt)	118,968								
P-star	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
ABC $Buffer_{Tier\ 1}$	0.9558	0.9128	0.8705	0.8280	0.7844	0.7386	0.6886	0.6304	0.5531
ABC $Buffer_{Tier\ 2}$	0.9135	0.8333	0.7577	0.6855	0.6153	0.5455	0.4741	0.3974	0.3060
E_{MSY}	0.30								
CUTOFF (mt)	18,200								
DISTRIBUTION (U.S.)	0.70								
Harvest Control Rule Values (mt)									
OFL =	24,983								
$ABC_{Tier\ 1}$ =	23,878	22,805	21,747	20,685	19,597	18,453	17,203	15,750	13,819
$ABC_{Tier\ 2}$ =	22,822	20,817	18,930	17,127	15,372	13,629	11,846	9,929	7,644
HG =	21,161								

Management performance
From 1985 to 1991, the biomass exceeded 136,000 mt and no state quota restrictions were in effect. State of California quotas for 1992-00 fishing years averaged roughly 24,000 mt. The harvest guidelines (HG) averaged roughly 15,000 mt from 2001-06. In 2007, the HG was increased substantially to 40,000 mt and remained at this quota until 2009, when the calculated HG (55,408 mt) was reduced by management (PFMC) to 10,000 mt based on limited landings in recent years, with the quota applicable through the 2010-11 fishing year. Following the full stock assessment conducted in 2011, a harvest guideline of roughly 31,000 mt was implemented for two consecutive fishing years. Catch-based projection assessments were used to set quotas for 2013-14 (~39,000 mt) and 2014-15 (~29,000 mt). From a management context, the fishery has not fully utilized HGs recently, with average yields over the last decade of roughly 5,000 mt. Landings and associated HGs since 2004 are presented in Figure ES-6.

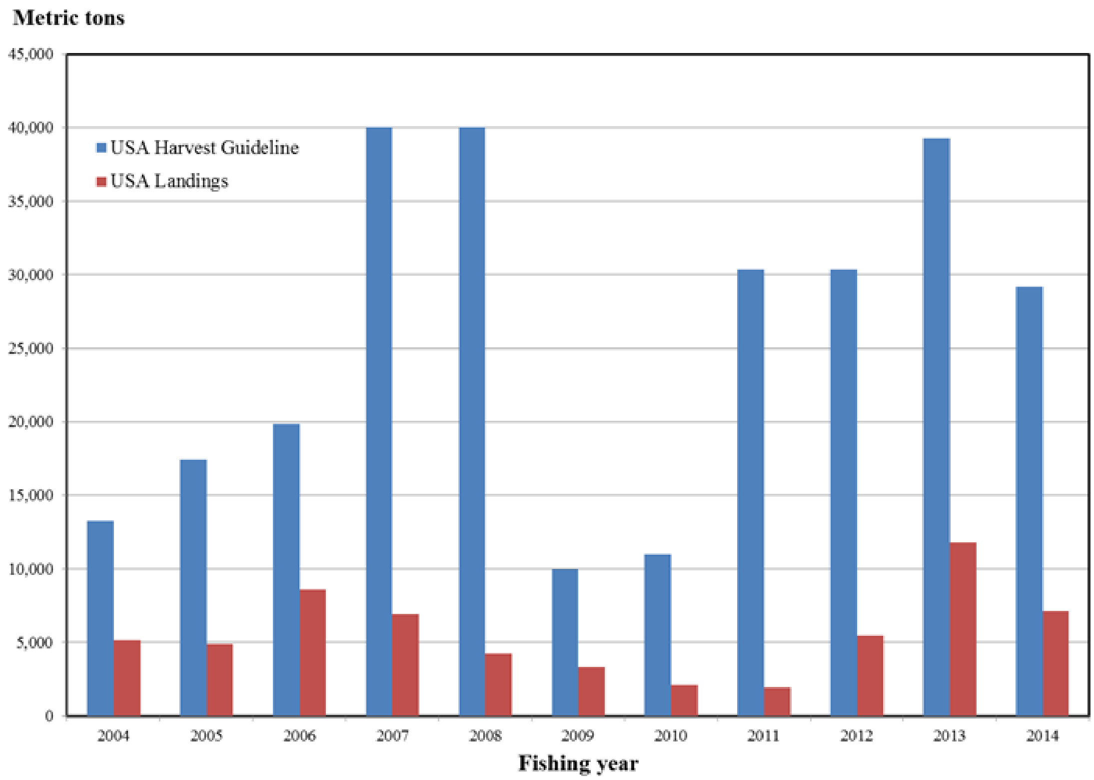

Figure ES-6. USA harvest guidelines (mt) and landings (mt) for Pacific mackerel since 2004.

Unresolved problems and major uncertainties
Overall, review criticisms focused on (STAR 2015): 1) the limitations of the AT survey data for assessing the status of the Pacific mackerel stock at this time for management, including justifying catchability coefficient (*q*) estimates, given the assumed, but uncertain distribution of this species in the context of the spatial boundaries of the survey area; and 2) problematic scaling within the model associated with assumptions regarding selectivity forms (dome-shaped vs. asymptotic) for the fishery age composition time series. Further discussion is presented in Unresolved problems and major uncertainties, and Research and Data Needs below.

Research and data needs

The most important research and associated data needed for improving the quality of the ongoing stock assessment of Pacific mackerel follow: 1) continued support of the AT survey effort conducted annually by the SWFSC, given its importance as the best scientific data collection program for developing a meaningful index of abundance for small pelagic fish stocks; 2) improving relations with Mexico federal administration and marine science institutions for purposes of expanding the present coverage of the AT survey operations for this transboundary stock, as well as to provide biological samples from both survey and fishery operations off the Pacific coast of Baja and mainland Mexico; 3) bolstering age/growth studies and production ageing efforts for this stock, including obtaining age samples systematically from the Pacific Northwest fisheries; 4) further model development that addresses an AT-based assessment model that provides justifiable estimates of catchability (both inside and outside the model), is based on plausible/supported biological assumptions, includes internally consistent sources of data (e.g., addresses selectivity tension among data sources and problematic scaling), and generates robust derived quantities useful to management; and finally, 5) revisiting harvest control rules for this fish population based on formal management strategy evaluations that consider the historical and recently available data, productivity/vulnerability of the stock, uncertainty surrounding recruitment/abundance, small pelagic fish assemblage at large, and economic factors. See Research and Data Needs below.

INTRODUCTION

Distribution and migration

Pacific mackerel (*Scomber japonicas*, also referred to as chub or blue mackerel) in the northeastern Pacific range from southeastern Alaska to Banderas Bay (Puerto Vallarta), Mexico, including the Gulf of California (Hart 1973), Figure 1. They are common from Monterey Bay, California to Cabo San Lucas, Baja California, but are assumed to be most abundant south of Point Conception, California in most years. Pacific mackerel usually occur within 30 km of shore, but have been captured as far as 400 km offshore (Fitch 1969; Frey 1971; MBC 1987; Allen et al. 1990).

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

Over the last two decades, the stock has been observed to more fully occupy the northernmost portions of its range in response to warmer oceanographic conditions that have persisted in the northeastern Pacific Ocean, being found at times as far north as British Columbia, Canada (Ware and Hargreaves 1993; Hargreaves and Hungar 1995). During the summer months, Pacific mackerel are sometimes caught incidentally in commercial whiting and salmon fisheries off the Pacific Northwest, but historically, these catches have been limited. Pacific mackerel sampled from Pacific Northwest incidental fisheries are generally older and larger than those captured in the southern California fishery (Hill 1999). In addition, this species is harvested by recreational anglers on commercial passenger fishing vessels (CPFV), private boats, piers, etc., but is typically not a targeted species, with comparatively low catches to landings from commercial operations (Table 1 and Figure 2).

Life history

Pacific mackerel found off the Pacific coast of North America are the same species found elsewhere in the Pacific, Atlantic, and Indian Oceans (Collette and Nauen 1983). Synopses regarding the biology of Pacific mackerel are presented in Kramer (1969) and Schaefer (1980). Spawning occurs from Point Conception, California to Cabo San Lucas from 3 to over 300 km offshore (Moser et al. 1993). Off California, spawning occurs from March to October (primarily, late April through August) at depths to 100 meters (Knaggs and Parrish 1973). Off central Baja California, spawning occurs year round, peaking from June through October. Around Cabo San Lucas, spawning occurs primarily from late fall to early spring. Pacific mackerel seldom spawn north of Point Conception (Fritzsche 1978; MBC 1987), although juvenile fish (roughly, age 0-1) have been reported in recent years as far north as Oregon and Washington.

As exhibited by similar SPS, Pacific mackerel have indeterminate fecundity and appear to spawn whenever sufficient food is available and favorable oceanographic conditions prevail. Individual fish may spawn eight times or more per year and can release batches of at least 68,000 eggs per spawning. Actively spawning fish appear capable of spawning daily or every other day (Dickerson et al. 1992). Pacific mackerel larvae eat copepods and other zooplankton, including fish larvae (Collette and Nauen 1983; MBC 1987). Juvenile and adult mackerel feed on small fish (e.g., northern anchovy), fish larvae, squid, and pelagic crustaceans, such as euphausids (Clemmens and Wilby 1961; Turner and Sexsmith 1967; Fitch 1969; Fitch and Lavenberg 1971; Frey 1971; Hart 1973; Collette and Nauen 1983). Pacific mackerel larvae are subject to predation from a number of invertebrate and vertebrate planktivores. Juveniles and adults are eaten by larger fishes, marine mammals, and seabirds. Principal predators include porpoises, California sea lions, pelicans, and large piscivorous fish, such as sharks and tunas. Pacific mackerel likely school as a line of defense against predation, often with other SPS, such as jack mackerel and Pacific sardine.

Population dynamics of the Pacific mackerel stock off southern California have been extensively studied in the past and of particular importance was pioneering research conducted during the 1970s and 1980s, e.g., Parrish (1974), Parrish and MacCall (1978), Mallicoate and Parrish (1981), MacCall et al. (1985), Prager and MacCall (1988), and Jacobson et al. (1994a). More recently, acoustic-trawl surveys have been conducted by the SWFSC (NOAA/NMFS) for purposes of monitoring the SPS assemblage off the USA Pacific coast, with particular focus on the Pacific sardine population (Zwolinski et al. 2011; STAR 2011b; Zwolinski and Demer 2012; Zwolinski et al. 2012; Demer et al. 2012; Demer and Zwolinski 2014; Zwolinski and Demer 2015). It is important to note that the southern extent of the Pacific mackerel distribution, particularly, a portion of the spawning aggregation in the late spring and summer, is generally believed to occupy waters off Mexico, with magnitudes influenced strongly by prevailing oceanographic conditions (Weber and McClatchie 2012; also, see Environmental and ecosystem data below, and Appendix A).

Pacific mackerel experience cyclical periods of notable abundance, a phenomenon exhibited by many SPS that have relatively short life spans, infrequent periods of good recruitment success and high productivity, and historically, observed to experience population ‘booms and busts,’ driven primarily by large-scale environmental factors (e.g., Pacific Decadal Oscillation (PDO), North Pacific Gyre Oscillation (NPGO), and related oceanographic parameters, such as sea-surface temperature, sea-surface height, upwelling, cholorophyll, etc.). Analysis of mackerel scale-deposition data (Soutar and Issacs 1974) indicates that periods of high biomass levels, such as during the 1930s and 1980s, are relatively rare events that might be expected to occur, on average, about once every 60 years (MacCall et al. 1985). Results from the ongoing assessment of this stock generally support the past research, with periods of high recruitment success observed no more frequently than at least every few decades. Relatedly, recruitment is highly variable both spatially and temporally and not likely related very strongly to spawning stock size (Parrish 1974; Parrish and MacCall 1978). Finally, at this time, spawning stock biomass-recruitment (SSB/R) relationships for this species are not well understood, however, it is likely the species exhibits some degree of population depensation (reduced production and/or survival of eggs/larvae associated with declining spawning stock abundance), particularly, during unfavorable oceanographic regimes.

Stock structure and management units

The full range of Pacific mackerel in the northeastern Pacific Ocean is from southeastern Alaska to Banderas Bay (Puerto Vallarta), Mexico, including the Gulf of California. The majority of the fish are typically distributed from Monterey Bay, California to Cabo San Lucas, Baja California Sur, being most abundant south of Point Conception, California. Although stock structure of this species off the Pacific coast of North America is not known definitively, it is generally hypothesized that three spawning aggregations exist currently: one in the Gulf of California; one in the vicinity of Cabo San Lucas; and one along the Pacific coast north of Punta Abreojos, Baja California Sur that extends north to areas off southern California, and even further during favorable oceanographic periods to waters off the Pacific Northwest. The latter sub-stock is harvested by fishermen in the USA and Baja California, Mexico, and is the population addressed in this assessment.

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

Fishery descriptions

Pacific mackerel are currently harvested by three fisheries (Table 1 and Figure 2): the USA commercial fishery that primarily operates out of southern California, as well as Oregon and Washington; a sport fishery based largely in southern California; and the Mexico commercial fishery that is based in Ensenada and Magdalena Bay, Baja California. In the commercial fisheries, Pacific mackerel are landed by the same boats that catch Pacific sardine, northern anchovy, jack mackerel, and market squid (commonly referred to as the west coast 'wetfish' fleet). In recent years, Oregon and Washington have landed limited amounts of Pacific mackerel, averaging less than 500 mt annually over the last decade. Pacific mackerel are also (incidentally) harvested in small volumes by whiting trawlers and salmon trollers. Available information concerning bycatch and discard mortality of Pacific mackerel, as well as other members of the small pelagic fish assemblage of the California Current Ecosystem, is presented in PFMC (2014b). Limited information from observer programs implemented in the past indicated little bycatch of other species and/or discard of Pacific mackerel in the commercial purse seine fishery that targets the small pelagic fish assemblage off the USA Pacific coast.

The history of California's Pacific mackerel fishery has been reviewed by Croker (1933, 1938), Roedel (1952), and Klingbeil (1983). Historically, Pacific mackerel have been landed in moderate amounts, supporting a viable fishery in California during the 1930s and 1940s and more recently, in the 1980s and early 1990s. During the early years of the fishery, Pacific mackerel were taken by lampara and pole-and-line boats, which were replaced in the 1930s by the same purse seine fleet that fished for Pacific sardine. Before 1929, Pacific mackerel were taken incidentally, in relatively small volumes with sardine and sold as a fresh product (Frey 1971). Canning of Pacific mackerel began in the late 1920s and increased as greater processing capacities and more marketable 'packs' were developed. Landings decreased in the early 1930s due to the economic depression and subsequent decline in demand, but increased significantly by the mid-1930s (66,400 mt in 1935-36). During this period, Pacific mackerel were second only to

Pacific sardine in total (annual) landings. Subsequently, harvests underwent a long-term decline and for many years, demand for canned mackerel remained steady and exceeded supply. Supply reached record low levels in the early 1970s, at which time the State of California implemented a 'moratorium' on the directed fishery.

Following a period of 'recovery' that spanned from the mid to late 1970s, the moratorium was lifted. During the 1980s through mid-1990s, catches of Pacific mackerel by California fishermen supported an economically viable fishery. The market for canned mackerel during the 1980s through early 1990s fluctuated substantially due largely to economic factors. Domestic demand for canned Pacific mackerel eventually waned and the last mackerel cannery in California closed in 1992. At present, most Pacific mackerel is used for human consumption or pet food, with a small, but increasing amount sold as fresh fish. Over the last decade, USA annual landings of Pacific mackerel have averaged less than 6,000 mt (Table 1).

Pacific mackerel are caught by recreational anglers in southern California, but seldom as a target species (Young 1969). During the 1980s, California's recreational catch averaged 1,500 mt per year, with Pacific mackerel being caught consistently by the California-based CPFV fleet. Pacific mackerel are also harvested in California's recreational fishery as bait for directed fishing on larger pelagic species, such as tunas, sharks, and billfishes. Additionally, Pacific mackerel are caught by anglers in central California, Oregon, and Washington, but typically, in very limited amounts. The sport harvest of Pacific mackerel in California comprises a very small fraction of the total landings of Pacific mackerel, e.g., over the last decade, recreational catch is less than 5% of the total weight landed (Table 1). It is likely that some (minor) amount of discard occurs regularly in some recreational modes of fishing for this non-targeted species, but accurate determination is necessarily problematic, given difficulties of collecting such information scientifically in the field.

The Mexico fishery for Pacific mackerel is primarily based in Ensenada and to a lesser extent, Magdalena Bay, Baja California Sur. The Mexico purse seine fleet has slightly larger vessels, but is similar to southern California's fleet with respect to gear (mesh size) and fishing practices. The fleet operates in the vicinity of the nearby ports and also targets other SPS. Demand for Pacific mackerel in Baja California increased after World War II. Mexico landings remained stable for several years, rose to 10,725 mt in 1956-57, then declined to a low of 100 mt in 1973-74, and remained relatively low through the late 1980s. Landings of Pacific mackerel in Ensenada peaked twice, first in 1991-92 at roughly 34,000 mt, and again in 1998-99 (~43,000 mt). For the most part, the Ensenada fishery has been generally comparable in volume to the southern California fishery since 1990 (averaging ~10,000 mt/yr), but differences exist for particular years (Table 1). In Mexico, Pacific mackerel are either canned for human consumption or reduced to fish meal.

Environmental and ecosystem data

Readers should consult PFMC (2014b, 2015) for information regarding environmental processes generally hypothesized to influence small pelagic finfish species, such as Pacific mackerel, that inhabit the California Current Ecosystem and broader northeastern Pacific Ocean. Also, see references included in AT survey index of abundance and Appendix A below.

Management history

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

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

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

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

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

California's recreational catch of Pacific mackerel is included within the USA HG, but there are no other restrictions (e.g., size or bag limits) on this fishery. Total annual harvest of Pacific mackerel by the Mexico fishery is not regulated by quotas, but there is a minimum legal size limit of 25.5 cm. International management agreements between the USA and Mexico regarding transboundary stocks, such as Pacific mackerel, have not been developed to date (see Research and Data Needs below).

Finally, recent legislation concerning management of exploited fisheries in the USA now requires additional harvest specifications that are used in concert with the HG formula above. Refer to PFMC (2011) and Ralston et al. (2011) for methods used to derive important quantities (acceptable biological catch, overfishing limit, etc.) associated with current management of this species. Also, see Harvest Control Rule for USA Management in 2015-16 and 2016-17 below.

Management performance

From 1985 to 1991, the biomass exceeded 136,000 mt and no state quota restrictions were in effect. State quotas for 1992-00 fishing years averaged roughly 24,000 mt. The HGs averaged roughly 15,000 mt from 2001-06. In 2007, the HG was increased substantially to 40,000 mt and remained at this quota until 2009, when the calculated HG (55,408 mt) was reduced by management (PFMC) to 10,000 mt based on limited landings in recent years, with the quota applicable through the 2010-11 fishing year. Following the full stock assessment conducted in 2011, a harvest guideline of roughly 31,000 mt was implemented for two consecutive fishing years. Catch-based projection assessments were used to set quotas for 2013-14 (~39,000 mt) and 2014-15 (~29,000 mt). Note that from a management context, the fishery has not fully utilized HGs recently, with average annual landings over the last decade of roughly 5,000 mt.

ASSESSMENT DATA

Biological parameters

Growth

A weight-length (W-L) relationship for Pacific mackerel was modeled using port sample data collected by the California Department of Fish and Wildlife (CDFW) from 1983 to 2014 (see Fishery data below). A simple power function was used to determine the relationship between weight (kg) and fork length (cm) for both sexes combined. Weight-length parameters based on data from 1983 to 2014 (a = 2.7E-06 and b = 3.4) were used (fixed) in all candidate model configurations investigated in this assessment (Figure 3a).

In the Stock Synthesis (SS) model, the von Bertalanffy growth equation is re-parameterized following Schnute (1981), with growth parameters defined in terms of size at two reference ages, *length-at-age_minimum* and *_maximum* (Methot and Wetzel 2013). A length-at-age relationship was estimated internally in most candidate model configurations and was generally robust, with parameter estimates for model H3 based on data from 1983 to 2014 approximately equal to: *length-at-age maximum* (‘L_∞’) = 39.2 cm, k = 0.39, and *length-at-age_minimum* = 20.5 cm (Figure 3a). Standard deviations associated with *length-at-age_maximum/_minimum* were fixed (SD=0.10), given little information is available for estimating variances in models based on age compositions and mean length-at-age time series for estimating growth. Of particular note is the rapid growth exhibited by juveniles of this species (Parrish and MacCall 1978; Mallicoate and Parrish 1981). Analysis conducted here based on biological data through 2014, indicated fish on average, realize over 50% of their total growth (in length) by age 1 to 1.5 and subsequently, grow a few cm per year until death at roughly 40 cm (age 6-8+ yr). As addressed in earlier reviews, size-at-age relationships by sex and sex ratio data did not indicate sexual dimorphism in growth or mortality rate (Figure 3b) and thus, sexes were pooled in all candidate models included in past and present assessments. Additionally, in one candidate model, internal growth estimation was essentially bypassed by using a matrix of empirical weight-at-age estimates by year to translate numbers-at-age directly to biomass-at-age (see Empirical weight-at-age compositions below).

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

Maturity

The estimated maturity schedule used in the past for this stock was assumed in all model scenarios here (Table 2 and Figure 4). Ultimately, the maturity schedule reflects normalized net fecundity-at-age estimates based on predicted fraction mature, spawning frequency investigations, and batch fecundity calculations from a laboratory study conducted in the mid-1980s (Dickerson et al. 1992). In this study, fraction mature was estimated by fitting a logistic regression model to maturity data, spawning frequency was estimated by fitting a straight line to age and spawning frequency data, and batch fecundity per gram of female body weight was assumed constant.

A study was conducted from 2009 to 2012 for purposes of re-evaluating maturity-at-age for this species. Histological analysis on 1,004 female Pacific mackerel was conducted to examine potential changes in maturity since the early 1990s. Fish were collected opportunistically from both fishery operations and survey efforts, given low population abundance over the recent timeframe. Predicted fraction mature was based on simple logistic regression: 50% maturity inflection point for size = 27 cm and age = 2.2 yr. The majority (90%) of the females in the recent study was composed of fish from ages 0 to 2, whereas, in the earlier study, most (90%) females were ages 3-5, with no age-0 fish present in the sample. Note that both batch fecundity and spawning frequency estimates were not updated, given few female Pacific mackerel with active ovaries were collected during 2009-12. In general, updated predicted fraction mature time series indicated that young fish mature slightly slower to the 50% maturity threshold, somewhat faster beyond this point for older fish (3-5 yr), until reaching a similar asymptotic level for fully mature fish (6-8+ yr) as compared to findings from the earlier study (Figure 4). Given the limitations of the recent study for determining an updated normalized net fecundity by age time series, as well as predicted fraction mature estimates being generally similar across the two studies, the maturity schedule used in past assessments was applied in all candidate models presented here. Finally, if further work regarding Pacific mackerel reproductive biology is conducted in the future, it is recommended that attempts be made to use a more rigorous design-based sampling approach across the protracted spawning period to ensure that samples are collected representatively from the fisheries (commercial and recreational) and surveys, and potential spatial/temporal differences in availability and gear selectivity can be accounted for in the overall analysis.

Natural mortality

Natural mortality rate (M) was assumed to be 0.5 yr^{-1} and constant over time for all ages and sexes in all candidate models evaluated in this assessment. Parrish and MacCall (1978) estimated natural mortality for Pacific mackerel using early catch curves (M = 0.3-0.5), regression of Z on f (M = 0.5), and comparative studies of maximum age (M = 0.3-0.7; Beverton 1963) and growth rate (M = 0.4-0.6; Beverton and Holt 1959). The above research and overall conclusions considered the regression of Z on f to be the most reliable method, with the estimate M = 0.5

falling within the range of the plausible estimates. The instantaneous rate $M = 0.5$ can be practically interpreted as an annual rate of roughly 40% of the stock dying each year due to natural causes. A constant rate of $M = 0.5$ across all ages was implemented in all model scenarios evaluated in this assessment. Also, see Research and Data Needs below.

Fishery data

Overview

Fishery-related data for assessing Pacific mackerel included: 1) landings from California, Oregon, and Washington commercial fisheries, California recreational fishery, and the Mexico commercial fishery; 2) port sample (length and age) data from California's commercial fishery; 3) biological (length) data from the Marine Recreational Fishing Statistical Survey (MRFSS, 1983-03) and California Recreational Fishery Survey (CRFS, 2004-14), which are archived in the Pacific Recreational Fishery Information Network (RecFIN) data base; and 3) logbook information from California's CPFV fleet. Since 1929, the CDFW has collected biological data on Pacific mackerel landed in the southern California fishery (primarily, San Pedro). Limited samples have also been collected from the Monterey fishery when available. In general, sample data collected from 1983 through December 2014 were used in modeling efforts conducted for this assessment. Biological samples from the commercial fishery generally include whole body weight, fork length, sex, maturity, and otoliths for age determination. Currently, CDFW strives to collect 12 'random' (port) samples per month (typically, 25 fish per sample) to determine length/age compositions, as well as catch-at-age, weight-at-age, etc. for the directed fishery. Although port sampling data for the commercial fishery in Mexico have been collected by the National Fisheries Institute (INAPESCA) since 1989, this information has not been made formally available to date and thus, commercial fishery data from the California purse seine fleet were assumed to be representative of the combined commercial fisheries. Lack of Baja California port sampling data is not a serious problem for some years when Mexico catches were low. However, in some years, Baja California and California catches have been roughly equal in volume (Table 1), which necessarily increases the likelihood that potential biases associated with the omission of (and subsequent assumptions concerning) sample data from the Mexico fishery.

Pacific mackerel are aged by CDFW biologists based on identification of annuli in whole sagittae. Historically, a birth date of May 1st was used to assign year class (Fitch 1951). In 1976, ageing protocols changed to a July 1st birth date, which coincided with an increasing population, resumed fishery sampling, and a change in the management season from a May 1st opening to a July 1st start date. Fishery inputs for this assessment were compiled by 'biological year,' based on the birth dates used to assign age. The biological year used in this assessment is synonymous with the 'fishing year' defined previously, as well as with 'fishing season' as reported in the historical literature (from 1976 onwards). All landings and biological compositions included in this assessment were developed on a fishing year (July – June) basis. Sample sizes associated with biological data used in this assessment are presented in Table 3.

Landings

The assessment includes commercial and recreational landings in California and commercial landings in Baja California (Mexico) from 1983 to 2014. Annual (fishing year) catch estimates of Pacific mackerel are presented in Table 1 and Figure 2. Commercial catch statistics are from the state fishery agencies CDFW (ongoing 'wetfish' tables), Oregon Department of Fish and

Wildlife (ODFW, C. Schmitt, pers. comm.), and Washington Department of Fish and Wildlife (WDFW, L. Wargo, pers. comm.). Landing estimates for January-June 2015 were assumed to be similar to the analogous time block of the previous year (January-June 2014). In past assessments, commercial landings from Oregon and Washington were not included in analyses (<300 mt/yr), however, in this assessment, annual landings from these states (recently, averaging <500 and <200 mt/yr for each state, respectively) are now included in the overall USA commercial catch time series. California recreational catch (mt) time series from 1983 to the present are based on all sport fishery modes (man-made, beach/bank, party/charter, and private/rental) and obtained from the RecFIN data base. It is important to note that in past assessments, fishery structure was modeled as two fisheries, a combined USA/Mexico commercial fishery and a USA recreational fishery. In this assessment, only update models A- B and model C maintained partitioned fisheries in this manner, with all other candidate models (D-G, H1b, and H3) based on a single, combined fishery. This pooling of catch data across fisheries is an important data/parameterization change for meeting the objective to develop a parsimonious assessment model that does not include unnecessary structure/process based on limited data and information content. In this context, the sport fishery has always composed a very small percentage of the overall landings of this species, as well as catches generally similar sized fish as the primary commercial fishery, e.g., over the last decade, the recreational fishery has averaged just roughly 4% to the total annual landings of Pacific mackerel (Table 1). For past and present assessments, discard was assumed negligible in both the commercial and recreational fisheries associated with this species (see Fishery descriptions above).

Mexico landings reflect catches in Baja California from commercial purse seine fleets operating off Ensenada, Cedros Island, and in Magdalena Bay. Ensenada landings were compiled as follows: quarterly data through December 1986 are from Jacobson et al. (1994b); monthly data from January 1987 through November 2003 were provided by INP-Ensenada (García and Sánchez, 2003; INP-Esenada, C. Eva-Cotero, pers. comm.); monthly landings from December 2003 through December 2004 were not available and thus, were substituted with corresponding months from the previous year; Ensenada landings in 2005, available from Cota et al. (2006), were apportioned into monthly catch using ratios from the previous few years; Ensenada landings for January to June 2006 were taken from Cota et al. (2006); monthly landing data for Cedros Island (January 1981-December 1994) and Magdalena Bay (January 1981 – May 2003) fisheries were provided by Instituto Politécnico Nacional Centro Interdisciplinario de Ciencias Marinas staff (CICIMAR-IPN, R. Felix-Uraga, pers. comm.), noting that the fishery off Cedros Island ceased in 1994; and for 2003 to 2013, commercial landings for the Ensenada and Magdalena Bay fisheries were taken from the National Commission of Aquaculture and Fishing (CONAPESCA) website that archives Mexico's fishery yearbook statistics (CONAPESCA 2014).

Length compositions

Sample sizes (number of fish) associated with biological compositions included or considered in this assessment are presented in Table 3. Past and current assessments incorporate age-based selectivity, however, age information is only available from the USA (California) commercial fishery. To model selectivity for the recreational fishery in past assessments, length data from the CPFV fleet were used and converted into age compositions internally in the model. For models A-C (two-fishery model scenarios), the USA recreational fishery included updated length compositions from the CPFV fleet (1985-14, no samples were available 1990-91). Selectivity for the combined (recreational and commercial) fishery models (D-G, H1b, and H3) were based on the age compositions associated with the primary commercial fishery (see Age compositions below). Length data associated with the commercial fishery were collected by CDFW and reflect the sums of catch-weighted length observations, with monthly landings within fishing year as the weighting unit. Note that length compositions were also available from the commercial fishery, but were not used in any candidate models evaluated here (Figure 5). All length data for the recreational fishery were obtained from the Pacific RecFIN data base (see Fishery data, Overview above).

For candidate models A-G, selectivity for the CPFV index of abundance (see CPFV index of abundance below) was also based on length data collected from the CPFV fleet from 1985-14. However, following recommendations from the review in April 2015, models H1b and H3 included only CPFV length information from 1992 to 2014, given concerns regarding the accuracy of these biological data collected during the 1980s (Figure 6). For purposes of beginning the review in April 2015, the respective candidate models (C-G) that included AT survey data were based on combining the seasonally collected length data (calendar years 2008, 2012-14) into a single, un-weighted length composition that represented the respective fishing year in the time series. Following recommendations during the review, further model configurations (e.g., H1b) that included AT data were based on individual cruises by season, including length compositions for spring (fishing years 2005-13) and summer (fishing years 2008, 2012-14), Figures 7a-b (selectivity was shared, 'mirrored,' between the two surveys). It is important to note that AT data were not included in model H3, i.e., the length compositions are presented for providing background information only. Finally, length compositions (non-CPFV modes) associated with the California Recreational Fisheries Survey (CRFS) index of abundance used in the assessment conducted in 2011 were available, but not used in any of the candidate models, with the exception of update model A (see CRFS index of abundance below).

All length compositions (in numbers of fish) were converted to proportion estimates according to 1-cm length (fork) bins from 1 to 60+ cm. In all model scenarios, input sample sizes for length compositions were based on the total number of lengths (number of fish) observed in each annual composition divided by 25, the typical number of fish collected per sampled load in the commercial fishery (also, see Age compositions below). This initial weighting scheme has been applied in past assessments, as well as for the similarly developed Pacific sardine assessment (Hill et al. 2015). Total length observations (number of fish) for each year associated with the CPFV fleet were similarly divided by 25 following the commercial fishery procedures. Finally, input sample sizes for length compositions developed annually/seasonally from the AT survey represented the number of hauls that had Pacific mackerel present.

Age compositions

Age-composition time series were developed from the same CDFW port sample information described above for length data (Figure 8), i.e., the sampling program provides length, sex, and age (from otoliths) information for each fish in the 25-fish sample taken from a completed fishing trip. Presently, age data are only available from the California commercial fishery, which typically contributes the majority of fish landed at USA Pacific coast ports (Table 1). Biological sampling directed towards Pacific mackerel has recently begun in the states of Oregon and

Washington, but only limited information is available at this time. Age compositions (in proportion-at-age) were based on 9 age bins that represented age-0 to age-8+ (8+ group includes ≥8-yr old fish). For the first time in this ongoing assessment, the age compositions reflect the sums of catch-weighted age observations, with monthly landings within fishing year as the weighting unit. For the most part, weighted and un-weighted compositions were generally similar, but in some years, estimated proportions of 0- and 1-yr old fish, which typically compose the majority of the overall composition, varied substantially. Input sample sizes associated with the age-composition time series were calculated in a similar manner as for the length compositions (see Length compositions above).

Ageing error
In efforts to provide a realistic measure of uncertainty associated with the estimated age-composition time series, an 'ageing error' vector based on standard 'double-read' methods conducted in a past laboratory study was also included in all candidate models (Figure 9). Further ageing error evaluations are underway, but no new estimates are available at this time.

Mean length-at-age compositions
For the primary purpose of evaluating growth dynamics associated with this species, mean length-at-age time series (1983-14) were developed from the same CDFW port sample data base described above, and used in conjunction with age compositions for most model configurations (Figure 10). Effective sample size estimates were obtained using the same 25-fish adjustment employed for the other biological (length and age) compositions. Mean length estimates for compositions that reflected fish decreasing in size (length) over time were omitted from the overall composition and treated as missing information; these limited cases were always for older fish (6-8+) and associated with very small sample sizes.

Empirical weight-at-age compositions
For the first time in this ongoing assessment, a matrix of empirically derived weight-at-age compositions were used in a candidate model scenario (model F) to translate numbers-at-age directly to biomass-at-age and essentially bypass estimating growth internally in the model (Figure 11). Mean weight-at-age (ages 0-12) compositions were based on the same CDFW sampling program described above and calculated similarly as the mean length-at-age compositions. In contrast to omitting poorly sampled age groups for deriving mean length-at-age compositions, mean weights are required for each age (0-12 yr) included in the matrix. Missing mean weight information for particular ages in a given year was substituted with an average weight value calculated across the entire time period (1983-14). Mean weight estimates for ages 9-12 in each year were assumed to be constant and equal to the 8+ age group. Ultimately, the empirical weight-at-age composition developed from the commercial fishery was assumed to be representative of the survey operations, as well as the population as treated in such model configurations in SS. The use of empirical weight-at-age is an efficient method to address the temporal variability in both the weight-length relationship and length-at-age relationship exhibited by the stock, without requiring parametric estimators within the model to represent these biological attributes. However, as indicated above for maturity investigations, this method requires the assumption that observations (sampled fish) provide a representative sample of the population and not potentially biased due to selectivity and/or availability issues associated with the sampled fishery. Focused trawl sampling with the AT survey is planned in the future to

provide additional biological data for bolstering empirical weight-at-age estimates. Finally, empirical weight-at-age composition time series were broadly compared with analogous weight-at-age estimates from models based on internally estimated growth. As indicated in Figure 12, weight-at-age estimates from the two different modeling approaches were very similar from ages 0 to 8+ and diverged slightly for the oldest ages, given treatment of ages 9-12 described above.

Commercial passenger fishing vessel (CPFV) index of abundance

California legislation has required CPFV captains to provide records of catch and effort data to CDFW since 1936. In the past, Pacific mackerel have been among the top ten species reported on CPFV logs, both in southern California and state-wide. However, the species is not typically targeted by anglers and thus, effective hours fished necessarily represents an uncertain parameter in catch-per-unit-effort (CPUE) calculations. This information resides in a logbook data base (Hill and Barnes 1998; Hill and Schneider 1999) that summarizes CPFV catch and effort by month and CDFW statistical blocks (10 nm^2). A single, state-wide CPUE index of relative abundance (Table 4 and Figure 13) was developed using a delta-Generalized Linear Model (delta-GLM) for estimating year effects (Dick 2010). The index is calculated on a fishing year basis, as is the case with other time series used in the models. Selectivity parameterization associated with this index mirrored the recreational fishery in candidate models A-C and estimated independently in models D, E, G, H1b, and H3, i.e., age-based selectivity based on length-composition time series.

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

(1) data were combined according to year/quarter/fleet strata (the statewide fishery was partitioned into a northern, southern, and Baja 'fleets' based on latitude/longitude spatial fishing blocks);
(2) CPUE was calculated (number of fish kept/1,000 angler-hours fishing) for each spatial/temporal stratum—beginning in 1995, number of released fish were recorded as well and thus, a 1995-14 'kept and released' index was also developed, although not used in any of the candidate models (Table 4 and Figure 14);
(3) latitude/longitude blocks were combined into broader spatial areas based on the fishing practices of the northern, southern, and Baja CPFV fleets. Historically, the southern fleet has exerted the most fishing pressure associated with this overall fishery (Pt. Conception was used as the 'north/south' delimiter to partition these two regional fleets, with a fleet assignment for catches off Baja California included as an independent region as well);
(4) the delta-GLM method models the probability of obtaining a zero catch and the catch (positive) rate separately (Stefansson 1996; Maunder and Punt 2004). In this

assessment, the estimated probability of a positive observation was based on a binomial distribution and a logit link function. The mean response for positive observations was estimated assuming a gamma distribution for the error term. The basic model for positive observations included the log of mean catch rate (μ) as a function of three main effects (fishing year i, quarter j, and fleet k),

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

where μ_{ijk} is the mean catch rate (number of fish/1,000 angler-hours) in year i, quarter j, and fleet k. The fishing year effect is denoted by Y_i (i=1, 2, ..., I; I=32 fishing years). The quarter of the year effect is denoted by Q_j (j=1, 2, ..., J; J=4 quarters). The regional fleet effect is denoted as F_k (k=1, ..., K; K=3 fleets). The error term is denoted ε_{ijk}, where for each combination of indices, ε_{ijk} is *iid* and gamma distributed;

(5) no temporal/spatial interactions (e.g., year and regional fleet or quarter and fleet) were included in the final delta-GLM model, given such interactions had little effect on increasing the amount of variability in mean catch rate as a function of the suite of explanatory variables (i.e., minor improvement of R^2 statistic, see Hill and Crone 2005, Crone et al. 2006); and

(6) a delta-GLM function written in the statistical programming language R (Dick 2010) was used to estimate a mean catch rate from the CPFV data set. Coefficients of variation (CV) associated with estimated catch rates were calculated using a jackknife (bootstrapping) method. In past assessments and followed here, constant error estimates (CV=0.3) were used for the annual estimates of catch rate for the CPFV index. Jackknife estimated CVs were calculated for the CPFV indices, but not used in any of the candidate models.

Note that other estimation techniques used to evaluate these data, including nominal mean-derived time series and GLMs resulted in generally similar catch rates as the delta-GLM estimator. The CPFV indices available for this assessment based on different time periods (1983-14 and 1995-14) and creel attributes (kept vs. kept and released) are presented in Table 4 and Figure 14.

California Recreational Fisheries Survey (CRFS) index of abundance

The California Recreational Fisheries Survey (CRFS) was implemented in 2004 by CDFW to provide catch/effort and biological data regarding California's marine recreational finfish fisheries; these survey data are included in the Pacific RecFIN data base. The CRFS index of relative abundance was introduced in the 2011 assessment (Crone et al. 20111) to compare/complement with the CPFV index of abundance (CDFW logbook sampling program) that has been included in assessment models used for management since the late 1990s. As indicated in the past assessment, the estimated trajectories of the two indices were generally similar, with final model results robust to the inclusion or omission of these additional recreational catch rate statistics. Following the last assessment conducted in 2011, the CRFS sampling design was modified in some years, with particular shore and boat modes for some districts being un-sampled due to budget/workforce limitations. The CRFS index (2004-10) was not updated and was omitted from candidate models C-G, H1b, and H3, given: 1) concerns regarding the representativeness of sample data collected recently across the varied non-CPFV modes, particularly, for non-targeted species such as Pacific mackerel; 2) similarities between estimated CPUE indices from this survey and the CPFV logbook sampling program described above (Crone et al. 2011); 3) drawbacks associated with assessment development that includes multiple indices of abundance from a fishery (recreational) that composes <5% to the total removals of this species (Table 1); and 4) the recent availability of data collected from a fishery-independent sampling effort (AT survey) that in the long-term is expected to provide the most accurate information for assessing abundance of this lightly exploited, small pelagic species on a systematic basis. Finally, note that the CRFS index and length compositions used in the past were included in update model A.

Survey data

Acoustic-trawl (AT) survey index of abundance

Acoustic sampling of marine environments for determining abundance of fish populations is a standard practice conducted worldwide that continues to receive more focused research in fisheries science, e.g., see Simmonds and MacLennan (2005) for general theory and application of fisheries acoustics. The acoustic-trawl (AT) time series were developed from SWFSC surveys conducted along the Pacific coast since 2006 (Cutter and Demer 2008; Zwolinski et al. 2011, 2012, and Zwolinski et al. (see Appendix A). The AT survey and estimation methods were reviewed by a panel in February 2011 and the results from these surveys have been included in the sardine assessment since 2011 (Hill et al. 2011; STAR 2011a, 2011b). Methods used to derive the biomass index of abundance associated with this survey (Figure 15) are presented in Appendix A. As stated above (Length compositions), for purposes of beginning the review in April 2015, the candidate models (C-G) that included AT survey data were based on combining seasonal (spring and summer) cruises (calendar years 2008, 2012-14) into respective fishing years (2005-13) to generate a single annual estimate based on a simple average across seasons, with the highest seasonal CV applied to the respective annual estimate. Following recommendations during the review in April 2015, further model configurations (e.g., H1b) that included AT data were based on partitioned cruises by season, including indices of abundance for spring (fishing years 2005-13) and summer (fishing years 2008, 2012-14), Figures 15a-b. It is important to note that AT data were not included in model H3, i.e., the index of abundance time series are presented for background information only. Treatment of length data collected from the AT survey is presented in Length compositions above. Finally, further details regarding general sampling design and recent survey operations are presented in Appendix A.

