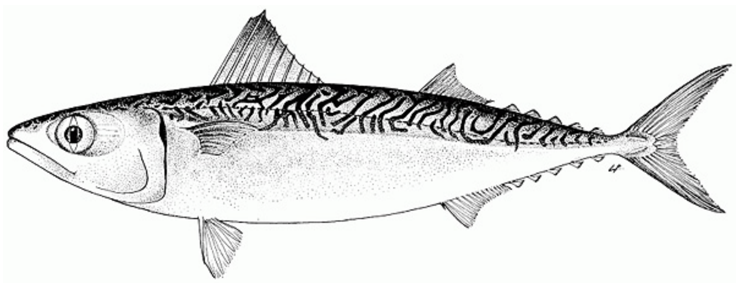
PACIFIC MACKEREL (*Scomber japonicus*) STOCK ASSESSMENT FOR USA MANAGEMENT IN THE 2009-10 FISHING YEAR



by

P. R. Crone, K. T. Hill, J.D. McDaniel, and N. C. H. Lo
NOAA Fisheries
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla, California, 92037

Submitted to

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

August 1, 2009

Crone, P. R., K. T. Hill, J. D. McDaniel, and N. C. H. Lo. 2009. Pacific mackerel (*Scomber japonicus*) stock assessment for USA management in the 2009-10 fishing year. Pacific Fishery Management Council, Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220, USA. 197 p.

TABLE OF CONTENTS

Page

Page

PREFACE

A Pacific mackerel stock assessment is conducted annually in support of the Pacific Fishery Management Council (PFMC) process, which ultimately establishes a harvest guideline ('HG' or quota) for the Pacific mackerel fishery that operates off the USA Pacific coast. The HG for mackerel applies to a fishing/management season that spans from July 1st and ends on June 30th of the subsequent year (henceforth, presented as a 'fishing year'). In this context, in this document, both a two-year (e.g., 2009-10) and single-year (e.g., 2009) reference refer to the same fishing year that spanned from July 1, 2009 to June 30, 2010. The primary purpose of the assessment is to provide an estimate of current abundance (in biomass), which is used in a harvest control rule for calculation of annual-based HGs. For details regarding this species' harvest control rule, see Amendment 8 of the Coastal Pelagic Species (CPS) Fishery Management Plan (FMP), section 4.0 (PFMC 1998).

The last updated assessment and quota-setting (HG) process was completed in May 2008, i.e., the assessment was considered a formal 'update,' as defined by the PFMC (see PFMC 2009). The 2008-09 fishing year (July1, 2008 – June 30, 2009) harvest guideline was 51,722 mt. The stock assessment presented here reflects a 'full' assessment that has undergone formal review as outlined by the PFMC and Science and Statistical Committee (SSC), see STAR (2009). Specifically, a week-long stock assessment review (STAR) panel was convened from May 4-8, 2009 (NOAA Fisheries, Southwest Fisheries Science Center in La Jolla, CA) to evaluate the ongoing Pacific mackerel stock assessment, as well as two independent surveys presently under consideration in the Pacific sardine assessment. Important areas of general consensus reached by the STAR panel that pertained to the stock assessment follow:

- The Pacific mackerel stock assessment team (STAT) met all four objective, including:
  1) produced an updated assessment based on the current model relied upon for management purposes, namely, the Age-structured Assessment Program (ASAP) model;
  2) produced a baseline Stock Synthesis (SS) model that generally mirrored the current management-based ASAP model;
  3) produced a suite of alternative SS model (scenarios) that improved upon the baseline SS model; and
  4) from the suite of SS model scenarios, identified the best configuration(s) based on both statistical and practical considerations.
- The recommended HG for the 2009-10 fishing year (July1, 2009 – June 30, 2010) is 55,408 mt:
  1) the final HG reflects substantial sensitivity analysis prior to and during the STAR;
  2) the final HG was based on SS model scenario (*AA*); and
  3) SS model scenario *AB* was identified as a meaningful alternative model and likely a candidate baseline model in the future, given issues surrounding critical areas of data availability (e.g., recreational fishery statistics) and related model parameterization (selectivity and catchability) can be addressed in the interim and within the overall assessment cycle.
- Documentation of the assessment report following the STAR should:
  1) 'begin with' the final consensus model from the STAR (namely, SS model *AA*) … objective four above;

2) provide cricital statistics from relevant scenarios involved in the overall sensitivity analysis (e.g., SS model *AB*) … objective three above;
3) use appendices for related analysis that supported the (draft) assessment initially presented at the STAR … objectives one and two above; and finally,
4) meet stipulations set forth in the CPS stock assessment 'terms of reference' (PFMC 2009).

EXECUTIVE SUMMARY

Stock

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

Catches

Pacific mackerel landings from both commercial and recreational fisheries in California and commercial landings in Baja California represent the catch time series (1962-08) used in the assessment, with landings pooled into the two broadly-defined fisheries for all modeling purposes, i.e., commercial and recreational fishing sectors, respectively. Historically, total catch time series over the last 100 years can be broadly defined by two or more 'modes,' e.g., late 1920s to mid 1960s and late 1970s to the present (Figure ES-1). Recent catches are presented in Table ES-1.

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

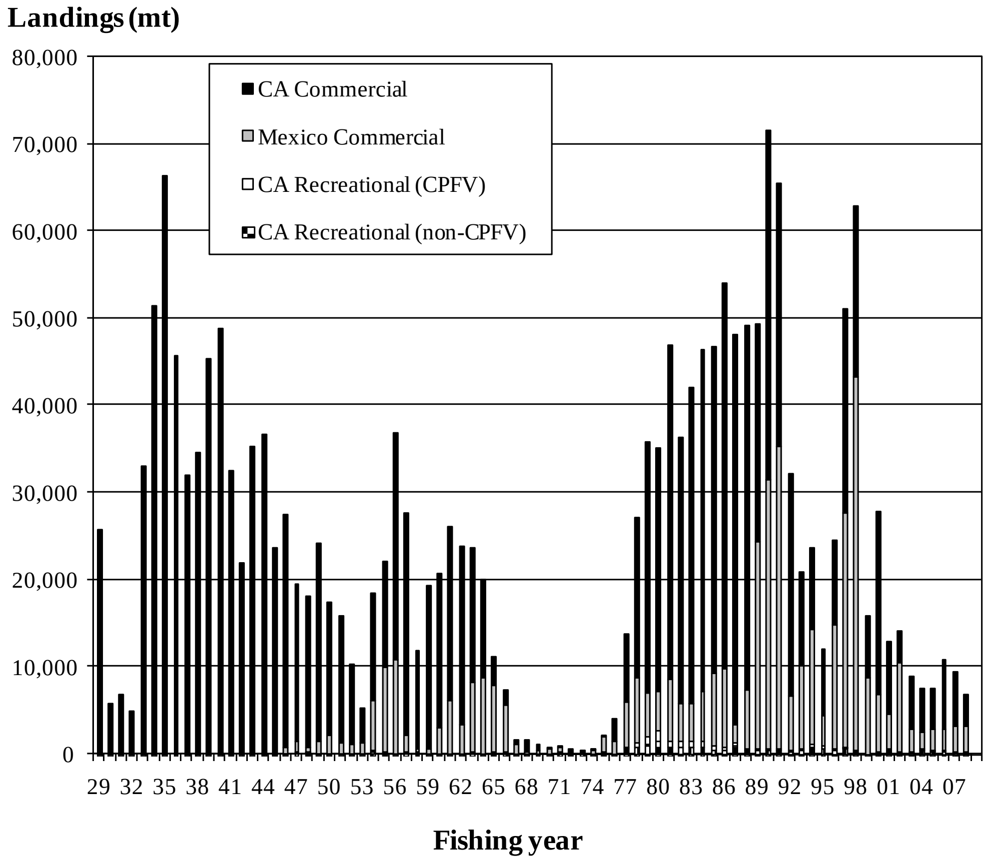


Figure ES-1. Commercial and recreational landings (mt) of Pacific mackerel in the USA (CA commercial, recreational-CPFV, and recreational-non-CPFV) and Mexico (commercial), (1929-08).