ASSESSMENT MODEL

History of modeling approaches

Parrish and MacCall (1978) were the first to provide stock status determinations for Pacific mackerel using an age-structured population model (virtual population analysis, VPA). Beginning in the mid-1990s, the ADEPT model, which was based on the ADAPT VPA and modified for Pacific mackerel (Jacobson 1993; Jacobson et al. 1994a), was used to evaluate stock status and establish management quotas for approximately 10 years. The assessment conducted in 2004 (for 2004-05 management) represented the final ADEPT-based analysis for this stock (see Hill and Crone 2004). The forward-simulation model ASAP (Legault and Restrepo 1998) was reviewed and adopted for Pacific mackerel at the STAR conducted in 2004 (Hill and Crone 2004). The ASAP model was used for assessments and management advice from 2005 through

2008. The STAR conducted in 2009 supported decisions to begin using the Stock Synthesis (SS) model for conducting formal stock assessments of Pacific mackerel in the future (Crone et al. 2009; STAR 2009); the SS model has been used for all assessments since 2009. A full stock assessment and review for this species were conducted in 2011 (Crone et al. 2011; STAR 2011a), with a HG serving for two fishing years. In 2013 and 2014, catch-based projection assessments were conducted and used to set the HGs (Crone 2013; Crone and Hill 2014). Finally, the stock assessment presented here was reviewed in April 2015 and is for management advice for two consecutive fishing years, 2015-16 and 2016-17. In 2017, a catch-based projection assessment is to be conducted for management of two consecutive fishing years, 2017-18 and 2018-19, with the next full assessment scheduled for 2019.

Responses to past STAR/SSC recommendations

The three overriding recommendations from past reviews emphasized data availability from Mexico, omission/inclusion/parameterization of available indices of relative abundance used in the ongoing assessment, and updating biological parameters considered influential in the overall modeling effort (STAR 2011a).

A) Biological (e.g., length, age, sex) data on mackerel caught in the Pacific Northwest should be collected if a directed fishery develops in this region.
   Ans: Some data collection efforts in Oregon and Washington have recently begun for Pacific mackerel, however, limited catches have resulted in few samples to date.
B) Improve collaboration with fishery researchers from Mexico and Canada. A large fraction of the catch is taken off Mexico. In particular, catches of Pacific mackerel have been as large as those off California in recent years. Efforts should continue to be made to obtain length, age, and related biological data from the Mexican fisheries for inclusion in stock assessments. Furthermore, collaboration with Mexico will be necessary for the development of a synoptic acoustic-trawl survey, which is especially pertinent given the need for a fishery independent survey for this stock.
   Ans.: SWFSC staff continue to engage in such discussions, meetings, conferences, etc. with academic colleagues, and federal administrators and researchers from Mexico. However, with the exception of more accurate landing information becoming available recently and some discussions regarding collaborative survey efforts in the future, only limited progress has been made to date.
C) Reconsider the suite of indices and make recommendations for future assessments. Especially important is the need to develop a fishery independent survey. For example, continue work on the acoustic (and CalCOFI) survey and develop new indices as available (as was done for CRFS in this assessment).
   Ans.: Substantial progress has been made with developing alternative indices of abundance, particularly, concerning fishery-independent information collected from the newly established AT survey conducted by the SWFSC (2006-14). Further, we view this new information as the most important data (time series) available for evaluating total abundance of this species (and other small pelagic species) on an ongoing basis for informing management (see Research and Data Needs below, and STAR 2015). In previous assessments, CalCOFI survey data have been used for purposes of developing indices of abundance for this species, but based on sparse sampling of egg/larvae, spawning aggregation/distribution considerations, estimation biases associated with

missing/substituted data, etc., the indices have been omitted over time. Given the general consensus regarding high larval mortality exhibited by small pelagic species in any year, extended periods of patchy stock distribution due to unfavorable oceanographic regimes, and the hypothesized southerly extent of the spawning stock in waters off Mexico, the utility of these data for informing estimation of total stock biomass on an annual basis for management purposes is necessarily limited. However, it is recommended that the CalCOFI data sets receive further scrutiny in the future for purposes of developing indices of abundance for other 'data-limited' small pelagic species (e.g., northern anchovy, jack mackerel, as well as revisiting Pacific mackerel). Deliverables from such a project should include minimally: guidance on the most objective use of these sample data for meeting the management goal; and density estimates, indices, etc. that can be defended quantitatively and qualitatively. Drawbacks associated with the CRFS index of abundance that has been omitted from the ongoing assessment are presented above (see CRFS index of abundance).

D) Review and analyse the raw data on which the CPFV index is based and consider area blocks (i.e., spatial blocks within areas) as a factor in generalized linear models (GLMs). *Ans.*: The CPFV index is developed from an appropriate level of detail (e.g., spatial/temporal factors used in the GLM-related analysis), given the qualitative basis of data recording, sampling, and information scrutiny involved with a fishery logbook sampling program. In past investigations, adding covariates had little effect on increasing the amount of variability in mean catch rate as a function of the suite of explanatory variables used in the GLM. Further, any nominal gains in precision associated with evaluating finer-scale spatial information potentially available in the logbook summaries are considered much less important than addressing the inherent biases associated with such indices of CPUE collected using less than rigorous, scientific data collection methods. The CPFV index of abundance likely provides reasonable results for evaluating strictly broader-scale (decadal or longer) increases and decreases exhibited by the stock, but as noted in previous reviews, such a fishery-dependent index of abundance is necessarily limited, given it is based on a recreational fishery that contributes <5% to the total catch of Pacific mackerel, which can be broadly distribution in some years, depending on oceanographic factors. In summary, the CPFV index of abundance: 1) is most accurately developed as presently, based on a minimum number of main factor effects, which minimizes concluding spurious trends from over-parameterized CPUE data; 2) evaluations of the various CRFS indices of abundance that were based on trip-level data, including CPFV fishing modes, resulted in similar estimated catch rates as indices developed from the CPFV logbook summary data (see CRFS index of abundance above and Crone et al. 2011); 3) should be considered as a placeholder in the ongoing assessment model until a fishery-independent index of abundance (e.g., AT survey) becomes available and deemed appropriate for using in formal assessments (see Research and Data Needs below, and STAR 2015); 4) can be used in concert (quantitatively) with the AT survey index to maintain continuity in the assessment model in the short-term, given estimated catch rates were generally similar between the two indices; and 5) can be used in concert (qualitatively) with the AT survey index outside the model in the long-term, by providing an alternative index for confirming abundance signals indicated from the AT survey time series.

E) Look at correlation of Pacific mackerel catch in CPFV with other CPS to explore the possibility of changes in targeting practices within the CPFV fleet among years.
Ans.: See D above. Further 'targeting' examinations associated with fishing records from these logbook summaries would necessarily be based on more subjective criteria and likely to introduce additional bias in final estimated catch rates.

F) Determine if CRFS training or protocol should be revisited so that samplers are more certain to inquire of bait fish caught. This recommendation stems from the observation that some fishermen may not currently report those mackerel caught and used for bait, and it is unknown if this amount is significant.
Ans.: See C, D, and CRFS index of abundance above.

G) Increase support of current port sampling and laboratory analysis programs for CPS. In particular, there is a need to reanalyse biological parameters including sex ratio, sex-specific parameters, and natural mortality rates (*M*), including the possibility of larger *M* on 0- and 1-year old Pacific mackerel.
Ans.: See Maturity above. Sex ratio evaluations and sex-specific growth have been evaluated (Figure 3b). Age/growth research on northern anchovy and Pacific mackerel is currently underway at the SWFSC. Both ODFW and WDFW have begun some biological sampling efforts for Pacific mackerel, as well as for jack mackerel and northern anchovy, but given limited landings, samples are limited to date. The CDFW is also aware of the need to obtain biological samples for other members of the small pelagic fish assemblage, including jack mackerel and northern anchovy. Following recommendations from the review in April 2015, further assessment model development will include re-visiting current assumptions/estimation approaches regarding longevity and interactions with plausible rates of *M* for this species, which is expected to assist diagnosing overall internal consistency and specific fitting conflicts among sources of data included in the present model (e.g., dome-shaped vs. asymptotic selectivity for the commercial fishery and related impacts on abundance scale in the assessment). See Research and Data Needs below.

H) Ageing error should be revisited. Few otoliths have currently been read multiple times, so additional readings need to be made. An age validation study should be conducted for Pacific mackerel. Such a study should compare age readings based on whole and sectioned otoliths and consider a marginal increment analysis and other validation methods. The method of Punt et al. (2009) for estimating ageing error should also likely be considered.
Ans.: Some progress has been made on formally conducting 'double-read' analysis for Pacific mackerel, but a more formal project needs to be supported and coordinated in the future to ensure quality results are obtained in a timely fashion.

I) Conduct a study to update the information used to determine maturity-at-length (and maturity-at-age).
Ans.: See G and Maturity above.

J) Revisit the basis for the current estimate of *M* and explore the use of historical tagging data to estimate *M*.
Ans.: See G above and Research and Data Needs below.

K) Indices of abundance based on the CPFV fishing mode of CRFS sampling and the CPFV logbook records were inconsistent. Paired trips sampled by CRFS and CPFV should be explored in an attempt to resolve this discrepancy.
Ans.: See D, E, and CRFS index of abundance above.

L) Compare catch rate trends of CPFV observer data and CPFV logbook data for the years 1985-89. This work may help validate trends in the logbook data.
Ans.: See C, D, E, and CRFS index of abundance above. Further, past efforts to obtain such observer data have been problematic and likely to produce limited, if not misleading information for conducting this type of comparative analysis. Finally, the years in question have been noted in past reviews as being associated with suspect data collection efforts, e.g., length compositions from these years have been omitted in the assessment.

M) Standard data processing procedures should be developed for CPS, similar to those developed for groundfish species, and a 'data document' should be developed which provides, in considerable detail, how the basic data sources (e.g., catches, CPFV indices, etc.) are constructed. Much of this information has been published in the past, but a single (and 'living') document describing the basic data will assist assessment authors and future review panels.
Ans.: All of this information has been documented in most assessment documents, many times appearing in multiple reports. However, we agree it would be beneficial if a single 'data document' was available that included a formal history of landings, biological data, indices of abundance, etc. associated with the small pelagic species assemblage/fisheries of the northeastern Pacific Ocean. For example, a well-designed catch reconstruction project for these species, including historical landings in Mexico and Canada, should be the first phase of such an effort. Finally, a project like this would provide additional benefit if it not only addressed efficient documentation, but also the related data base issues associated with efficiently archiving actual data and time series used in stock assessment, which would help minimize considerable time demands on analysts charged with carrying out the technical (and documentation) work associated with typical assessments reviewed through the NMFS Council process.

Responses to recent STAR panel requests

During the review in April 2015, numerous additional model configurations were investigated, which included evaluating different combinations of data and parameterizations in particular candidate models, revising outputs and contrasting results across similar models, conducting diagnostic analysis for particular configurations, etc. Detailed requests, rationales, and responses associated with sensitivity analysis conducted during the review in April are presented under Requests to the STAT in STAR (2015).

Model description

The Stock Synthesis model (SS; Methot 2013; Methot and Wetzel 2013; Punt and Maunder 2013) is founded on the AD Model Builder software environment, which essentially represents a C++ library of automatic differentiation code for nonlinear statistical optimization (Otter Research 2001). The modeling framework is very flexible and allows full integration of both population size and age structure, with capability for explicit spatial and temporal parameterizations. The model incorporates all relevant sources of variability and estimates goodness of fit in terms of the original data, producing final estimates of precision that accurately reflect uncertainty associated with the sources of data used as input in the overall modeling effort.

The SS model comprises three sub-models: (1) a population dynamics sub-model, where abundance, mortality, and growth patterns are incorporated to create a synthetic representation of the true population; (2) an observation sub-model that defines various processes and filters to derive expected values for different types of data; and (3) a statistical sub-model that quantifies the difference between observed data and their expected values and implements algorithms to search for the set of parameters that maximizes goodness of fit. Finally, from an international context, the SS model is rapidly gaining popularity, with SS-based stock assessments being conducted on numerous marine species throughout the world. The SS model used in the last full assessment was version 3.20b (Crone et al. 2011) and version 3.24s (December 2013) was used for the recently conducted assessment presented here. All SS files for model H3 are presented in Appendix B.

Model selection and evaluation

Overview

Assessment model development conducted prior to the review in April 2015 was based on preparing updated time series of catch, biological compositions, and indices of abundance, and addressing five important modeling areas to efficiently meet the management goal (current estimate of total stock biomass): 1) utility of an acoustic-trawl (AT) time series as a relative index of abundance for estimating population biomass annually; 2) specification of fishery structure; 3) selectivity parameterization; 4) using empirical weight-at-age data vs. internally estimating growth in the model; and 5) consideration of an abbreviated time period in the model. Also, as noted previously, further sensitivity analysis was conducted during the review in April, which required developing, running, and evaluating numerous additional model configurations that largely reflected variants of particular candidate models (see Responses to recent STAR panel requests above).

Candidate models A-G represented a meaningful suite of configurations from update models (A and B) to models (C-G) that addressed survey, fishery, selectivity, growth, and time period choices/assumptions for critical data sources and parameterizations. For beginning discussion at the review in April 2015, model D was selected as the preferred model from the group of candidate models presented. Final runs from candidate models were scrutinized closely, whereby convergence was confirmed and the model was further perturbed by ‘jittering,’ which involved adding a small random normal deviate (SD = 0.1 – 0.2) to the initial value of each estimated parameter. Convergence confirmation entailed an iterative process for determining numerical solutions in the model continuing until the difference between successive likelihood estimates was <0.0001.

Summary results for model XA (final model in 2011), candidate model configurations A-G, model H1b (example model that included AT survey data partitioned by season), and final model H3 are presented in Table 5. In addition, both model D (prior to the review) and model H3 (during the review) received further diagnostic examinations, including running re-ordered phases associated with estimated parameters, virgin recruitment ($\log R_0$) and terminal-year ($B_{current}$) stock biomass (age 1+ fish) profiles, and retrospective analysis.

Ultimately, model H3 was chosen as the most objective configuration for advising management in the short-term, given: 1) it represented an updated configuration that closely resembled the previously accepted model (XA) for management in 2011; 2) was a plausible configuration ('state of nature'), with reasonable fits to input time series; 3) was stable in diagnostic-related perturbations; 4) was consistent with external information concerning stock availability to the fisheries, including results that reflected historically low estimates of recent stock biomass as indicated in the AT survey index of abundance time series, recent history of unrealized quotas by the USA commercial fishery, and limited catches reported in Mexico; and finally, 5) resulted in generally similar derived quantities useful to management as analogous models that included the AT survey data.

Unresolved problems and major uncertainties
Overall, review criticisms focused on (STAR 2015): 1) limitations of the AT survey data for assessing the status of the Pacific mackerel stock at this time for management, including justifying catchability coefficient (*q*) estimates, given the assumed, but uncertain distribution of this species in the context of the spatial boundaries of the survey area; and 2) problematic estimation of scale in the model associated with assumptions regarding selectivity forms (dome-shaped vs. asymptotic) for the fishery age composition time series. Also, see Research and Data Needs below).

It is important to note that both the STAR panel and STAT viewed the fishery-independent data collected in the AT survey as the most objective information available for monitoring this stock's abundance in the long-term. However, before using these data in formal assessments of the stock in the short term, further research is recommended for providing more basic information to better assess what can be considered plausible estimates of *q* for this species and determining reasonable bounds (priors) on *q*, which can be supported outside and inside the model (STAR 2015). This general issue regarding uncertainty surrounding species range vs. survey design was addressed in the Pacific sardine assessment by assuming that the AT survey provides estimates of 'absolute' abundance (fixed *q*=1) for this population, which was deemed an unrealistic assumption for Pacific mackerel due to its hypothesized distribution beyond particularly the latitudinal (south), and less so longitudinal (west) extents of the current survey design (STAR 2015).

Also, the problematic estimation of scale (absolute size of population abundance or biomass) for particular model configurations investigated here is often characteristic in data-limited assessments of small pelagic fish stocks: that have few age classes representing mostly young fish, with limited numbers of old fish observed in some years; extensive ranges; and dynamics largely driven by infrequent periods of recruitment success and high abundance that are likely influenced primarily by oceanographic factors (STAR 2015). For example, in sensitivity analysis that involved perturbing (jittering) final model configurations (e.g., H3 and H1b) that included dome-shaped selectivity for the fishery age compositions, at least one-half of the runs resulted in similar fits, estimated parameters, derived management quantities, etc. as indicated in analogous models based on asymptotic selectivity for the fishery. The remaining collection of runs generally converged to a better overall model fit, but produced results indicating implausibly high estimates of abundance, often along with unrealistic selectivity curves. One of the highest priorities in future modeling work will be to generally address selectivity considerations, assumptions, and estimation in the integrated assessment, including: use more flexible forms/methods (e.g., non-parametric) for modeling age, or length, selectivity for the fishery;

evaluate time-varying assumptions; consider a shorter time period in the model; examine conflicts with other (size) compositions included in the assessment; employ data weighting schemes to investigate the impact that selectivity and fitting to composition data have on baseline results used by management; etc. Also, see related model development discussion that is highlighted in Research and Data Needs below.

Candidate model configurations

Candidate models A-G were developed prior to the review in April 2015 for purposes of beginning critique and discussion, and conducting further sensitivity analysis at the meeting. Models A-B were generally similar to model XA (final model from assessment conducted in 2011, Crone et al. 2011), with updated data and parameterizations that closely followed the last full assessment model. The underlying structure of candidate models C-G was also generally similar to model XA, but the respective models included additional changes based on one or more of the sensitivity areas noted above. Sensitivity areas were chosen based on prioritizing recommendations from past reviews, along with evaluating model robustness to alternative choices, assumptions, and estimators relied on currently in the assessment. Model H1b represents a candidate model developed during the review in April 2015 and is presented here as an example configuration that included AT survey information partitioned into seasons (i.e., models C-G included AT survey data combined across seasons within respective fishing years). Candidate models are summarized below, with more extensive descriptions, discussion, and results presented for final model H3. Refer to Model H3 configuration below for further details associated with data/parameterizations noted in the respective models, particularly model XA.

Model XA:

- Final model from last assessment/review (Crone et al. 2011);
- Model is contrasted in detail with model H3 below;
- Time period: 1983-10 and annual time step;
- Fisheries: Two (USA/Mexico commercial and USA recreational);
- Surveys: Two CPUE indices of relative abundance from recreational fisheries, including a CPFV index and CRFS (non-CPFV) index;
- Sex: Combined sexes;
- Longevity: 12 years;
- Maturity: Fixed vector of maturity-at-age;
- Natural mortality: $M = 0.5\ yr^{-1}$ for all ages and constant over time;
- Growth: Estimated based on von-Bertalanffy growth curve;
- Fishing mortality: *F* calculations based on Pope’s approximation (initial *F* estimated for the commercial fishery and fixed for the recreational fishery);
- Selectivity (fisheries): Age-based and constant for all fisheries. Asymptotic selectivity was assumed for the commercial fishery (based on age data from production ageing sampling/lab program) and dome-shaped for the recreational fishery (based on CPFV length data from RecFIN data base);
- Selectivity (indices): Age-based and constant for all indices. CPFV index of abundance was dome-shaped (mirrored the recreational fishery selectivity) and CRFS index of abundance was dome-shaped (based on length data from non-CPFV modes);
- Catchability: *q* estimated and constant for both indices of abundance (CPFV and CRFS), with CVs = 0.30 for all annual estimates for both indices;

- Stock-recruitment: Beverton-Holt stock-recruitment relationship, with estimated steepness (*h*), virgin recruitment (R_0), and initial equilibrium recruitment offset (R_1), and fixed recruitment variance (assumed SD of the log-deviations about the stock-recruitment relationship, σ_R);
    - Estimates for 'early period' recruitment deviations (1977-82), 'main period' (1983-09), 'late period' (2010), and 'forecast period' (2011);
    - Recruitment bias adjustments were not implemented; and
- Variance adjustments (additional data weighting schemes) for biological compositions and indices: None.

Model A:

- Similar to model XA, with updated model dimensions, data, and parameterizations;
- Differences to model XA (Crone et al. 2011):
    - Fishery age compositions were weighted by monthly landings (see Age compositions above);
    - CRFS index of abundance and length compositions were not updated (see CRFS index of abundance above), but were included in the model;
    - Weight-length relationship was updated;
    - Standard deviation estimates for *length-at-age_maximum/_minimum* were fixed (SD=0.10);
    - Fishing mortality (*F*) calculations are based on the hybrid estimation method in SS and initial *F* estimates set to 0 for both the commercial and recreational fisheries;
    - Average recruitment variance (σ_R) was set to 0.75; and
    - Recruitment bias adjustments were implemented (1983-13).

Model B:

- Similar to model A, but CRFS index of abundance and length compositions were omitted and asymptotic selectivity was implemented for the recreational fishery (CPFV index selectivity mirrored the recreational fishery);

Model C:

- Similar to model B, but AT survey data were included, with length compositions and index of abundance based on combined seasons in respective fishing years (dome-shaped selectivity was implemented and catchability was estimated for the annual index of abundance);

Model D:

- Similar to model C, but commercial and recreational fisheries were combined into a single fishery, with asymptotic selectivity as assumed in the commercial fishery;

Model E:

- Similar to model D, but with dome-shaped selectivity for the fishery and asymptotic selectivity assumed for both indices of abundance (CPFV and AT);

Model F:

- Similar to model D, but growth was based on empirical weight-at-age time series and not internally estimated in the model. Given no length data are used in models based on empirical weight-at-age data, selectivity for the indices of abundance (CPFV and AT survey) mirrored (asymptotic) the fishery.

Model G:

- Similar to model D, but the modeled time period was abbreviated (1995-14).

Model H1b:

- Similar to model H3 below, but AT survey data were included, with surveys partitioned by season (spring and summer) and respective fishing year (asymptotic selectivity was implemented and catchability was estimated for the seasonal indices of abundance).

Data sources, parameterizations, likelihood components, and derived quantities of interest associated with the candidate model configurations are presented in Table 5. The most meaningful results useful to management are the estimated stock biomass (age 1+ fish) time series for the candidate models, which are presented in Figure 29.

Model H3 configuration

Model H3 specifications follow, with changes from model XA noted in parentheses:

- Time period:1983-14 (XA: 1983-10) and annual time step (seasonal models were evaluated in previous assessments/reviews, Crone et al. 2009);
- Fisheries: One, commercial and recreational fisheries were combined into a single fishery (XA: fisheries were separated into a USA/Mexico commercial fishery and USA recreational fishery);
- Surveys: One index of abundance from CPFV fleet (XA: two indices, CPFV and CRFS)
- Sex: Combined sexes;
- Longevity: 12 years;
- Natural mortality: $M = 0.5$ yr^{-1} for all ages and constant over time;
- Maturity: Fixed vector of maturity-at-age;
- Growth: Based on von-Bertalanffy growth curve, with estimated parameters for *length-at-age_maximum*, *length-at-age*_minimum, and *k*, and fixed (SD=0.10) error parameters associated with *length-at-age_maximum/_minimum* (XA: SD was estimated for *length-at-age_maximum* and fixed for *length-at-age_minimum*), noting that past recommendations included fixing error terms at reasonable levels, given no information for obtaining variance estimates are available in respective models based on age and mean length-at-age compositions for growth estimation);
    - Weight-length relationship was updated, with resulting estimated power function coefficients that were similar to model XA;
    - Age compositions were updated based on weighted composition calculations, with sample sizes reflecting the number of fish observed divided by 25 (XA: age compositions were un-weighted);

- Mean length-at-age compositions were updated based on weighted composition calculations, with sample sizes reflecting the number of fish observed divided by 25 (XA: mean length-at-age compositions were un-weighted);
- Fishing mortality: *F* calculations based on the hybrid method, which is based on Pope's approximation to provide initial values for iterative adjustment of the continuous *F* values to closely approximate the observed catch (XA: Pope's approximation was implemented);
  - Initial *F* estimates based on a non-equilibrium analysis and set to 0 for combined fishery (XA: initial *F* estimated for commercial fishery and fixed = 0.001 for recreational fishery), noting that in past and present sensitivity analysis, model configurations based on estimated initial *F* resulted in very low values);
- Selectivity (fishery): Age-based, asymptotic, and constant for the single, combined (commercial and recreational) fishery (XA: selectivity was asymptotic for commercial fishery and dome-shaped for the recreational fishery), noting that in past and present sensitivity analysis, poor fits or lack of convergence resulted from models that included a simple 2-parameter logistic form for modeling asymptotic selectivity for the fishery and thus, a 6-parameter double-normal form with 3 parameters fixed was used to estimate asymptotic selectivity in most configurations;
- Selectivity (indices): Age-based, asymptotic, and constant for the CPFV index of abundance based on CPFV length data from 1992-14 (XA: dome-shaped and based on CPFV length data from 1985-10);
- Catchability: *q* estimated for CPFV index of abundance, with CVs = 0.30 for all observations (annual estimates of standardized catch rate);
- Stock-recruitment: Beverton-Holt stock-recruitment relationship, with estimated steepness (*h*), virgin recruitment (R_0), and initial equilibrium recruitment offset (R_1), and fixed recruitment variance (assumed SD of the log-deviations about the stock-recruitment relationship, σ_R = 0.75) (XA: σ_R = 1.0), noting that σ_R was reduced in the present assessment to be similar with assumed value for Pacific sardine (Hill et al. 2015), as well as a robust estimation in sensitivity analysis conducted during the review in April 2015 (STAR 2015);
  - Estimates for 'early period' recruitment deviations (1977-82), 'main period' (1983-13), 'late period (2014), and 'forecast period' (2015-16) (XA: 'main period' (1983-09), 'late period' (2010), and 'forecast period' (2011);
  - Recruitment bias adjustments are implemented (1983-13) (XA: no recruitment bias adjustments implemented, noting that this SS parameterization option had not been thoroughly tested at that time); and
- Variance adjustments (additional data weighting schemes) for biological compositions and indices: None.

Model H3 results

Parameter estimates and errors

Parameter estimates and associated errors (SDs) for model H3 are presented in Table 6.

Growth

Estimated length-at-age is presented in Figure 3a. *Length-at-age_minimum* (0.5 yr) was estimated to be 20.5 cm (fork length), *length-at-age_maximum* (12 yr, L_∞) was 39.3 cm, and the growth coefficient *k* was 0.39. Model fits to mean length-at-age compositions with associated residual plots, which are used along with age compositions for estimating growth in the integrated model, are presented in Figure 16. Growth estimation in the integrated model has been largely robust in past and present sensitivity analysis conducted for this assessment.

Fits to biological compositions
Estimated age-based selectivity curves for the fishery (combined commercial and recreational fisheries) and CPFV index of abundance are presented in Figure 17. Model fits and associated residual plots for the biological-composition time series are presented in Figures 18-19, respectively, for the fishery age compositions and CPFV length compositions. Reasonably good fits were observed for the composition time series. However, assumptions regarding appropriateness of asymptotic (vs. dome-shaped) selectivity for particularly the fishery and compromised fits to the AT survey length compositions (e.g., model H1b) require further attention in future model development. As found in past assessments, asymptotic selectivity for the fishery provided model stability in terms of population scale, but observed age composition time series, particularly, for recent years indicated dome-shaped forms were more applicable. See Unresolved problems and major uncertainties above, and Research and Data Needs below.

For comparative purposes, length compositions (averaged across years from 2005-14) from the commercial fishery, recreational fisheries for the CPFV mode and all modes, and AT survey are presented in Figure 20. Similarly-sized fish are caught in the commercial fishery and recreational fisheries (all modes), which supported combining fisheries in the assessment model—noting that this parameterization change was also based on the sport fishery's minor contribution to the total annual landings of this species.

Fits to index of abundance
Model fits to the CPFV index of abundance are presented in Figure 21. Overall, fits to the CPFV index were reasonable, but for some years, predicted estimates were not captured within 95% confidence intervals associated with observed estimates. For example, poorer fits are most pronounced at the end of the time series from 2004 onwards and particularly, for 2011-14 that represents additional data included in the model since the last assessment. Relatedly, the steeper decline of the index at the end of the time series directly influences, to some degree, the consistent retrospective patterns observed previously with this assessment over time (see Retrospective analysis below). Also, as indicated in the terminal-year stock biomass profile, the CPFV index is informative in the model for determining the magnitude of current biomass (2014), given other structure (assumptions, data, and parameterizations) included in the configuration (see Likelihood profiles for virgin recruitment and terminal-year stock biomass below).

Population numbers/biomass-at-age
Estimates of population numbers-at-age (July 1st) are presented in Table 7. The vast majority of the Pacific mackerel population is comprised of young fish, with an annual average over the last decade (2004-15) of approximately 87% of the stock being $\leq$2 years old, 12% ages 3-8, and 1% age 9 and older. Estimates of population biomass-at-age (July 1st) are presented in Table 8. Average annual biomass of age 0-2 fish over the last decade (2004-15) was roughly 56%, 42% for ages 3-8, and 2% for $\geq$9 year-old fish.

Stock-recruitment
The Beverton-Holt stock-recruitment (S-R) relationship is presented in Figure 22. Spawning stock biomass and associated recruitment dynamics for this species are not well understood at this time, however, it is likely Pacific mackerel exhibit some degree of population depensation (reduced production and/or survival of eggs/larvae associated with declining spawning stock abundance), particularly, during unfavorable large-scale environmental regimes. General consensus indicates that periods of high recruitment success for Pacific mackerel are not evident on decadal bases, but rather, on a multi-decadal cycles spanning 30 to 50 or more years, whereby favorable oceanographic conditions exist along with relatively high spawning stock biomass levels (Parrish 1974; MacCall et al. 1985). High recruitment abundance was last observed in the mid to late 1980s and then to a lesser extent in the mid-1990s (see Spawning stock biomass and Recruitment below). Estimated steepness (h) was relatively robust across candidate model scenarios (Table 5, h = 0.48 for model H3).

Recruitment deviations and SEs associated with the S-R estimation for the early, main, late, and forecast periods in the model are presented in Figure 23. Recruitment deviation SEs relative to σ_R are plotted in Figure 24. Finally, the adjustment ramp implemented for the bias-corrected recruitment estimation is presented in Figure 25.

Spawning stock biomass
Estimated (female) spawning stock biomass (SSB) time series along with 95% confidence intervals is presented in Figure 26. Since the mid-1980s, SSB has continually declined and has remained consistently low over the last decade.

Recruitment
Estimated recruitment (age-0 fish, numbers) abundance time series is presented in Figure 27. Virgin recruitment (R_0) for model H3 was estimated to be roughly 0.54 billion age-0 fish, based on a virgin (female) spawning stock biomass estimate of approximately 78,425 mt. As indicated above (see Stock-recruitment), relatively good recruitment success for Pacific mackerel was last observed in the early 1990s, followed by very low estimates of recruitment from the mid-1990s to 2012, with somewhat higher levels estimated most recently, noting that estimates are highly uncertain.

Stock biomass for PFMC management
Time series of estimated stock biomass (mt, age 1+ fish) that is used for setting management specifications on an annual basis is presented in Figure 28. Similar to estimated SSB, estimates of stock biomass have continually declined since the mid-1980s, remaining at low levels since 2004, with some increase noted in the last few years. Past and present assessments of this stock indicate that since at least the late 1990s, abundance has remained at historically low levels (<150,000 mt). Stock biomass estimated in model H3 is compared with other candidate models in Figure 29 (see Candidate model configurations above).

Fishing mortality and exploitation rates
Estimated rates of instantaneous fishing mortality (F, yr^{-1}) for this stock have fluctuated over time, from <0.1 to nearly 0.4 observed from the late 1990s to early 2000s (Figure 30). Recent estimates of fishing intensity indicate F has been generally <0.2 over the last decade.

Exploitation rate (annual catch/mid-year total biomass) time series closely follow the estimated *Fs* over time, with annual removal rates (including Mexico catches) reaching roughly 25-35% from the late 1990s to mid-2000s and <5 to 20% over the last decade (Figure 31).

Diagnostics

Likelihood profiles for virgin recruitment and terminal-year stock biomass

Likelihood profiles for virgin recruitment ($\log R_0$) and terminal-year ($B_{current}$) stock biomass (age 1+ fish) can provide information regarding which data components influence scale in a stock assessment model. Additionally, these diagnostic analyses are useful for identifying areas of conflict among data sources and tension between particular parameterizations included in the assessment model. A $\log(R_0)$ profile was conducted for model H3, with values ranging from 12.4 to 14.0 (Figure 32). Profiles for the total likelihood and individual model components (e.g., indices of abundance, biological compositions, and total) indicated smooth forms (parabolic curves). Conflict among components was evident with respect to scale, where most components fit better at moderate to higher $\log(R_0)$ values, whereas the fishery age composition data fit better at lower $\log(R_0)$ values and had the steepest gradient (Figure 32). The final solution for model H3 resulted in a similar estimate of virgin recruitment, $\log(R_0) = 13.2$, as observed in the best fit runs from the profile, providing some evidence that this model's solution reflected a global minimum (see Convergence tests below).

The terminal-year ($B_{current}$) stock biomass (age 1+ fish) profile provides generally similar information as the $\log(R_0)$ profile, but is based on a recent derived quantity of population biomass, rather than an initial estimate of recruitment abundance from the assessment model (Figure 33). This profile is conducted similarly to the $\log(R_0)$ evaluation, using a re-configured model H3 that included an additional artificial 'survey' that is based on a single, precise, terminal-year estimate (2014) that essentially equals the estimated stock biomass in 2014 from model H3, has fixed catchability ($q = 1.0$), and has high emphasis (weight, e.g., lambda value in SS) relative to other data components in the model. A $B_{current}$ profile is potentially a more important diagnostic for this species, as well as other stocks (e.g., Pacific sardine) that are managed based primarily on a current estimate of stock biomass. Both diagnostic profiles for model H3 indicate similar areas of data conflict, with the $B_{current}$ profile also providing evidence that the CPFV index is informative in the model for determining current biomass (2014), given other structure (assumptions, data, and parameterizations) included in the configuration (Figure 33).

Retrospective analysis

Retrospective analysis provides another means of examining model properties and characterizing uncertainty. A retrospective analysis was conducted on model H3 based on removing data sequentially (on an annual basis) from the terminal year backwards to 2009. Estimated stock biomass time series are presented in Figure 34. As indicated in past assessments, a systematic pattern of overestimation in the terminal year was evident from this analysis. Another diagnostic investigation that supported this finding is presented in Figure 35, which presents estimated stock biomass time series related to model XA (1983-10), whereby data were added sequentially to the model to evaluate the sensitivity of results to including updated time series (catch, index of abundance, and biological compositions) to the model on an annual basis (2011-13). Beginning in 2011, addition of each time series resulted in a decreasing trajectory of estimated stock biomass. Note that this investigation was based on candidate model A that included similar data as model XA, and indicated that the most influential data were the index of abundance estimates, followed by the biological compositions, and finally catch time series.

Convergence tests

Convergence properties of model H3 were investigated to ensure the results represented an optimal solution, given the structure (assumptions, data, and parameterizations) specified in the model (Table 9). Convergence confirmation entailed an iterative process for determining numerical solutions in the model continuing until the difference between successive likelihood estimates was <0.0001. Additionally, the model was run across a wide range of virgin recruitment ($\log R_0$) values (12.4 to 14.0) to evaluate convergence sensitivity to an important global scale parameter. For each run, phase order for estimating parameter components (growth, $\log R_0/\log R_1$, steepness, index q, and selectivity) was randomized from 1 to 4, and all initial parameters were jittered by 20%. The vast majority of the runs resulted in the best likelihood as indicated in model H3 ($-\log(L)$ = 1,077.71), with similar final estimates of $\log(R_0)$ = 13.2. This diagnostic investigation indicated that model H3 appeared to converge to a global minimum.

Historical analysis

Estimated stock biomass time series from previous stock assessments are contrasted in Figure 36. Full and updated assessment models since 2004 were included in the comparison. Trends of stock biomass were generally similar across the various models used over the last decade. As discussed above under Retrospective analysis, decreased stock biomass trends since 2004 are indicated in model H3 results, attributed to the addition of recent data collected since 2010, particularly, the CPFV index of abundance and fishery age compositions.

HARVEST CONTROL RULE FOR USA MANAGEMENT IN 2015-16 AND 2016-17

The following harvest control rule results are applicable to model H3 (Table 10a-b). Since 2000, the Pacific mackerel stock has been managed under a Federal Management Plan (FMP) harvest policy, stipulating that an optimum yield for this species should be set according to the following harvest control rule:

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

where Harvest is the harvest guideline (HG), Biomass is age 1+ stock biomass (mt) in the respective fishing year (120,435 mt in July 2015 and 118,968 mt in July 2016), Cutoff (18,200 mt) is the lowest level of estimated biomass above which harvest is allowed, E_{MSY} (30%, also referred to as Fraction) is the proportion of biomass above the Cutoff that can be harvested by fisheries, and Distribution (70%) is the average proportion of stock Biomass (ages 1+) assumed in USA waters (PFMC 1998). Harvest stipulations under the federal FMP are applied to a July-June fishing year. The HG estimate based on model H3 for July 2015 was 21,469 mt (Table 10a) and 21,161 mt for July 2016 (Table 10b). Note that the forecasted HG for 2016 was based on the assumption that the HG for 2015 (21,469 mt) would be fully utilized, with predicted recruitment (i.e., 2015 year-class) for the forecast period estimated directly from the stock-recruitment relationship (see STAR 2015). Landings and associated HGs since 2004 are presented in Table 11 and Figure 37. Finally, additional harvest control rule statistics recently required for USA

Pacific coast fisheries (PFMC 2011) are also included in Table 10a-b for specifying overfishing limits, as well as a range of acceptable biological catches and limits (ABCs and ACLs) based on different probability levels of overfishing using 'P-star' and associated ABC 'buffer' calculations.

Regional management considerations

Pacific mackerel, as well as other species considered in the CPS FMP, are not managed formally on a regional basis within the USA, due primarily to the extensive distribution and annual migration exhibited by these stocks. Noting that a form of regional (spatial/temporal) management has been adopted for Pacific sardine, whereby seasonal allocations are stipulated in attempts to ensure regional fishing sectors have at least some access to the directed harvest each year (PFMC 2014b). However, given the recent history of relatively limited landings of Pacific mackerel in California, and particularly Oregon and Washington, region-specific catch regulations would not likely provide further benefits for management of the stock at this time.

RESEARCH AND DATA NEEDS

The most important research support needed for improving the quality of the ongoing stock assessments of Pacific mackerel should address improvements to the newly implemented AT survey conducted annually by the SWFSC, given this fishery-independent monitoring effort has the capability of providing the most objective time series for measuring total biomass of Pacific mackerel, as well as other member of the small pelagic species assemblage off the USA Pacific coast. The ability to extend the AT survey operations beyond particularly the latitudinal (south) and less so longitudinal (west) extents of the current survey design would greatly benefit the quality of data provided by this survey effort, given the assumed extensive distribution of the stock in any given year, believed to be influenced strongly by environmental factors. Recent review criticisms focused on the limitations of the AT survey data for assessing the status of the Pacific mackerel stock at this time for management, including justifying catchability coefficient (q) estimates, given the assumed, but uncertain distribution of this species in the context of the spatial boundaries of the survey area (STAR 2015). In the interim, additional model development research should proceed in parallel with re-evaluations of the available data from the AT survey. For example, the typically problematic selectivity tension between data sources in the integrated model is the result, at least in part, to underlying assumptions related to longevity, mortality, and growth. Assessment model development should re-visit current assumptions/estimation approaches regarding longevity and interactions with plausible rates of M for this species, as well as more fully examine present growth estimation (K has been shown to be relatively robust from past/present studies, but asymptotic size/age needs to be consistent with recent composition time series that are being fitted). This modeling research will assist diagnosing overall internal consistency and specific fitting conflicts among sources of data included in the present model (e.g., dome-shaped vs. asymptotic selectivity for the commercial fishery and related impacts on abundance scale in the assessment). Additionally, catch rate data from the CPFV fleet should be continued to be collected using as rigorous methods as possible via the CDFW logbook sampling program, given it represents the only index of abundance presently included in the assessment of this stock and as importantly, represents a data source that can be used qualitatively for comparisons with fishery-independent data from the AT survey.

Second and related to all research/data needs presented here, given the trans-boundary status of this fish population, it is imperative that efforts continue for encouraging collaborative research and data exchange between NOAA Fisheries (Southwest Fisheries Science Center) and researchers from both Canada's and in particular, Mexico's academic and federal fishery bodies, i.e., such cooperation is necessary for providing a synoptic assessment that is based on representative sample data that have been collected using consistent methods across the full (southerly) range of this species.

Third, given the importance of age (as well as size, weight, and length) composition time series for developing a sound understanding of population dynamics exhibited by this stock, it is critical that data collection programs at the federal and particularly, the state level continue to be supported in the future. In particular, federal/state funding should be bolstered to ensure ongoing ageing-related laboratory work is not interrupted, as well as providing necessary funds for related biological research that is long overdue, such as 'double-read' diagnostics, first-annuli deposition and identification investigations, etc. Further, currently only age data from the California commercial fishery are processed and available for conducting this ongoing assessment and thus, it is important that the states of Oregon and Washington also begin formal biological sampling programs for this species, providing otoliths to the centralized laboratory in California for analysis. Also, it is important to continue support of CDFW's CRFS program for purposes of providing valuable biological data from the various modes of recreational fishing associated with this stock, including fish from CPFV operations used to model selectivity associated with the CPFV index of abundance included in the assessment. Given the second data need noted above, biological samples from Mexico's commercial fishery are also lacking in this assessment. Relatedly, fish collected as part of the trawling operations associated with the AT survey need to be processed for age determination, along with measures of length and weight. Finally, age/growth studies and systematic sampling in the field for size/age attributes for other members of the small pelagic species assemblage should be committed to as quickly as possible, given the ever increasing management demands for these species, including northern anchovy and jack mackerel.

Fourth, the harvest control rule utilized in the Pacific mackerel federal CPS-FMP was developed in the mid-1980s based on estimated abundance and stock-recruitment data available at that time and thus, harvest strategies should be re-examined using updated data and simulation methods. Formal management strategy evaluations (MSE) should be undertaken in the near future, which address not only single species, but also include assemblage-based management options. It is important that the MSEs consider recent market conditions and economic factors affecting the overall wetfish fleet, which will primarily dictate the fishery's present and future operations.

Finally, a generally similar assessment/review schedule that would allow sample data and model development progress made during interim periods to be accommodated more efficiently for informing management in both the short- and long-term would benefit greatly from a two-phase meeting approach: 1) the first meeting should be held with members of the CPS-subcommittee of the SSC before the next formally scheduled STAR to critique/discuss a revised model based on the goals noted above, e.g., 1-day meeting held in concert with a previously scheduled SSC meeting (potentially, summer/fall 2016); and 2) a second, more typical STAR meeting would then be conducted that fully meets the CPS terms of reference for purposes of providing management advice for the coming fishing year(s). Although the current assessment schedule for this species stipulates that the next review meeting should take place in spring 2017 (catch-based projection only), we feel that the best deliverable would entail using the summer/fall 2016 meeting with the CPS subcommittee for guidance concerning the type of assessment that should go forward for review in spring of 2017, e.g., update or full assessment, rather than a simple catch-based projection. It is important to note that this type of meeting schedule was also highlighted in the recently completed SWFSC stock assessment review (July 2014) that was part of a national program coordinated by NOAA/NMFS (NMFS 2014).