Table ES-1. Commercial and recreational landings (mt) of Pacific mackerel in the USA (CA commercial, recreational-CPFV, and recreational-non-CPFV) and Mexico (commercial), (1998-08).

Fishing year	USA Commercial (mt)	Mexico Commercial (mt)	Recreational CPFV (mt)	Recreational non-CPFV (mt)	Total (mt)
98	19,578	42,815	108	322	62,823
99	7,170	8,587	55	97	15,910
00	20,936	6,530	78	248	27,792
01	8,436	4,003	51	520	13,010
02	3,541	10,328	22	232	14,123
03	5,972	2,618	28	295	8,913
04	5,012	2,017	23	510	7,562
05	4,572	2,507	21	375	7,475
06	7,870	2,567	15	356	10,808
07	6,208	2,914	18	289	9,429
08	3,599	2,914	19	272	6,803

Data and assessment
Historically, various age-structured assessment models have been used to assess the status of Pacific mackerel off the west coast of North America, which were generally based on fishery landings, fishery age/length distributions, and relative indices of abundance. The last assessment of Pacific mackerel was completed in 2008 for USA management in the 2008-09 fishing year. The current assessment includes the following data (i.e., time series, with 'additional year' updates noted where applicable): catch (1962-08, updated); and a CPFV-based catch-per-unit-effort (CPUE) index (1962-08, updated). The final model (scenario) for management advice for the upcoming fishing year (2009-10) was based on the Stock Synthesis (SS) model (i.e., model scenario *AA*), which realized fruition through general consensus from STAR deliberations (see Preface).

Unresolved problems and uncertainties
First and foremost, given Pacific mackerel is a 'transboundary' stock, the assessment would benefit greatly from additional biological and/or 'survey' (e.g., relative abundance index data) from Mexico. In particular, there is currently no synoptic survey (fishery-independent) index of abundance that pertains to the entire (hypothesized) range of the modeled stock. Secondly, alternative model scenarios (e.g., model scenario *AB*) that included more detailed parameterization of both historical and recent patterns in selectivity and catchability provided a more realistic envelope of the uncertainty associated with stock status determinations for this species than otherwise indicated in a single baseline model, i.e., as expected, recent estimates of absolute abundance differ depending on assumptions regarding time-varying selectivity/catchability in the baseline model. Also, see Research and data needs below.

Total stock biomass
Total biomass (age-1+ biomass, *B*) remained low from the early 1960s to the mid 1970s, at which time the population began to rapidly increase in size, reaching a peak in the early 1980s (see Recruitment below). From the mid 1980s to early 2000s, the stock declined steadily, with some signs of 'rebuilding' (on an increasing limb of a historical distribution say) observed recently (Figure ES-2 and Table ES-2). However, as noted previously, recent estimates of stock size are necessarily related to assumptions regarding the dynamics of the fish (biology) and fishery (operations) over the last several years, which generally confounds long-term (abundance) forecasts for this species. For example, see estimated *B* time series from alternative SS model *AB*, which generally mirrored SS model *AA*, except in the most recent years, with stock size plateauing at historically low levels, rather than increasing (Figure ES-2).

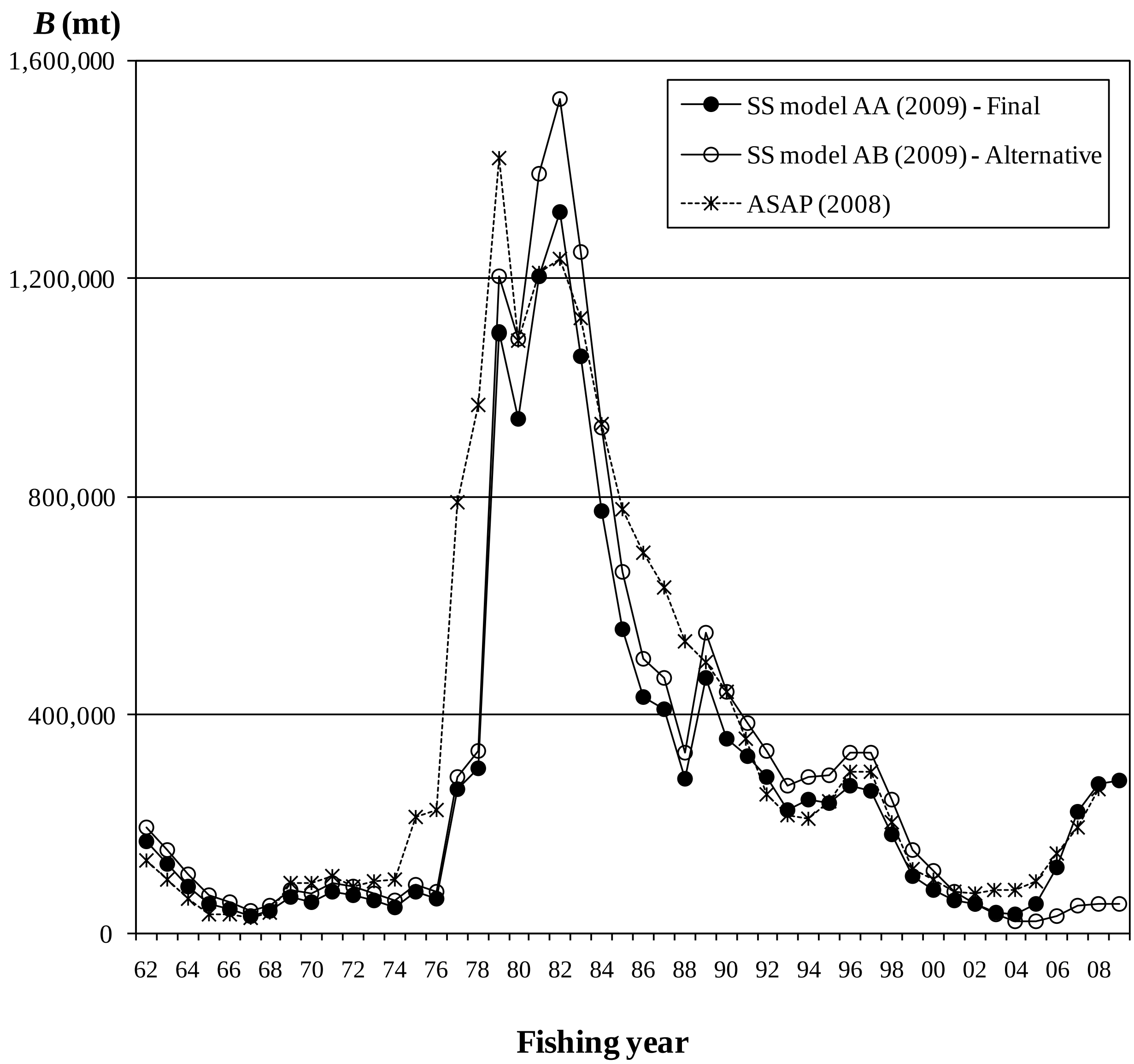


Figure ES-2. Estimated total stock biomass (age 1+ fish in mt, *B*) of Pacific mackerel based on the final SS model *AA* and alternative model *AB* (1962-09). Also, *B* time series from previous year's assessment (ASAP 2008) is presented for comparative purposes.