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TABLES

Table 1. Landings (mt) for Pacific mackerel by fishery (1983-14). Recreational fishery proportion of total landings is also presented. Model H3 is based on a single, combined (commercial and recreational) fishery (see total estimates).

	Commercial				Recreational		Recreational
Fishing year	**MX**	**CA**	**OR**	**WA**	**CA**	**Total**	**Proportion**
1983	2,377.2	36,309.1	4.9	0.0	1,544.1	40,235.4	0.04
1984	4,534.2	39,239.8	0.0	0.0	1,467.3	45,241.4	0.03
1985	6,815.5	37,614.9	0.0	0.0	1,015.9	45,446.3	0.02
1986	7,314.4	44,298.0	0.0	0.0	859.2	52,471.6	0.02
1987	1,809.1	44,838.0	1.5	0.0	1,264.5	47,913.0	0.03
1988	5,998.9	41,967.8	0.6	0.0	688.6	48,655.9	0.01
1989	21,987.2	25,063.2	4.7	0.2	666.3	47,721.6	0.01
1990	30,541.2	39,973.8	10.4	0.1	705.3	71,230.9	0.01
1991	33,871.1	30,268.1	41.1	0.2	705.3	64,885.8	0.01
1992	5,780.8	25,583.6	470.5	5.6	705.8	32,546.3	0.02
1993	9,108.3	10,787.1	271.0	30.6	608.8	20,805.8	0.03
1994	13,302.3	9,372.1	355.0	32.9	1,037.8	24,100.1	0.04
1995	3,367.7	7,614.7	48.1	42.2	1,013.4	12,086.1	0.08
1996	14,089.3	9,787.9	118.2	6.2	685.6	24,687.1	0.03
1997	26,859.5	23,412.8	1,638.3	155.9	804.0	52,870.4	0.02
1998	42,815.0	19,578.0	454.5	42.3	429.6	63,319.4	0.01
1999	8,587.0	7,170.2	256.9	46.0	152.6	16,212.7	0.01
2000	6,530.2	20,936.4	138.5	48.5	325.3	27,978.9	0.01
2001	4,003.5	8,435.9	302.5	270.7	571.0	13,583.7	0.04
2002	10,327.6	3,541.1	127.4	248.8	254.1	14,499.0	0.02
2003	2,617.7	5,972.1	159.1	53.2	323.3	9,125.3	0.04
2004	1,711.4	5,011.8	110.4	23.7	544.0	7,401.3	0.07
2005	3,084.9	4,572.1	314.3	22.3	412.0	8,405.5	0.05
2006	1,986.1	7,870.2	669.4	41.8	372.0	10,939.5	0.03
2007	2,218.4	6,208.4	697.8	37.5	310.4	9,472.5	0.03
2008	803.1	4,203.9	57.6	9.0	280.3	5,353.9	0.05
2009	49.4	3,278.7	54.4	4.9	268.6	3,656.0	0.07
2010	1,916.7	2,047.0	47.8	1.6	216.6	4,229.7	0.05
2011	2,232.0	1,665.2	201.9	83.0	127.0	4,309.0	0.03
2012	7,390.0	3,201.5	1,587.8	693.4	100.2	12,972.9	0.01
2013	2,825.2	11,165.3	437.9	178.5	139.9	14,746.9	0.01
2014	2,825.0	5,445.5	1,172.3	544.8	136.4	10,124.0	0.01
Avg. (2004-14)	2,458.4	4,970.0	486.5	149.1	264.3	8,328.3	0.04

Table 2. Normalized net fecundity calculations by age for Pacific mackerel reflect the maturity schedule used in model H3. Observed fraction mature and observed spawning frequency from Dickerson et al. (1992). Predicted fraction mature from logistic regression. Predicted spawning frequency from linear regression. Net fecundity is adjusted (normalized) to a maximum value of 1.0. Batch fecundity is assumed constant.

Age (yrs)	Obs. fraction mature	Pred. fraction mature	Obs. spawning freq. (% spawning day^{-1})	Pred. spawning freq. (% spawning day^{-1})	Net fecundity (eggs g^{-1})	Norm. net fecundity (eggs g^{-1})
0	0.000	0.000	0.000	0.000	0.000	**0.000**
1	0.214	0.487	0.000	1.380	0.672	**0.074**
2	0.867	0.636	3.900	3.520	2.240	**0.246**
3	0.815	0.763	6.800	5.660	4.320	**0.474**
4	0.851	0.855	9.900	7.800	6.670	**0.733**
5	0.882	0.916	7.700	9.940	9.110	**1.000**
6+	0.882	0.916	7.700	9.940	9.110	**1.000**

Table 3. Age and length sample (numbers of fish) information from CDFW data collection programs for Pacific mackerel (1983-14). Age samples for commercial fishery also generally apply to size samples for constructing mean length-at-age and empirical weight-at-age time series for respective model scenarios. Acoustic-trawl numbers reflect combined spring and summer surveys. Length samples for the recreational fishery represent the CPFV mode and *All* modes in parentheses. Acoustic-trawl data are for information only, i.e., not included in model H3.

Fishing Year	Commercial Age	Acoustic-trawl Length	Recreational Length
1983	2,668		
1984	2,291		
1985	2,606		1,980 (2,919)
1986	3,000		1,301 (2,236)
1987	4,129		568 (1,557)
1988	4,477		494 (1,009)
1989	3,583		344 (788)
1990	2,114		
1991	1,655		
1992	1,994		160 (710)
1993	2,688		786 (1,736)
1994	3,114		475 (1,561)
1995	2,706		1130 (2,034)
1996	2,189		837 (1,899)
1997	2,714		1181 (2,278)
1998	2,255		611 (1,524)
1999	1,666		617 (1,253)
2000	1,910		390 (1,084)
2001	2,111		413 (1,015)
2002	2,145		526 (1,149)
2003	1,570		540 (1,148)
2004	2,529		543 (2,901)
2005	2,299	11	621 (3,747)
2006	2,393		602 (4,144)
2007	1,609	103	1118 (3,782)
2008	723		1117 (2,947)
2009	422	34	944 (2,656)
2010	497	383	377 (1,161)
2011	771	487	661 (2,241)
2012	1,195	113	548 (1,612)
2013	1,793	217	679 (1,975)
2014	400		570 (1,584)

Table 4. Indices of abundance for Pacific mackerel associated with the CPFV fleet and acoustic-trawl survey. Acoustic-trawl data are for information only, i.e., not included in model H3. Model H3 included the 'kept' fish time series (1983-14).

	CPFV						**AT**			
	1983-14 (kept)		1995-14 (kept)		1995-14 (kept+rel)		Spring		Summer	
Fishing year	*Est*	*CV*	*Est*	*CV*	*Est*	*CV*	*B* (mt)	*CV*	*B* (mt)	*CV*
1983	68.50	0.08								
1984	76.45	0.08								
1985	58.71	0.08								
1986	46.94	0.09								
1987	31.54	0.09								
1988	21.95	0.10								
1989	31.49	0.09								
1990	33.34	0.10								
1991	37.24	0.09								
1992	27.91	0.10								
1993	33.01	0.10								
1994	30.95	0.09								
1995	27.55	0.10	34.59	0.15	45.20	0.11				
1996	30.89	0.09	39.30	0.13	60.33	0.11				
1997	17.11	0.10	16.48	0.14	26.08	0.11				
1998	9.42	0.11	11.81	0.16	16.45	0.12				
1999	5.47	0.12	6.94	0.16	9.30	0.13				
2000	10.87	0.12	15.23	0.16	22.16	0.13				
2001	8.21	0.12	10.51	0.17	18.48	0.13				
2002	6.61	0.14	8.99	0.19	12.14	0.14				
2003	3.99	0.19	4.72	0.19	6.80	0.14				
2004	7.13	0.22	7.85	0.19	13.98	0.18				
2005	11.50	0.28	9.90	0.27	15.19	0.20	47,000	0.62		
2006	10.48	0.23	8.67	0.19	15.03	0.17				
2007	14.90	0.23	12.13	0.19	22.82	0.15	18,000	0.52		
2008	20.72	0.26	15.79	0.23	24.24	0.18			55,000	0.38
2009	17.73	0.54	19.81	0.53	25.34	0.40	18,000	0.46		
2010	5.43	0.26	7.61	0.30	10.64	0.20	257,000	0.29		
2011	2.61	0.17	3.48	0.21	7.94	0.16	14,000	0.53		
2012	2.30	0.28	3.12	0.32	7.00	0.21	13,000	0.32	109,000	0.34
2013	10.13	0.71	15.15	0.74	16.51	0.55	14,000	0.5	8,000	0.61
2014	3.07	0.31	4.97	0.33	16.92	0.33			8,000	0.56

Table 5. Summary information and results for candidate models, including sensitivity areas, data components, likelihoods, and estimated quantities. Notation: selectivity is A= asymptotic and D=dome-shaped; and growth is EST=estimated and WAA=empirical weight-at-age.

DATA / PARAMETERIZATION		MODEL SCENARIO XA	A	B	C	D	E	F	G	H1b	H3
Survey		CPFV+CRFS	CPFV+CRFS	CPFV	CPFV+AT	CPFV+AT	CPFV+AT	CPFV+AT	CPFV+AT	CPFV+AT(split)	CPFV
Fishery		COM+REC	COM+REC	COM+REC	COM+REC	COMBINED	COMBINED	COMBINED	COMBINED	COMBINED	COMBINED
Selectivity	Fishery	COM-A\REC-D	COM-A\REC-D	COM-A\REC-A	COM-A\REC-A	FISH-A	FISH-D	FISH-A	FISH-A	FISH-A	FISH-A
	Indices	CPFV\CRFS-D	CPFV\CRFS-D	CPFV-A	CPFV-A\AT-D	CPFV-A\AT-D	CPFV-A\AT-A	CPFV-A\AT-A	CPFV-A\AT-D	CPFV-A\AT-A	CPFV-A
Growth		EST	EST	EST	EST	EST	EST	WAA	EST	EST	EST
Time Period		83-11	83-15	83-15	83-15	83-15	83-15	83-15	95-15	83-15	83-15

	DATA COMPONENT	XA	A	B	C	D	E	F	G	H1b	H3
FISHERY	Commercial catch	■	■	■	■	■	■	■	■	■	■
	Recreational catch	■	■	■	■	■	■	■	■	■	■
	Commercial age composition	■	■	■	■	■	■	■	■	■	■
	Commercial mean length-at-age composition	■	■	■	■	■	■		■	■	■
	Commercial emp. weight-at-age							■			
INDICES	CPFV index of abundance	■	■	■	■	■	■	■	■	■	■
	CPFV length composition	■	■	■	■	■	■		■	■	■
	CRFS index of abundance	■	■								
	CRFS non-CPFV length composition	■	■								
	AT index of abundance				■	■	■	■	■	■	
	AT length composition				■	■	■	■	■	■	

LIKELIHOODS	XA	A	B	C	D	E	F	G	H1b	H3
CPFV index of abundance	-0.622494	27.0786	27.3636	27.1963	27.2052	28.4164	19.7996	31.1689	24.8849	25.2581
CRFS index of abundance	-5.32432	-7.5561	---	---	---	---	---	---	---	---
AT index of abundance	---	---	---	26.9134	26.9273	24.2056	19.2057	23.2081	27.5819 / 9.13455	---
Index subtotal	**-5.9468**	**19.5225**	**27.3636**	**54.1097**	**54.1325**	**52.6220**	**39.0053**	**54.3770**	**61.6013**	**25.2581**
Commercial age composition	**368.3380**	**534.0110**	**529.9040**	**533.6810**	**533.6620**	**532.8950**	**459.345**	**245.137**	**533.715**	**529.389**
CPFV length composition	184.491	259.1890	261.4350	260.9990	261.0130	255.1550	---	107.052	160.409	159.405
CRFS (non-CPFV) length composition	57.1463	37.7251	---	---	---	---	---	---	---	---
AT length composition	---	---	---	58.3037	58.3192	64.4841	---	59.3077	40.3628 / 39.2636	---
Length composition subtotal	**241.6373**	**296.9141**	**261.4350**	**319.3027**	**319.3322**	**319.6391**	**---**	**166.3597**	**240.0360**	**159.4050**
Commercial length-at-age composition	**232.3010**	**345.6270**	**342.8390**	**344.1160**	**344.1690**	**343.1900**	**---**	**170.0750**	**345.7190**	**345.3350**
Catch	0.0000E+00	8.0373E-13	1.0388E-12	1.0776E-12	3.8717E-13	2.8084E-13	1.6471E-12	1.2080E-12	5.3064E-13	3.9597E-13
Recruitment	11.4081	17.1982	18.1270	16.9446	17.1770	16.8241	33.6658	5.1704	17.2991	18.1602
Forecast recruitment	0.2347	0.3616	0.1874	0.2634	0.1344	0.1657	0.0172	0.0952	0.0084	0.1644
Parm_softbounds	2.91E-03	5.24E-03	1.67E-03	3.45E-03	3.45E-03	3.53E-03	1.26E-04	1.62E-03	1.84E-03	1.68E-03
Total -log(L)	**847.975**	**1213.640**	**1179.858**	**1268.421**	**1268.611**	**1265.339**	**532.033**	**641.216**	**1198.381**	**1077.713**
Number of estimated parameters	**57**	**60**	**50**	**57**	**57**	**56**	**46**	**45**	**54**	**51**

ESTIMATED QUANTITIES	XA	A	B	C	D	E	F	G	H1b	H3
Ln(R0)	13.5383	13.2529	13.2075	13.2000	13.2053	13.3088	12.6307	12.2836	13.1679	13.1946
B-H Steepness	0.681454	0.465944	0.478568	0.473756	0.471256	0.434983	0.647027	0.631959	0.457402	0.475177
AT survey *q*	---	---	---	1.91	1.91	0.97	2.35	7.67	1.25 / 0.86	---
Stock Biomass - Peak	1,071,020	1,370,390	1,284,900	1,280,420	1,278,240	1,545,100	870,245	346,729	1,169,790	1,232,150
Stock Biomass - 2011	202,027	67,683	59,566	62,717	62,734	78,649	31,432	27,728	49,328	57,122
Stock Biomass - 2015	---	149,236	136,171	111,023	114,510	151,076	29,772	32,614	65,043	120,435
HG 2015-16	---	27,518	24,774	19,493	20,225	27,904	2,430	3,027	9,837	21,469

Table 6. Parameters and asymptotic standard deviations (SD) for model H3.

Parameter	Phase	Min	Max	Initial Value	Final Value	Std Dev
NatM_p_1_Fem_GP_1	-3	0.3	0.7	0.5	0.5	_
L_at_Amin_Fem_GP_1	3	4	35	20.5559	20.5148	0.132533
L_at_Amax_Fem_GP_1	3	30	70	39.198	39.264	0.353243
VonBert_K_Fem_GP_1	3	0.1	0.7	0.387149	0.388536	0.0180183
CV_young_Fem_GP_1	-3	0.01	0.5	0.1	0.1	_
CV_old_Fem_GP_1	-3	0.01	0.5	0.1	0.1	_
Wtlen_1_Fem	-3	-1	5	2.73E-06	2.73E-06	_
Wtlen_2_Fem	-3	1	5	3.44377	3.44377	_
Mat50%_Fem	-3	-3	3	3	3	_
Mat_slope_Fem	-3	-3	3	3	3	_
Eggs/kg_inter_Fem	-3	-3	3	1	1	_
Eggs/kg_slope_wt_Fem	-3	-3	3	0	0	_
SR_LN(R0)	1	1	30	14	13.1946	0.144374
SR_BH_steep	5	0.1	1	0.469845	0.475177	0.087092
SR_sigmaR	-3	0	2	0.75	0.75	_
SR_R1_offset	1	-15	15	0.289513	0.266717	0.286222
InitF_1FISHERY	-1	0	3	0	0	_
AgeSel_1P_1_FISHERY	4	-1	8	0.0811923	0.0812374	1.95368
AgeSel_1P_2_FISHERY	-4	-10	10	1	1	_
AgeSel_1P_3_FISHERY	4	-10	10	-6.3687	-6.36701	55.6498
AgeSel_1P_4_FISHERY	-4	-10	10	5	5	_
AgeSel_1P_5_FISHERY	4	-10	10	-0.316017	-0.365454	14.8528
AgeSel_1P_6_FISHERY	-4	-10	10	10	10	_
AgeSel_2P_1_CPFV	4	-5	12	1	0.92582	0.0801805
AgeSel_2P_2_CPFV	4	-5	15	1	0.691653	0.10752

Table 7. Pacific mackerel population numbers-at-age (1,000s of fish) for model H3.

	POPULATION NUMBERS-AT-AGE (1,000s of fish)												
Model Year	0 (R)	1	2	3	4	5	6	7	8	9	10	11	12
VIRG	537,463	325,988	197,722	119,924	72,738	44,118	26,759	16,230	9,844	5,971	3,621	2,196	3,386
INIT	701,750	425,633	258,159	156,582	94,972	57,603	34,938	21,191	12,853	7,796	4,728	2,868	4,421
1983	250,589	170,851	2,585,480	142,738	464,260	41,619	20,763	21,191	12,853	7,796	4,728	2,868	4,421
1984	437,011	149,260	100,057	1,514,160	83,593	271,890	24,374	12,160	12,410	7,527	4,566	2,769	4,269
1985	1,092,450	258,238	86,079	57,704	873,224	48,208	156,800	14,057	7,013	7,157	4,341	2,633	4,059
1986	1,141,330	640,379	146,630	48,876	32,765	495,823	27,373	89,032	7,981	3,982	4,064	2,465	3,800
1987	237,297	660,429	354,623	81,199	27,066	18,144	274,570	15,158	49,303	4,420	2,205	2,250	3,469
1988	2,684,290	136,729	362,733	194,771	44,597	14,866	9,965	150,804	8,325	27,079	2,428	1,211	3,141
1989	461,985	1,540,200	74,490	197,615	106,111	24,296	8,099	5,429	82,157	4,536	14,753	1,323	2,371
1990	625,826	267,217	852,241	41,218	109,347	58,714	13,444	4,481	3,004	45,460	2,510	8,163	2,044
1991	733,587	349,652	138,274	440,995	21,328	56,582	30,382	6,957	2,319	1,554	23,524	1,299	5,282
1992	309,215	406,207	177,826	70,323	224,280	10,847	28,776	15,452	3,538	1,179	791	11,964	3,347
1993	1,070,320	177,590	221,708	97,057	38,382	122,412	5,920	15,706	8,433	1,931	644	431	8,356
1994	582,126	624,919	100,065	124,923	54,688	21,627	68,974	3,336	8,850	4,752	1,088	363	4,952
1995	1,063,880	338,728	349,809	56,013	69,928	30,612	12,106	38,609	1,867	4,954	2,660	609	2,975
1996	457,112	632,611	197,721	204,190	32,696	40,818	17,869	7,066	22,537	1,090	2,892	1,553	2,092
1997	99,158	266,914	356,511	111,426	115,072	18,426	23,003	10,070	3,982	12,701	614	1,630	2,054
1998	117,030	54,532	133,963	178,930	55,924	57,754	9,248	11,545	5,054	1,999	6,374	308	1,849
1999	83,227	59,101	23,209	57,015	76,153	23,801	24,580	3,936	4,914	2,151	851	2,713	918
2000	126,122	46,823	30,995	12,172	29,900	39,937	12,482	12,891	2,064	2,577	1,128	446	1,904
2001	157,532	62,575	19,258	12,748	5,006	12,297	16,425	5,134	5,302	849	1,060	464	967
2002	59,808	83,067	28,953	8,910	5,898	2,316	5,690	7,600	2,375	2,453	393	490	662
2003	143,769	29,988	34,869	12,154	3,740	2,476	972	2,388	3,190	997	1,030	165	484
2004	179,264	75,041	13,605	15,819	5,513	1,697	1,123	441	1,084	1,447	452	467	294
2005	314,605	97,410	36,798	6,671	7,757	2,704	832	551	216	531	710	222	373
2006	221,319	174,099	49,482	18,693	3,389	3,940	1,373	423	280	110	270	360	302
2007	160,740	122,768	88,847	25,252	9,539	1,729	2,011	701	216	143	56	138	338
2008	125,712	90,786	64,874	46,949	13,344	5,041	914	1,063	370	114	75	30	252
2009	54,106	73,216	50,908	36,378	26,327	7,483	2,827	512	596	208	64	42	158
2010	158,783	31,850	41,912	29,143	20,825	15,071	4,283	1,618	293	341	119	37	114
2011	263,888	92,674	17,934	23,600	16,409	11,726	8,486	2,412	911	165	192	67	85
2012	225,612	154,399	52,431	10,146	13,352	9,284	6,634	4,801	1,365	515	93	109	86
2013	499,332	124,449	77,944	26,468	5,122	6,740	4,687	3,349	2,424	689	260	47	98
2014	387,989	276,234	63,177	39,568	13,437	2,600	3,422	2,379	1,700	1,230	350	132	74
2015	300,935	224,311	152,709	34,926	21,874	7,428	1,437	1,892	1,315	940	680	193	114
2016	327,350	166,547	113,962	77,584	17,744	11,113	3,774	730	961	668	477	346	156

Table 8. Pacific mackerel population biomass-at-age (mt) for model H3. SSB is total (female and male) spawning stock biomass

	POPULATION BIOMASS-AT-AGE (mt)													SUMMARY BIOMASS		
Model Year	0	1	2	3	4	5	6	7	8	9	10	11	12	Age 0+	Age 1+	SSB
VIRG	6	51,568	60,411	53,797	41,398	29,246	19,598	12,698	8,048	5,028	3,111	1,912	2,991	289,811	289,805	156,849
INIT	8	67,331	78,877	70,242	54,052	38,185	25,588	16,579	10,508	6,565	4,062	2,497	3,905	378,398	378,390	204,793
1983	3	27,027	789,957	64,032	264,228	27,589	15,207	16,579	10,508	6,565	4,062	2,497	3,905	1,232,158	1,232,155	509,274
1984	5	23,611	30,571	679,246	47,576	180,236	17,851	9,513	10,146	6,339	3,922	2,411	3,771	1,015,198	1,015,193	597,460
1985	12	40,851	26,300	25,886	496,985	31,957	114,839	10,997	5,733	6,027	3,729	2,292	3,585	769,193	769,181	563,560
1986	13	101,302	44,801	21,926	18,648	328,681	20,048	69,654	6,525	3,353	3,491	2,146	3,357	623,942	623,930	479,463
1987	3	104,473	108,350	36,425	15,404	12,028	201,092	11,859	40,309	3,722	1,894	1,959	3,065	540,583	540,580	338,693
1988	30	21,629	110,828	87,373	25,382	9,854	7,298	117,982	6,807	22,803	2,085	1,054	2,775	415,901	415,871	259,474
1989	5	243,644	22,759	88,649	60,392	16,106	5,931	4,247	67,169	3,819	12,672	1,151	2,095	528,642	528,637	221,688
1990	7	42,271	260,390	18,490	62,234	38,922	9,846	3,506	2,456	38,281	2,156	7,107	1,806	487,471	487,464	226,256
1991	8	55,311	42,248	197,829	12,139	37,508	22,251	5,443	1,896	1,309	20,207	1,131	4,666	401,944	401,936	210,684
1992	3	64,258	54,332	31,546	127,646	7,190	21,075	12,088	2,893	993	679	10,415	2,956	336,077	336,074	184,380
1993	12	28,093	67,740	43,539	21,845	81,147	4,336	12,288	6,895	1,626	553	376	7,382	275,830	275,819	169,913
1994	6	98,856	30,573	56,040	31,125	14,336	50,516	2,610	7,235	4,001	935	316	4,374	300,923	300,917	147,946
1995	12	53,583	106,879	25,127	39,798	20,293	8,866	30,206	1,527	4,171	2,285	530	2,628	295,906	295,894	141,839
1996	5	100,073	60,411	91,599	18,608	27,058	13,087	5,528	18,425	918	2,484	1,352	1,848	341,396	341,391	149,443
1997	1	42,223	108,927	49,985	65,492	12,214	16,847	7,878	3,256	10,695	528	1,419	1,814	321,280	321,279	156,141
1998	1	8,626	40,931	80,267	31,829	38,285	6,773	9,032	4,132	1,683	5,476	268	1,633	228,936	228,935	139,079
1999	1	9,349	7,091	25,577	43,341	15,778	18,002	3,079	4,017	1,811	731	2,362	811	131,951	131,950	92,679
2000	1	7,407	9,470	5,460	17,017	26,474	9,142	10,085	1,688	2,170	969	388	1,682	91,954	91,952	70,473
2001	2	9,899	5,884	5,718	2,849	8,152	12,030	4,016	4,334	715	910	404	854	55,767	55,766	38,347
2002	1	13,140	8,846	3,997	3,357	1,535	4,167	5,946	1,942	2,066	337	427	585	46,346	46,345	24,465
2003	2	4,744	10,654	5,452	2,129	1,641	712	1,869	2,608	840	884	144	427	32,105	32,103	16,237
2004	2	11,871	4,157	7,096	3,138	1,125	823	345	886	1,219	389	407	260	31,716	31,714	12,948
2005	3	15,409	11,243	2,993	4,415	1,792	609	431	177	447	610	193	330	38,653	38,649	13,108
2006	2	27,541	15,119	8,385	1,929	2,612	1,006	331	229	93	232	314	267	58,058	58,056	16,139
2007	2	19,421	27,146	11,328	5,429	1,146	1,473	548	176	120	48	120	299	67,256	67,254	21,364
2008	1	14,361	19,821	21,061	7,594	3,342	669	831	303	96	65	26	222	68,394	68,392	26,957
2009	1	11,582	15,554	16,319	14,984	4,960	2,070	401	487	175	55	37	139	66,764	66,763	31,632
2010	2	5,038	12,806	13,073	11,852	9,990	3,137	1,266	240	287	102	32	101	57,927	57,925	33,506
2011	3	14,660	5,479	10,587	9,339	7,773	6,215	1,887	745	139	165	58	75	57,125	57,122	31,247
2012	2	24,424	16,020	4,552	7,599	6,154	4,859	3,756	1,116	434	80	95	76	69,166	69,164	29,970
2013	6	19,687	23,815	11,873	2,915	4,468	3,432	2,620	1,981	580	224	41	87	71,728	71,723	28,474
2014	4	43,697	19,303	17,750	7,647	1,724	2,506	1,861	1,390	1,036	300	115	65	97,400	97,395	30,807
2015	3	35,484	46,658	15,668	12,449	4,924	1,053	1,480	1,075	791	584	168	101	120,439	120,435	40,777
2016	4	26,346	34,819	34,804	10,099	7,367	2,764	571	786	563	410	301	138	118,971	118,968	47,178

Table 9. Convergence tests for model H3, whereby randomized parameter phase orders and 20% jittering were applied over a wide range of virgin recruitment values, $\log(R_0)$. Estimated virgin recruitment for model H3 was $(\log)R_0 = 13.195$.

	PHASE ORDER BY PARAMETER COMPONENT				RESULTS	
$\ln(R_0)$	Growth	R_0/R_1	Steepness	Selectivity	Final $\ln(R_0)$	Total -log(L)
12.4	1	3	4	2	13.1946	1077.71
12.5	1	2	4	3	13.1946	1077.71
12.6	2	4	3	1	13.1946	1077.71
12.7	4	2	1	3	13.1946	1077.71
12.8	3	1	4	2	13.1946	1077.71
12.9	3	1	2	4	13.1946	1077.71
13.0	2	4	3	1	13.1946	1077.71
13.1	3	1	2	4	13.1946	1077.71
13.2	4	3	1	2	13.1946	1077.71
13.3	2	3	4	1	13.1946	1077.71
13.4	3	2	1	4	13.1946	1077.71
13.5	1	3	2	4	13.1946	1077.71
13.6	3	4	1	2	13.1946	1077.71
13.7	3	1	4	2	13.1946	1077.71
13.8	3	2	4	1	13.1946	1077.71
13.9	1	4	2	3	13.1946	1077.71
14.0	4	3	1	2	13.1946	1077.71

Table 10. Pacific mackerel harvest control rules for model H3: a) for 2015-16 management year based on estimated stock biomass in July 2015; and b) for 2016-17 management year based on estimated stock biomass in July 2016.

a)

Harvest Control Rule Formulas									
OFL = BIOMASS * E_{MSY} * DISTRIBUTION									
$ABC_{P\text{-}star}$ = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION									
HG = (BIOMASS - CUTOFF) * E_{MSY} * DISTRIBUTION									
Harvest Formula Parameters									
BIOMASS (ages 1+, mt)	120,435								
P-star	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
ABC $Buffer_{Tier\ 1}$	0.9558	0.9128	0.8705	0.8280	0.7844	0.7386	0.6886	0.6304	0.5531
ABC $Buffer_{Tier\ 2}$	0.9135	0.8333	0.7577	0.6855	0.6153	0.5455	0.4741	0.3974	0.3060
E_{MSY}	0.30								
CUTOFF (mt)	18,200								
DISTRIBUTION (U.S.)	0.70								
Harvest Control Rule Values (mt)									
OFL =	25,291								
$ABC_{Tier\ 1}$ =	24,173	23,087	22,016	20,940	19,839	18,681	17,415	15,944	13,990
$ABC_{Tier\ 2}$ =	23,104	21,074	19,164	17,338	15,562	13,798	11,992	10,052	7,738
HG =	21,469								

b)

Harvest Control Rule Formulas									
OFL = BIOMASS * E_{MSY} * DISTRIBUTION									
$ABC_{P\text{-}star}$ = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION									
HG = (BIOMASS - CUTOFF) * E_{MSY} * DISTRIBUTION									
Harvest Formula Parameters									
BIOMASS (ages 1+, mt)	118,968								
P-star	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
ABC $Buffer_{Tier\ 1}$	0.9558	0.9128	0.8705	0.8280	0.7844	0.7386	0.6886	0.6304	0.5531
ABC $Buffer_{Tier\ 2}$	0.9135	0.8333	0.7577	0.6855	0.6153	0.5455	0.4741	0.3974	0.3060
E_{MSY}	0.30								
CUTOFF (mt)	18,200								
DISTRIBUTION (U.S.)	0.70								
Harvest Control Rule Values (mt)									
OFL =	24,983								
$ABC_{Tier\ 1}$ =	23,878	22,805	21,747	20,685	19,597	18,453	17,203	15,750	13,819
$ABC_{Tier\ 2}$ =	22,822	20,817	18,930	17,127	15,372	13,629	11,846	9,929	7,644
HG =	21,161								

Table 11. USA harvest guidelines (mt) and landings (mt) for Pacific mackerel since 2004.

Fishing Year	USA Harvest Guideline	USA Landings
2004	13,268	5,146
2005	17,419	4,909
2006	19,845	8,581
2007	40,000	6,944
2008	40,000	4,270
2009	10,000	3,338
2010	11,000	2,096
2011	30,386	1,950
2012	30,386	5,483
2013	39,268	11,782
2014	29,170	7,163

FIGURES

Figure 1. Map of Pacific mackerel stock distribution, spawning range, and fisheries.

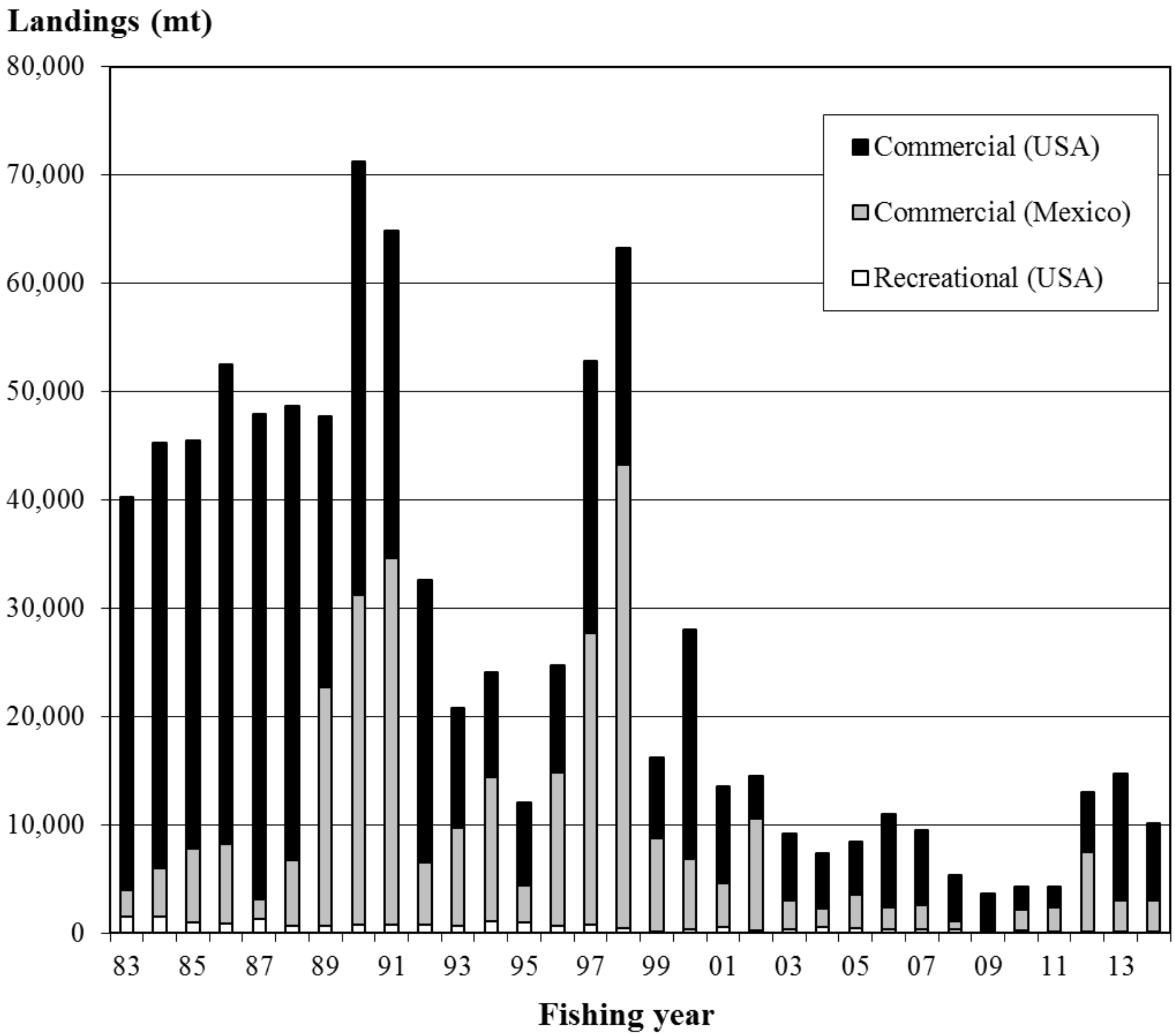


Figure 2. Landings of Pacific mackerel by fishery (1983-14). Model H3 is based on a single, combined (commercial and recreational) fishery (see total estimates in Table 1).

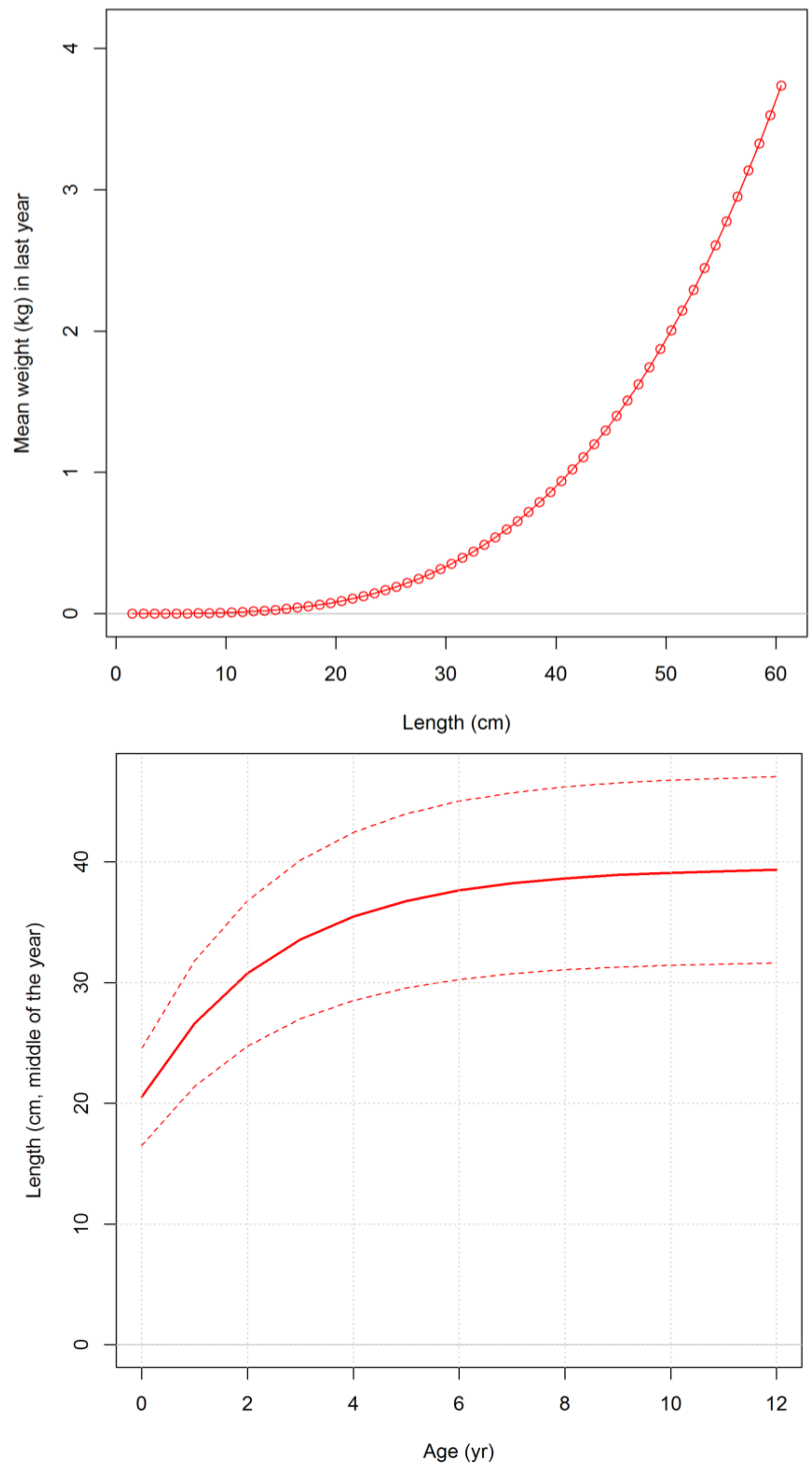


Figure 3a. Pacific mackerel estimated weight-at-length and length-at-age relationships for model H3.

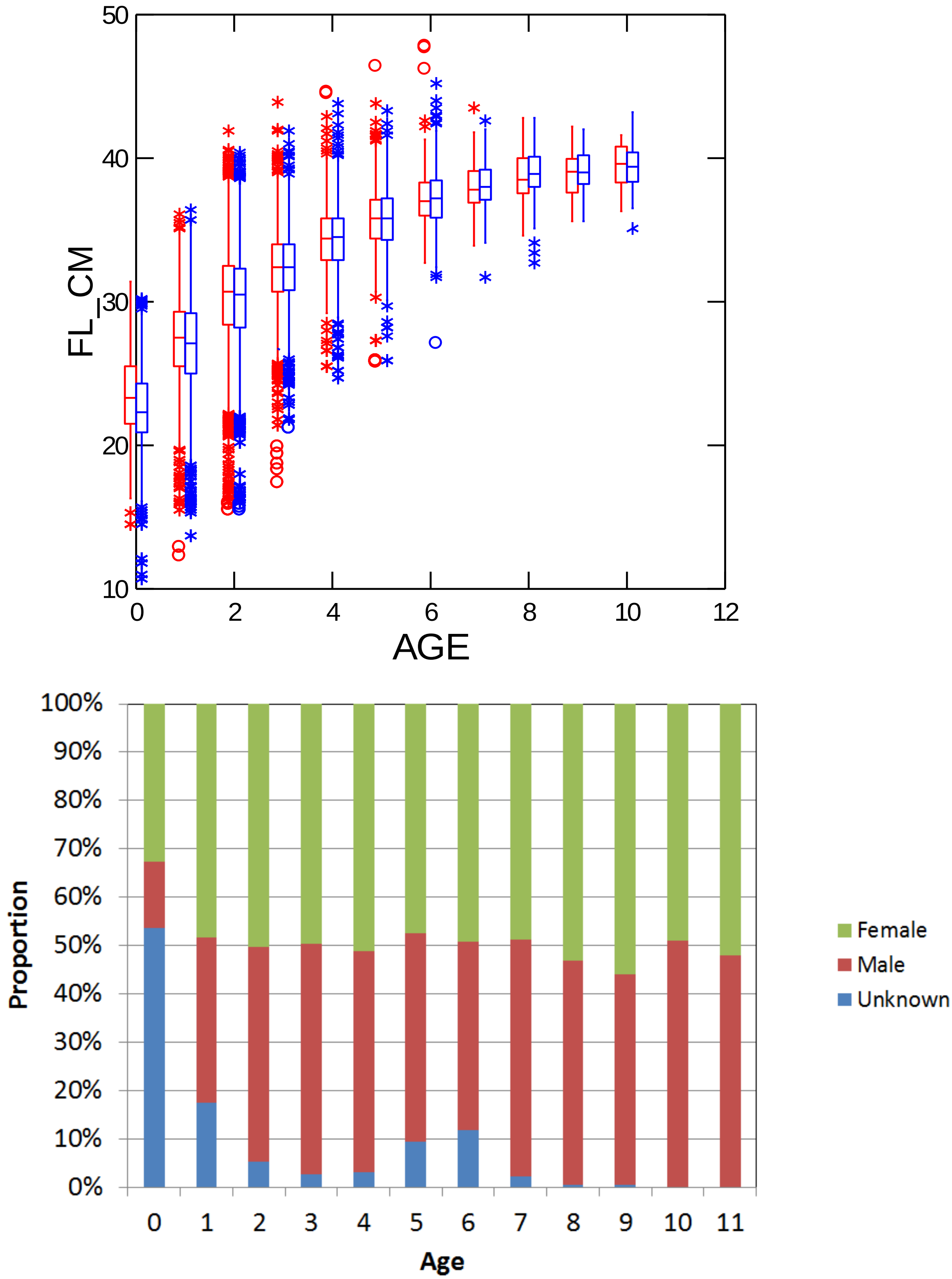


Figure 3b. Pacific mackerel length-at-age by sex (red=male, blue=female) and sex ratios by age for the fishery catches.