Table ES-2. Estimated recruitment (*R*), total biomass (*B*), and spawning stock biomass (*SSB*) of Pacific mackerel based on SS model *AA* (1962-09).

Fishing year	***R* (age-0, in 1,000s)**	***B* (age-1+, mt)**	***SSB* (mt)**
98	161,490	183,255	98,203
99	123,450	105,797	62,788
00	180,740	82,186	49,944
01	138,930	61,600	31,390
02	74,874	55,063	24,482
03	94,906	40,828	19,203
04	254,870	36,511	16,281
05	607,540	56,348	16,684
06	939,810	122,581	24,639
07	688,600	222,969	44,981
08	452,530	275,211	76,440
09		282,049	

Spawning stock biomass

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

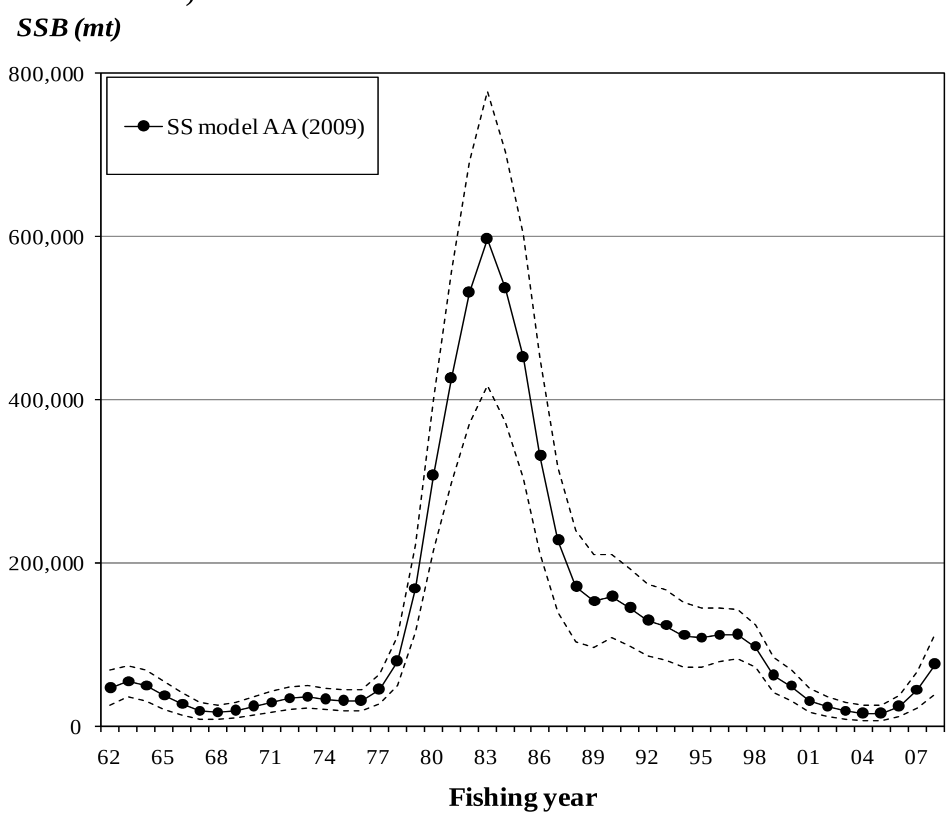


Figure ES-3. Estimated spawning stock biomass (*SSB*) of Pacific mackerel based on SS model *AA* (1962-08). Confidence interval (± 2 SD) is also presented as dashed lines.

Recruitment

As expected, historically, estimated recruitment (*R*) has been highly variable, remaining relatively low up until the mid 1970s, increasing markedly in magnitude from the late 1970s through the early 1980s, with stock productivity remaining relatively low since this time (Figure ES-4 and Table ES-2).

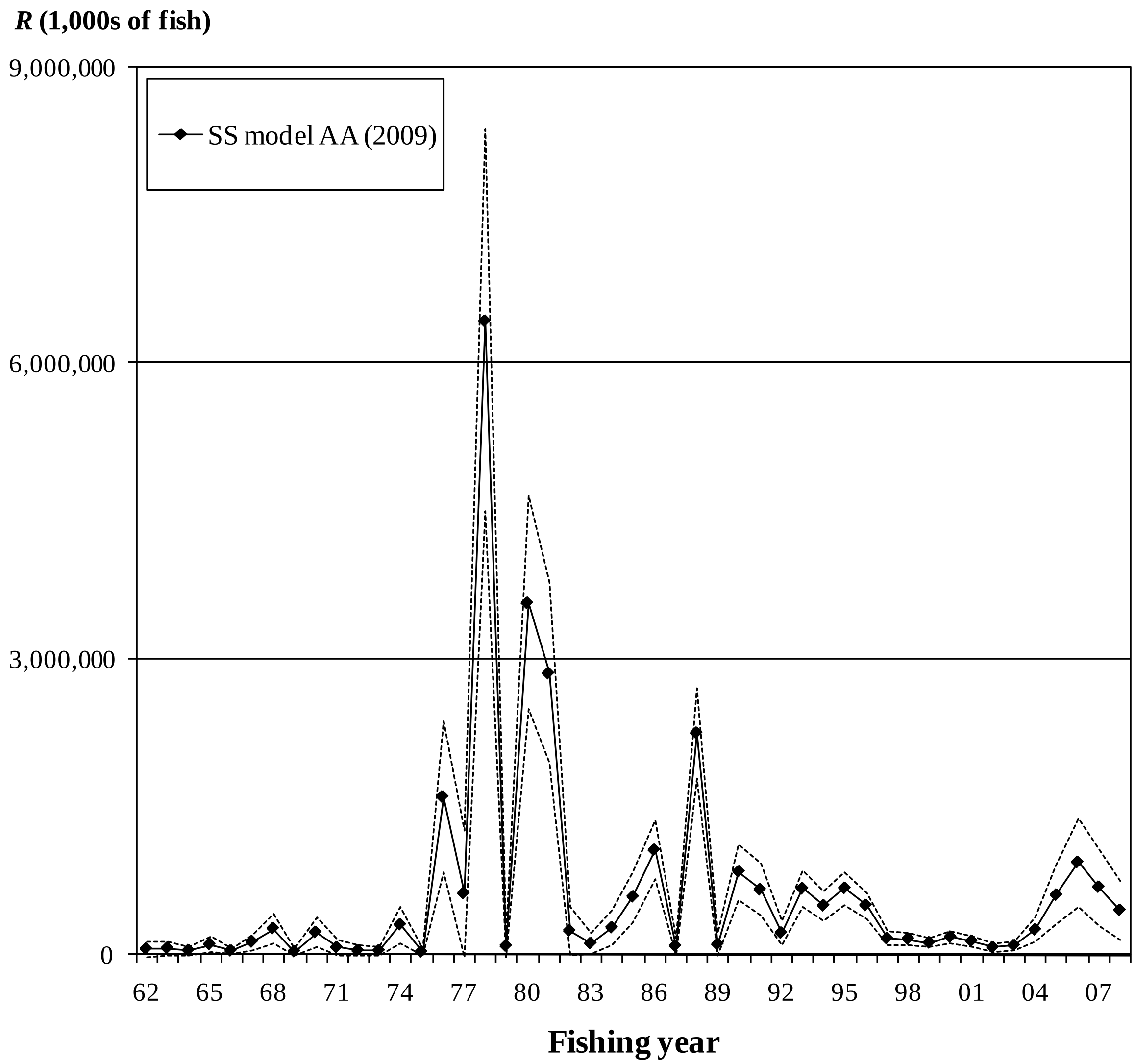


Figure ES-4. Estimated recruitment (age-0 fish in 1,000s, *R*) of Pacific mackerel based on SS model *AA* (1962-08). Confidence interval (± 2 SD) is also presented as dashed lines.