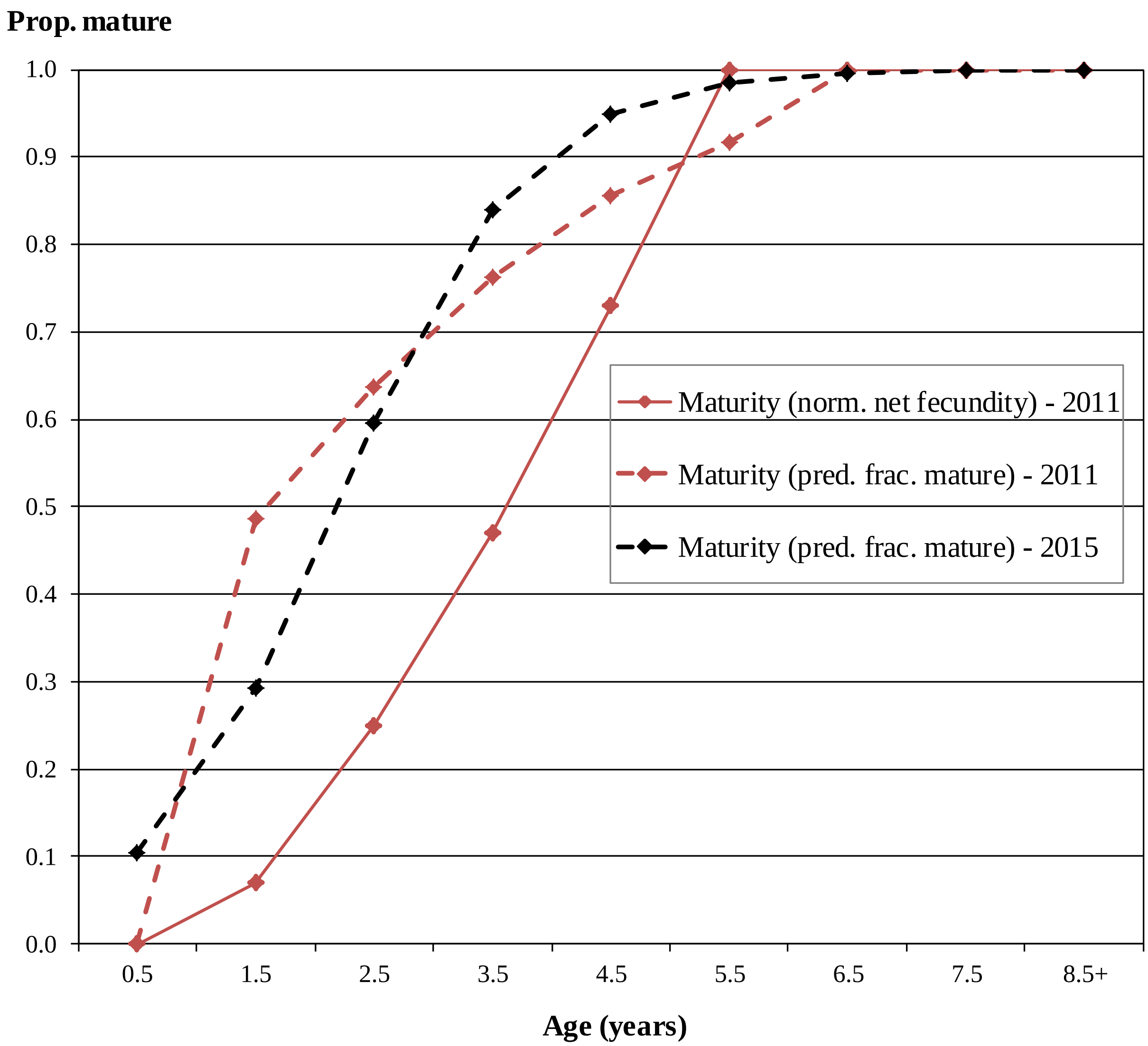


Figure 4. Pacific mackerel maturity schedule (normalized net fecundity curve) used in model H3. See Maturity above.

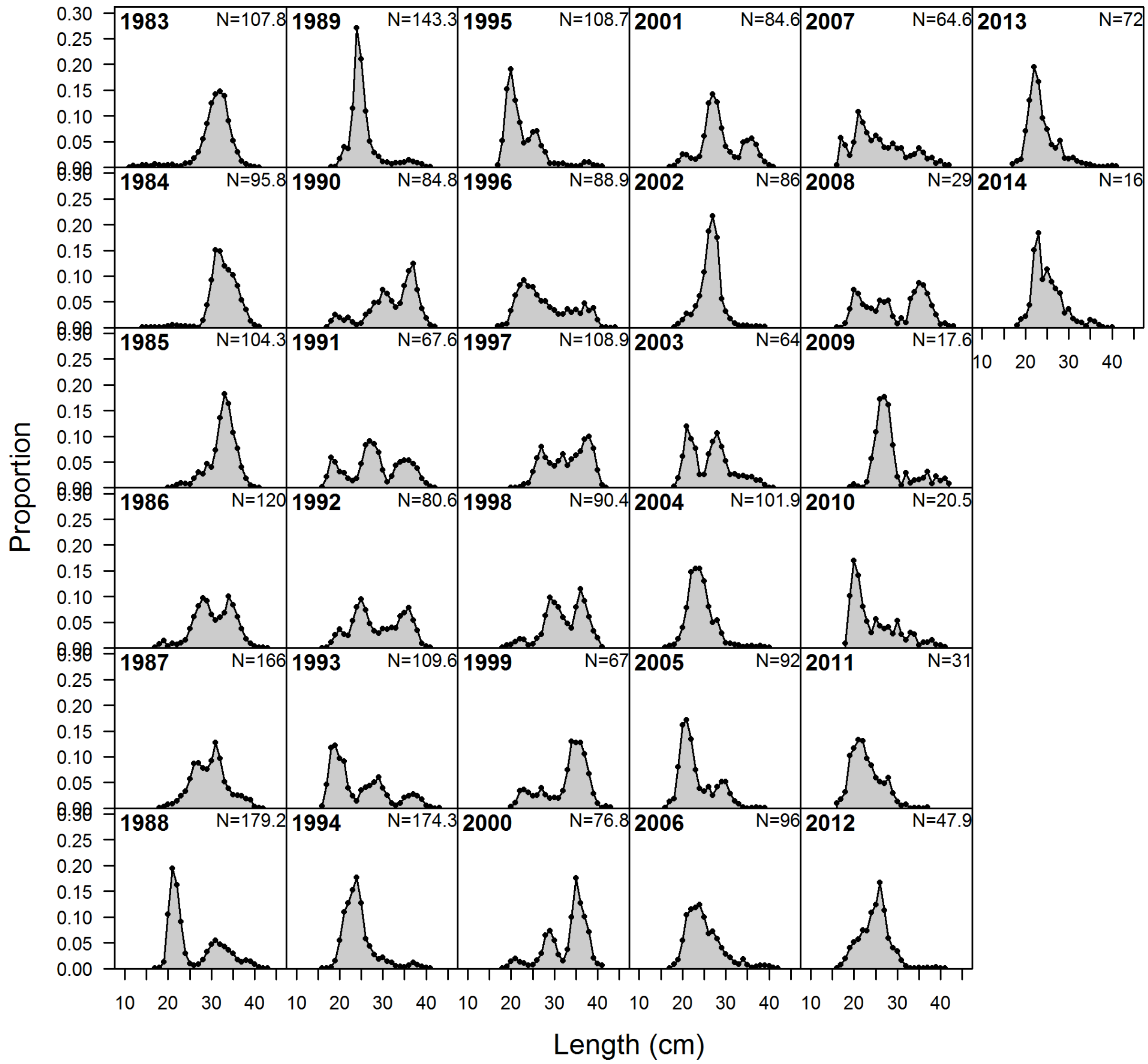


Figure 5. Length-composition time series (1983-14) for Pacific mackerel from the commercial fishery. Note that length data from the commercial fishery were not included in any candidate models.

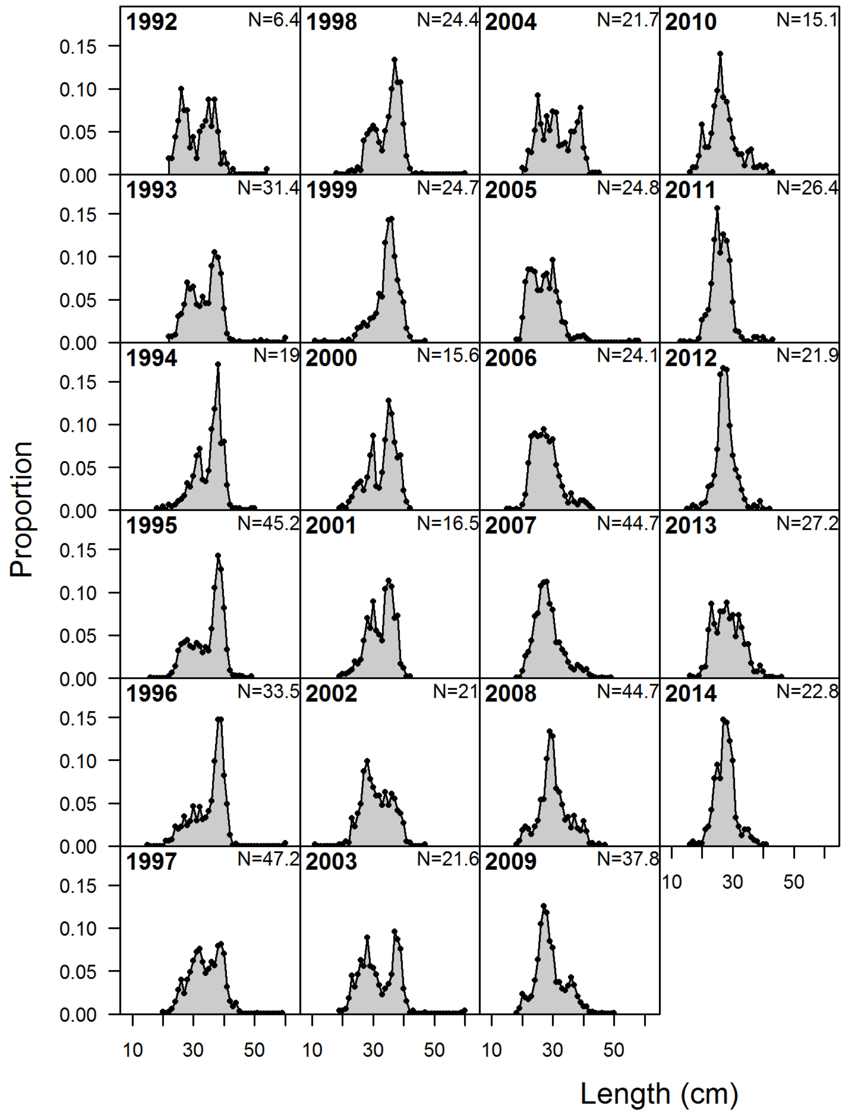


Figure 6. Length-composition time series (1992-14) for Pacific mackerel from the CPFV fleet included in model H3.

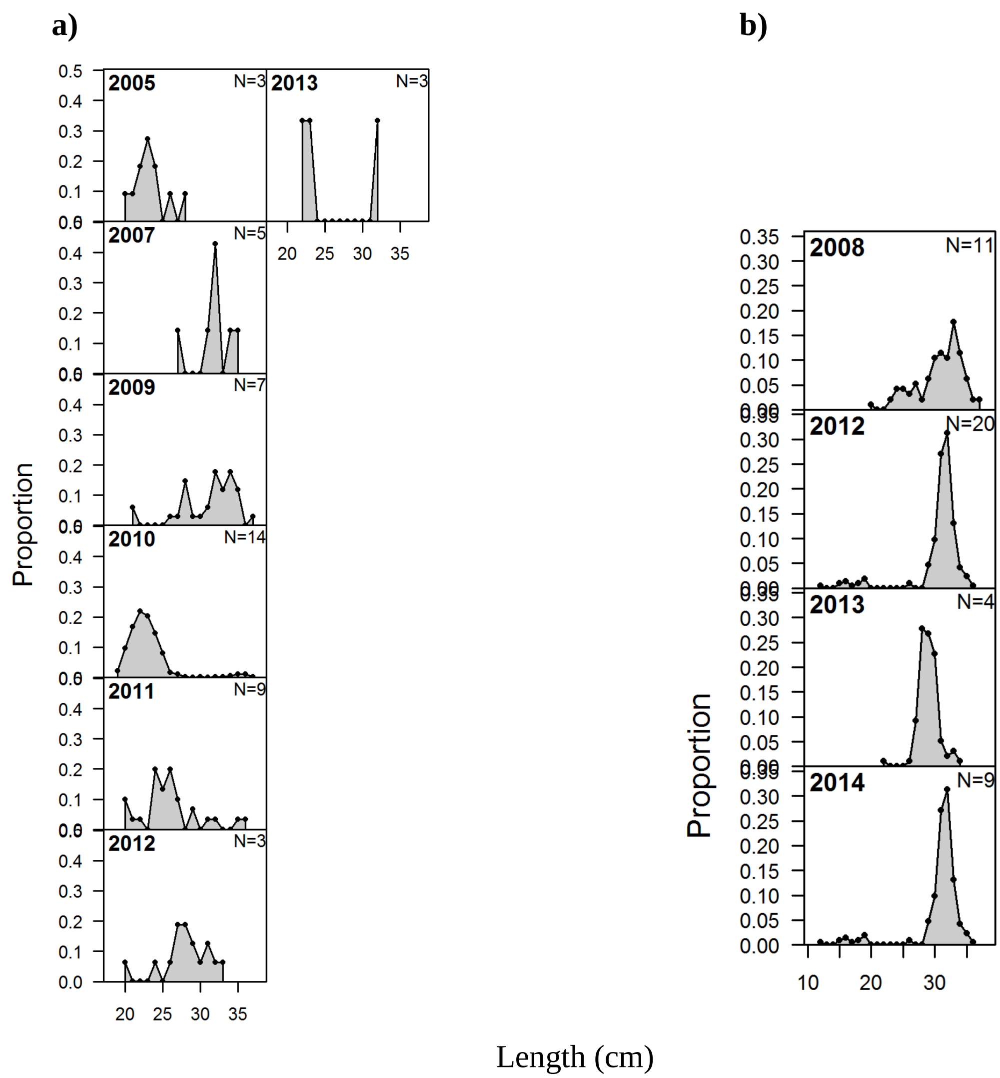


Figure 7. Length-composition time series for Pacific mackerel from the AT survey: a) spring (2005-13); and b) summer (2008-14), e.g., model H1b. Acoustic-trawl data are for background information only, i.e., not included in model H3.

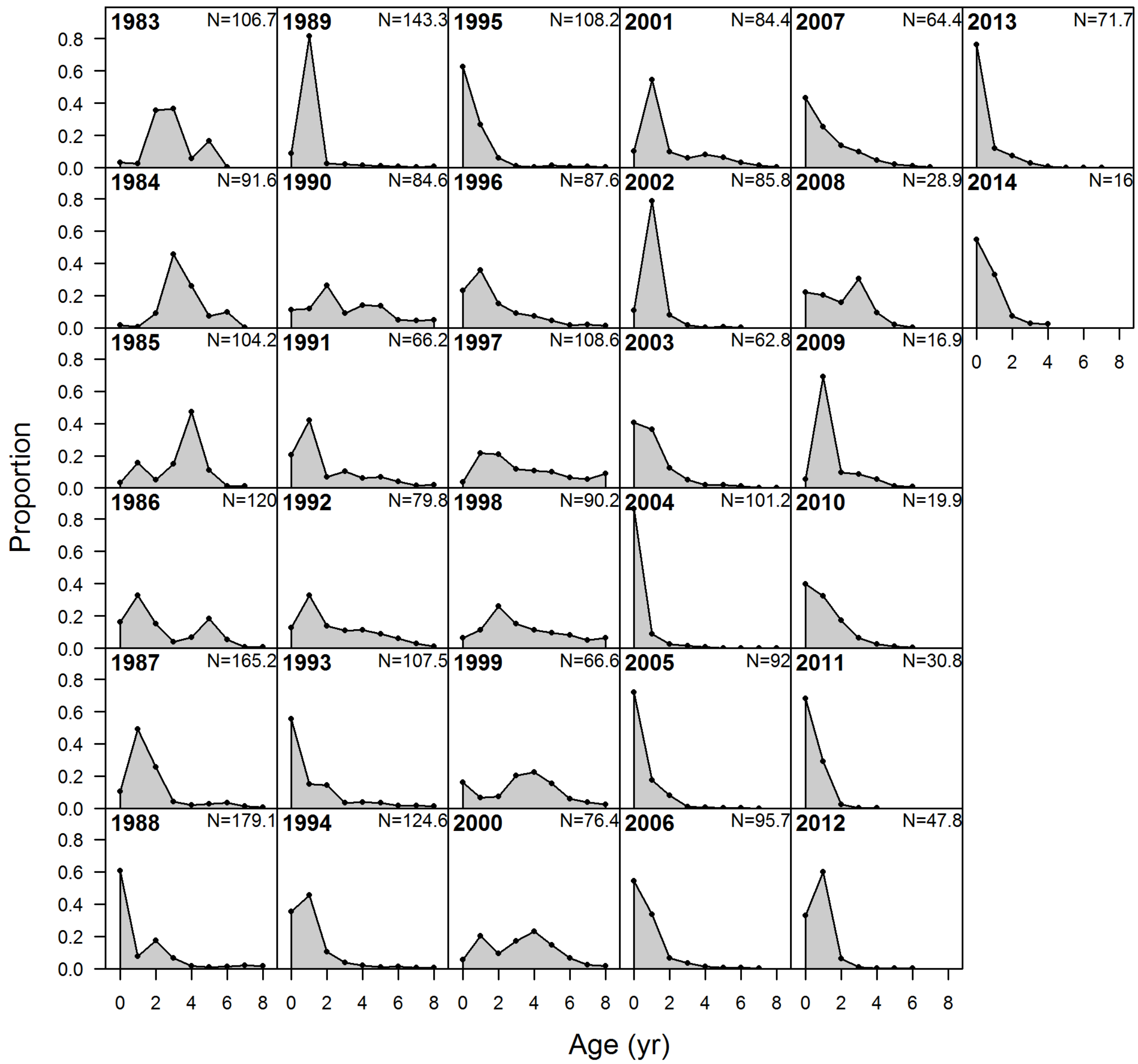


Figure 8. Age-composition time series (1983-14) for Pacific mackerel from the commercial fishery.

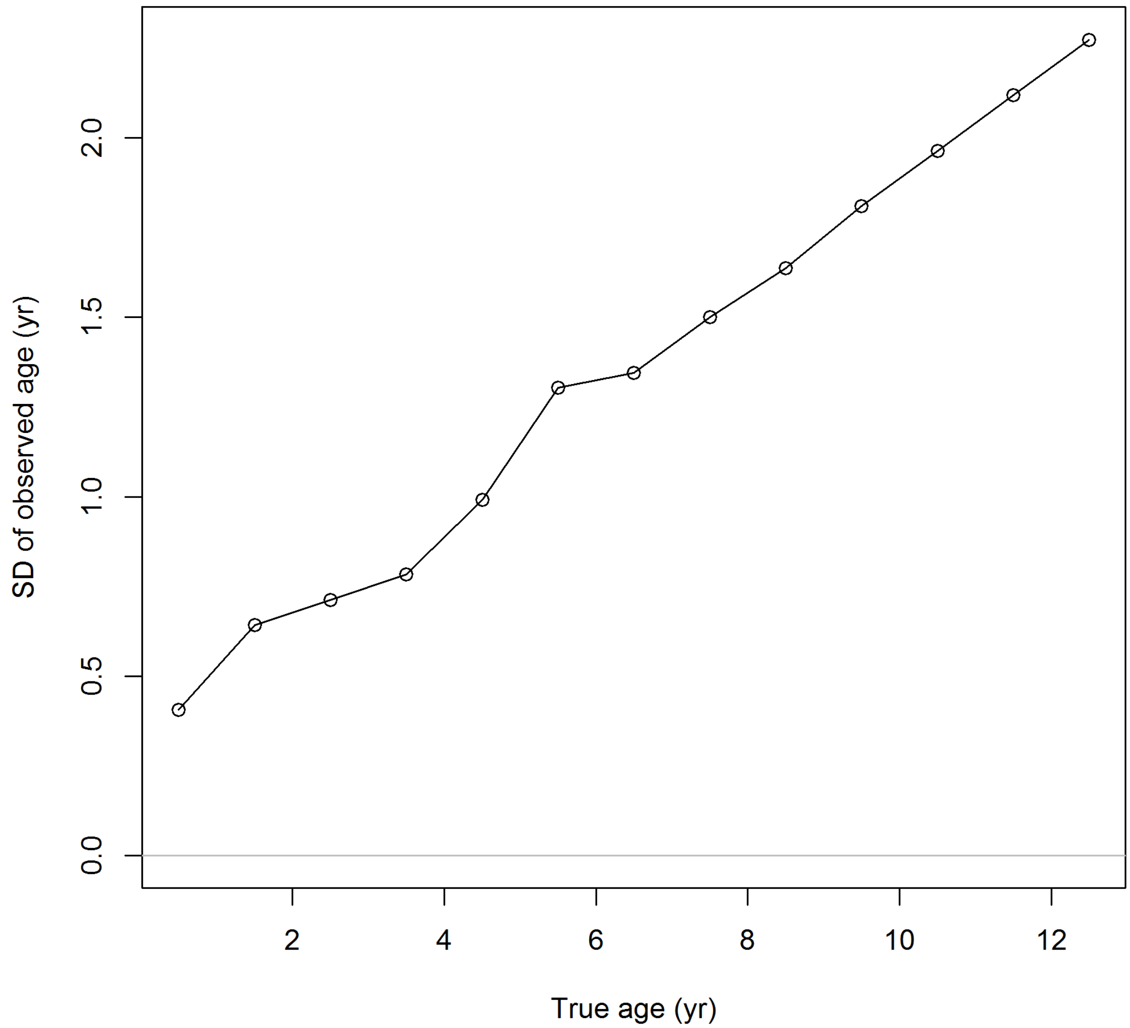


Figure 9. Ageing error vector used with age-composition time series.

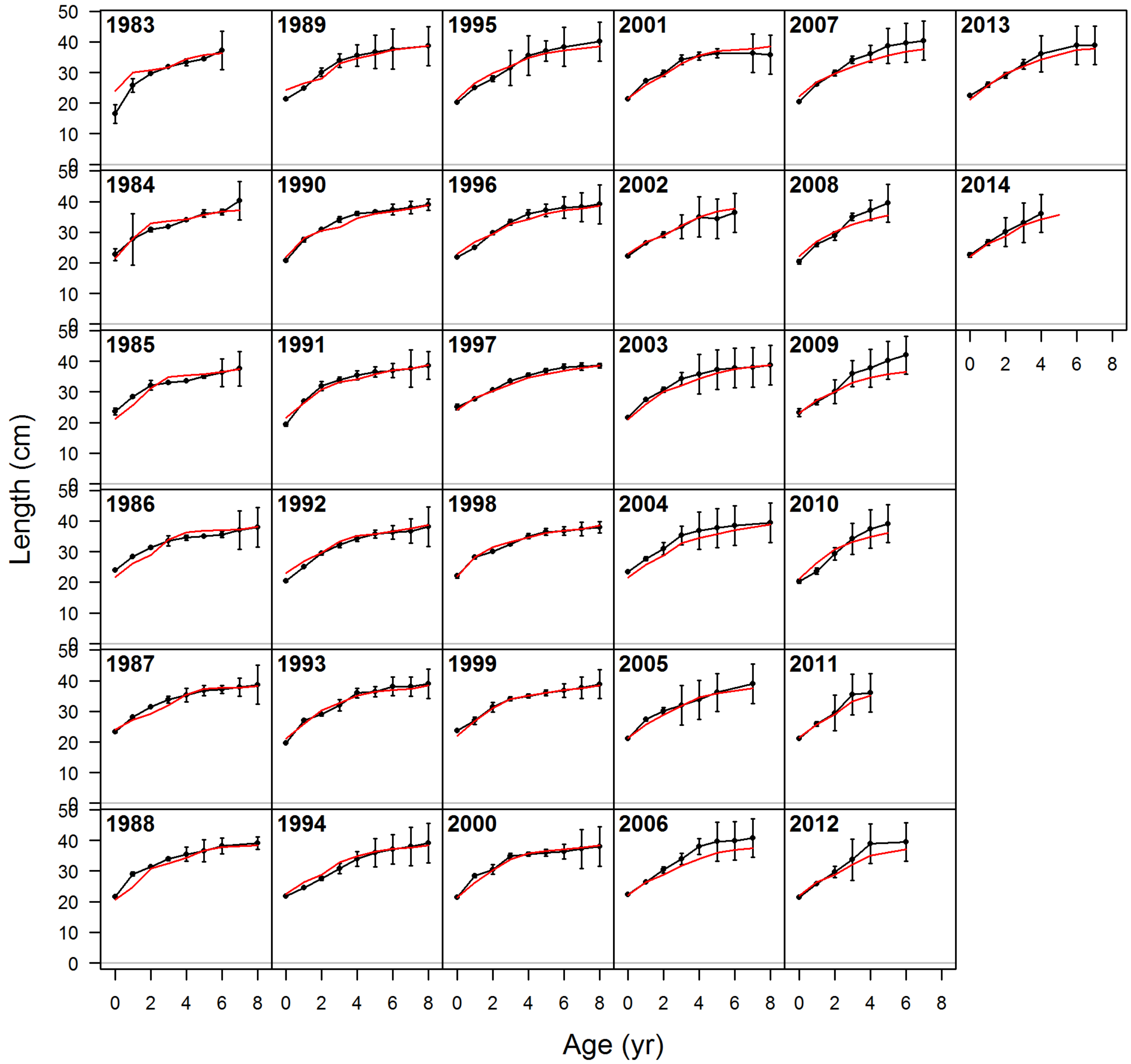


Figure 10. Mean length-at-age composition time series for Pacific mackerel from commercial fishery samples.

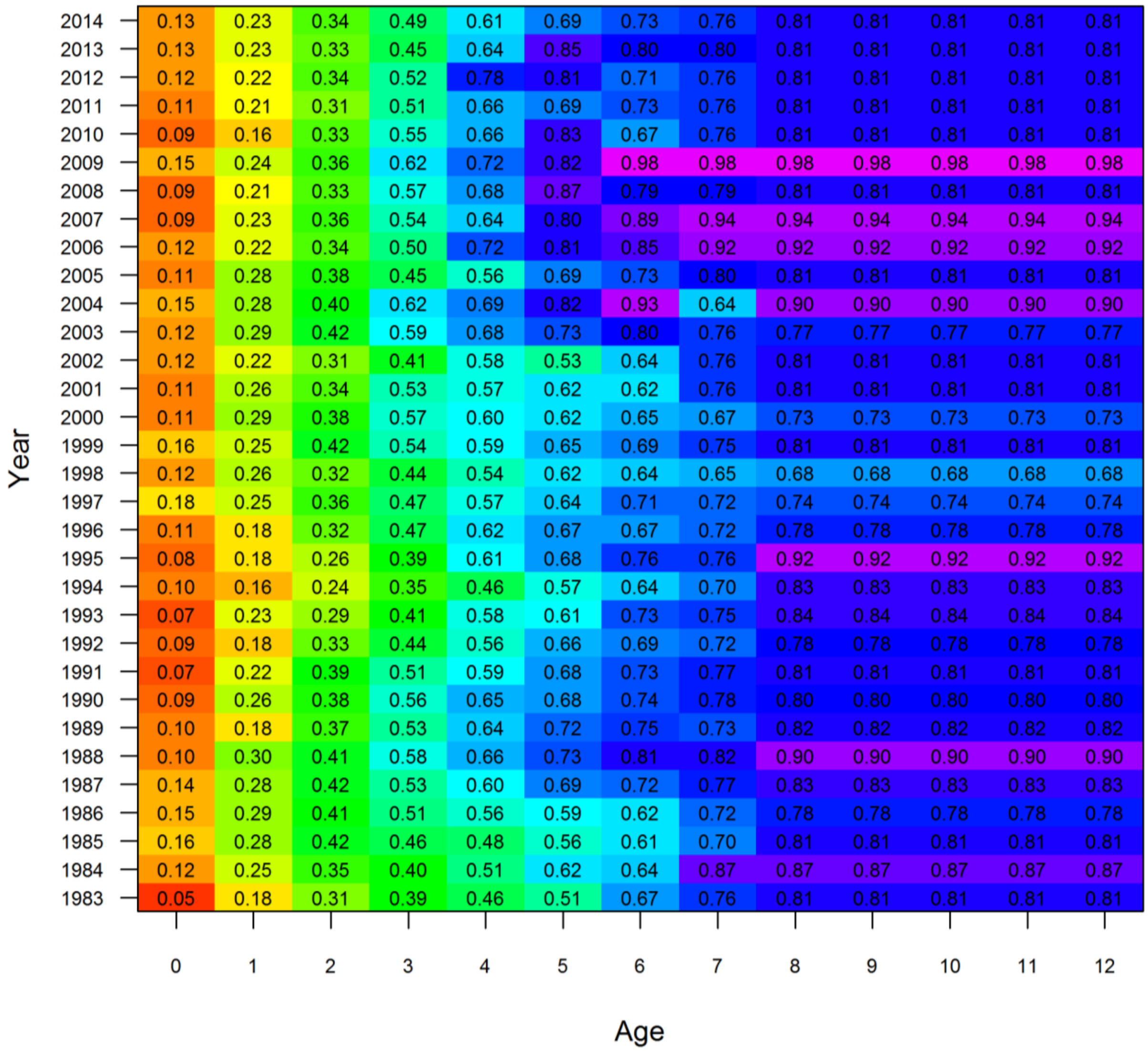


Figure 11. Empirical weight-at-age composition time series for Pacific mackerel from commercial fishery samples.

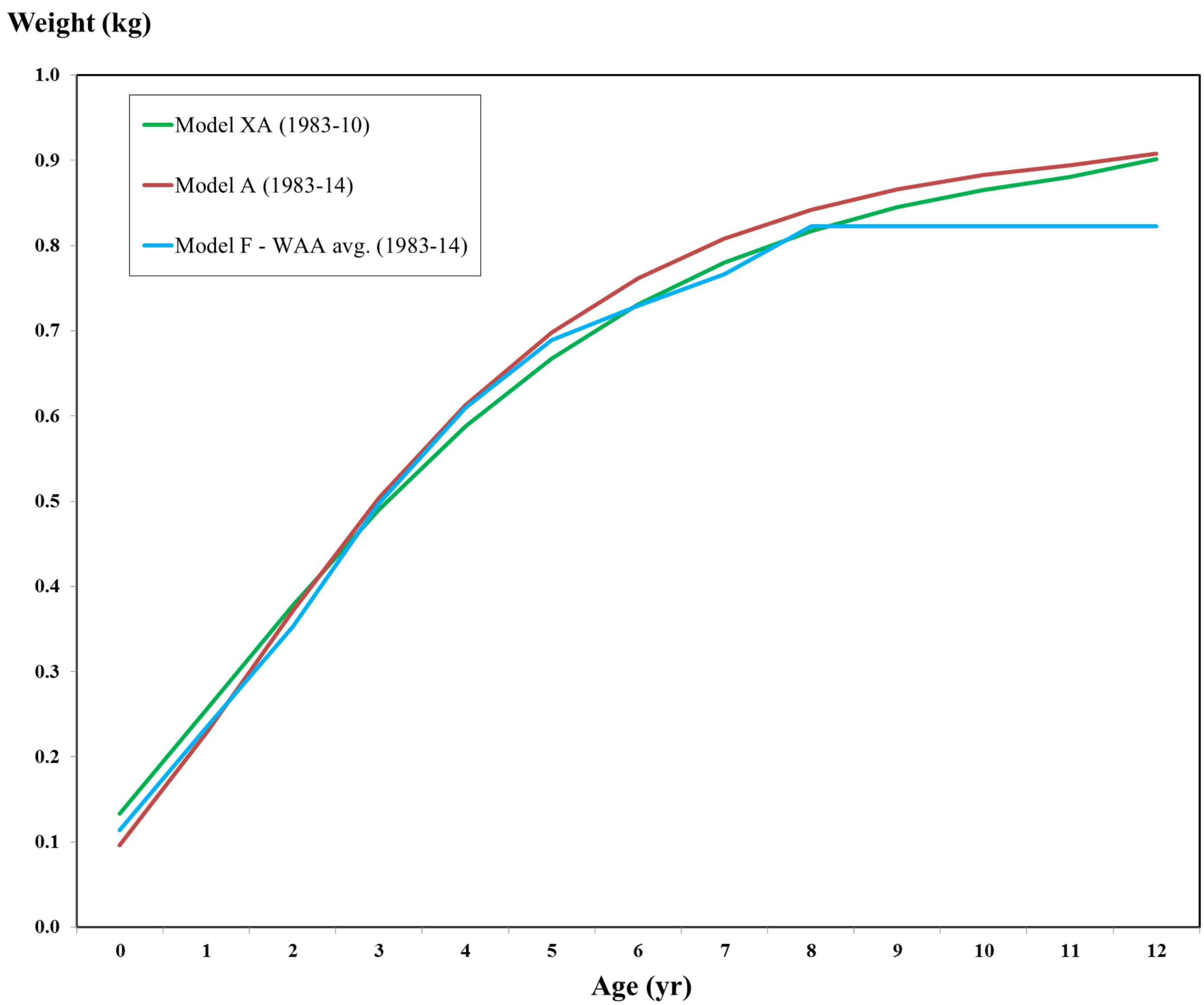


Figure 12. Empirical weight-at-age composition time series for Pacific mackerel compared across respective models. Note that model XA (2011) and model A (2015) were based on internally estimated growth, with time series presented here reflecting derived estimates from the model, i.e., constant weight-at-age across years is assumed in these models. Whereas, the weight-at-age curve for model F reflects an average weight-at-age composition calculated across years that are associated with different (empirically derived) weight-at-age compositions.

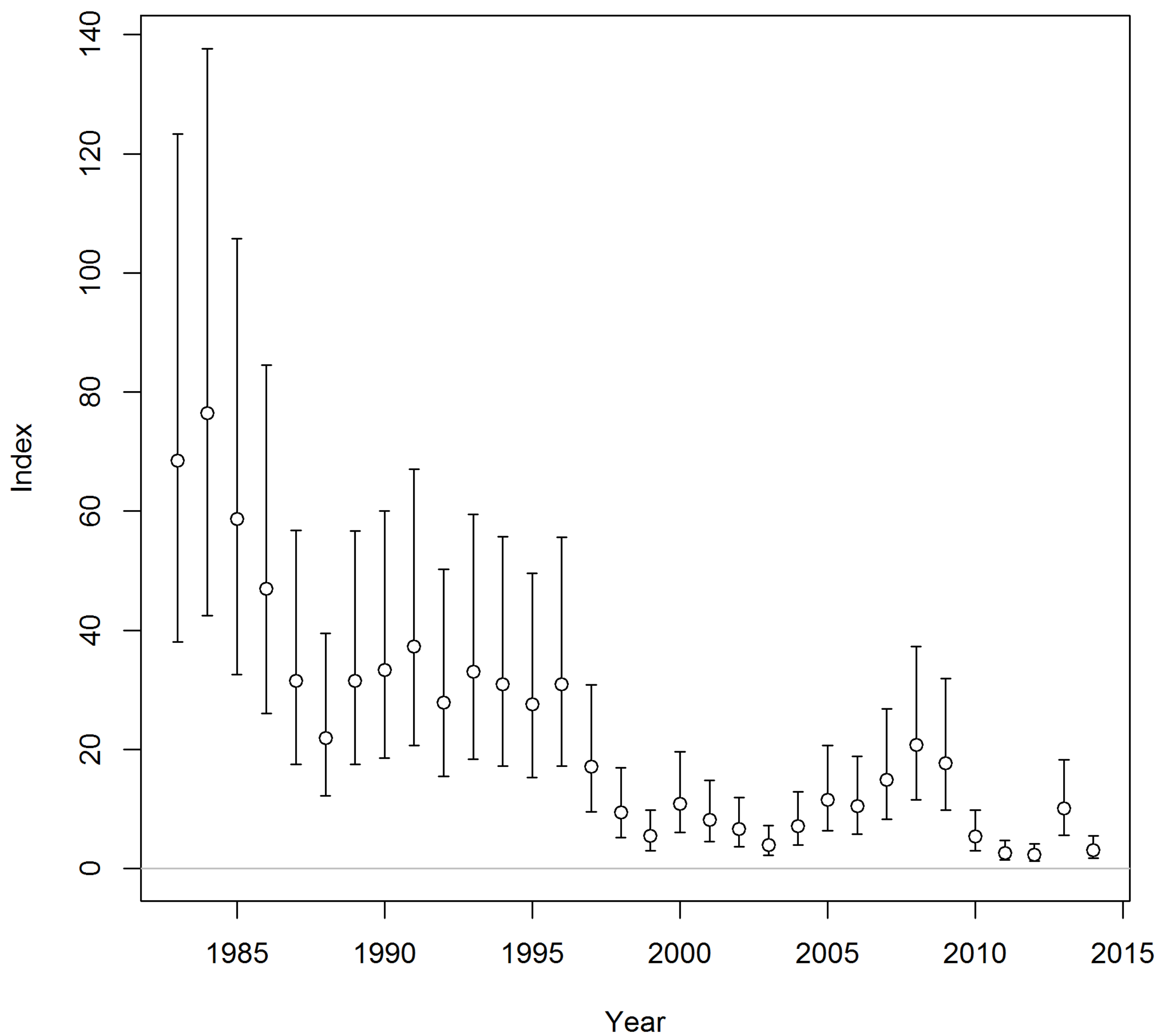


Figure 13. CPFV index of abundance for Pacific mackerel collected from a logbook sampling program conducted by CDFW (1983-14). Index represents standardized estimates catch/effort (CPUE, number of fish kept/1,000 angler hrs) and is based on a delta-GLM estimation method.

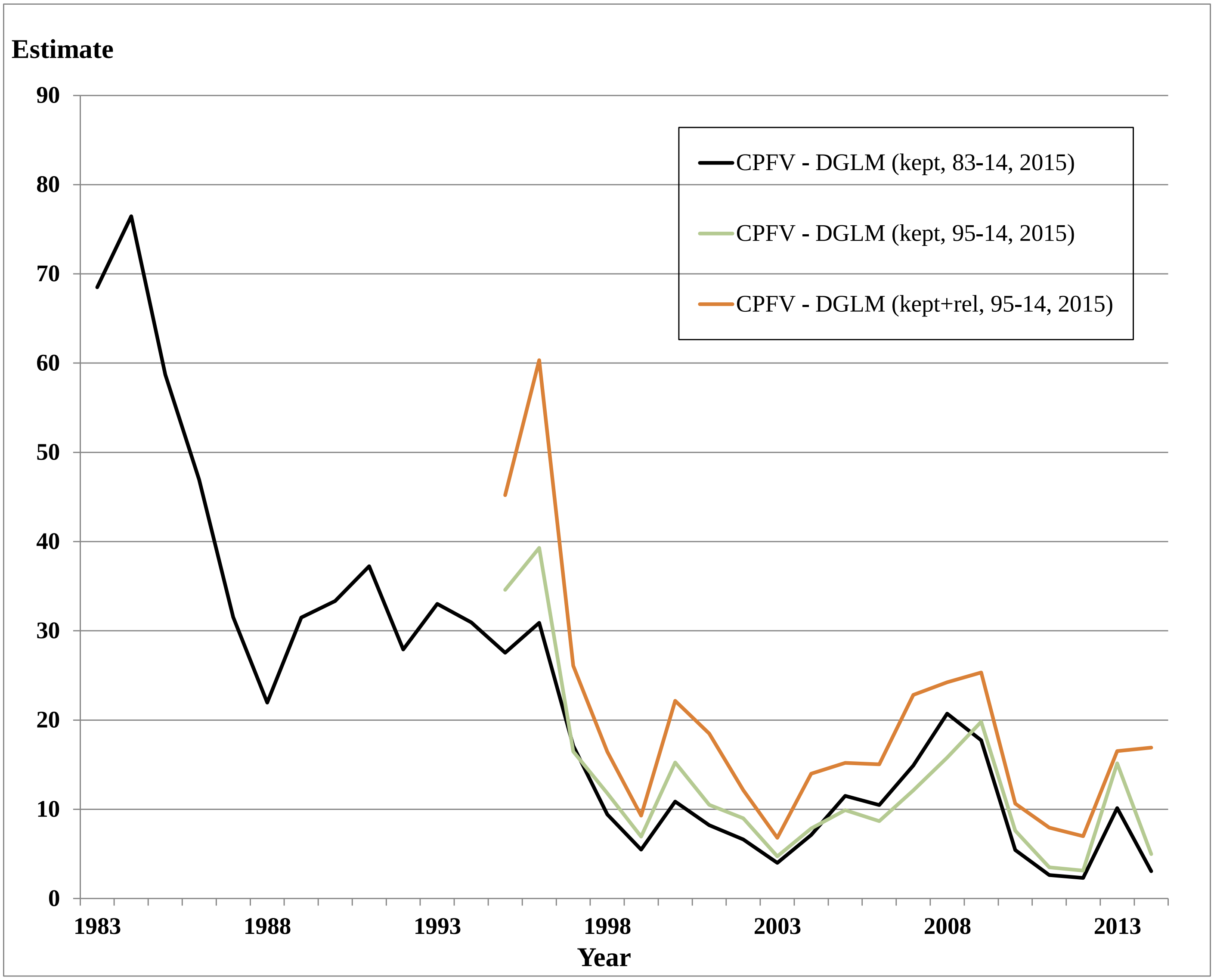
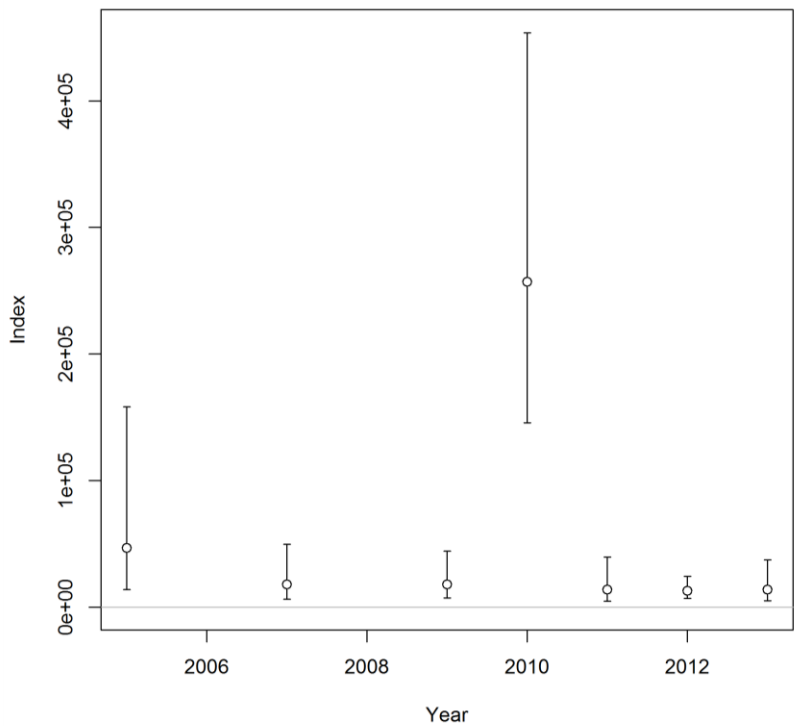


Figure 14. CPFV indices of abundance (number of fish/1,000 angler hrs) for Pacific mackerel collected from a logbook sampling program conducted by CDFW (1983-14). Indices that start in 1995 are based on standardized estimates of for both 'kept fish' (model G) and 'kept and released' fish.

a)



b)

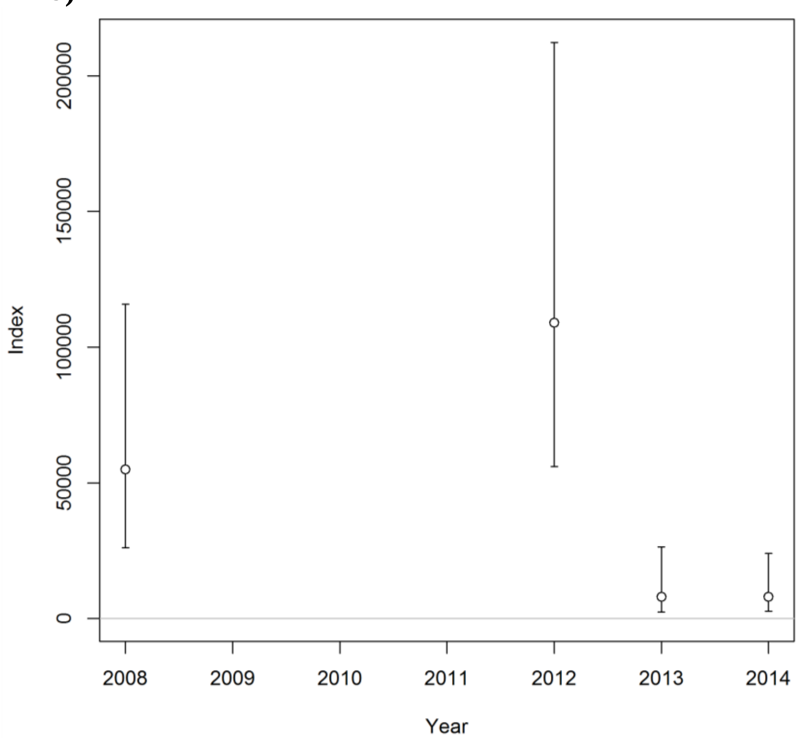


Figure 15. AT survey indices of abundance (mt) for Pacific mackerel: a) spring (2005-13); and b) summer (2008-14), e.g., model H1b. Acoustic-trawl data are for backgroiund information only, i.e., not included in model H3.

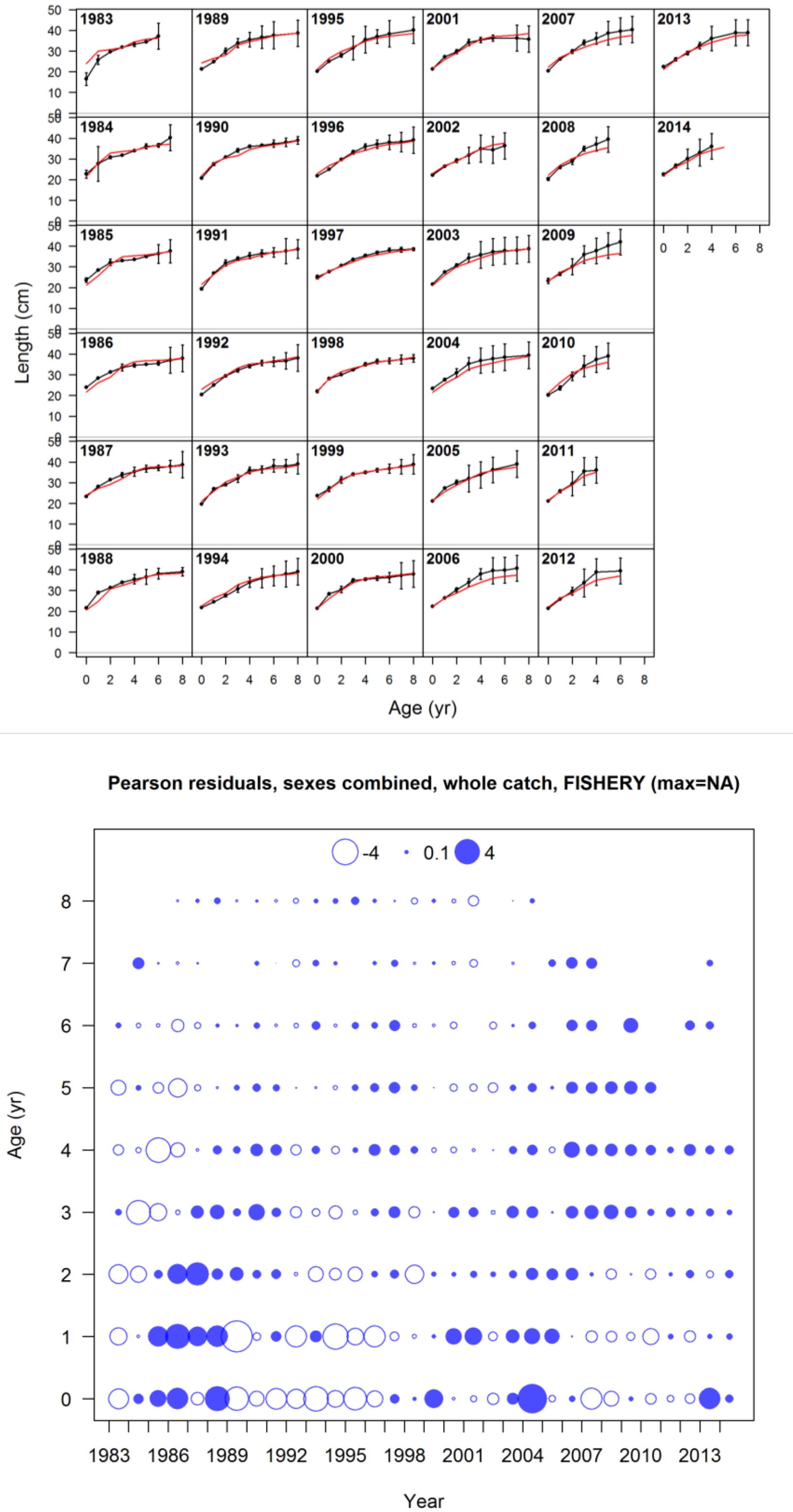


Figure 16. Fits and Pearson residuals associated the commercial fishery mean length-at-age composition for model H3.

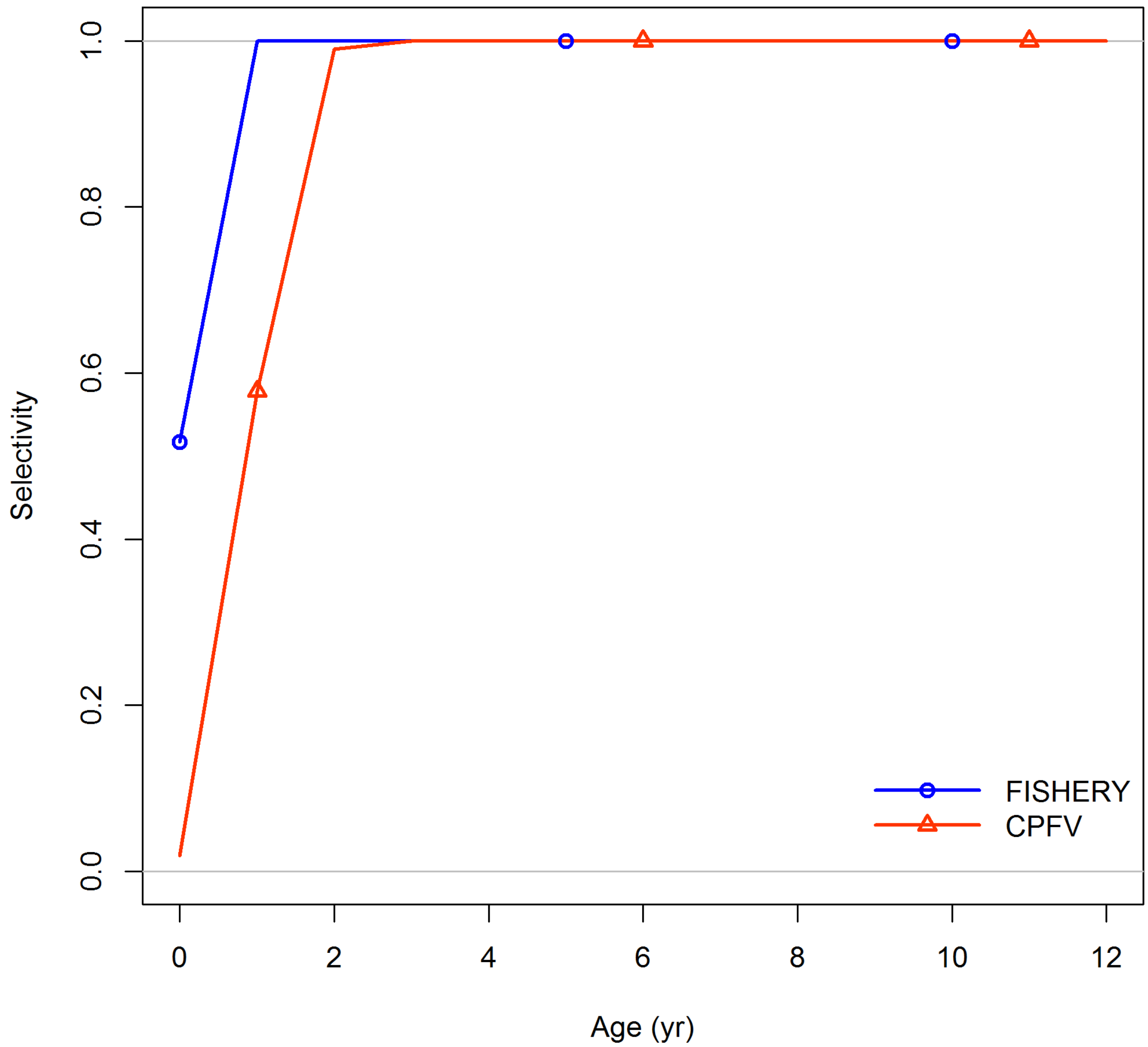


Figure 17. Estimated age-based selectivity curves for the fishery and CPFV index of abundance for model H3.

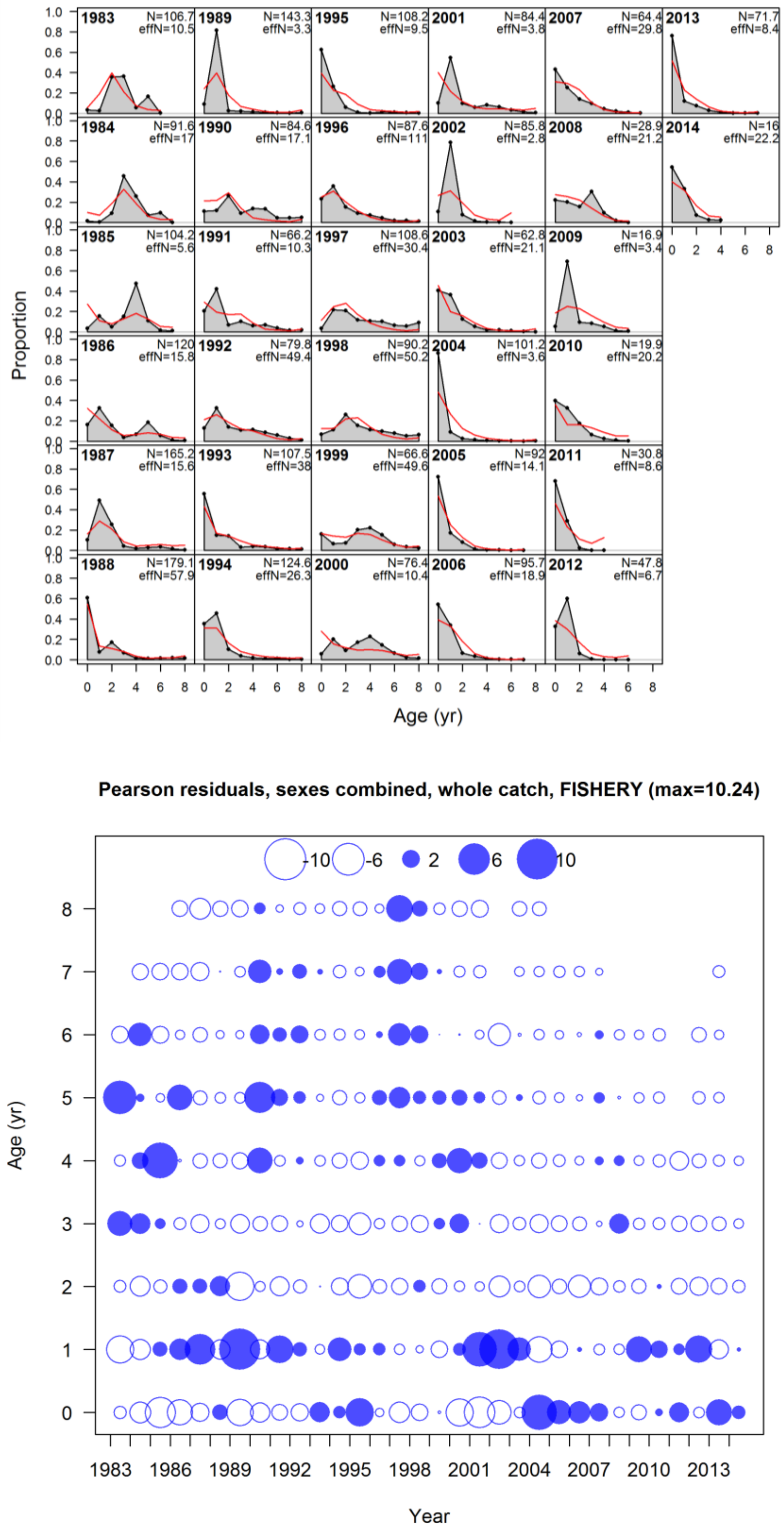
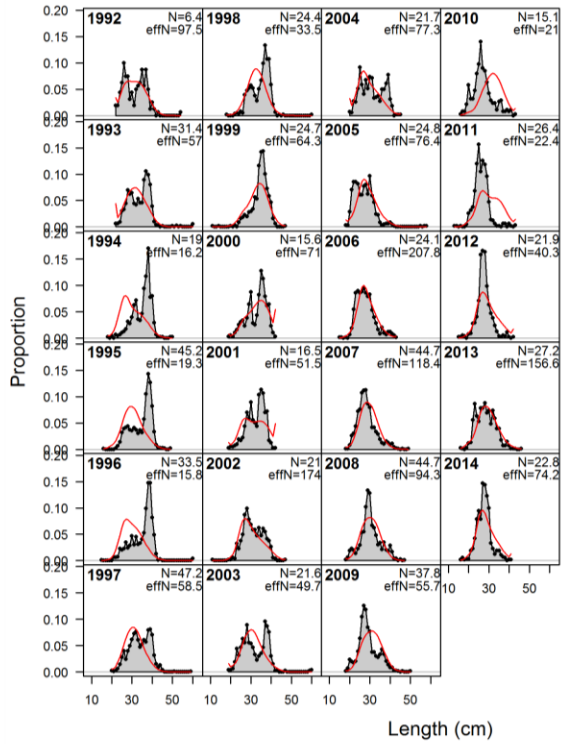


Figure 18. Fits and Pearson residuals associated with fishery age compositions for model H3.



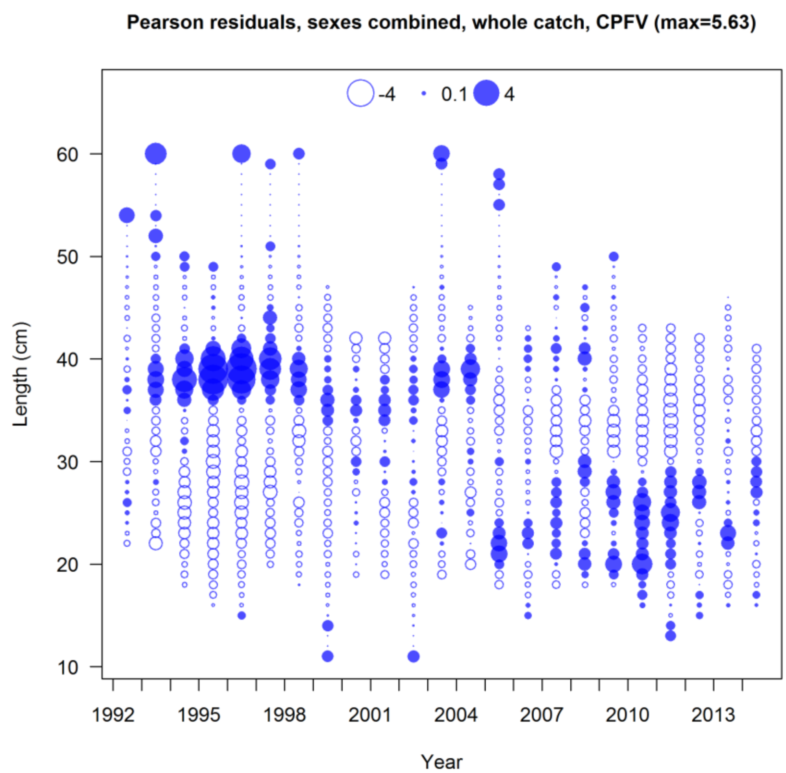


Figure 19. Fits and Pearson residuals associated with CPFV length compositions for model H3.

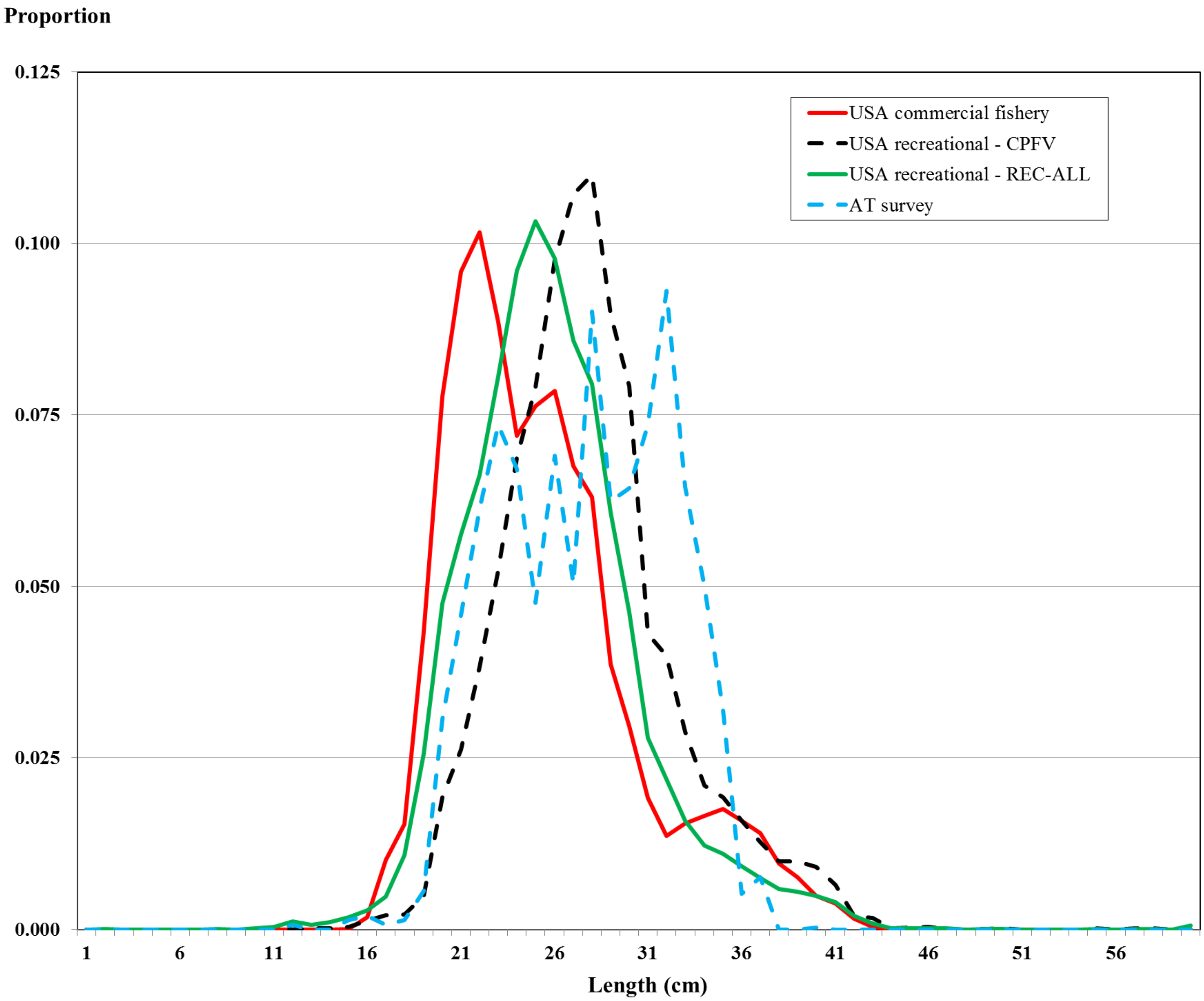


Figure 20. Length-composition time series for Pacific mackerel from the USA commercial fishery, recreational fisheries for CPFV mode and all modes, and AT survey averaged across years from 2005-14.

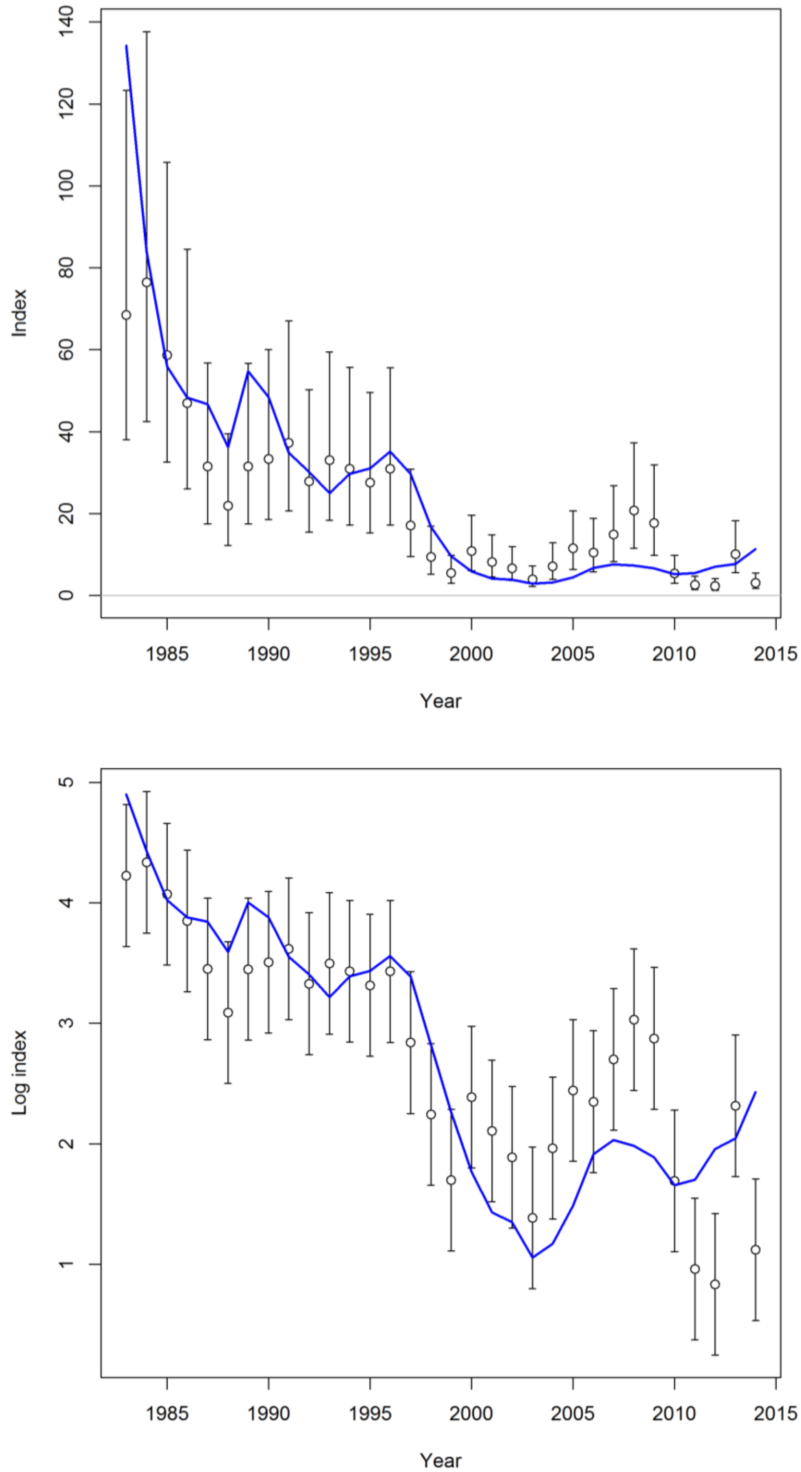


Figure 21. Fits (arithmetic and log scales) to CPFV index of abundance for Pacific mackerel for model H3. Index represents standardized estimates catch/effort (CPUE, number of fish kept/1,000 angler hrs) and is based on a delta-GLM estimation method.

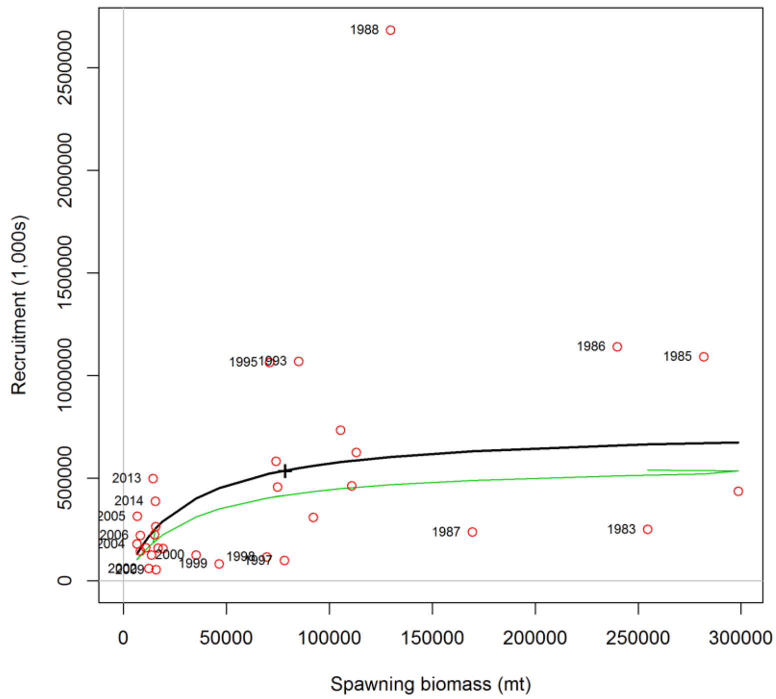


Figure 22. Beverton-Holt stock-recruitment relationship for model H3.

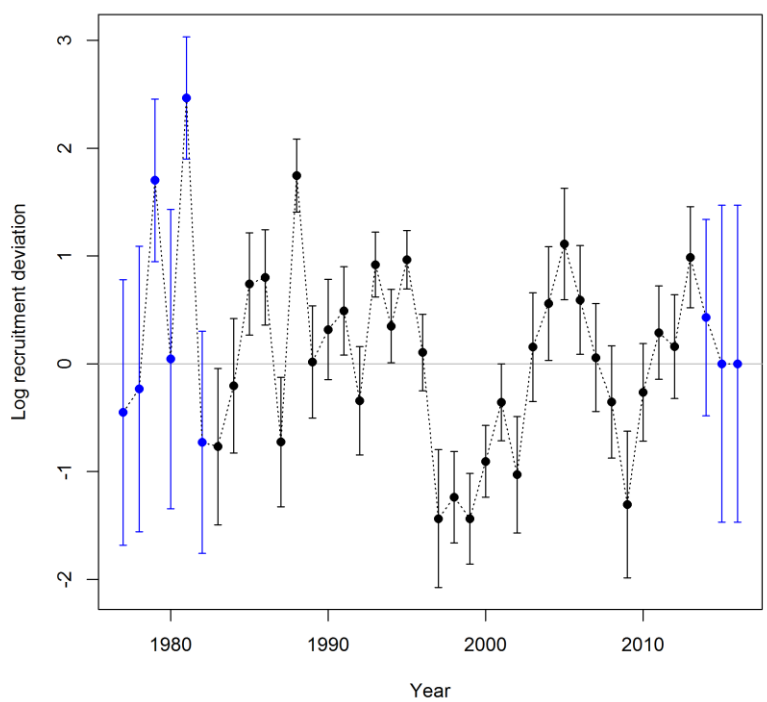


Figure 23. Recruitment deviations and standard errors for model H3.

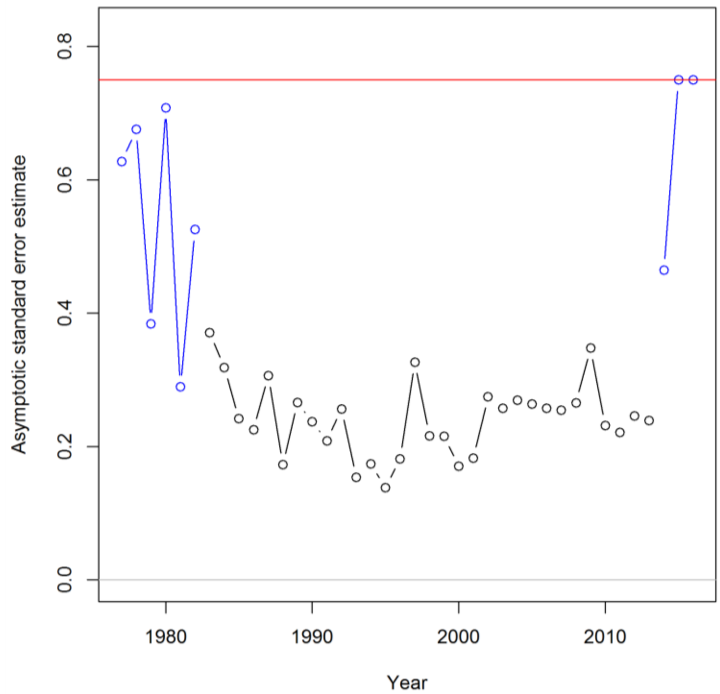


Figure 24. Standard errors (SE) of recruitment deviations relative to σ_R for model H3.

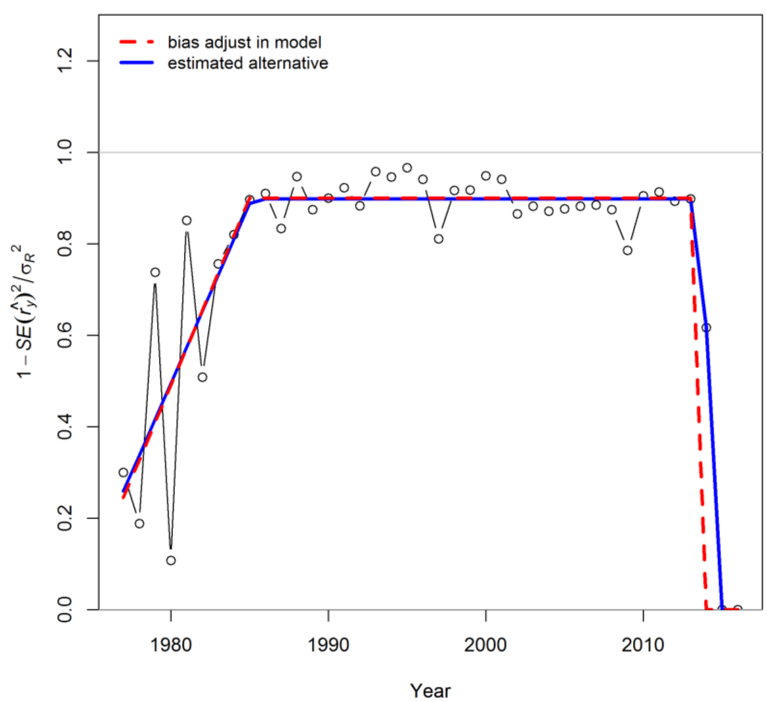


Figure 25. Bias adjustment ramp for model H3.

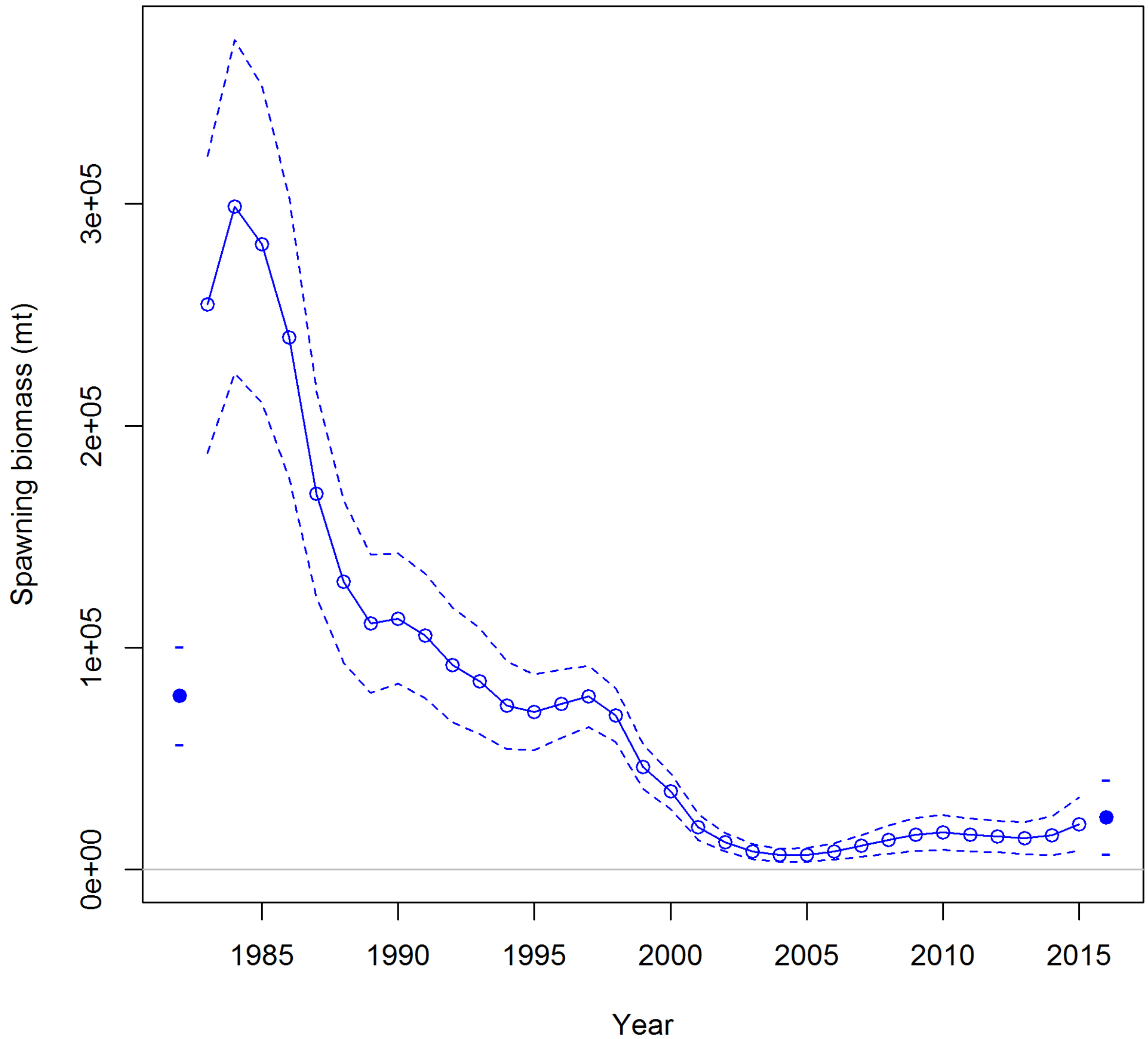


Figure 26. Estimated spawning stock biomass (female, SSB) time series and 95% confidence intervals for Pacific mackerel for model H3. Solid dots reflect estimate of virgin (female) SSB and forecasted (female) SSB (July 2016).

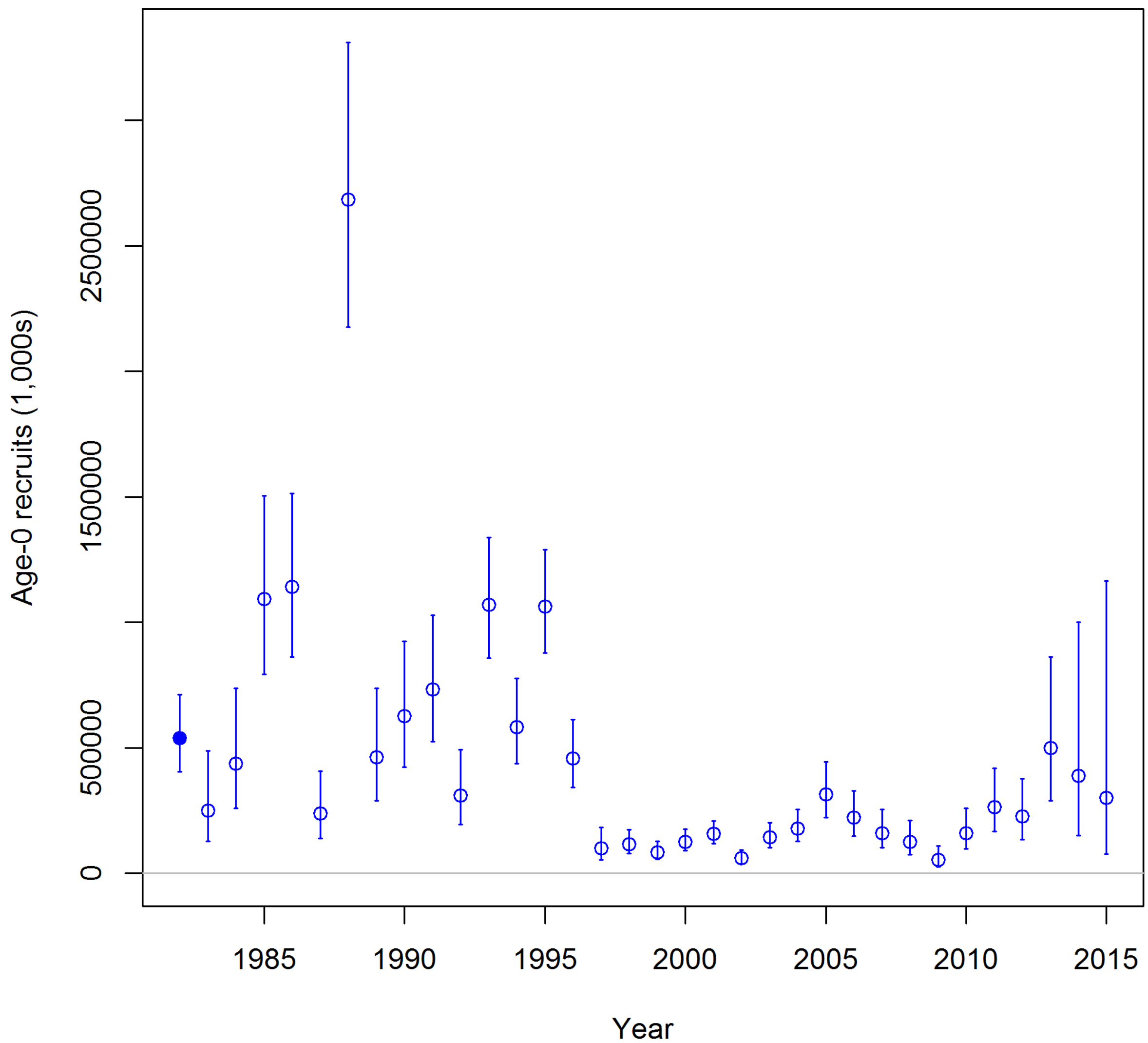


Figure 27. Estimated recruitment (1,000s of age-0 fish) time series and 95% confidence intervals for Pacific mackerel for model H3. Solid dot reflects estimate of virgin recruitment.

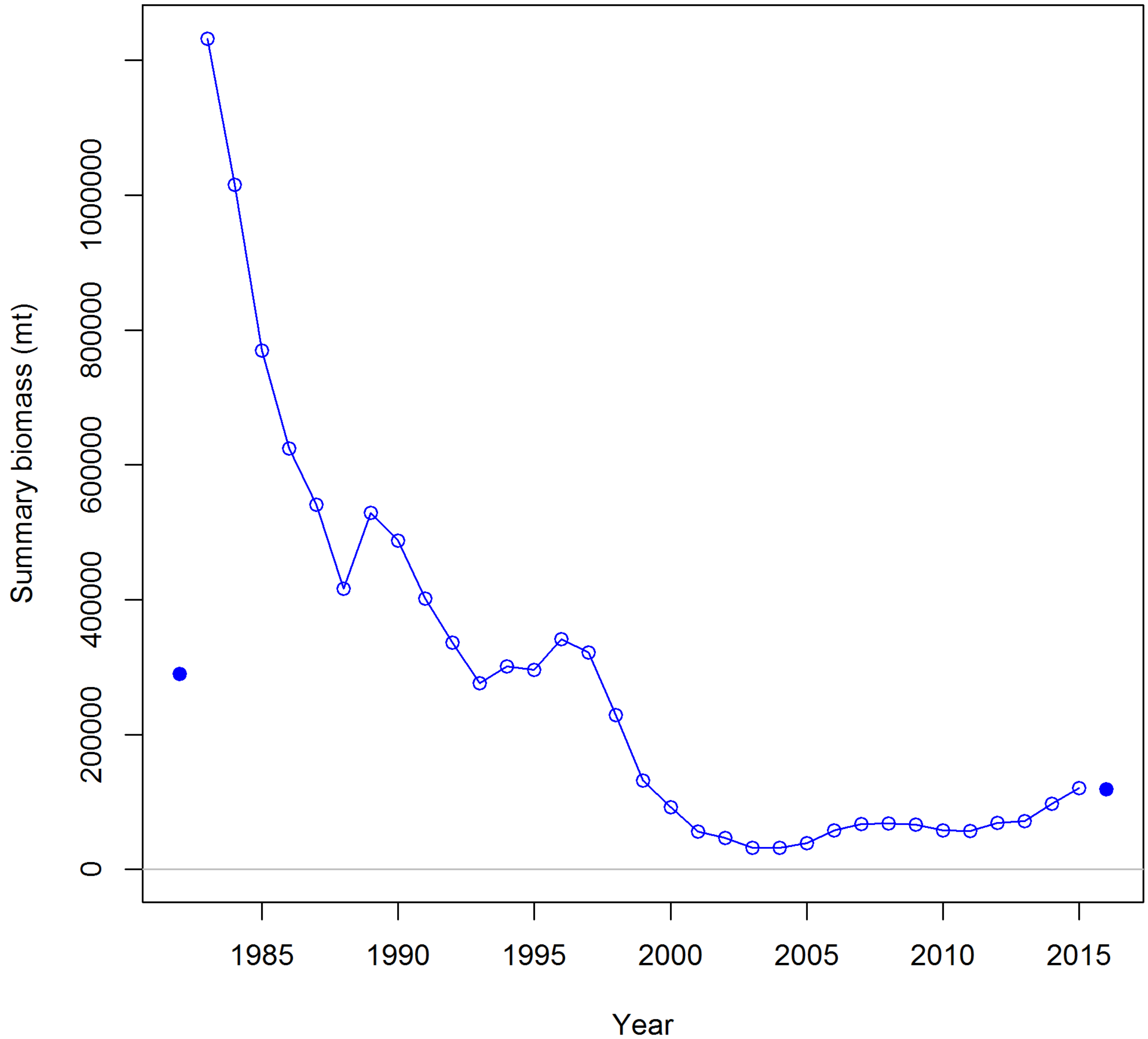


Figure 28. Estimated stock biomass (age 1+ fish, mt) time series for Pacific mackerel for model H3. Solid dots reflect estimate of virgin stock biomass and forecasted stock biomass in July 2016.