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

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

where Harvest is the harvest guideline (HG), Biomass is the estimated total stock biomass (age 1+) in 2009 (282,049 mt), Cutoff (18,200 mt) is the lowest level of estimated biomass at which harvest is allowed, Fraction (30%) is the proportion of biomass above the Cutoff that can be harvested by fisheries, and Distribution (70%) is the average fraction of total biomass assumed in USA waters (PFMC 1998). The HGs under the federal FMP are applied to a July-June fishing 'year.' Landings and associated HGs since 1992 are presented in Figure ES-5.

The HG for the 2009-10 fishing year based on SS model *AA* is 55,408 mt (Table ES-3).

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 20,000 mt from 2001-06. In 2007, the HG was increased substantially to over 100,000 mt based largely on assumptions regarding variability surrounding estimated recruitment and has remained at an elevated level since then (Figure ES-5). It is important to note that since the 2001 fishing year, from a management context, the fishery has failed to fully utilize HGs, with average yields since this time of roughly 5,000 mt (Figure ES-5).

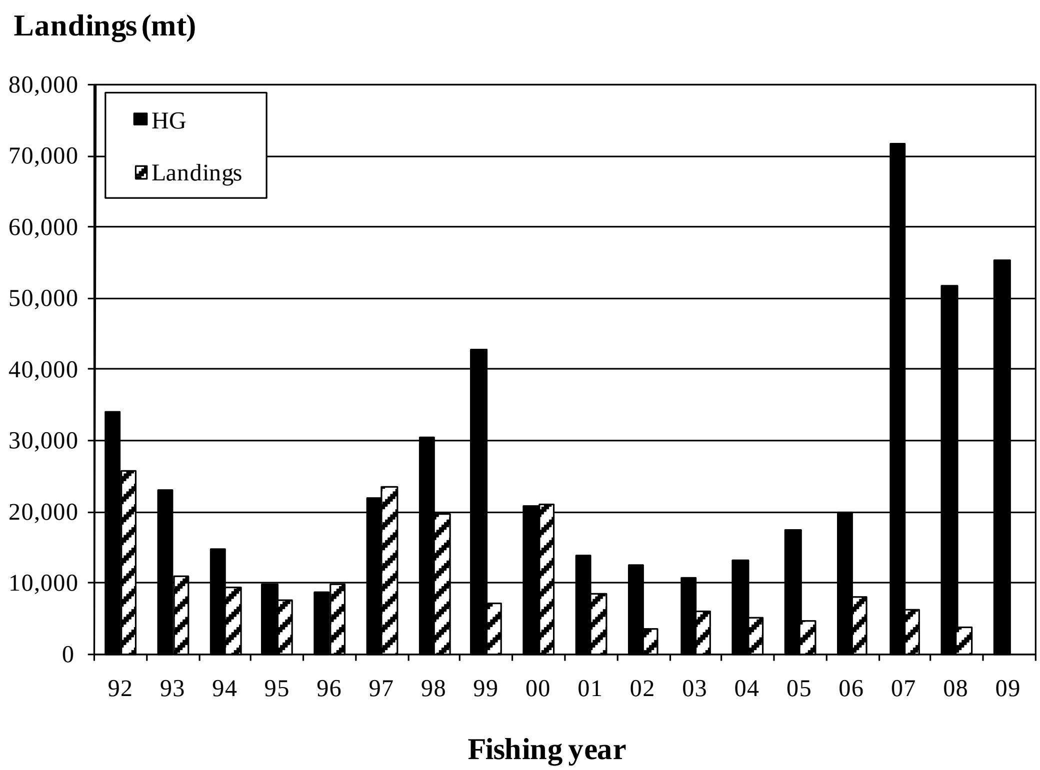


Figure ES-5. Commercial landings (California directed fishery, mt) and quotas (HGs, mt) for Pacific mackerel (1992-08).

Table ES-3. Harvest control rule statistics for the Pacific mackerel fishing year 2009-10.

B **(Age 1+, mt)**	**Cutoff (mt)**	**Fraction**	**Distribution**	**HG (mt)**
282,049	18,200	30%	70%	**55,408**

Research and data needs

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

Second, fishery-independent survey data for measuring (relative) changes in mackerel spawning (or total) biomass are currently lacking. Further, at this time, a single index of relative abundance is used in the assessment, which is developed from a marine recreational fishery (CPFV fleet) that typically does not (directly) target the species. In this context, it is imperative that future research funds be focused on improvement of the current CPFV survey, with emphasis on a long-term horizon, which will necessarily rely on cooperative efforts between the industry, research, and management bodies. Additionally, we strongly support development of a well-designed logbook monitoring program associated with the current commercial (purse-seine) fishery, which has been long overdue.

Third, given the importance of age (and length) distribution time series to developing a sound understanding of this species' population dynamics, it is critical that data collection programs at the federal and particularly, the state-level continue to be supported adequately. In particular, CDFG/NOAA funding should be bolstered to ensure ongoing ageing-related laboratory work is not interrupted, as well as providing necessary funds for related biological research that is long overdue. For example, maturity-related time series currently relied upon in the assessment model are based on data collected over twenty years ago during a period of high spawning biomass that does not reflect current levels. Also, further work is needed to obtain more timely error estimates from production ageing efforts in the laboratory, i.e., accurate interpretation of age-distribution data used in the ongoing assessment necessarily requires a reliable ageing error time series. Finally, examinations of sex-specific age distributions will allow hypotheses regarding natural mortality/selectivity (i.e., absence of older animals in sex-combined age distributions) to be more fully evaluated.

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

INTRODUCTION

Distribution

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

Migration

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

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

Life history

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

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

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

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

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

Stock structure and management units

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

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

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

Fishery descriptions

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

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

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

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

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

Management history

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

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

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

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

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

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

Management performance

From 1985 to 1991, the biomass exceeded 136,000 mt and no state quota restrictions were in effect. State quotas for 1992-00 fishing years averaged roughly 24,000 mt. From 2001-06, HGs averaged roughly 20,000 mt. In 2007, the HG was increased substantially to over 100,000 mt based largely on assumptions regarding variability surrounding estimated recruitment and has remained at an elevated level since then. It is important to note that since the 2001 fishing year, from a management context, the fishery has failed to fully utilize HGs, with average yields since this time of roughly 5,000 mt.

ASSESSMENT

Ultimately, the final Pacific mackerel stock assessment model presented here reflects two primary changes from recently conducted assessments: (1) a transition from the ASAP model to the SS model was completed; and (2) two survey-related indices of abundance were omitted due to concerns associated with potential sampling biases (applicable to this species strictly), i.e., a spotter survey based on aerial sightings from planes and a California Cooperative Oceanic Fisheries Investigations (CalCOFI) index of daily larval abundance (see STAR 2009). Other changes associated with estimation methods for influential areas of parameterization were also necessary, given the transition to the new modeling platform (SS), e.g., more flexibility examining: the spatial/temporal structure of the baseline model; starting the model; recruitment; fishing mortality; and selectivity/catchability (pertinent changes are documented below). Parameterization details associated with SS model *AA* are presented below (see Model description). Also, see Responses to past STAR/SSC recommendations below.