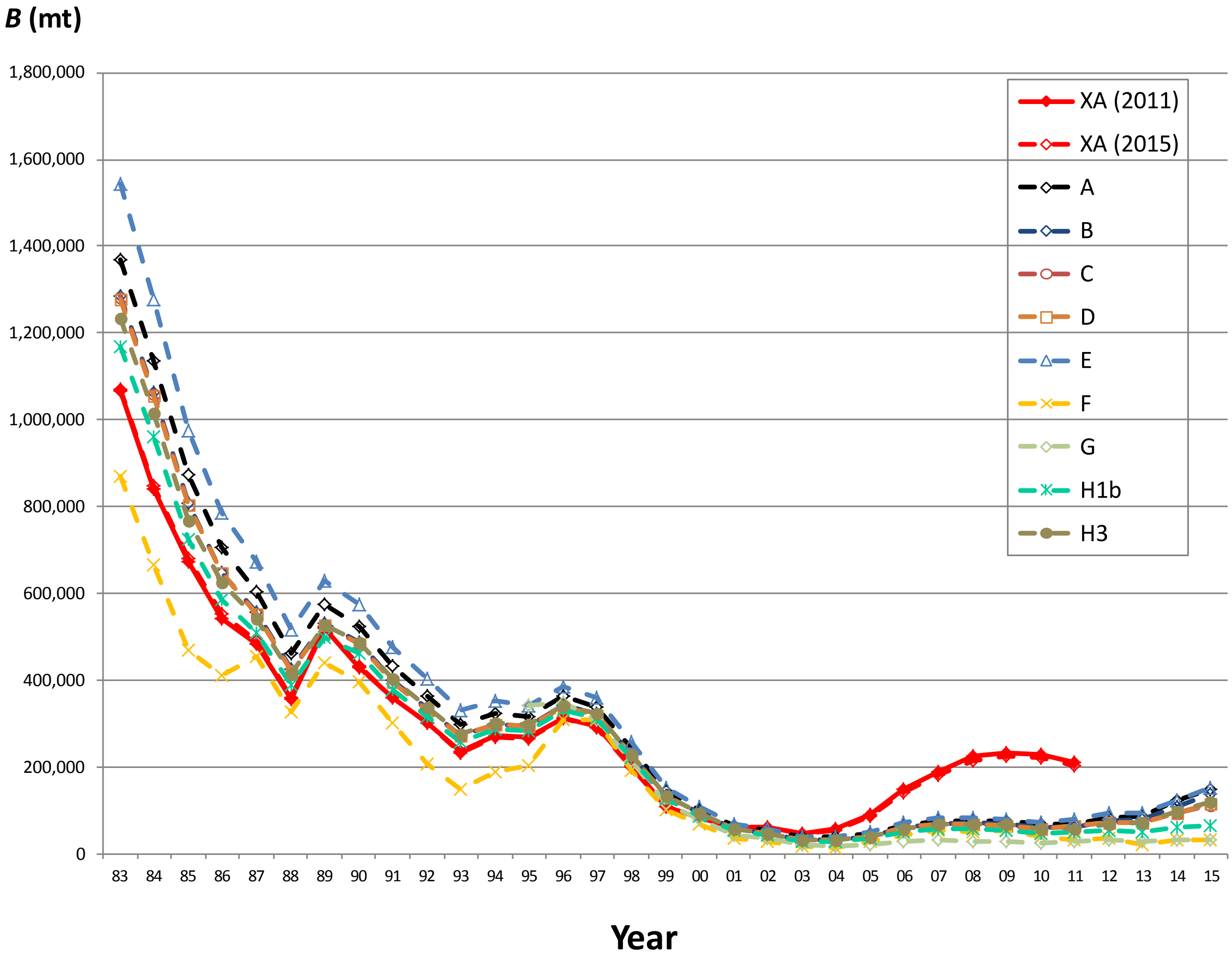


Figure 29. Estimated stock biomass (age 1+ fish, mt) time series for candidate model scenarios A-G, H1b, and H3. Model XA (2011) and Model XA (2015, SS ver. 3.24s) biomass time series are also presented. Also, see Table 5.

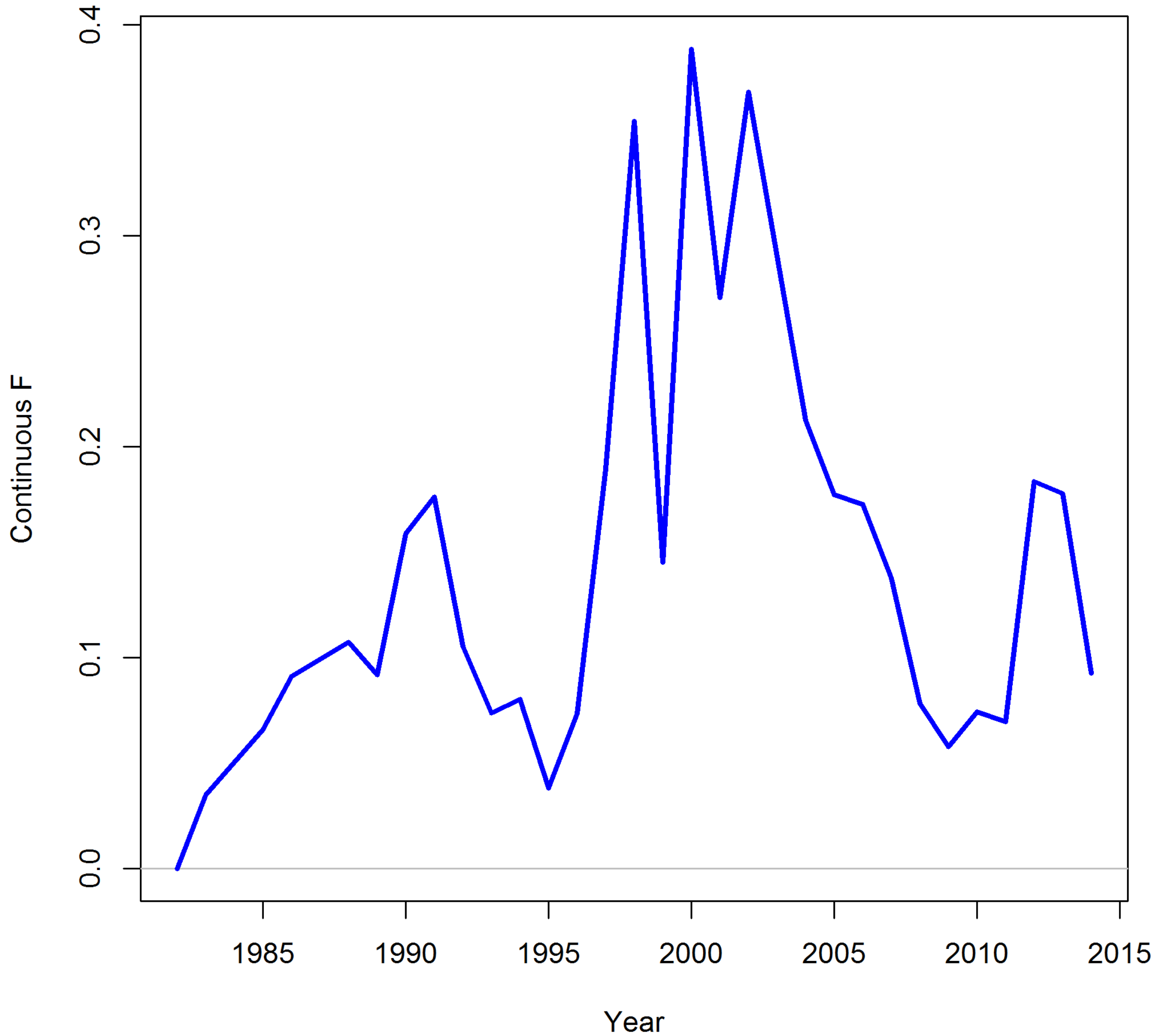


Figure 30. Estimated fishing mortality (*F*) time series for Pacific mackerel for model H3.

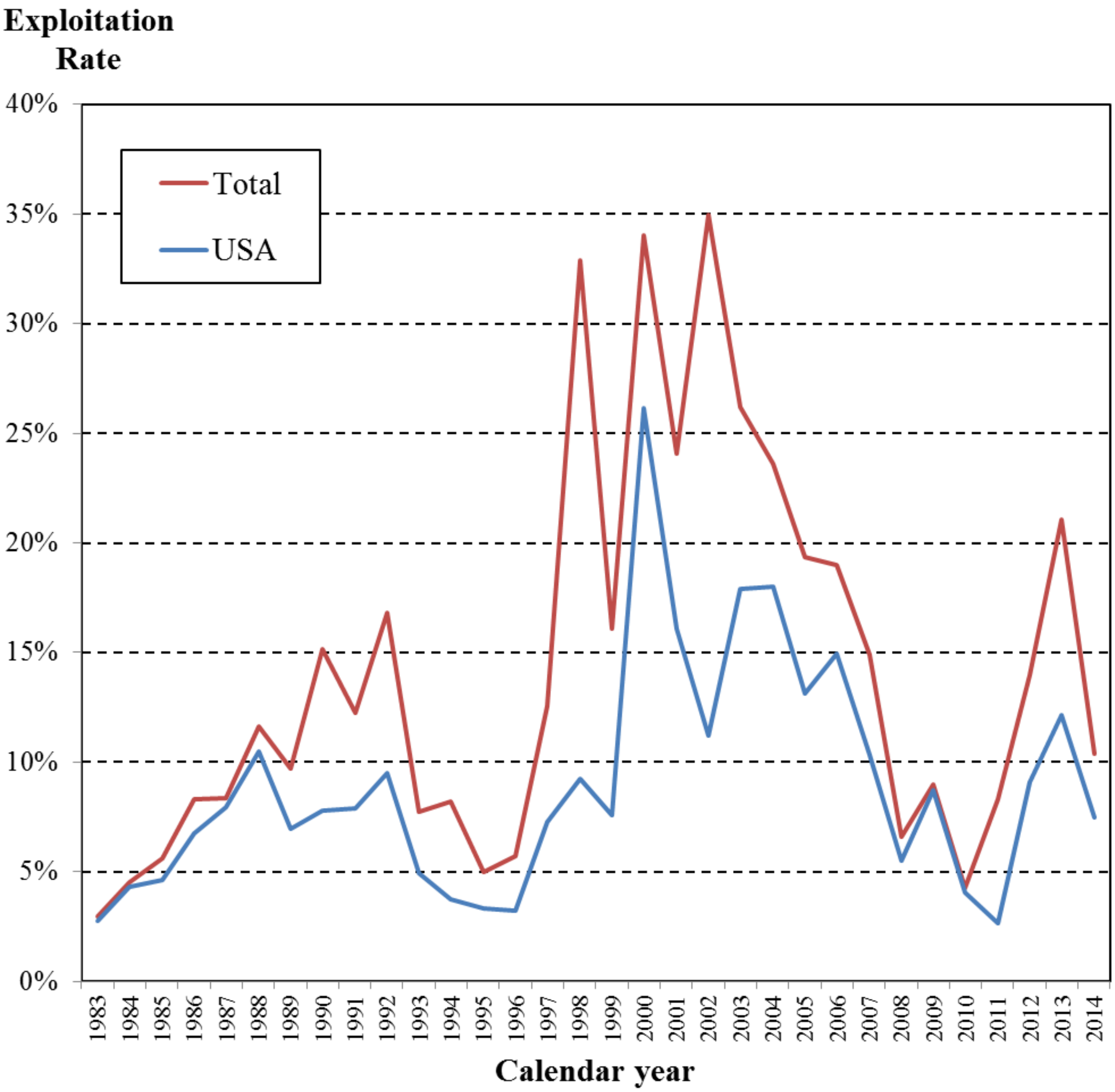


Figure 31. Estimated exploitation rate (catch/estimated stock biomass) time series (USA and total) for Pacific mackerel for model H3. Note that the reference year is the calendar, not fishing year in this display.

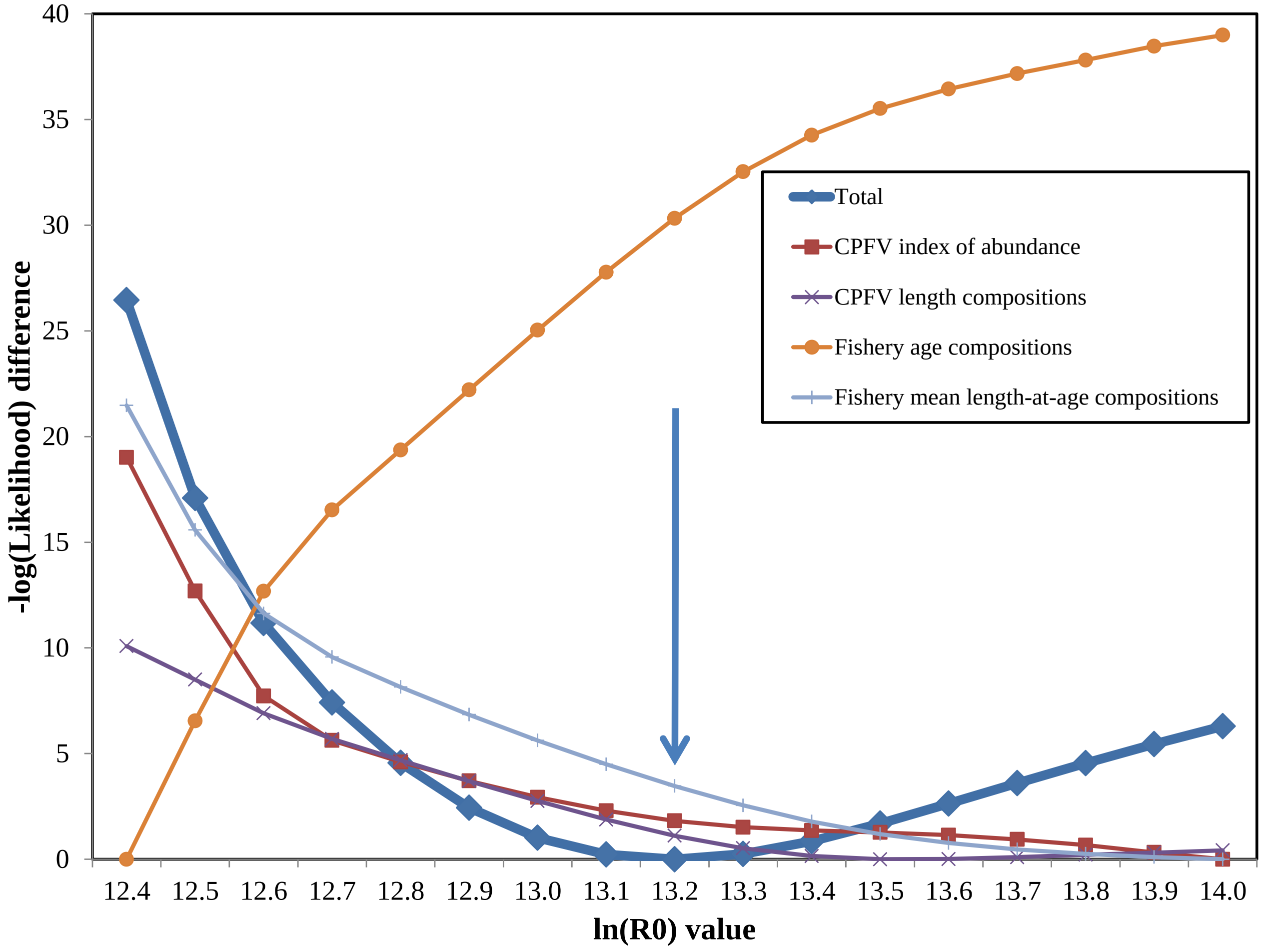


Figure 32. Virgin recruitment ($\log R_0$) –log(likelihood) profile (by data component and total) for model H3. Vertical arrow indicates Model H3 estimate of $\log(R_0) = 13.2$.

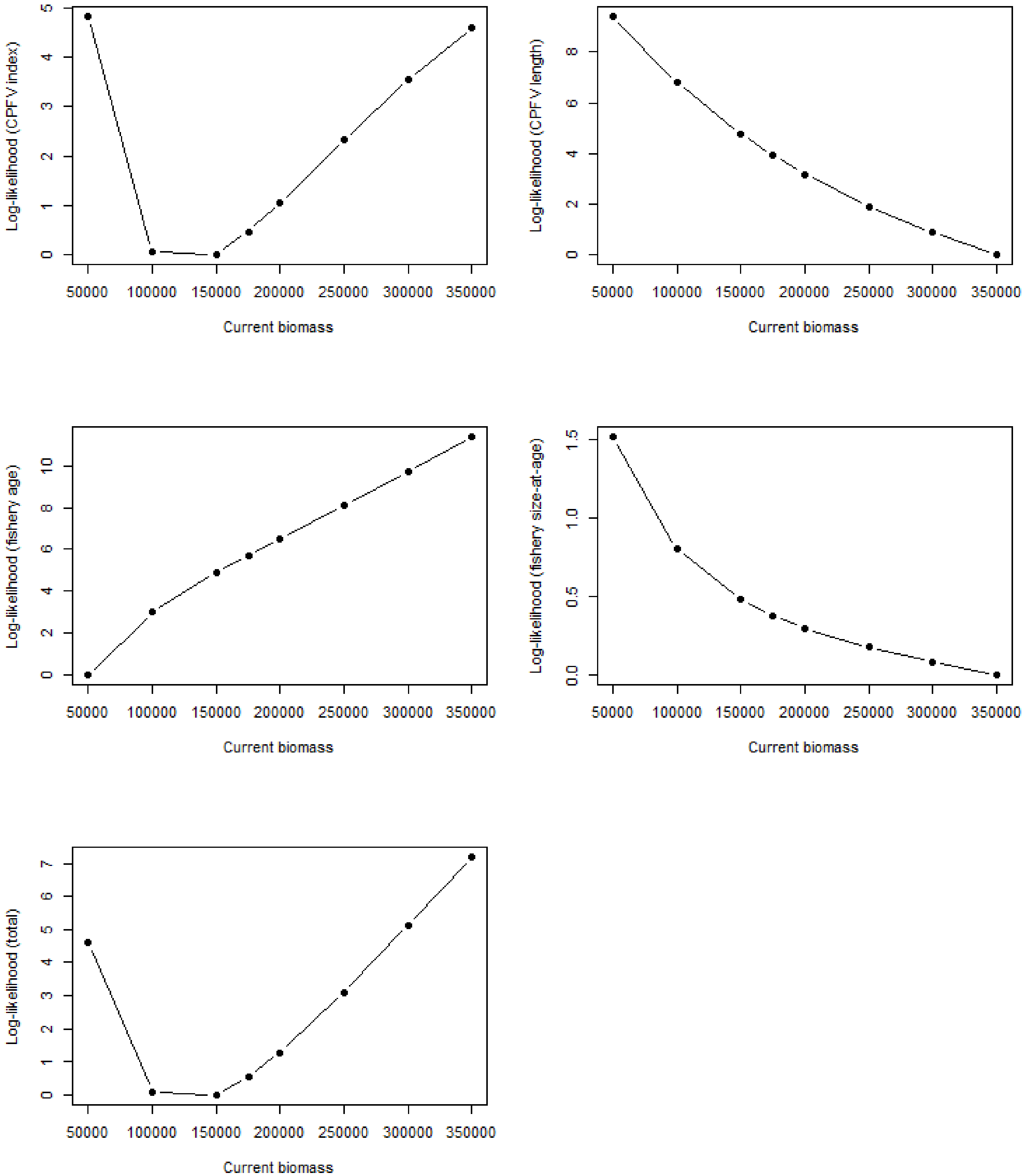


Figure 33. Terminal-year ($B_{current}$) stock biomass (age 1+ fish) –log(likelihood) profile (by data component and total) for model H3.

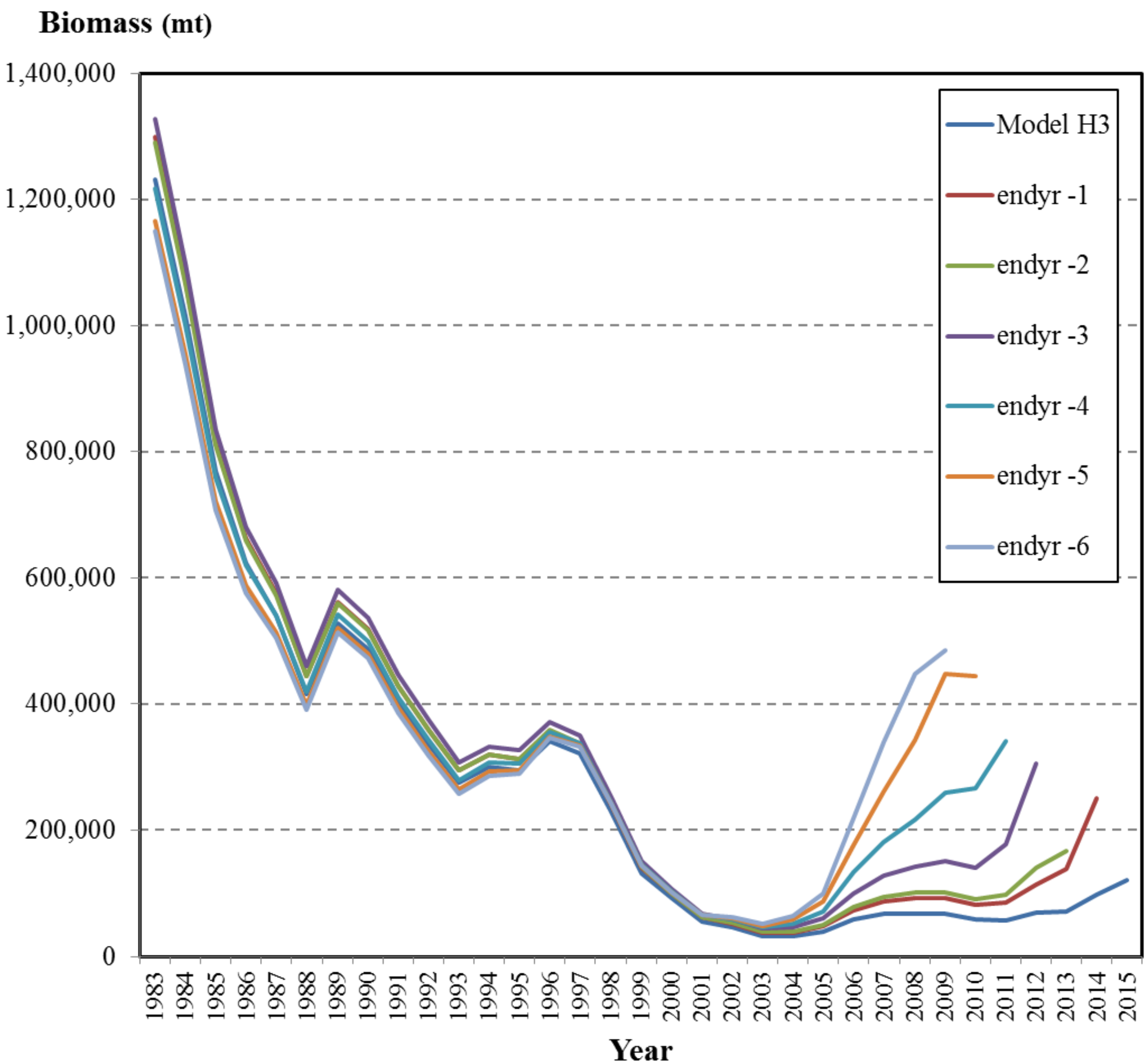


Figure 34. Retrospective analysis of estimated stock biomass (age 1+ fish, mt) for Pacific mackerel for model H3.

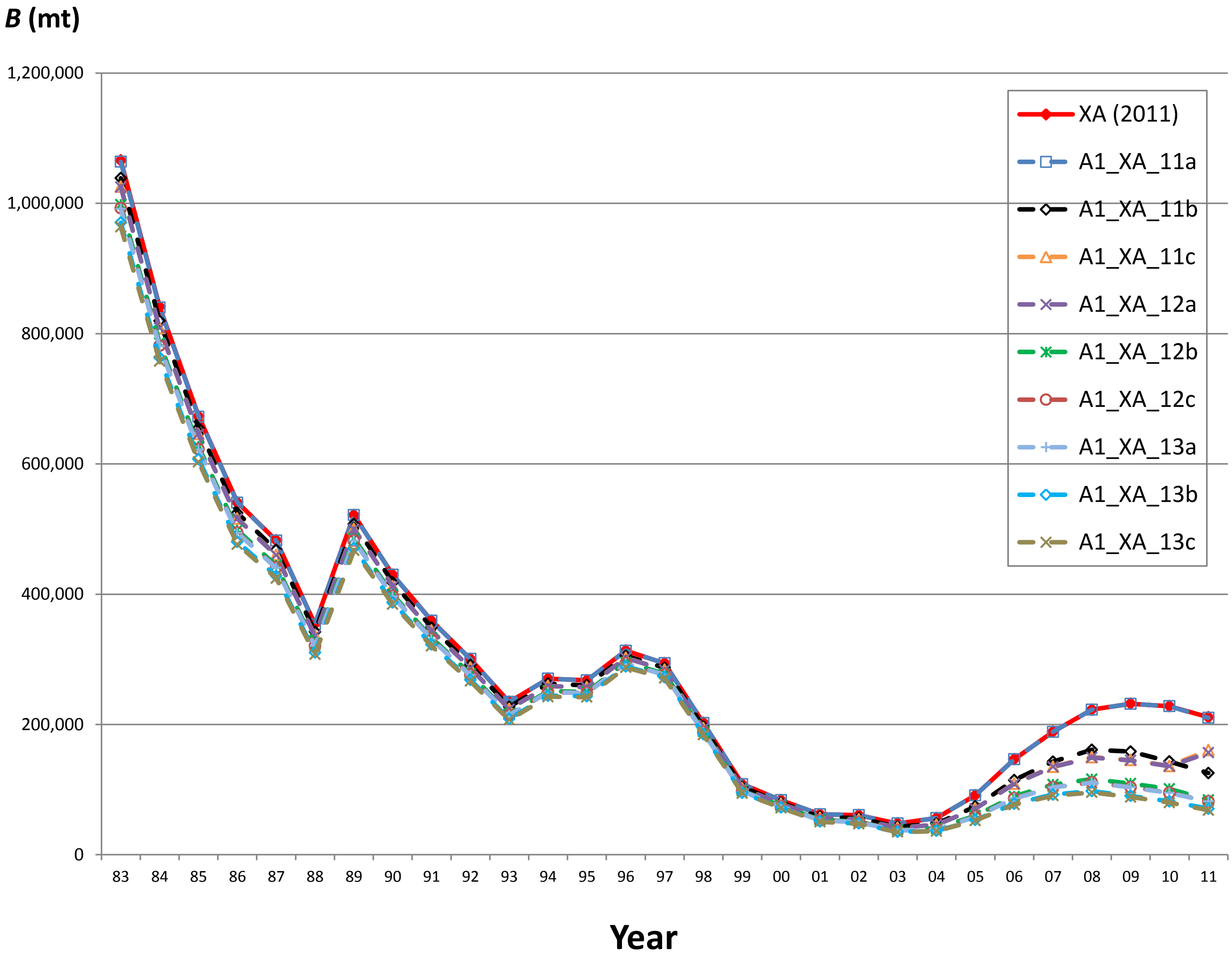


Figure 35. Estimated stock biomass (age 1+ fish, mt) time series related to model XA (1983-10), whereby data sources were added to the model sequentially to investigate sensitivity of model results to including data from 2011-13. Notation is as follows: number=year, a=catch from fisheries,; b=CPFV index of abundance; and c=age/size compositions from fisheries/CPFV. Note that each biomass time series is presented through 2011 only regardless of year, given plot is used for strictly diagnostic purposes (see Retrospective analysis).

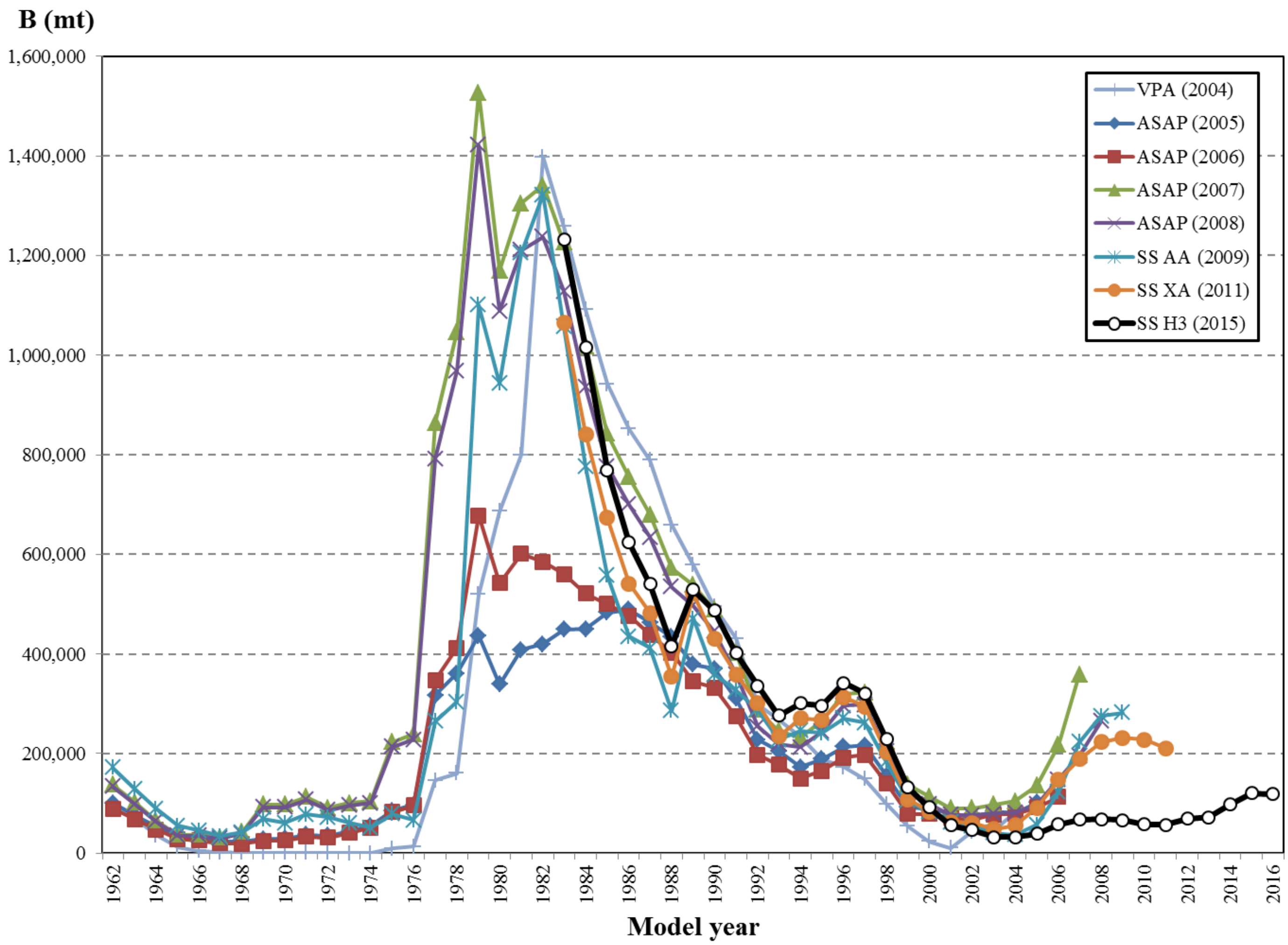


Figure 36. Estimated (historical) stock biomass (age 1+ fish, mt) time series used for Pacific mackerel management since 2004.

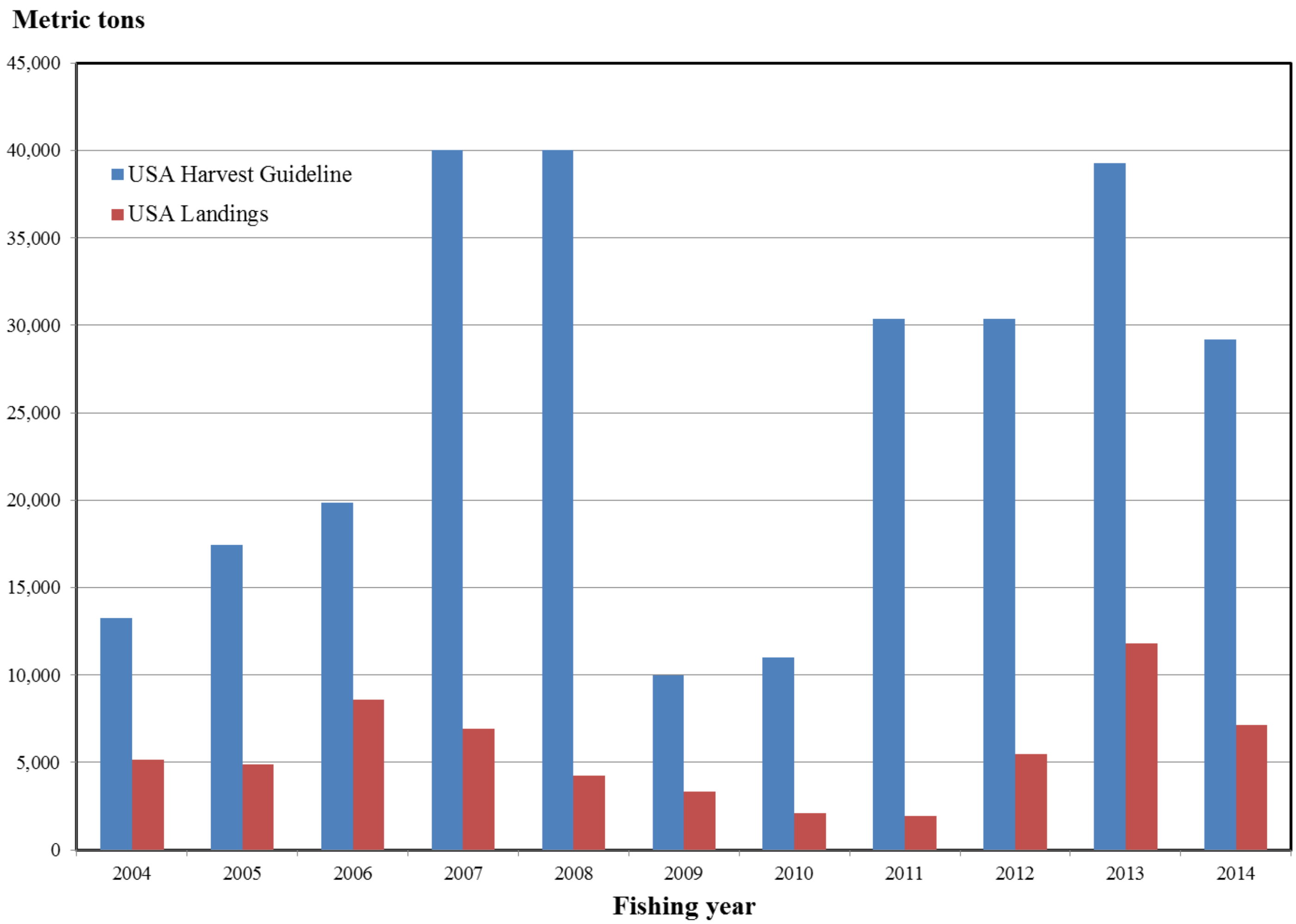


Figure 37. USA harvest guidelines (mt) and landings (mt) for Pacific mackerel since 2004.

APPENDICES

Appendix A
Acoustic-trawl survey

Acoustic-trawl estimates of Pacific mackerel biomass off USA and Canada during spring 2014

Juan P. Zwolinski, David A. Demer, Beverly J. Macewicz, George R. Cutter Jr., Brian E. Elliot, Scott A. Mau, David W. Murfin, Josiah S. Renfree, Thomas S. Sessions, and Kevin L. Stierhoff

Introduction

The acoustic-trawl method (ATM) is a standard survey tool for estimating the abundances and distributions of krill (Hewitt and Demer, 2000); Coastal Pelagic Species (CPS) such as Pacific mackerel, anchovy, mackerels, and herring (Mais, 1974; Johannesson and Mitson, 1983; Zwolinski et al., 2014); and semi-demersal species such as hake (Swartzman, 1997) and Pollock (Williams et al., 2013). Its utility has been expanding to provide a broader ecosystem perspective (Demer et al., 2009). In the ATM, multi-frequency split-beam echosounders transmit sound pulses vertically beneath the ship and receive echoes from animals and the seabed in the path of the sound waves (Simmonds and MacLennan, 2005). The intensities of the echoes that are scattered back (the backscatter signal) normalized to the range-dependent observational volume (the volume backscatter coefficient) provide indications of the target type and behavior. Fish, particularly those with highly reflective swimbladders, create high intensity echoes. Under certain conditions, the summed intensities of the echoes from an ensemble of targets is linearly related to the density of the fish or plankton aggregations that contributed to the echoes (Foote, 1983). This attribute of the summed intensities allows animal densities to be estimated by dividing the resulting “integrated backscatter coefficients” of the ensemble by the average echo energy from a representative animal (Simmonds and MacLennan, 2005). Trawl catches are used to apportion the echo energy to species and convert those values to fish densities (Demer et al., 2012). This procedure results in maps of fish densities and estimates of their biomasses, by species, along with their demographics.

Decades after a successful ATM campaign to survey the then abundant anchovy and mackerels off the coast of California (Mais, 1974), the ATM was reintroduced in the CCE in spring 2006 to sample the abundant Pacific mackerel population (Cutter Jr. and Demer, 2008). Since then, this survey effort has continued and expanded through annual or semi-annual surveys (Zwolinski et al., 2014; Demer et al., 2013; Demer et al., 2012; Zwolinski et al., 2012). The current ATM method used in the California Current Ecosystem has been reviewed positively by an independent panel from the Center for Independent Experts (CIE; PFMC, 2011) and, beginning in 2011, the ATM estimates of Pacific mackerel abundance and age structure have been incorporated in the annual Pacific mackerel assessments (Hill et al., 2011). The ATM is equally suitable for sampling all CPS with a clear schooling nature like herring, mackerel or anchovy (Mais, 1974; Johannesson and Mitson, 1983; Zwolinski et al., 2014).

Here, we report the abundance and length composition of Pacific mackerel sampled off central and southern California (Fig.1) during spring 2014. Abundance and length compositions from earlier ATM surveys (Zwolinski et al., 2014; Demer et al., 2013; Demer et al., 2012; Zwolinski et al., 2012) are also presented.

Material and methods

The 2004 Spring ATM survey was conducted from NOAA FSV *Bell M. Shimada* and chartered FV *Ocean Starr*. The survey spanned the expected distribution of the stock (Fig. 1), from the US-Mexico border to north of San Francisco. From sunrise to sunset, multi-frequency echosounders were used to sample acoustic backscatter from epipelagic coastal pelagic species (CPS). Day and night, a continuous underway fish egg sampler (CUFES) was used to sample CPS eggs within 5 m of the sea-surface. During nighttime, catches from as many as four surface trawls each night were combined into clusters to identify the proportions of CPS and their lengths.

With considerations to the sampling intensity, the presence of CPS in the echosounder and net samples, and the existence of Pacific mackerel in the trawl catches (Fig. 1), two strata were defined: central and south (Fig. 2). Twelve trawl-catch clusters included CPS, but only three of these clusters included Pacific mackerel (3 total).

The estimated total Pacific mackerel biomass in the survey area was 0.014 Mt ($CI_{95\%}$ = [0.001; 0.029]; *CV* = 49.6%) (Table 1). Because only three Pacific mackerel were sampled in the entire survey, inference on their modal lengths is not dependable (Table 2, Fig. 4).

Table 1. Pacific mackerel biomass by stratum for the spring 2014 survey.

Stratum		**Transect**		**Trawls**		**Pacific mackerel**		
Name	**Area ($n.mi.^2$)**	**Number**	**Distance (n.mi.)**	**CPS clusters**	**Number of Pacific mackerel**	**Biomass (1000 tons)**	**95% confidence interval (1000 tons)**	**CV**
Central	9213	4	432	1	1	3394	510-8624	69.2
Southern	10576	6	752	3	2	11136	5136-32591	36.3
Total	19789	10	1184	4	3	14363	1341-2908	49.6

Table 2. Pacific mackerel abundance versus standard length for the spring 2014 survey.