A full suite of assessment-related displays for the final SS model *AA* are presented in the body of this document. Addtionally, for comparative purposes, results from alternative models examined through sensitivity analysis (e.g., SS model *AB*) are presented along with model *AA* for pertinent displays. Program files associated with SS model *AA* are presented in Appendix 1. Appendix 2A-B is used to present particular displays associated with the initial baseline SS model (*S1_aa*) and ASAP (2009) model, i.e., objectives one and two (see Preface). Finally, Table 4 (as well as Appendix Table A2B-1) presents a broad range of important parameter-related statistics associated with the key model scenarios reviewed during the recently conducted STAR in May 2009.

History of modeling approaches

Parrish and MacCall (1978) were the first to provide stock status determinations for Pacific mackerel using an age-structured population model (i.e., traditional virtual population analysis, VPA). The ADEPT model (the 'ADAPT' VPA modified for Pacific mackerel; Jacobson 1993 and Jacobson et al. 1994b) was used to evaluate stock status and establish management quotas for approximately 10 years. The assessment conducted in 2004 (for 2004-05 management) represented the final ADEPT-based analysis for this stock (see Hill and Crone 2004a). The forward-simulation model ASAP (Legault and Restrepo 1998) was reviewed and adopted for Pacific mackerel at the 2004 STAR (Hill and Crone 2004b). The ASAP model has been in place for assessments and management advice since the 2005-06 fishing year (e.g., see Dorval et al. 2008). The STAR conducted in 2009 determined that the SS model provided the best (most flexible) platform for assessing the status of Pacific mackerel currently (i.e., the 2009-10 fishing year) and in the future, see Preface and STAR (2009).

Sources of data

Fishery-dependent data

Overview

Fishery-related data for assessing Pacific mackerel included landings (California commercial, California recreational, and Mexico commercial), port sample (biological) data from California's commercial (purse seine) and recreational (CPFV) fisheries, as well as logbook data from the CPFV fleet used to develop a catch-per-unit-effort (CPUE) index. Since 1992, the CDFG has collected biological data on Pacific mackerel landed in the southern California fishery (primarily San Pedro). Samples have also been collected from the Monterey fishery when available. For this assessment, raw sample data were available from 1939 through 2008. Biological samples include whole body weight, fork length, sex, maturity, and otoliths for age determination. Currently, CDFG collects 12 'random' (port) samples per month (25 fish per sample) to determine length/age distributions, catch-at-age, weight-at-age, etc. for the directed fishery. Mexico port sampling data have been collected by INP-Ensenada since 1989, but have not been available for purposes of inclusion in this ongoing assessment effort and thus, California commercial data were assumed to be representative of the combined commercial fisheries. Lack of Baja California port sampling data is not a serious problem for some years when Mexico catches were low. However, in recent years, Baja California and California catches have been roughly equal in volume, which necessarily increases the likelihood that potential biases associated with the omission of (and subsequent assumptions concerning) sample data from the Mexico fishery. Sample sizes associated with this data collection program are presented in Table 1.

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

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

Catches

The assessment includes commercial and recreational landings in California and commercial landings in Baja California (Mexico) from 1962 to 2008. Annual (fishing year) landing estimates of Pacific mackerel are presented in Table 2 and Figure 1.

California commercial landings of Pacific mackerel were obtained from a variety of sources based on dealer landing receipts (CDFG) and in some cases, augmented with port sampling for mixed load portions. Data from 1929-61 were obtained from Parrish and MacCall (1978). Monthly landings for the period May 1962 to September 1976 were obtained from CDFG fish bulletins recovered to an electronic data base format (PFEL 2005). Raw landing receipt data for Pacific mackerel from 1976 to 1991 were of marginal quality, owing to the large quantities of Pacific mackerel landed as mixed loads with jack mackerel. During this period, many processors reported either species as 'unspecified' mackerel on landing receipts. For these years, mackerel landings receipts were augmented with shoreside 'bucket' sampling of mixed loads to estimate species compositions. The CDFG reported these data in two forms: (1) annual stock status reports to the California legislature; and (2) single page 'CDFG Wetfish Tables.' Both sources are considered more accurate than PacFIN or other landing receipt-based statistics for this period. Data sources from late 1976 to the present are as follows: October-December 1976 are from Klingbeil and Wolf (1986); January-December 1977 are from Wolf and Worcester (1988); January 1978-December 1981 are from Jacobson et al. (1994a); January 1982-February 2009 are from CDFG Wetfish Tables; and finally, landing estimates for March-June 2009 and July 2009-June 2010 were assumed to be similar to the analogous time blocks of the previous year, namely, March-June 2008 and July 2008-June 2009, respectively. Pacific mackerel landings from 1976-81 were only reported by quarterly increments and thus, for purposes of weighting catch-at-age estimates for this period (see Catch-at-age below), we apportioned quarters to months using monthly 'unspecified mackerel' landings from the PFEL LAS database (PFEL 2005).

California recreational landings (mt) from 1980 to the present (2-month 'wave' resolution) were obtained directly from Pacific RecFIN estimates. Historical estimates (pre-1980) of total recreational catch were derived from CPFV logbook data collected since 1936 (Hill and Schneider 1999). The CPFV catch (number) was converted to metric tons using an assumed average weight of 0.453 kg (1 lb) per individual, based on RecFIN samples and consistent with Parrish and MacCall (1978). The CPFV harvest was expanded to total recreational tonnage using wave-specific ratios from RecFIN. Nominal amounts of recreational removals were assumed for 1929-35 and 1941-46 when no recreational statistics were available.

Baja California data include landings from commercial purse seine fisheries in Ensenada, Cedros Island, and Magdalena Bay. Ensenada landings were compiled as follows: 1946-47 through 1969-70 (May-April) data are from Parrish and MacCall (1978); 1970-71 through 1975-76 (May-April) data are from Schaefer (1980); quarterly data from July 1976 through December 1986 are from Jacobson et al. (1994b); monthly data from January 1987 through November 2003 were provided by INP-Ensenada (Garcia and Sánchez, 2003; Celia Eva-Cotero, INP-Ensenada, personal communication, INP-Ensenada staff); monthly landings from December 2003 through December 2004 were not available and thus, were substituted with corresponding months from the previous year. Ensenada landings in 2005, available from Cota et al. (2006), were apportioned into monthly catch using ratios from the previous few years. Ensenada landings for January to June 2006 were taken from Cota et al. (2006). Monthly landing data for the Cedros Island (January 1981-December 1994) and Magdalena Bay (January 1981 – May 2003) fisheries were provided by R. Felix-Uraga (CICIMAR-IPN, La Paz, personal communication). The fishery off Cedros Island ceased in 1994. Magdalena Bay landings for June 2003 through June 2007 were substituted with corresponding months from the previous year. Monthly-resolution catch statistics for Mexico were not available for all seasons and thus, for purposes of weighting catch-at-age estimates (see Catch-at-age section), aggregate catch data (season or quarter) were apportioned to months by inflating the corresponding California data.