Fork length (cm)	**Number of specimens**
≤8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	0
18	0
19	0
20	0
21	0
22	1
23	1
24	0
25	0
26	0
27	0

28	0
29	0
30	0
31	0
32	1
33	0
34	0
35	0
36	0
37	0
38	0
39	0
40	0
41	0
42	0
43	0
44	0
45	0
46	0
47	0
48	0
49	0
50	0
51	0
52	0
53	0
54	0
55	0
56	0
57	0
58	0
59	0
60	0

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

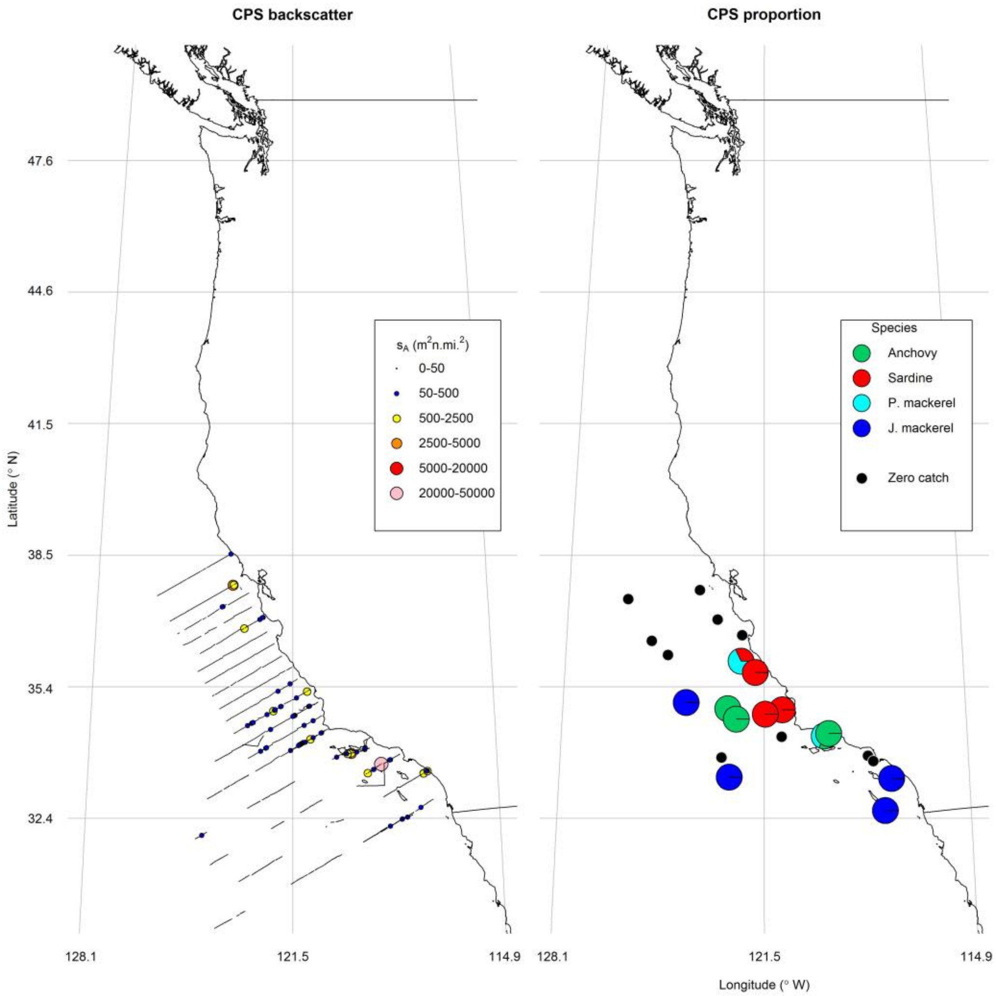


Figure 2. Pacific mackerel biomass densities for the, central stratum and southern strata (Table 1) estimated using the acoustic-trawl method (ATM). The numbers in blue represent the locations of trawl-cluster catches including at least 1 CPS.

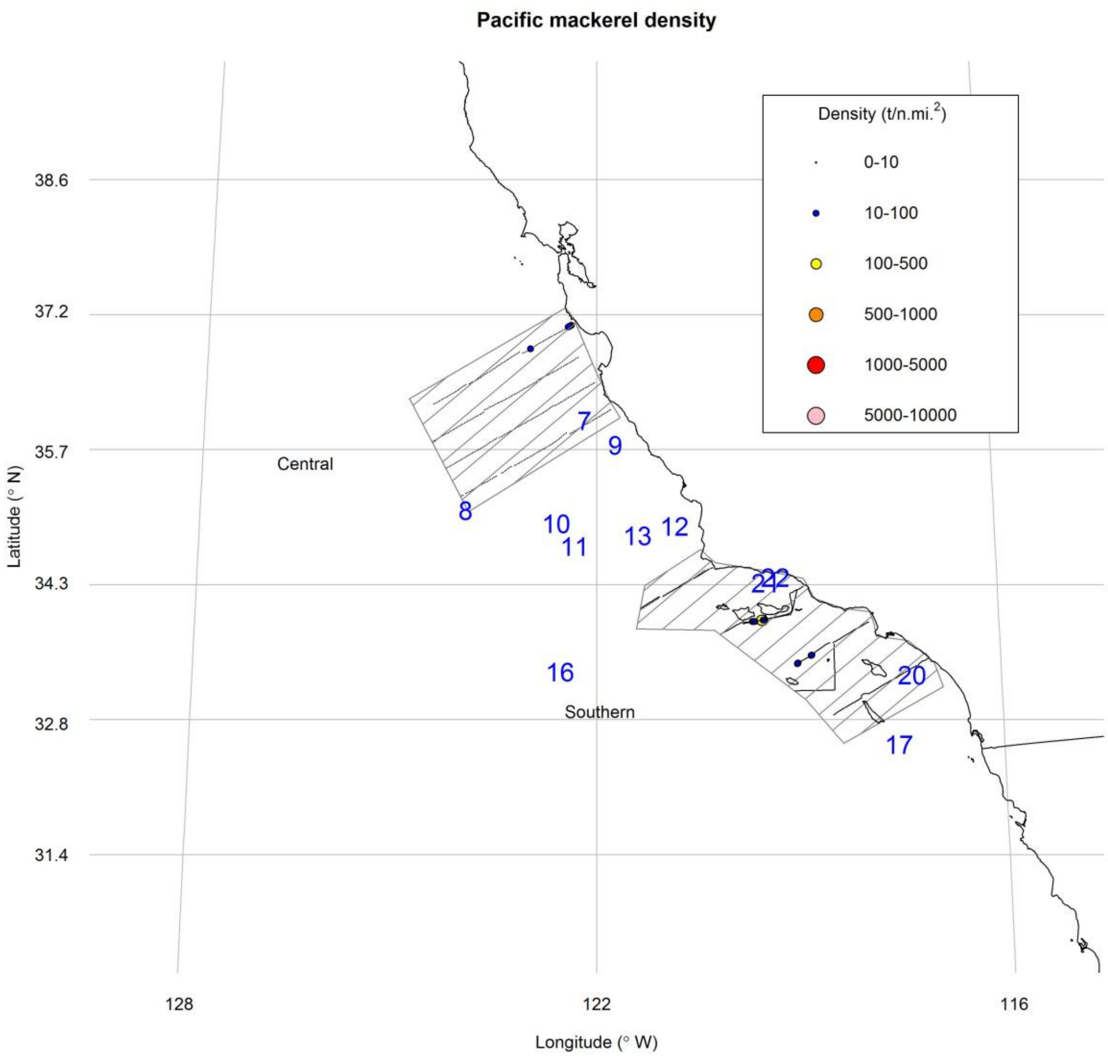


Figure 3. Distribution of Pacific mackerel fork lengths sampled in the trawl during spring 2014 (see Table 2).

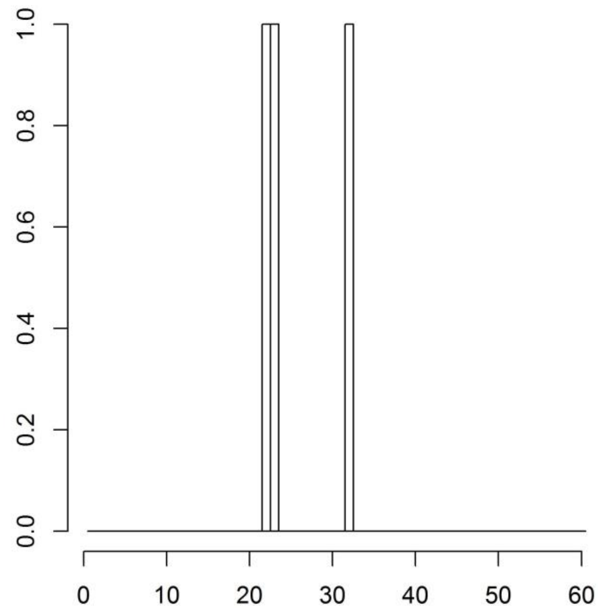


Figure 4. Pacific mackerel fork lengths sampled in the trawl from spring 2006 through spring 2014.

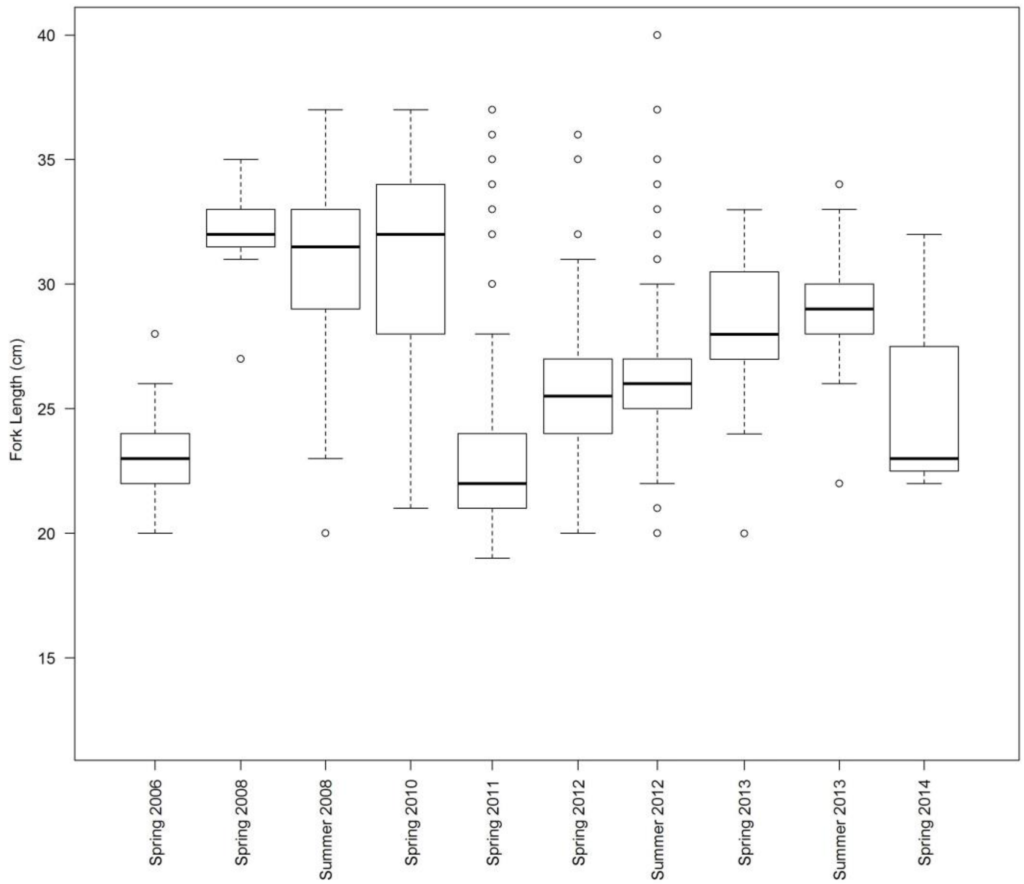
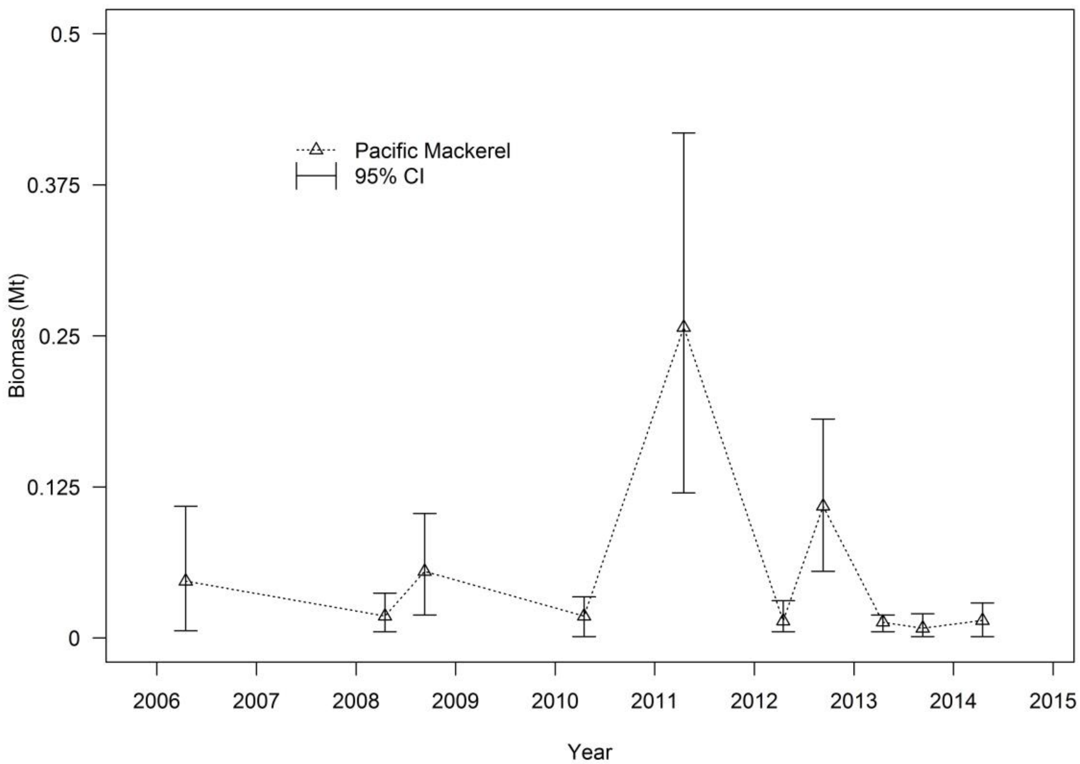


Figure 5. Biomass of Pacific mackerel sampled in ATM surveys from spring 2006 through spring 2014.



Acoustic-trawl estimates of Pacific mackerel biomass off USA and Canada during summer 2014

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Introduction

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Decades after a successful ATM campaign to survey the then abundant anchovy and mackerels off the coast of California (Mais, 1974), the ATM was reintroduced in the

CCE in spring 2006 to sample the abundant sardine population (Cutter Jr. and Demer, 2008). Since then, this survey effort has continued and expanded through annual or semi-annual surveys (Zwolinski et al., 2014; Demer et al., 2013; Demer et al., 2012; Zwolinski et al., 2012). The current ATM method used in the California Current Ecosystem has been reviewed positively by an independent panel from the Center for Independent Experts (CIE; PFMC, 2011) and, beginning in 2011, the ATM estimates of sardine abundance and age structure have been incorporated in the annual sardine assessments (Hill et al., 2011). The ATM is equally suitable for sampling all CPS with a clear schooling nature like herring, mackerel or anchovy (Mais, 1974; Johannesson and Mitson, 1983; Zwolinski et al., 2014).

Here, we report the abundance and length composition of Pacific mackerel sampled off the west coasts of the USA and Vancouver Island, Canada during the summer 2014 CPS survey (Fig. 1). Abundance and length compositions from earlier ATM surveys (Zwolinski et al., 2014; Demer et al., 2013; Demer et al., 2012; Zwolinski et al., 2012) are also presented.

Material and methods

The survey was conducted from NOAA FSV *Bell M. Shimada*, and the survey region spanned from northern Vancouver Island to the Strait of Juan de Fuca (leg I) and from Cape Flattery, Washington to Morro Bay, California (leg II), to at least 35 n.mi. offshore or 1500 m depth (both legs, Fig. 1). The spacing of the east-west tracklines was 20 nm. A provision was made to this spacing to 10 nm in areas where schools of coastal pelagic species (CPS) were observed acoustically or in trawl catches, or both, provided there was sufficient time to survey the original sampling region in its entirety.

From sunrise to sunset, multi-frequency echosounders were used to sample acoustic backscatter from epipelagic CPS. During nighttime, catches from as many as four surface trawls each night were combined into clusters to identify the proportions of CPS and their lengths. With considerations to the sampling intensity, the presence of CPS in the echosounder and net samples, and the existence of Pacific mackerel in the trawl catches (Fig. 1), the survey data were apportioned to 3 independent and non-overlapping strata (Table 1; Fig. 2).

Results

Nine of the 21 trawl-catch clusters with CPS included a total of 279 total Pacific mackerel. Pacific mackerel were predominantly found in the Washington-Oregon stratum, south of the Columbia River mouth (Figs. 1, and 2). Relatively fewer Pacific mackerel were acoustically sampled off western Vancouver Island, and the central California coast (Fig. 2). The three strata (Table 1) contained a total Pacific mackerel biomass of 0.008 Mt ($CI_{95\%}$ = [0.001; 0.015]; *CV* = 56.4). The sampled population had a modal fork length (*SL*) of ~ 32.5 cm (Table 2; Fig. 3).

Table 1. Estimated Pacific mackerel biomass by stratum during summer 2014.

Stratum		**Transect**		**Trawls**		**Pacific mackerel**		
Name	**Area (n.mi.)**	**Number**	**Distance (n.mi.)**	**CPS clusters**	**Number of Pacific mackerel**	**Biomass (1000 tons)**	**95% confidence interval (1000 tons)**	***CV***
Vancouver Island (Leg I)	2520	4	245	4	122	1.809	0.000-0.004	76.1
Washington-Oregon (Leg II)	8020	9	396	4	142	5.659	0.108-13.551	75.5
California (Leg II)	6697	9	335	5	15	0.557	0.054-1.349	67.9
Total	**17238**	**22**	**976**	**13**	**279**	**8.024**	**1.082–15.120**	**56.4**

Table 2. Distribution of Pacific mackerel lengths (214 specimens) sampled by the trawl during the summer 2014 ATM survey.

Fork length (cm)	**Number of specimens**
≤8	0
9	0
10	0
11	0
12	1
13	0

14	0
15	2
16	3
17	1
18	2
19	4
20	0
21	0
22	0
23	0
24	0
25	0
26	2
27	0
28	0
29	10
30	21
31	58
32	67
33	28
34	9
35	5
36	1
37	0
38	0
39	0
40	0
41	0
42	0
43	0
44	0
45	0
46	0
47	0
48	0
49	0
50	0
51	0
52	0
53	0
54	0
55	0
56	0
57	0
58	0
59	0
60	0

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

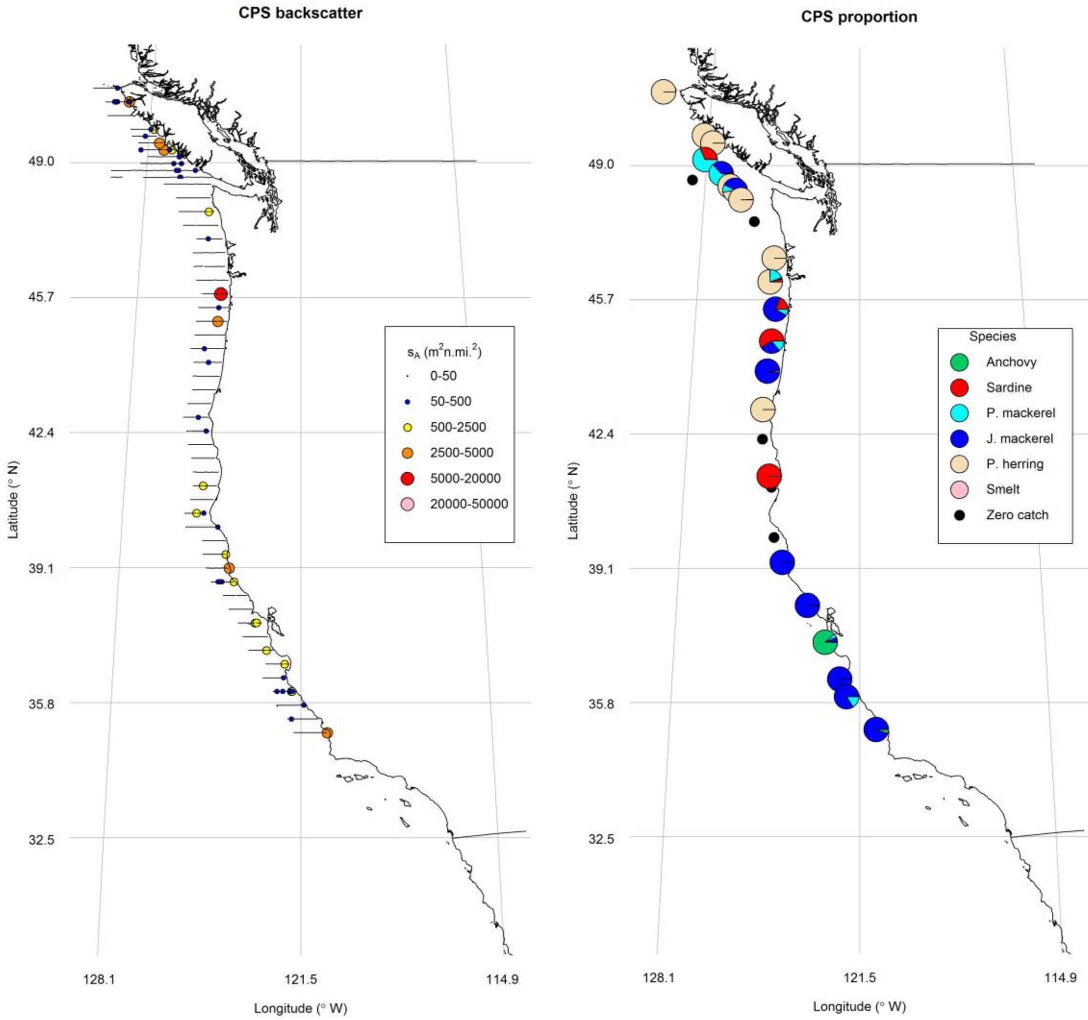


Figure 2. Estimated Pacific mackerel biomass densities by stratum (see **Table 1**). The numbers in blue represent the locations of trawl cluster catches with at least one CPS specimen.

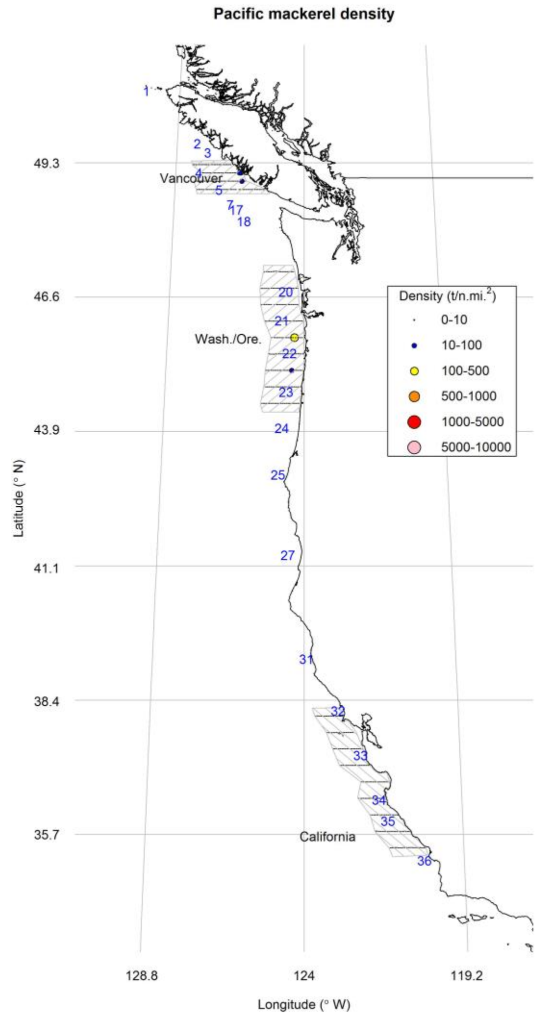


Figure 3. Distribution of Pacific mackerel fork lengths sampled in the trawl during summer 2014 (see Table 2).

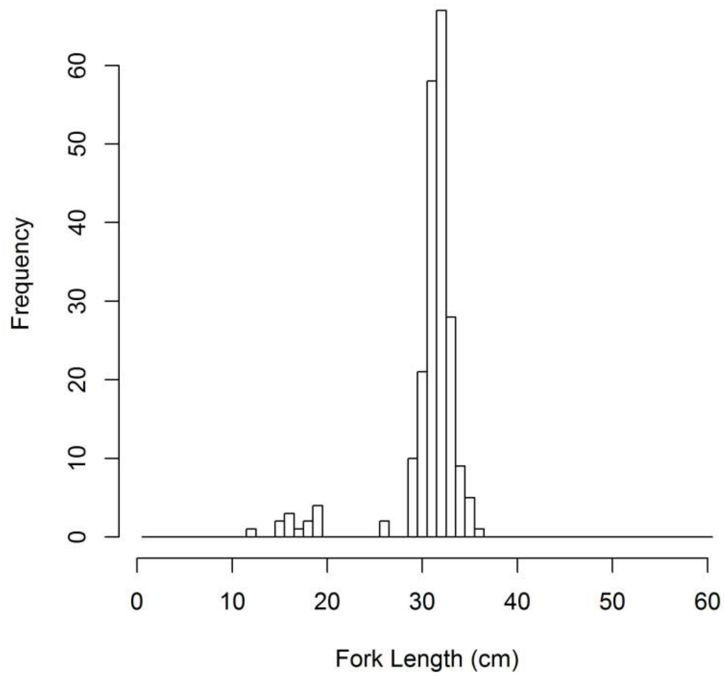


Figure 4. Pacific mackerel fork lengths sampled in the trawl from spring 2006 through summer 2014.

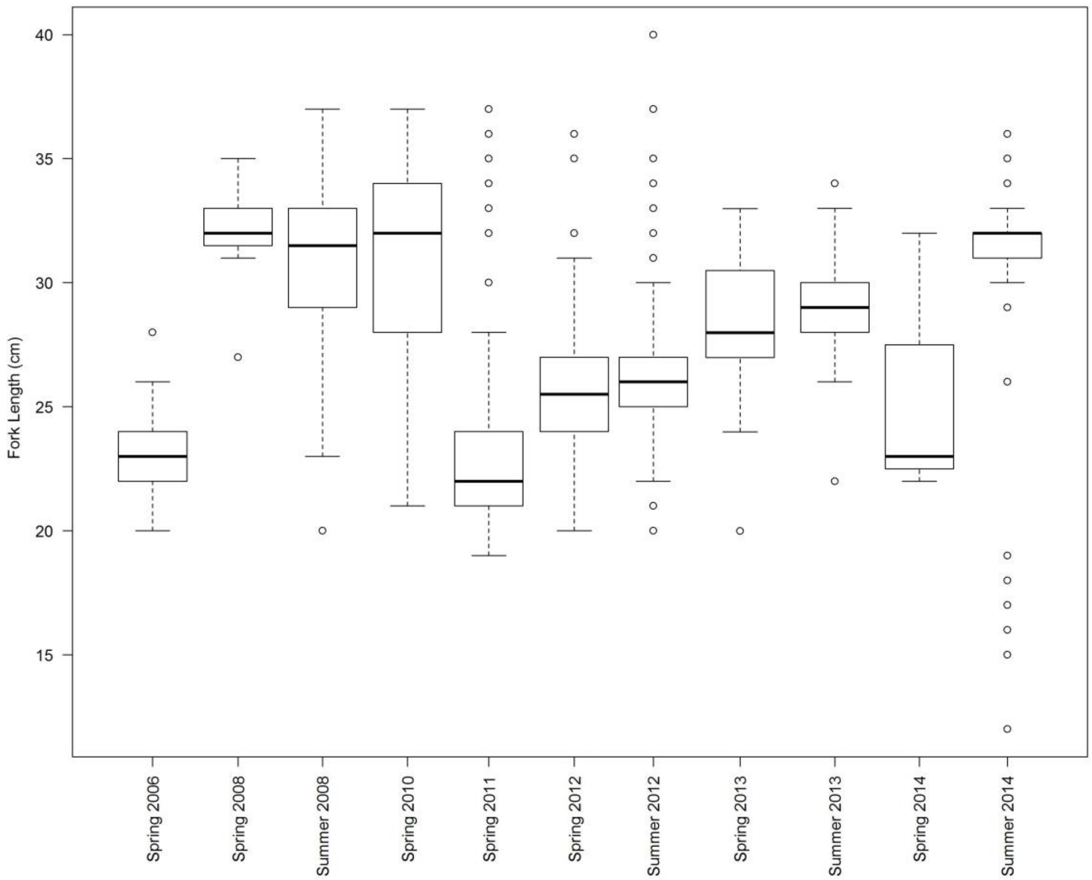
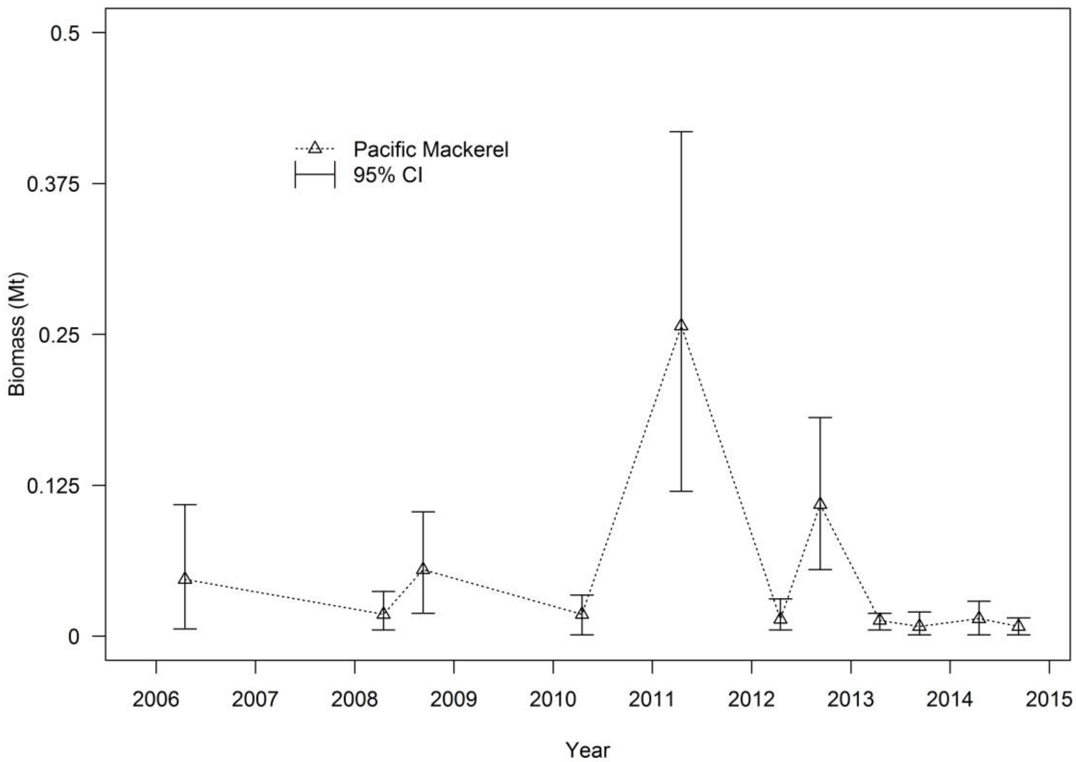


Figure 5. Biomass of Pacific mackerel sampled in ATM surveys from spring 2006 through summer 2014.



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Appendix B
SS input files for model H3

STARTER.SS

```
# P. mackerel stock assessment (April 2015)
# Stock Synthesis 3 (v. 3.24s)
# Model H3
#
# STARTER FILE
#
H3.dat # Data file
H3.ctl # Control file
0 # Read initial values from 'par' file: 0 = no, 1 = yes
1 # DOS display detail: 0, 1, 2
2 # Report file detail: 0, 1, 2
1 # Detailed checkup.sso file: 0 = no, 1 = yes
3 # Write parm values to ParmTrace.sso: 0=no, 1=good,active; 2=good,all;
3=every_iteration,all_parms; 4=every,active
2 # Write cumulative report: 0 = skip, 1 = short, 2 = full
0 # Include prior likelihood for non-estimated parameters
1 # Use soft boundaries to aid convergence: 0 = no, 1 = yes (recommended)
1 # Number of bootstrap data files to produce
10 # Last phase for estimation
10 # MCMC burn-in interval
2 # MCMC thinning interval
0 # Jitter initial parameter values by this fraction
-1 # Minimum year for SSB sd_report: (-1 = styr-2, i.e., virgin population)
-2 # Maximum year for SSB sd_report: (-1 = endyr, -2 = endyr+N_forecastyrs)
0 # N individual SD years
0.0001 # Final convergence criteria (e.g., 1.0e-04)
0 # Retrospective year relative to end year (e.g., -4)
1 # Minimum age for 'summary' biomass
1 # Depletion basis (denominator is: 0 = skip, 1 = relative X*B0, 2 = relative X*Bmsy, 3 =
relative X*B_styr
0.6 # Fraction for depletion denominator (e.g., 0.4)
4 # (1-SPR)_report basis: 0 = skip, 1 = (1-SPR)/(1-SPR_tgt), 2 = (1-SPR)/(1-SPR_MSY), 3 = (1-
SPR)/(1-SPR_Btarget), 4 = raw_SPR
1 # F_std report: 0=skip, 1=exploitation(Bio), 2=exploitation(Num), 3=sum(frates), 4=true F for
range of ages
2 # F report basis: 0 = raw, 1 = F/Fspr, 2 = F/Fmsy, 3 = F/Fbtgt
999 # End of file
```

FORECAST.SS

```
# P. mackerel stock assessment (April 2015)
# Stock Synthesis 3 (v. 3.24s)
# Model H3
#
# FORECAST FILE
#
1 # Benchmarks: 0 = skip, 1 = calculate (F_SPR, F_btgt, F_MSY) ** Related to Benchmark relative_F
basis, Forecast, and F and SPR report basis (in ctl file) options **
2 # MSY: 0 = none, 1 = set to F_SPR, 2 = calculate F_MSY, 3 = set to F_Btgt, 4 = set to F(endyr)
0.5 # SPR target - relative to B0 (e.g., 0.3)
0.5 # Biomass target - relative to B0 (e.g., 0.5)
# Benchmark years: begin_bio, end_bio, begin_selex, end_selex, begin_relative F, end_relative F
(enter actual year, -999 = start_yr, 0 = end_yr, <0 = relative end_yr)
0 0 0 0 0 0
1 # Benchmark relative_F basis: 1 = use year range, 2 = set relative_F same as Forecast below
1 # Forecast: 0 = none, 1 = F_SPR, 2 = F_MSY, 3 = F_Btgt, 4 = Avg_F (uses first-last relative_F
years), 5 = input annual F scalar
2 # Number of forecast years
0 # F scalar (only used for Forecast = 5)
# Forecast years: begin_selex, end_selex, begin_relative F, end_relative F (enter actual year, -
999 = start_yr, 0 = end_yr, <0 = relative end_yr)
0 0 0 0
1 # Control rule method: 1 = catch = f(SSB) West Coast, 2 = F = f(SSB)
0.5 # Control rule Biomass level (as fraction of B0, e.g. 0.40) above which F is constant
```

```
0.1 # Control rule Biomass level (as fraction of B0, e.g. 0.10) below which F is set to 0
0.75 # Control rule target as fraction of F_limit (e.g., 0.75)
3 # Number of forecast loops (1-3: fixed at 3 for now)
3 # First forecast loop with stochastic recruitment
0 # Forecast loop control #3 (reserved for future bells&whistles)
0 # Forecast loop control #4 (reserved for future bells&whistles)
0 # Forecast loop control #5 (reserved for future bells&whistles)
2020 # First year for caps and allocations (should be after years with fixed inputs)
0 # SD of log(realized F/target F) in forecast (set value >0.0 to cause active implementation
error)
0 # Do West Coast groundfish rebuilder output (0 = no, 1 = 0)
0 # Rebuilder: first year catch could have been set to zero (Ydecl)(-1 to set to 1999)
0 # Rebuilder: year for current age structure (Yinit) (-1 to set to endyear+1)
1 # Fleet relative F: 1 = use first-last allocation year, 2 = read season(row) x fleet(column)
below
# Note: Fleet allocation is used directly as average F if Forecast = 4
2 # Basis for forecast catch tuning and for forecast catch caps and allocation: 2 = dead_bio, 3 =
retain_bio, 5 = dead_num, 6 = retain_num
# Maximum total catch by fishery (-1 to have no max)
-1
# Maximum total catch by area (-1 to have no max)
-1
# Fleet assignment to allocation group (enter group ID# for each Fishery, 0 for not included in
an allocation group)
0
2 # Number of forecast catch levels to input (otherwise calculate catch from forecast F)
3 # Basis for input forecast catch: 2 = dead catch, 3 = retained catch, 99 = input Hrate(F) with
units that are from fishery units
# Input fixed catch values: year, season, fishery, catch (or F)
2015 1 1 21469
2016 1 1 21469
999 # End of file
```

CONTROL FILE

```
# P. mackerel stock assessment (April 2015)
# Stock Synthesis 3 (v. 3.24s)
# Model H3
#
# CONTROL FILE
#
# MODEL DIMENSION PARAMETERS
==============================================================================================
# Morph parameterization
1 # Number of growth patterns (morphs)
1 # Number of sub-morhps within morphs
# Time block parameterization (time-varying parameterization)
0 # Number of block designs
#
# BIOLOGICAL PARAMETERS
==============================================================================================
0.5 # Fraction = female (at birth)
# Natural mortality (M)
0 # Natural mortality type: 0 = 1 parameter, 1 = N_breakpoints, 2 = Lorenzen, 3 = age-specific, 4
= age-specific with season interpolation
# Growth
1 # Growth model: 1 = VB with L1 and L2, 2 = VB with A0 and Linf, 3 = Richards, 4 = readvector
0.5 # Growth_age at L1 (L_min): Age_min for growth
12 # Growth_age at L2 (L_max) - (to use L_inf = 999): Age_max for growth
0 # SD constant added to length-at-age (LAA)
0 # Variability of growth: 0 = CV_f(LAA), 1 = CV_f(A), 2 = SD_f(LAA), 3 = SD_f(A)
# Maturity
3 # Maturity option: 1 = logistic (length), 2 = logistic (age), 3 = fixed (vector of proportion-
at-age), 4 = read age-fecundity, 5 = read fecundity and weight from wtatage.ss
# Maturity-at-age (if maturity option = 3)
0 0.07 0.25 0.47 0.73 1 1 1 1 1 1 1 1 # Maturity-at-age (proportion) for option = 3, i.e.,
'Accumulator age' + 1;
1 # First mature age (no read if maturity option = 3)
1 # Fecundity option: 1 is eggs=Wt*(a+b*Wt), 2 is eggs=(a*L^b), 3 is eggs=(a*Wt^b)
0 # Hermaphroditism option: 0 = none, 1 = invoke female to male transition
```

```
1 # MG parameter offset option: 1 = none, 2 = M,G,CV_G as offset from GP1, 3 = like SS2
1 # MG parameter adjust method: 1 = do SS2 approach, 2 = use logistic transformation to keep
between bounds of base parameter approach
# M, maturity, and growth parameterization
# Low High Initial Prior_mean Prior_type SD Phase Env_var Use_dev Dev_minyr Dev_maxyr Dev_stddev
Block_def Block_type
# M parameterization
0.3 0.7 0.5 0 -1 0 -3 0 0 0 0 0 0 0 # M_p1 (M = 0.5, all ages)
# Growth parameterization
# Length-at-age
4 35 20.5559 0 -1 0 3 0 0 0 0 0 0 0 # L_at_Amin_Fem_GP_1
30 70 39.198 0 -1 0 3 0 0 0 0 0 0 0 # L_at_Amax_Fem_GP_1
0.1 0.7 0.387149 0 -1 0 3 0 0 0 0 0 0 0 # VonBert_K_Fem_GP_1
0.01 0.5 0.1 0 -1 0 -3 0 0 0 0 0 0 0 # CV_young_Fem_GP_1
0.01 0.5 0.1 0 -1 0 -3 0 0 0 0 0 0 0 # CV_old_Fem_GP_1
# Weight-length
-1 5 0.0000027314 0 -1 0 -3 0 0 0 0 0 0 0 # W-L_a
1 5 3.44377 0 -1 0 -3 0 0 0 0 0 0 0 # W-L_b
# Maturity and fecundity parameterization
-3 3 3 0 -1 0 -3 0 0 0 0 0 0 0 # Maturity (inflection)
-3 3 3 0 -1 0 -3 0 0 0 0 0 0 0 # Maturity (slope)
-3 3 1 0 -1 0 -3 0 0 0 0 0 0 0 # Eggs/gm (intercept)
-3 3 0 0 -1 0 -3 0 0 0 0 0 0 0 # Eggs/gm (slope)
# Population recruitment apportionment (distribution)
-4 4 0 0 -1 0 -4 0 0 0 0 0 0 0 # Recruitment distribution (growth pattern)
-4 4 1 0 -1 0 -4 0 0 0 0 0 0 0 # Recruitment distribution (area)
-4 4 0 0 -1 0 -4 0 0 0 0 0 0 0 # Recruitment distribution (season)
# Cohort growth deviation
1 5 1 0 -1 0 -4 0 0 0 0 0 0 0 # Cohort growth deviation
# Seasonal effects on biology parameters
# Columns: femwtlt1, femwtlt2, mat1, mat2, fec1, fec2, malewtlt1, malewtlt2, L1, K
0 0 0 0 0 0 0 0 0 0
# Stock-recruit (S-R)
3 # S-R function: 1 = B-H w/flat top, 2 = Ricker, 3 = standard B-H, 4 = no steepness or bias
adjustment
# Low High Initial Prior_mean Prior_type SD Phase
1 30 14 0 -1 0 1 # log(R0)
0.1 1 0.469845 0 -1 0 5 # Steepness
0 2 0.75 0 -1 0 -3 # Sigma_R
-5 5 0 0 -1 0 -3 # Env link coefficient
-15 15 0.289513 0 -1 0 1 # Initial eqilibrium recruitment offset
0 2 0 0 -1 0 -3 # Autocorrelation in recruitment devs
0 # SR_env link
0 # SR_env target: 0=none, 1=devs, 2=R0, 3=steepness
# Recruitment residual (recruitment devs) parameterization
1 # Recruitment dev type: 0 = none, 1 = dev_vector, 2 = simple
1983 # Start year for main recruitment devs
2013 # Last year for main recruitment devs
2 # Phase for recruitment devs
1 # Read 13 advanced recruitment options: 0 = off, 1 = on
-6 # Start year for (early) recruitment devs (0 = none; negative value makes relative to start
year above)
2 # Phase for (early) recruitment devs
0 # Phase for forecast recruitment devs: 0 = maxphase+1
1 # Lambda for forecast recruitment devs (before endyr+1)
1974 # Last_early_yr recruitment dev with no bias adjustment in MPD
1985 # First year full bias correction adjustment in MPD
2013 # Last year for full bias correction adjustment in MPD
2014 # First recent_year no bias adjustment in MPD
0.90 # Max bias adjustment in MPD (-1 to override ramp and set biasadj=1.0 for all estimated
recruitment devs)
0 # Period of cycles in recruitment (N parms read below)
-5 # Min recruitment dev
5 # Max reccruitment dev
0 # Read recruitment devs
#
# FISHING MORTALITY PARAMETERS
=============================================================================================
# Fishing mortality (F) parameterization
0.1 # F ballpark for tuning early phases
-2000 # F ballpark year (negative value = off)
```

```
3 # F method: 1 = Pope, 2 = instantaneous F, 3 = hybrid
4 # F or Harvest rate (depends on F method)
# Read overall start F value, overall phase, N detailed inputs to read for F method = 2
10 # Read N iterations for tuning for F method = 3 (recommend 3 to 7)
# Initial F parameters ** non-equilibrium initial age distribution implemented **
# Low High Initial Prior_mean Prior_type SD Phase
0 3 0 0 -1 0 -1 # Initial F (F1)
#
# CATCHABILITY (q) PARAMETERS
==============================================================================================
# Columns: Do den_dep power: 0 = off and survey is proportional to abundance, 1 = add parameter
for non-linearity
#          Do env_link: 0 = off, 1 = add parameter for env effect on q
#          Do extra SD: 0 = off, 1 = add parameter for additive constant to input SE in ln space
#          q_type: <0 = mirror other fishery/survey, 0 = no parameter q - median unbiased, 1 = no
parameter q - mean unbiased, 2 = estimate parameter for ln(q),
#                          3 = ln(q)+set of devs about ln(q) for all years - parm_rand_dev, 4 =
ln(q)+set of devs about q for index_yr-1 - parm_rand_walk
0 0 0 0 # F1 = FISHERY
0 0 0 0 # S1 = CPFV
#
# SELECTIVITY (S) PARAMETERS
==============================================================================================
# Selectivity/retention parameterization
# Size (length) parameterization
# A = selectivity option: 1 - 34
# B = do retention: 0 = no, 1 = yes
# C = male offset to female: 0 = no, 1 = yes
# D = mirror selectivity (fishery/survey)
# A B C D
# Size selectivity (S)
0 0 0 0 # F1
0 0 0 0 # S1
#
# Age selectivity (S)
20 0 0 0 # F1 (double-normal, asymptotic)
12 0 0 0 # S1 (simple logistic)
# F1 (double-normal, forced asymptotic)
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block
Block_Fxn
-1 8 0.0811923 0 -1 0 4 0 0 0 0 0 0 0 # AgeSel_1P_1_FISHERY
-10 10 1 0 -1 0 -4 0 0 0 0 0 0 0 # AgeSel_1P_2_FISHERY
-10 10 -6.3687 0 -1 0 4 0 0 0 0 0 0 0 # AgeSel_1P_3_FISHERY
-10 10 5 0 -1 0 -4 0 0 0 0 0 0 0 # AgeSel_1P_4_FISHERY
-10 10 -0.316017 0 -1 0 4 0 0 0 0 0 0 0 # AgeSel_1P_5_FISHERY
-10 10 10 0 -1 0 -4 0 0 0 0 0 0 0 # AgeSel_1P_6_FISHERY
#
# S1 (logistic, asymptotic)
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block
Block_Fxn
-5 12 1 0 -1 0 4 0 0 0 0 0 0 0 # AgeSel_1P_1_CPFV
-5 15 1 0 -1 0 4 0 0 0 0 0 0 0 # AgeSel_2P_2_CPFV
#
# Tag loss and reporting parameterization
0 # TG_custom: 0 = no read, 1 = read if tags exist
#
# LIKELIHOOD COMPONENT PARAMETERS
==============================================================================================
1 # Variance and sample size/effective sample size adjustments (by fleet/survey): (0/1)
# F1 S1
0 0 # constant (added) to survey CV
0 0 # constant (added) to discard CV
0 0 # constant (added) to body weight CV
1 1 # scalar (multiplied) to length distribution sample size (effective ss)
1 1 # scalar (multipled) to age distribution sample size (effective ss)
1 1 # scalar (multiplied) to size-at-age distribution sample size (effective ss)
#
1 # Maximum lambda phase: 1 = none
1 # SD offset: 1 = include
#
# Likelihood component (lambda) parameterization
```

```
# Likelihood component codes: 1 = survey, 2 = discard, 3 = mean body weight, 4 = length
distribution, 5 = age distribution, 6 = weight distribution,
#                              7 = size-at-age distribution, 8 = catch, 9 = initial equilibrium
catch, 10 = recruitment devs, 11 = parameter priors,
#                             12 = parameter devs, 13 = crash penalty, 14 = morph composition, 15
= tag composition, 16 = tag neg_bin
8 # Number of changes to likelihood components
# Columns: Likelihood_comp Fishery/Survey Phase Lambda_value Size_distribtuion_method
# Surveys
1 2 1 1 1 # Survey S1
# Length distributions
4 1 1 0 1 # Length distribution F1 = off
4 2 1 1 1 # Length distribution S1
# Age distributions
5 1 1 1 1 # Age distribution F1
# Mean size-at-age distributions
7 1 1 1 1 # Size-at-age distribution F1
# Equilibrium catch
9 1 1 0 1 # Equilibrium catch F1 = off
# Priors
11 1 1 0 1 # Priors F1 = off
11 2 1 0 1 # Priors S1 = off
#
0 # SD reporting option: (0/1)
999 # End of file
```