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

Length distributions

The SS model scenarios included length distributions for the USA recreational (CPFV) fishery only, i.e., utilizing age-based selectivity. In general, age-based selectivity was used in SS model scenarios, including: age distribution time series from the fishery, as well as mean length-at-age time series (see Age distributions and Mean length-at-age distributions below); and length distribution time series (no age data available) from the recreational fishery. Length distributions for the recreational fishery (CPFV fishing mode only) were developed from the Pacific RecFIN data base using angler examined catch data from 1992 to 2008 (Figure 2).

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

Age distributions

Age distribution time series were developed from the same (CDFG) port sample data base described previously, i.e., the sampling program entails recording length, sex, age (via otolith collections), etc. from each fish in the 25-fish sample taken from a completed fishing trip. It is important to note that age (and length) distributions developed from this sampling program are considered to be representative of the landings associated with the (commercial) fishery and thus, serve as the foundation for evaluating cohort dynamics in the fully-integrated models. Ultimately, age distributions (in proportion-at-age) were based on 9 age bins that represented age-0 to age-8+, i.e., a 'plus group' that includes $\geq$8-yr old fish. The total number of ages (say specimens measured for age) observed in each distribution was divided by 25 (the average number of fish collected per sample) and subsequently, used as the effective sample size in baseline model configurations. Ultimately, age distributions (in numbers of fish) were converted to proportion estimates for all modeling efforts. In sensitivity analysis, biological distributions were based on both annual and quarter time-steps, depending on the model scenario, with the final SS model *AA* being annual-based. Annual age distributions (1962-08) associated with all models are presented in Figure 3. Mean age (annual) statistics are presented in Figure 4.

Mean length-at-age distributions

For the primary purpose of evaluating growth dynamics associated with this species, mean length-at-age time series (1962-08) were developed from the same (CDFG) port sample data base described above and used in conjunction with age distributions in SS model scenarios (Figure 5). Effective sample size estimates were obtained using the same 25-fish adjustment employed for the other biological distributions, based on typically sample sizes from a completed fishing trip.

Ageing error distribution

In efforts to provide the most realistic measure of uncertainty associated with estimated age distribution time series, an ageing error vector, based on standard 'double-read' methods, was also included in all model scenarios, i.e., a SD vector by age was used in all SS model scenarios (Figure 6). It is important to note that further ageing error analysis pertaining to this species is warranted, given the current vector is considered preliminary at this time.

Commercial passenger fishing vessel (CPFV) index of abundance

California Fish and Game legislation has required CPFV captains to provide records of catch and effort data to CDFG since 1936. In the past, Pacific mackerel have been among the top five species reported on CPFV logs, both in southern California and state-wide. This information resides in a logbook data base (Hill and Barnes 1998; Hill and Schneider 1999) that summarizes CPFV catch and effort by month and Fish and Game statistical blocks (10 nm^2). A single state-wide index of relative abundance was developed, based on a Delta-Generalized Linear Model (delta-GLM) approach for estimating year effects, i.e., a CPUE time series of relative abundance (Figure 7). The index is based on a fishing year basis, as is the case with other time series used in the models. Selectivity parameterization associated with this index mirrored the recreational fishery (i.e., age-based selectivity based on length distribution time series).

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

(1) data were combined within year/quarter/fleet strata (i.e., the overall, statewide fishery was partitioned into a northern and southern 'fleet' based on latitude/longitude spatial fishing 'blocks');
(2) CPUE was calculated (number of fish/1,000 angler-hours fishing) for each spatial/temporal stratum;
(3) fishing years 1935-36 to 2008-09 were used in the analysis, with the exception of a few years that were omitted due to missing data (e.g., 1941-42 to 1945-46);
(4) latitude/longitude blocks were combined into broader spatial areas based on the fishing practices of the northern and southern CPFV fleets, i.e., historically, the southern fleet has exerted the vast amount of fishing pressure associated with this overall fishery (Pt. Conception was used as the 'north/south' delimiter to partition the two regional fleets);
(5) the delta-GLM method models the probability of obtaining a zero catch and the catch rate separately, given the catch rate is non-zero (Stefansson 1996; Maunder and Punt 2004). In this assessment, we estimate the probability of a positive observation using a binomial distribution and a logit link function. Then, the mean response for positive observations was estimated assuming a gamma distribution for the error term. The basic model for positive observations included the log of mean catch rate (μ) as a function of three main effects (fishing year i, quarter j, and fleet k),

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

where μ_{ijk} is the mean catch rate (number of fish/1,000 angler-hours) in year i, quarter j, and fleet k. The fishing year effect is denoted by Y_i (i=1, 2, ..., I; I=67 fishing years). The quarter of the year effect is denoted by Q_j (j=1, 2, ..., J; J=4 quarters). The fleet effect is denoted as F_k (k=1, ..., K; K=2 fleets). The error term is denoted ε_{ijk}, where for each combination of indices, ε_{ijk} is *iid* and gamma distributed. Finally, the reference cell is denoted as UR (R=1 reference cell, i.e., year=2004, quarter=4, and fleet=south);
(6) no temporal/spatial interactions (e.g., year and fleet or quarter and fleet) were included in the final delta-GLM model, given such interactions had little effect on increasing the amount of variability in mean catch rate as a function of the suite of explanatory variables (i.e., minor improvement of R^2 statistic, see Hill and Crone 2005, Crone et al. 2006); and
(7) a delta-GLM function written in the statistical programming language R (personal communication, E. J. Dick, NOAA Fisheries, SWFSC, Santa Cruz, CA) was used to estimate a mean catch rate from the CPFV data set. A major feature of this function is that it estimates coefficients of variation (CV) for the relative index of abundance using a jackknife (leave-one-out) method. However, because the CPFV data were very extensive (over 80,000 observations), estimation of both year effects for the survey simultaneously with measures of dispersion (i.e., CVs) was problematic. In the current assessment, a year effect is first estimated using all available data and

subsequently, straightforward bootstrap re-sampling methods were employed for purposes of estimating variance (CV) estimates associated with the year effect estimates. Ultimately, the CVs were based on 200 bootstrap samples (with replacement), taken in each fishing year from 1935-36 to 2007-08.

Biological data

Weight-length

A weight-length (W-L) relationship for Pacific mackerel was modeled using port sample data collected by CDFG from 1962 to 2008 (see Fishery-dependent data above). A straightforward power function was used to determine the relationship between weight (kg) and fork length (cm) for both sexes combined:

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

where W_L is weight-at-length L, and a and b are the estimated regression coefficients. Weight-length parameters based on data from 1962-08 (a = 3.1E-06 and b = 3.4) were used (fixed) in all model scenarios (Figure 8A). Also, time-varying weight-length relationships were evaluated in sensitivity analysis; however, little change in W-L has been observed over time (Appendix Figure A2B-6).

Length-at-age

The von Bertalanffy growth equation was used to model the relationship between fork length (cm) and age for Pacific mackerel (1962-08):

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

where L_A is the length-at-age A, L_∞ ('L-infinity') is the theoretical maximum length of the fish, k is the growth coefficient, and t_o ('t-zero') is the theoretical age at which a fish would have been zero length. Length-at-age was estimated internally in all SS model scenarios, generally based on the following baseline growth equation for this population calculated from the CDFG data base (1962-08): L_∞ = 39.3 mm, k = 0.342, and t_o = -1.752 (Figure 8B). Of particular note is the rapid growth exhibited by this species, i.e., past research (Parrish and MacCall 1978; Mallicoate and Parrish 1981), as well as analysis conducted here on recent biological sample data, indicates fish, on average, realize over 50% of their total growth (in length) in the first year of life and subsequently, grow a few cm per year until death at roughly 40 cm (approximately, age 7-8). Sensitivity analysis resulted in relatively robust estimates of K (von Bertalanffy growth equation) that ranged from roughly 0.2 to 0.4 (k = 0.22 for SS model *AA*).

Maximum size and age

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

Maturity-at-age

The estimated maturity schedule (ogive) used in the past for this stock was assumed in all model scenarios here (Table 3 and Figure 8C). That is, normalized net fecundity-at-age (the product of fraction mature, spawning frequency, and batch fecundity) was used to interpret CalCOFI ichthyoplankton data and ultimately, generate estimates of *SSB*. Fraction mature was estimated by fitting a logistic regression model to age and fraction mature data from Dickerson et al. (1992). Spawning frequency was estimated by fitting a straight line to age and spawning frequency data from the same study. Following Dickerson et al. (1992), batch fecundity per gram of female body weight was assumed constant.

Natural mortality

Natural mortality rate (*M*) was assumed to be 0.5 yr^{-1} for all ages and both sexes, and used in all modeling efforts presented here (Figure 8C). Parrish and MacCall (1978) estimated natural mortality for Pacific mackerel using early catch curves (M = 0.3-0.5), regression of Z on f (M = 0.5), and comparative studies of maximum age (M = 0.3-0.7; Beverton 1963) and growth rate (M = 0.4-0.6; Beverton and Holt 1959). The above authors considered the regression of Z on f to be the most reliable method, with the estimate M = 0.5 falling within the range of the plausible estimates, i.e., an instantaneous M = 0.5 can be practically interpreted as an annual rate of roughly 40% of the stock dying each year due to 'natural causes.' Finally, a range of *M*s was examined formally through sensitivity analysis on the initial baseline SS model reviewed early in the STAR (see Appendix Figure A2B-40 for estimated *B* time series from this profile).

Stock-recruitment

A Beverton-Holt (B-H) stock-recruitment (*S/R*) relationship was assumed for this population for all models scenarios, i.e., as observed in the historical literature, as well as from modeling efforts here, recruitment is highly variable and not likely related closely to absolute levels of *SSB* biomass (*SSB*). However, it is important to note that steepness (*h*) ranged from roughly 0.3 to 0.5 (h = 0.47 for SS model *AA*), depending on the model scenario, indicating that at low *SSB* levels, recruitment is estimated to decrease slightly to moderately (Figure 9). Parrish (1974) and Parrish and MacCall (1978) discussed general life history strategies for this population that are tightly linked to oceanographic conditions and further, that periods of strong year classes (cohorts) are likely produced only when *SSB* is high (or moderately so) and more importantly, not likely to occur more than once or twice every 60 years.

Responses to past STAR/SSC recommendations

The three overriding recommendations from past reviews focused on data availability from Mexico, omission/inclusion of available indices of relative abundance used in this ongoing assessment, and development of a robust alternative (SS) model that can be used for formal management advice. See STAR (2009) for further discussion regarding these issues.

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

Regarding indices of relative abundance used in the current assessment … *both the spotter and CalCOFI survey indices were omitted from final baseline model scenarios for the current fishing year (2009-10), as well as in future assessment models. The remaining CPFV index, as well as related recreational fishery data, have now increased in importance in overall modeling efforts and subsequently, will need increased research support, as well as monitoring (see Research and Data Needs below).*

Regarding transitioning to the SS model for providing management advice … *the SS model was identified as the best modeling platform for assessing the status of the Pacific mackerel stock currently and in the future.*

Model description

Overview

The Stock Synthesis (SS, Methot 2005, 2009) model is founded on the AD Model Builder software environment, which essentially is a C++ library of automatic differentiation code for nonlinear statistical optimization (Otter Research 2001). The model framework allows full integration of both population size and age structure, with explicit parameterization both spatially and temporally. The model incorporates all relevant sources of variability and estimates goodness of fit in terms of the original data, allowing for final estimates of precision that accurately reflect uncertainty associated with the sources of data used as input in the overall modeling effort.

The SS model comprises three sub-models: (1) a population dynamics sub-model, where abundance, mortality, and growth patterns are incorporated to create a synthetic representation of the true population; (2) an observation sub-model that defines various processes and filters to derive expected values for different types of data; and (3) a statistical sub-model that quantifies the difference between observed data and their expected values and implements algorithms to search for the set of parameters that maximizes goodness of fit. This modeling platform is also very flexible in terms of estimation of management quantities typically involved in forecast analysis. Finally, from an international context, the SS model is rapidly gaining popularity, with SS-based stock assessments being conducted on numerous marine species throughout the world. The SS model used in this assessment was the most recently distributed version, namely, version 3.0.12 (January 2009).

Likelihood components and model parameters

Likelihood components and estimates for important SS model scenarios are presented in Table 4 (and Appendix Table A2B-1), including, fits to catch, age/length distributions, and indices, as well as parameter estimates for initial conditions (age distribution, recruitment, and fishing mortality), growth, recruitment, stock-recruitment relationship, etc.

Convergence criteria

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

Model selection and evaluation

We strongly adhered to model development (say parameterization involved in the various scenarios) that was based on the following: supports general consensus regarding this species' life history; results in no noticeable inconsistencies (across likelihood components) within the fully-integrated model scenario; addresses uncertainty in a sound, robust, and parsimonious manner; and finally, produces realistic (meaningful) results that can be directly assimilated into ongoing management efforts. Markov chain Monte Carlo (MCMC) methods were conducted on the initial baseline SS Model (*S1_aa*), whereby the Markov chain achieved a stationary (equilibrium) distribution, with no significant statistical violations observed across the estimated parameters, inclusive; however, due to time constraints, such diagnostics have not been conducted on the final SS model *AA* to date. The following outline summarizes model selection/evaluation development for the Pacific mackerel stock assessment conducted in 2009:

- developed the baseline (management) ASAP model (2009) … input data (i.e., time series updated with additional year) and parameterization similar to previous model used in the final assessment conducted in 2008 (see Appendix A2A);
- developed a baseline (alternative) SS model (*S1_aa*) … input data and parameterization similar to ASAP model (2009) above, i.e., a robust model that most closely resembled the ASAP model (see Appendix A2B);
- developed (two) suites of SS model scenarios via sensistivity analysis … one prior to the STAR and presented at the start of the review meeting (see Appendix Table A2B-1) and another during the review meeting (see Table 4); and
- developed a preferred SS model *AA* from the suites of alternative scenarios … this model scenario (along with SS model *AB*) provides the basis for the final assessment conclusions.

Key features of SS model *AA* follow, with comparative discussion regarding SS model *AB* presented where applicable, as well as identification of influential areas of parameterization that will likely be addressed further in future model development:

- *Time period*: 1962-08.
  Sensitivity analysis included starting the model later (late 1970s), but had little effect on overall results; however, it is likely that this area of parameterization in future models will need further evaluation.
- *Fishery structure*: two (USA/Mexico commercial and USA recreational).
- *Surveys*: One (CPFV index of relative abundance).
  Following much discussion and review of model scenarios, it was determined that both the spotter and CalCOFI indices be omitted from the current assessment analysis, given concerns regarding potential sampling biases associated with these indices at particular time periods, due to both the dynamics of the fish/fishery and implemented sampling designs (see STAR 2009).
- *Time-step*: annual.
  Sensitivity analysis included many scenarios based on a quarter time-step, with most of these configurations producing results generally similar to analogous (annual) time-step model scenarios.
- *Gender structure*: combined sexes.
- *Growth*: estimated and constant over time.