DATA FILE

```
# P. mackerel stock assessment (April 2015)
# Stock Synthesis 3 (v. 3.24s)
# Model H3
#
# DATA FILE
#
1983 # Start year
2014 # End year
1 # Number of 'seasons' (quarters)
12 # Number of months per season
1 # Spawning season
1 # Number of fishing 'fleets' (fisheries) (F1 = FISHERY (USA commercial+Mexico commercial+USA
recreational)
1 # Number of 'surveys' (S1 = CPFV CPUE)
1 # Number of areas (populations)
#
FISHERY%CPFV
0.5 0.5 # Fishery/survey timing within time block
1 1 # Area assignment for each fishery/survey
1 # Catch units: 1=biomass, 2=numbers
0.01 # SE of ln(catch)
1 # Number of genders
12 # Number of ages (accumulator age)
# Catch: initial (annual) 'equilibrium' catch (mt)
0
# Number of catch records (lines)
32
# Catch time series (biomass in mt): Columns=fisheries, year, season
40235.4 1983    1
45241.4 1984    1
45446.3 1985    1
52471.6 1986    1
47913.0 1987    1
48655.9 1988    1
47721.6 1989    1
71230.9 1990    1
64885.8 1991    1
32546.3 1992    1
20805.8 1993    1
24100.1 1994    1
12086.1 1995    1
24687.1 1996    1
```

```
52870.4 1997    1
63319.4 1998    1
16212.7 1999    1
27978.9 2000    1
13583.7 2001    1
14499.0 2002    1
9125.3  2003    1
7401.3  2004    1
8405.5  2005    1
10939.5 2006    1
9472.5  2007    1
5353.9  2008    1
3656.0  2009    1
4229.7  2010    1
4309.0  2011    1
12972.9 2012    1
14746.9 2013    1
10124.0 2014    1
#
# Number of observations (lines) for all surveys (indices)
32
# Columns: Fishery/Survey, Units (0=numbers, 1=biomass, 2=F), Error type (-1=normal,
0=lognormal), >0=t-dist. (df = input value
#
1 1 0 # F1 = FISHERY
2 0 0 # S1 = CPFV
# Columns:  Year,   Season,   Survey,   Observation,   Error
# CPFV CPUE
1983   1      2      68.50   0.3 # 0.08
1984   1      2      76.45   0.3 # 0.08
1985   1      2      58.71   0.3 # 0.08
1986   1      2      46.94   0.3 # 0.09
1987   1      2      31.54   0.3 # 0.09
1988   1      2      21.95   0.3 # 0.10
1989   1      2      31.49   0.3 # 0.09
1990   1      2      33.34   0.3 # 0.10
1991   1      2      37.24   0.3 # 0.09
1992   1      2      27.91   0.3 # 0.10
1993   1      2      33.01   0.3 # 0.10
1994   1      2      30.95   0.3 # 0.09
1995   1      2      27.55   0.3 # 0.10
1996   1      2      30.89   0.3 # 0.09
1997   1      2      17.11   0.3 # 0.10
1998   1      2      9.42    0.3 # 0.11
1999   1      2      5.47    0.3 # 0.12
2000   1      2      10.87   0.3 # 0.12
2001   1      2      8.21    0.3 # 0.12
2002   1      2      6.61    0.3 # 0.14
2003   1      2      3.99    0.3 # 0.19
2004   1      2      7.13    0.3 # 0.22
2005   1      2      11.50   0.3 # 0.28
2006   1      2      10.48   0.3 # 0.23
2007   1      2      14.90   0.3 # 0.23
2008   1      2      20.72   0.3 # 0.26
2009   1      2      17.73   0.3 # 0.54
2010   1      2      5.43    0.3 # 0.26
2011   1      2      2.61    0.3 # 0.17
2012   1      2      2.30    0.3 # 0.28
2013   1      2      10.13   0.3 # 0.71
2014   1      2      3.07    0.3 # 0.31
#
# Discard parameterization
0 # Number of Fisheries with discard
# Columns: Fishery, Units, Error type
0 # Number of discard observations (lines)
# Mean body weight parameterization
0 # Number of mean body weight observations (lines)
100 # df for t-dist - not conditional, i.e., needs number even if no mean body weight
observations
# Population size distributions
```

```
1 # Length bin method: 1 = use fishery length bins below, 2 = generate from min/max/width below,
3 = read count and vector below
0 # Compression of length/age distribution 'tails'
0.0001 # Constant added to length/age data (constant added to expected frequencies)
0 # Combine males and females at or below this bin number
# Fishery/Survey size distributions
60 # Number of length bins
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
55 # Number of fishery length distribution observations (lines) ** Length distributions for
Fishery 1 are not used **
# Length distributions (1983-14) - annual (percent)
# Length distributions: Columns=year, season, fishery/survey, gender, partition, sample size,
length bin observations (in numbers)
# Commercial fishery
1983    1       1       0       0       107.76  0       0       0       0       0       0       0
        0       0       0       0.00051 0.00309 0.00103 0.00412 0.00412 0.00206 0.00671 0.00414 0.00373
        0.00455 0.00554 0.00267 0.00267 0.0073  0.00934 0.01826 0.02943 0.05492 0.08524 0.12456 0.14253
        0.14796 0.13965 0.09109 0.05229 0.02945 0.01259 0.00664 0.0018  0.00166 0.00033 0       0
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0
1984    1       1       0       0       95.76   0       0       0       0       0       0       0
        0       0       0       0       0       0       0.00029 0.00043 0.00085 0.00114 0.00074 0.00129
        0.00287 0.00483 0.00444 0.00307 0.00341 0.0016  0.00198 0       0.01358 0.04433 0.09257 0.15088
        0.14844 0.12001 0.11182 0.10213 0.08172 0.05358 0.03468 0.01266 0.0049  0.00178 0       0
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0
1985    1       1       0       0       104.28  0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0       0       0
        0.00025 0.0018  0.00547 0.00967 0.00789 0.00669 0.01827 0.03019 0.027   0.04712 0.04066 0.07364
        0.13568 0.182   0.16408 0.10772 0.07676 0.03996 0.01756 0.00492 0.00182 0.00085 0       0
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0
1986    1       1       0       0       120     0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0.0008  0.00791 0.01481
        0.00363 0.00903 0.00714 0.00989 0.01574 0.03733 0.06093 0.0817  0.09699 0.0921  0.06523 0.05427
        0.06008 0.06887 0.1     0.08347 0.06098 0.03734 0.01728 0.00857 0.00348 0.00144 0.00077 0.00021
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0
1987    1       1       0       0       166     0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0       0.00092 0.00281
        0.00773 0.00899 0.01462 0.02403 0.03322 0.0571  0.08708 0.08753 0.07858 0.07557 0.0926  0.12775
        0.09659 0.05212 0.03795 0.02617 0.02545 0.02404 0.01827 0.0167  0.00352 0.00047 0.00018 0
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0
1988    1       1       0       0       179.16  0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0.00017 0.00147 0.01289
        0.10495 0.19485 0.16238 0.09122 0.02914 0.00958 0.00615 0.00854 0.0168  0.03295 0.04738 0.05438
        0.04697 0.04208 0.03528 0.02965 0.01739 0.01275 0.01624 0.01402 0.00862 0.00295 0.00096 0.00022
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0
1989    1       1       0       0       143.32  0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0       0.00097 0.00105
        0.01623 0.03961 0.03608 0.1151  0.27105 0.21053 0.10905 0.05121 0.02927 0.02127 0.01097 0.01027
        0.00688 0.00943 0.00887 0.01044 0.01441 0.01093 0.00849 0.00624 0.00101 0.00063 0       0
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0
1990    1       1       0       0       84.84   0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0.00133 0.01339 0.02467
        0.01973 0.01403 0.01918 0.0102  0.00485 0.00828 0.02453 0.03208 0.04772 0.04952 0.07317 0.06633
        0.05207 0.03945 0.0471  0.08189 0.10969 0.1245  0.07357 0.03678 0.01832 0.00563 0.002   0
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0
1991    1       1       0       0       67.56   0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0.00105 0.02127 0.05875 0.0499
        0.03122 0.02887 0.01809 0.01319 0.01773 0.04722 0.08367 0.09064 0.08493 0.0692  0.0346  0.01162
        0.02256 0.04359 0.05019 0.05373 0.05289 0.0471  0.03762 0.0179  0.00886 0.00271 0.0009  0
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0
1992    1       1       0       0       80.6    0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0.00054 0.00096 0.01085 0.02585
```

	0.03671	0.02616	0.02442	0.05285	0.07975	0.09465	0.07378	0.04793	0.03342	0.02864	0.03762	0.03641
	0.0396	0.03926	0.06174	0.06867	0.07897	0.0539	0.03421	0.00924	0.00311	0.00075	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0							
1993	1	1	0	0	109.6	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0.00417	0.04571	0.11772	0.12186
	0.0972	0.09109	0.03997	0.0239	0.01395	0.03512	0.04096	0.04396	0.05066	0.06065	0.03998	0.02477
	0.01021	0.0055	0.00916	0.02095	0.02442	0.02768	0.02355	0.01745	0.0055	0.00353	0	0.0004
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0							
1994	1	1	0	0	174.28	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0.00019	0	0.00268	0.0146
	0.05403	0.10952	0.12686	0.15286	0.17661	0.1277	0.05756	0.04323	0.02742	0.01801	0.02138	0.01333
	0.01153	0.00525	0.00362	0.00286	0.00603	0.01109	0.00737	0.0042	0.00137	0.00071	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0							
1995	1	1	0	0	108.72	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.052	0.152
	0.191	0.130	0.087	0.047	0.053	0.068	0.071	0.042	0.030	0.008	0.008	0.007
	0.008	0.003	0.003	0.002	0.003	0.010	0.010	0.005	0.003	0.002	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
1996	1	1	0	0	88.88	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.005	0.007
	0.033	0.062	0.082	0.092	0.080	0.079	0.064	0.051	0.052	0.039	0.034	0.026
	0.026	0.036	0.030	0.035	0.027	0.047	0.033	0.038	0.015	0.001	0.001	0.000
	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
1997	1	1	0	0	108.88	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.001	0.001	0.002	0.007	0.009	0.031	0.058	0.080	0.059	0.048	0.042	0.052
	0.065	0.043	0.055	0.063	0.071	0.094	0.100	0.076	0.035	0.006	0.001	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
1998	1	1	0	0	90.44	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.006
	0.007	0.012	0.018	0.017	0.006	0.008	0.019	0.027	0.063	0.098	0.088	0.080
	0.060	0.048	0.039	0.080	0.115	0.092	0.061	0.033	0.020	0.002	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
1999	1	1	0	0	66.96	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.003	0.011	0.034	0.036	0.031	0.024	0.025	0.039	0.026	0.019	0.021	0.020
	0.034	0.074	0.129	0.127	0.127	0.105	0.067	0.028	0.010	0.001	0.004	0.002
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2000	1	1	0	0	76.76	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.004
	0.014	0.019	0.013	0.010	0.006	0.007	0.016	0.029	0.064	0.073	0.055	0.027
	0.015	0.037	0.100	0.176	0.128	0.101	0.071	0.020	0.009	0.006	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2001	1	1	0	0	84.56	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.012
	0.025	0.024	0.018	0.016	0.021	0.060	0.124	0.142	0.126	0.076	0.041	0.030
	0.020	0.019	0.048	0.052	0.056	0.044	0.023	0.011	0.004	0.001	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2002	1	1	0	0	86.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.007
	0.015	0.027	0.025	0.042	0.062	0.108	0.188	0.217	0.175	0.056	0.032	0.017
	0.009	0.004	0.004	0.004	0.002	0.003	0.002	0.002	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2003	1	1	0	0	63.96	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.019
	0.061	0.120	0.095	0.077	0.026	0.026	0.066	0.090	0.106	0.080	0.052	0.026
	0.027	0.023	0.024	0.020	0.021	0.015	0.015	0.006	0.001	0.001	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							

2004	1	1	0	0	101.88	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.005	0.007	0.018
	0.040	0.078	0.148	0.154	0.154	0.130	0.080	0.050	0.054	0.029	0.010	0.009
	0.007	0.006	0.002	0.003	0.004	0.002	0.004	0.002	0.001	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2005	1	1	0	0	92.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.013	0.019	0.080
	0.162	0.172	0.134	0.075	0.038	0.033	0.042	0.025	0.042	0.052	0.052	0.028
	0.014	0.009	0.002	0.000	0.001	0.002	0.001	0.001	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2006	1	1	0	0	96.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.008	0.017
	0.055	0.104	0.115	0.119	0.124	0.100	0.068	0.072	0.058	0.040	0.028	0.021
	0.011	0.008	0.018	0.007	0.002	0.004	0.006	0.006	0.005	0.002	0.001	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2007	1	1	0	0	64.60	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.057	0.043	0.023
	0.049	0.108	0.087	0.067	0.052	0.062	0.054	0.039	0.038	0.046	0.036	0.037
	0.019	0.022	0.025	0.037	0.029	0.017	0.019	0.008	0.012	0.005	0.004	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2008	1	1	0	0	29.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.009	0.036
	0.074	0.066	0.045	0.039	0.037	0.032	0.053	0.049	0.053	0.022	0.007	0.018
	0.010	0.056	0.069	0.087	0.083	0.066	0.043	0.025	0.006	0.008	0.003	0.003
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2009	1	1	0	0	17.60	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
	0.007	0.003	0.001	0.011	0.057	0.109	0.173	0.177	0.161	0.083	0.021	0.005
	0.029	0.009	0.015	0.016	0.019	0.031	0.008	0.023	0.014	0.018	0.008	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2010	1	1	0	0	20.48	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.101
	0.170	0.141	0.080	0.052	0.030	0.056	0.043	0.038	0.041	0.028	0.053	0.026
	0.016	0.030	0.026	0.006	0.011	0.011	0.016	0.007	0.006	0.002	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2011	1	1	0	0	31.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.017	0.032	0.102
	0.117	0.133	0.131	0.097	0.084	0.059	0.052	0.048	0.059	0.030	0.013	0.005
	0.007	0.000	0.001	0.001	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2012	1	1	0	0	47.92	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.007	0.019	0.040
	0.051	0.057	0.075	0.074	0.109	0.124	0.167	0.113	0.059	0.040	0.034	0.016
	0.005	0.001	0.000	0.002	0.000	0.002	0.001	0.003	0.001	0.001	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2013	1	1	0	0	72.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.012	0.015
	0.071	0.130	0.195	0.167	0.096	0.074	0.044	0.038	0.052	0.018	0.017	0.019
	0.012	0.009	0.007	0.006	0.002	0.001	0.001	0.002	0.003	0.002	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
2014	1	1	0	0	16.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.016
	0.022	0.044	0.151	0.184	0.093	0.113	0.089	0.076	0.067	0.028	0.036	0.017
	0.012	0.010	0.003	0.015	0.012	0.005	0.001	0.000	0.001	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000							
# CPFV												
1992	1	2	0	0	6.4		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0188	0.0188	0.0438	0.0625	0.1000	0.0750	0.0750	0.0313	0.0438
	0.0188	0.0500	0.0563	0.0625	0.0875	0.0563	0.0875	0.0500	0.0125	0.0250	0.0125	0.0000

	0.0063	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0063
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000						
1993	1	2	0	0	31.44	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0064	0.0064	0.0089	0.0305	0.0331	0.0445	0.0700	0.0623	0.0649	0.0445
	0.0420	0.0534	0.0458	0.0458	0.0891	0.1056	0.0992	0.0802	0.0394	0.0102	0.0038	0.0025
	0.0000	0.0013	0.0000	0.0000	0.0000	0.0000	0.0013	0.0000	0.0025	0.0000	0.0013	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0051							
1994	1	2	0	0	19		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0021
	0.0000	0.0042	0.0000	0.0063	0.0042	0.0063	0.0105	0.0126	0.0168	0.0316	0.0274	0.0400
	0.0632	0.0716	0.0358	0.0337	0.0463	0.0947	0.1179	0.1705	0.0779	0.0800	0.0295	0.0063
	0.0021	0.0021	0.0021	0.0000	0.0000	0.0000	0.0021	0.0021	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000						
1995	1	2	0	0	45.2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0009	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0018	0.0062	0.0142	0.0319	0.0398	0.0416	0.0443	0.0372	0.0354	0.0407
	0.0372	0.0301	0.0363	0.0319	0.0575	0.1053	0.1434	0.1274	0.0823	0.0336	0.0089	0.0035
	0.0027	0.0027	0.0018	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000							
1996	1	2	0	0	33.48	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0012	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0060	0.0060	0.0072	0.0227	0.0203	0.0227	0.0347	0.0239	0.0287	0.0466	0.0299
	0.0454	0.0311	0.0335	0.0406	0.0526	0.0992	0.1482	0.1482	0.0824	0.0490	0.0131	0.0012
	0.0024	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0036							
1997	1	2	0	0	47.24	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0025	0.0009	0.0025	0.0059	0.0144	0.0279	0.0398	0.0237	0.0398	0.0491	0.0618	0.0728
	0.0762	0.0610	0.0474	0.0525	0.0610	0.0567	0.0796	0.0813	0.0703	0.0313	0.0152	0.0085
	0.0127	0.0034	0.0000	0.0000	0.0000	0.0000	0.0000	0.0009	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0009	0.0000							
1998	1	2	0	0	24.44	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0016	0.0000
	0.0000	0.0000	0.0033	0.0049	0.0033	0.0082	0.0049	0.0393	0.0475	0.0524	0.0573	0.0524
	0.0376	0.0278	0.0507	0.0671	0.0998	0.1342	0.1080	0.1080	0.0589	0.0213	0.0066	0.0000
	0.0016	0.0000	0.0016	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0016							
1999	1	2	0	0	24.68	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0016	0.0000	0.0000	0.0016	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0016	0.0000	0.0032	0.0000	0.0081	0.0162	0.0178	0.0227	0.0195	0.0276	0.0292	0.0340
	0.0567	0.0535	0.1167	0.1426	0.1443	0.1005	0.0729	0.0584	0.0470	0.0162	0.0065	0.0000
	0.0000	0.0000	0.0000	0.0016	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000							
2000	1	2	0	0	15.6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0026
	0.0051	0.0026	0.0103	0.0154	0.0256	0.0308	0.0333	0.0231	0.0385	0.0641	0.0872	0.0282
	0.0256	0.0436	0.0821	0.1282	0.1128	0.0795	0.0615	0.0641	0.0231	0.0103	0.0026	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000							
2001	1	2	0	0	16.52	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0024
	0.0048	0.0048	0.0073	0.0097	0.0194	0.0170	0.0218	0.0436	0.0702	0.0581	0.0896	0.0557
	0.0509	0.0436	0.1041	0.1138	0.1065	0.0702	0.0726	0.0170	0.0121	0.0024	0.0024	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000							
2002	1	2	0	0	21.04	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0019	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0019
	0.0019	0.0057	0.0038	0.0323	0.0228	0.0380	0.0494	0.0875	0.0989	0.0780	0.0684	0.0589
	0.0589	0.0475	0.0627	0.0475	0.0608	0.0551	0.0418	0.0380	0.0266	0.0057	0.0038	0.0000
	0.0000	0.0000	0.0000	0.0019	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000							
2003	1	2	0	0	21.6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0037
	0.0037	0.0056	0.0185	0.0444	0.0315	0.0463	0.0630	0.0556	0.0889	0.0556	0.0537	0.0463
	0.0333	0.0222	0.0296	0.0352	0.0463	0.0963	0.0870	0.0759	0.0296	0.0148	0.0019	0.0037
	0.0000	0.0000	0.0000	0.0019	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0019	0.0037							
2004	1	2	0	0	21.72	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0074	0.0055	0.0276	0.0258	0.0516	0.0921	0.0589	0.0405	0.0681	0.0516	0.0737	0.0718

```
        0.0332 0.0350 0.0368 0.0276 0.0497 0.0497 0.0608 0.0774 0.0313 0.0184 0.0000 0.0018
        0.0018 0.0018 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000
2005    1      2      0      0      24.84  0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0032 0.0032
        0.0290 0.0709 0.0854 0.0854 0.0821 0.0612 0.0612 0.0773 0.0805 0.0628 0.0966 0.0596
        0.0467 0.0242 0.0225 0.0081 0.0032 0.0048 0.0064 0.0064 0.0081 0.0048 0.0016 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0016
        0.0000 0.0016 0.0016 0.0000 0.0000
2006    1      2      0      0      24.08  0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0017 0.0017 0.0000 0.0017 0.0000
        0.0066 0.0183 0.0548 0.0864 0.0897 0.0864 0.0880 0.0947 0.0864 0.0797 0.0831 0.0532
        0.0399 0.0282 0.0166 0.0083 0.0199 0.0100 0.0066 0.0116 0.0116 0.0083 0.0050 0.0017
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000
2007    1      2      0      0      44.72  0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0009 0.0009
        0.0081 0.0259 0.0304 0.0438 0.0725 0.0760 0.1073 0.1118 0.1127 0.0868 0.0796 0.0420
        0.0420 0.0331 0.0286 0.0188 0.0125 0.0098 0.0152 0.0125 0.0089 0.0107 0.0045 0.0018
        0.0009 0.0000 0.0009 0.0000 0.0000 0.0009 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000
2008    1      2      0      0      44.68  0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0018 0.0063
        0.0188 0.0224 0.0197 0.0134 0.0224 0.0295 0.0537 0.0546 0.1021 0.1334 0.1280 0.0671
        0.0627 0.0483 0.0304 0.0340 0.0215 0.0349 0.0206 0.0179 0.0287 0.0170 0.0036 0.0036
        0.0000 0.0027 0.0000 0.0009 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000
2009    1      2      0      0      37.76  0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0011 0.0064
        0.0233 0.0191 0.0170 0.0201 0.0392 0.0636 0.1049 0.1261 0.1186 0.0848 0.0773 0.0371
        0.0371 0.0297 0.0275 0.0328 0.0424 0.0339 0.0201 0.0138 0.0085 0.0085 0.0021 0.0021
        0.0011 0.0000 0.0011 0.0000 0.0000 0.0000 0.0011 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000
2010    1      2      0      0      15.08  0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0027 0.0080 0.0080 0.0212
        0.0584 0.0318 0.0318 0.0478 0.0796 0.0981 0.1406 0.0902 0.0849 0.0637 0.0424 0.0292
        0.0239 0.0239 0.0106 0.0265 0.0292 0.0080 0.0080 0.0106 0.0080 0.0106 0.0000 0.0027
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000
2011    1      2      0      0      26.44  0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0015 0.0015 0.0000 0.0015 0.0000 0.0000 0.0045
        0.0257 0.0318 0.0378 0.0681 0.1195 0.1558 0.1044 0.1256 0.1180 0.0953 0.0469 0.0136
        0.0121 0.0061 0.0015 0.0015 0.0000 0.0061 0.0061 0.0000 0.0061 0.0015 0.0000 0.0030
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000
2012    1      2      0      0      21.92  0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0018 0.0018 0.0055 0.0037 0.0000
        0.0073 0.0091 0.0274 0.0292 0.0402 0.0712 0.1588 0.1661 0.1642 0.0985 0.0639 0.0475
        0.0383 0.0237 0.0128 0.0037 0.0018 0.0055 0.0037 0.0110 0.0018 0.0000 0.0018 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000
2013    1      2      0      0      27.16  0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0030 0.0015 0.0000 0.0030
        0.0118 0.0133 0.0560 0.0869 0.0633 0.0530 0.0781 0.0781 0.0884 0.0692 0.0736 0.0486
        0.0736 0.0589 0.0398 0.0398 0.0177 0.0074 0.0074 0.0147 0.0074 0.0015 0.0015 0.0015
        0.0000 0.0000 0.0015 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000
2014    1      2      0      0      22.8   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0018 0.0053 0.0018 0.0035
        0.0035 0.0193 0.0228 0.0421 0.0790 0.0947 0.0790 0.1474 0.1439 0.1228 0.1000 0.0333
        0.0228 0.0123 0.0193 0.0193 0.0105 0.0070 0.0053 0.0000 0.0018 0.0018 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
        0.0000 0.0000 0.0000 0.0000 0.0000
#
# Fishery age distributions
9 # Number of age_bins
0 1 2 3 4 5 6 7 8
1 # Number of ageing error matrices ('Accumulator age' -12 + 1 vectors)
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 # Age bin mid-points
0.406 0.642 0.712 0.784 0.992 1.304 1.345 1.5 1.637 1.809 1.964 2.119 2.273 # Age bin SD
#
```

```
32 # Number of age distributions observations (lines)
2 # Length bin method for Lbin_lo and Lbin_hi: 1 = use population length bin index, 2 = use
length data bin index, 3 = actual lengths (must use population length index option)
-1 # Combine males and females at or below this bin number
#
# Fishery age distributions (1983-14) - annual (percent)
# Age distributions: Columns=year, season, fishery/survey, gender, partition, ageing error (age
bin  SD), Lbin_lo, Lbin_hi, sample size, age bin observations (in percent)
1983    1       1       0       0       1       -1      -1      106.72  0.0337  0.0237  0.3555  0.3644
        0.0552  0.1652  0.0024  0.0000  0.0000
1984    1       1       0       0       1       -1      -1      91.64   0.0157  0.0051  0.0910  0.4566
        0.2605  0.0722  0.0966  0.0025  0.0000
1985    1       1       0       0       1       -1      -1      104.24  0.0333  0.1553  0.0505  0.1506
        0.4735  0.1110  0.0139  0.0118  0.0000
1986    1       1       0       0       1       -1      -1      120.00  0.1607  0.3262  0.1530  0.0383
        0.0675  0.1840  0.0545  0.0088  0.0072
1987    1       1       0       0       1       -1      -1      165.16  0.1041  0.4923  0.2558  0.0425
        0.0219  0.0284  0.0343  0.0148  0.0060
1988    1       1       0       0       1       -1      -1      179.08  0.6065  0.0764  0.1727  0.0667
        0.0164  0.0100  0.0138  0.0207  0.0170
1989    1       1       0       0       1       -1      -1      143.32  0.0893  0.8171  0.0266  0.0225
        0.0146  0.0106  0.0074  0.0043  0.0078
1990    1       1       0       0       1       -1      -1      84.56   0.1108  0.1180  0.2624  0.0910
        0.1393  0.1355  0.0485  0.0457  0.0488
1991    1       1       0       0       1       -1      -1      66.20   0.2065  0.4218  0.0672  0.1026
        0.0620  0.0670  0.0392  0.0147  0.0190
1992    1       1       0       0       1       -1      -1      79.76   0.1273  0.3260  0.1379  0.1098
        0.1116  0.0872  0.0608  0.0299  0.0096
1993    1       1       0       0       1       -1      -1      107.52  0.5541  0.1491  0.1431  0.0330
        0.0388  0.0350  0.0164  0.0179  0.0126
1994    1       1       0       0       1       -1      -1      124.56  0.3518  0.4550  0.1026  0.0387
        0.0209  0.0102  0.0123  0.0048  0.0039
1995    1       1       0       0       1       -1      -1      108.24  0.6261  0.2660  0.0604  0.0102
        0.0042  0.0145  0.0090  0.0064  0.0032
1996    1       1       0       0       1       -1      -1      87.56   0.2321  0.3573  0.1517  0.0906
        0.0724  0.0457  0.0185  0.0199  0.0119
1997    1       1       0       0       1       -1      -1      108.56  0.0353  0.2175  0.2105  0.1169
        0.1068  0.1010  0.0660  0.0558  0.0903
1998    1       1       0       0       1       -1      -1      90.20   0.0653  0.1138  0.2623  0.1529
        0.1142  0.0969  0.0797  0.0504  0.0644
1999    1       1       0       0       1       -1      -1      66.64   0.1614  0.0675  0.0726  0.2042
        0.2235  0.1533  0.0580  0.0367  0.0229
2000    1       1       0       0       1       -1      -1      76.40   0.0562  0.2017  0.0927  0.1714
        0.2297  0.1443  0.0658  0.0230  0.0152
2001    1       1       0       0       1       -1      -1      84.44   0.1015  0.5450  0.0978  0.0604
        0.0818  0.0625  0.0313  0.0142  0.0056
2002    1       1       0       0       1       -1      -1      85.80   0.1069  0.7857  0.0784  0.0167
        0.0036  0.0056  0.0031  0.0000  0.0000
2003    1       1       0       0       1       -1      -1      62.80   0.4068  0.3640  0.1244  0.0520
        0.0178  0.0198  0.0108  0.0033  0.0013
2004    1       1       0       0       1       -1      -1      101.16  0.8643  0.0889  0.0246  0.0129
        0.0061  0.0014  0.0009  0.0001  0.0009
2005    1       1       0       0       1       -1      -1      91.96   0.7213  0.1740  0.0820  0.0111
        0.0058  0.0037  0.0014  0.0007  0.0000
2006    1       1       0       0       1       -1      -1      95.72   0.5422  0.3375  0.0642  0.0327
        0.0133  0.0054  0.0036  0.0011  0.0000
2007    1       1       0       0       1       -1      -1      64.36   0.4314  0.2523  0.1382  0.0979
        0.0456  0.0219  0.0093  0.0035  0.0000
2008    1       1       0       0       1       -1      -1      28.92   0.2199  0.2015  0.1580  0.3034
        0.0948  0.0205  0.0019  0.0000  0.0000
2009    1       1       0       0       1       -1      -1      16.88   0.0544  0.6898  0.0957  0.0848
        0.0538  0.0129  0.0086  0.0000  0.0000
2010    1       1       0       0       1       -1      -1      19.88   0.3981  0.3235  0.1735  0.0651
        0.0267  0.0108  0.0023  0.0000  0.0000
2011    1       1       0       0       1       -1      -1      30.84   0.6824  0.2906  0.0240  0.0018
        0.0013  0.0000  0.0000  0.0000  0.0000
2012    1       1       0       0       1       -1      -1      47.80   0.3283  0.5993  0.0602  0.0077
        0.0013  0.0019  0.0013  0.0000  0.0000
2013    1       1       0       0       1       -1      -1      71.72   0.7624  0.1185  0.0753  0.0297
        0.0083  0.0020  0.0021  0.0017  0.0000
```

```
2014   1      1      0      0      1      -1     -1     16.00  0.5460 0.3304 0.0746 0.0269
       0.0222 0.0000 0.0000 0.0000 0.0000
#
# Fishery mean length-at-age distributions
32 # Number of mean length-at-age observations (lines)
# Mean length-at-age distributions (1983-14) - annual (cm)
# Mean length-at-age distributions: Columns=year, season, fishery/survey, gender, partition,
ageing  error, sample size (nominal only), mean length-at-age observations (in  cm), mean length-
at-age sample sizes
1983   1      1      0      0      1      1      16.5   25.8   29.7   31.9   33.4   34.4
       37.2   -1.0   -1.0   2.68   2.68   41.96  37.04  5.84   16.28  0.24   0.00   0.00
1984   1      1      0      0      1      1      22.7   27.7   30.8   31.8   34.0   36.1
       36.6   40.3   -1.0   2.84   0.56   9.48   45.04  21.20  5.32   7.04   0.16   0.00
1985   1      1      0      0      1      1      23.7   28.5   32.2   33.1   33.6   35.0
       36.3   37.6   -1.0   4.24   15.76  5.28   16.12  49.36  10.96  1.40   1.12   0.00
1986   1      1      0      0      1      1      24.0   28.4   31.4   33.6   34.6   35.1
       35.6   37.1   38.0   20.96  39.88  17.88  4.56   7.68   20.96  6.20   0.96   0.92
1987   1      1      0      0      1      1      23.3   28.1   31.4   33.9   35.4   36.8
       37.2   37.9   38.7   25.04  82.48  36.76  6.08   3.16   3.88   4.76   2.12   0.88
1988   1      1      0      0      1      1      21.6   29.0   31.4   34.0   35.5   36.6
       38.2   -1.0   39.1   112.00 13.20  28.44  11.52  2.72   1.84   2.44   0.00   3.12
1989   1      1      0      0      1      1      21.3   24.9   30.1   33.9   35.6   36.7
       37.6   -1.0   38.6   19.36  111.00 4.76   3.00   1.72   1.16   0.88   0.00   0.92
1990   1      1      0      0      1      1      20.7   27.6   30.8   34.2   36.1   36.6
       37.4   38.1   39.0   18.20  9.92   20.48  6.24   9.56   9.84   3.64   3.20   3.48
1991   1      1      0      0      1      1      19.3   27.0   31.9   34.0   35.5   36.5
       37.0   37.6   38.6   13.56  28.00  4.88   6.60   4.00   4.00   2.68   1.04   1.44
1992   1      1      0      0      1      1      20.5   25.1   29.5   32.2   34.2   35.8
       36.3   36.7   38.1   12.80  30.32  11.68  8.20   6.76   4.80   2.96   1.60   0.64
1993   1      1      0      0      1      1      19.7   27.1   29.0   32.0   36.0   36.4
       38.1   38.1   39.0   60.44  15.32  14.84  3.60   4.08   3.80   2.04   2.04   1.36
1994   1      1      0      0      1      1      21.7   24.5   27.6   30.8   33.9   36.0
       37.1   38.1   39.2   55.60  48.60  10.08  4.04   2.64   1.36   1.32   0.56   0.36
1995   1      1      0      0      1      1      20.2   25.1   28.0   31.5   35.6   37.0
       38.4   -1.0   40.1   67.16  28.64  6.36   1.12   0.80   1.92   1.00   0.00   0.40
1996   1      1      0      0      1      1      21.8   25.0   29.7   33.3   36.0   37.2
       38.0   38.2   39.1   27.64  29.16  11.88  6.96   4.60   3.16   1.80   1.36   1.00
1997   1      1      0      0      1      1      25.1   27.6   30.7   33.5   35.5   36.9
       38.0   38.3   38.6   7.28   28.20  23.92  12.48  8.92   8.52   6.08   5.00   8.16
1998   1      1      0      0      1      1      22.0   28.1   30.0   32.5   35.1   36.5
       36.7   37.4   38.0   8.52   14.20  28.84  14.40  7.52   5.76   4.60   2.92   3.44
1999   1      1      0      0      1      1      23.7   27.0   31.4   34.1   35.0   36.1
       36.8   37.8   38.9   24.80  5.44   4.68   9.56   9.32   6.88   2.80   1.80   1.36
2000   1      1      0      0      1      1      21.4   28.4   30.5   34.9   35.5   36.0
       36.4   37.2   38.0   33.28  12.48  4.32   7.28   9.08   5.80   2.60   0.96   0.60
2001   1      1      0      0      1      1      21.3   27.2   29.7   34.2   35.4   36.3
       -1.0   36.3   35.8   23.68  36.88  6.88   4.28   5.04   4.32   0.00   0.88   0.40
2002   1      1      0      0      1      1      22.2   26.5   29.2   31.8   35.0   34.4
       36.4   -1.0   -1.0   20.52  55.44  7.04   1.72   0.36   0.44   0.28   0.00   0.00
2003   1      1      0      0      1      1      21.6   27.5   30.7   34.3   35.8   37.3
       37.8   38.0   38.7   32.60  17.24  7.12   3.04   0.96   0.96   0.60   0.20   0.08
2004   1      1      0      0      1      1      23.4   27.7   31.0   35.3   36.9   37.7
       38.5   -1.0   39.5   84.00  10.76  3.28   2.08   0.72   0.12   0.08   0.00   0.08
2005   1      1      0      0      1      1      21.2   27.3   30.2   32.0   33.8   36.2
       -1.0   39.0   -1.0   68.96  15.36  5.84   1.00   0.44   0.24   0.00   0.04   0.00
2006   1      1      0      0      1      1      22.3   26.4   30.4   34.0   38.1   39.6
       39.9   40.8   -1.0   55.60  26.28  5.88   3.48   2.44   1.00   0.80   0.24   0.00
2007   1      1      0      0      1      1      20.5   26.1   29.8   34.1   36.1   38.7
       39.7   40.4   -1.0   32.68  15.52  7.00   5.20   2.32   1.08   0.44   0.12   0.00
2008   1      1      0      0      1      1      20.4   26.0   28.8   35.0   37.1   39.5
       -1.0   -1.0   -1.0   7.84   9.04   4.56   5.12   1.84   0.44   0.00   0.00   0.00
2009   1      1      0      0      1      1      23.3   26.7   30.1   36.0   37.8   40.3
       42.0   -1.0   -1.0   5.16   7.64   1.68   1.48   0.72   0.12   0.08   0.00   0.00
2010   1      1      0      0      1      1      20.3   23.6   29.3   34.2   37.4   39.1
       -1.0   -1.0   -1.0   7.08   7.56   3.24   1.24   0.52   0.20   0.00   0.00   0.00
2011   1      1      0      0      1      1      21.2   25.9   29.5   35.5   36.1   -1.0
       -1.0   -1.0   -1.0   19.76  9.72   1.20   0.08   0.08   0.00   0.00   0.00   0.00
2012   1      1      0      0      1      1      21.5   25.8   29.7   33.7   38.9   -1.0
       39.5   -1.0   -1.0   17.12  26.56  3.28   0.52   0.12   0.00   0.08   0.00   0.00
2013   1      1      0      0      1      1      22.4   26.0   29.1   32.7   36.1   -1.0
       38.9   38.9   -1.0   50.96  8.48   6.20   4.16   1.08   0.00   0.36   0.16   0.00
```

```
2014   1      1      0      0      1      1      22.6   26.6   30.1   33.1   36.1   -1.0
       -1.0   -1.0   -1.0   7.20   6.64   1.36   0.48   0.32   2.00   0.00   0.00   0.00
#
0 # Number of 'environmental' variables
0 # Number of 'environmental' observations
0 # Weight distributions
0 # Tag data
0 # Morph data
999 # End of file
```