As presented in previous literature that addressed growth dynamics associated with this stock (Parrish and MacCall 1978), there is little evidence in support of growth changes over time (i.e., in terms of length-at-age). Further, sensitivity analysis resulted in robust estimates of *K* (von Bertalanffy growth equation) that ranged from approximately 0.2-0.4 (*k* = 0.22 for SS model *AA*). Additionally, sensitivity analysis that considered time-varying changes for growth in weight (i.e., in terms of weight-length/age), which in the vast majority of animal populations is the more ‘plastic’ growth attribute, revealed no indication that this growth parameter has changed markedly over the last 50 years (Appendix Figure A2B-6). Finally, additional mean size (length)-at-age time series allowed for detailed growth parameterization in all model scenarios. In this context, a model scenario was developed to address this issue (see below).

- *Selectivity (catch)*: Age-based and time-varying (three time blocks).
  Selectivity issues regarding age- or size-based approaches were given much attention, based on relations to the actual operation of the fisheries and dynamics of the stock. That is, we feel that the distribution exhibited by this species on any given year and subsequently, its probability of capture (selectivity) is more influenced by ‘time’ (say age) than by size (say length); this is true for all age groups, from the variability observed in the presence/absence of 0-1 yr-old fish to the adults in the estimated age distributions modeled here. Recognizing that in reality, both attributes are likely influential to some degree, it is more likely that movement (and capture) are driven by age, i.e., versus gear (mesh) constraints that also generally influence vulnerability. Given the biological sampling design in place provides ‘random’ samples of fish (for purposes of length, age, etc.) from completed boat trips, selectivity parameterization based on representative age distributions of the catch becomes the logical approach. Although the biological distributions from the recreational fishery were in terms of size (length, given no age data available), age-based selectivity was implemented for this fishery as well. Finally, preliminary modeling efforts indicated age- or size-based selectivity resulted in similar conclusions of stock status.
  - SS model *AB* included an additional time block (2000-08) for both the commercial and recreational fisheries, based on visual evaluations of changes in age/length distributions over time.
  - As with the modeled time period above, time-varying selectivity will likely be an important area of examination as the Pacific mackerel assessment model continues development in the future.
- *Selectivity (index)*: age-based (i.e., mirrors recreational fishery) and constant.
  - SS model *AB* included the CPFV index split into two indices (one that spanned 1962-99 and another for 2000-08) in efforts to keep both time-varying selectivity and catchability in line with one another.
  - As with the modeled time period and catch-related selectivity above, parameterization of time-varying catchability will necessarily be another important area of examination in future model development for this species.

- *Stock-recruitment*: Beverton-Holt stock-recruitment model.
  An asymptotic relationship between parents and offspring was assumed in all model scenarios. Estimated steepness (*h*) from sensitivity analysis ranged from roughly 0.3 to 0.5 (*h* = 0.47 for SS model *AA*). See Stock-recruitment above.
  - σ_R = 1.0.

  In recent previously conducted assessments, σ_R = 0.7. Increasing the variability surrounding recruitment estimation was supported in most model scenarios, with internal model estimates of root mean square errors associated with estimated recruitment ranging from roughly 0.9 to 1.3.
- *Variance adjustments to time series*: variance adjustments were used following diagnostic evaluations of input vs. effective sample size results from final model runs. That is, adjustments reflected doubled input sample sizes for the recreational length distributions only, i.e., in effect, reweighted effective sample sizes reflected total number of fish divided by 12.5 (vs. 25 as used for initial (baseline) sample sizes, see Length distributions above). Also, in some model scenarios, age distributions (commercial fishery) were 'down-weighted' (0.25) accordingly; however, model convergence (with no penalties) was problematic.
  - As with the modeled time period and selectivity/catchability above, variance adjustments to both biological distributions via sample size allocations and index of relative abundance via assumed error (CVs) associated with the CPFV index will necessarily warrant further consideration, given the influence such parameterization has on fully-integrated stock assessment models in general.

Sensitivity analysis
Alternative SS model scenarios are briefly summarized below, i.e., see Table 4. That is, many model scenarios were presented and reviewed at the start of the STAR, particularly; configurations based on a quarter time-step (see Appendix Table A2B-1 and Figure A2B-41). The following model scenarios represent key configurations developed during the STAR, which collectively, served to further the development of the final (consensus) SS model *AA* (and alternative SS model *AB*), see Model description above.

SS model *H2*: Similar to SS model *AA*, but no variance adjustment (effective sample sizes) to recreational length distribution time series.
SS model *N*: Similar to SS model *AA*, but σ-*R*=0.7 (i.e., more precise) and no variance adjustment (effective sample sizes) to recreational length distribution time series.
SS model *Q*: Similar to SS model *AA*, but σ-*R*=0.7 (i.e., more precise), fish greater than 55 cm in recreational length distribution were omitted, and no variance adjustment (effective sample sizes) to recreational length distribution time series.
SS model *U*: Similar to SS model *AB*, but no variance adjustment (effective sample sizes) to recreational length distribution time series.
SS model *P*: Similar to SS model *AB*, but CalCOFI ('super years') index was included, σ-*R*=0.7 (i.e., more precise), and no variance adjustment (effective sample sizes) to recreational length distribution time series.

Assessment model results (SS model *AA*)

Model fits to biological distributions are presented in the following displays: Figure 10A is observed vs. predicted estimates for the age distribution time series for the commercial fishery; Figure 10B is the associated Pearson residual plot for the age distribution fits; Figure 10C is the associated input vs. effective sample size plot for the age distribution fits; Figure 11A is observed vs. predicted estimates for the length distribution time series for the recreational fishery; Figure 11B is the associated Pearson residual plot for the length distribution fits; Figure 11C is the associated input vs. effective sample size plot for the length distribution fits; Figure 4 is the observed vs. predicted estimates for the mean length-at-age distribution time series for the commercial fishery; and Figure 12 is the associated Pearson residual plot for the mean length-at-age distribution fits. Estimated selectivity for the fishery catches is presented in Figure 13A (commercial fishery – three time blocks) and Figure 13B (recreational fishery – single time block).

In general, fits to biological distributions were relatively good; however, in some years, large 'pulses' of younger fish were not fit with high precision, i.e., 0-1 yr-old fish in the commercial fishery age distributions. Also, the rapid decline of older animals in many years may be due to non-constant natural mortality (say by sex) or potentially, due to selectivity changes over time (see Model selection and evaluation above).

Fits (normal and log space) to the CPFV index of relative abundance are presented in Figure 14A-B. In general, model fits to the CPFV index were very good and further, in all model runs (inclusive), this index was fit much more precisely than either of the other indices (i.e., spotter and CalCOFI indices) that were eventually omitted in final model scenarios. Selectivity for the CPFV index mirrored that estimated for the recreational fishery (Figure 13B).

Estimated Beverton-Holt stock-recruitment relationship is presented in Figure 9 (see Stock-recruitment above). Estimates of Pacific mackerel recruitment deviations and asymptotic standard errors for the deviations are presented in Figure 15A-B.

Harvest rate estimates are presented in Figure 16. As expected, harvest rates have varied substantially over time, with exploitation declining markedly since roughly 2000 to historically low levels.

Estimated time series for management-related derived quantities of interest are presented in the following displays: Figure 17 is total stock biomass (age 1+ fish in mt, *B*) for both the final SS model *AA* and alternative model *AB*; Figure 18 is spawning stock biomass (*SSB* in mt); and Figure 19 is recruitment (age-0 fish in numbers). Estimated *B* (and *SSB*) remained low from the early 1960s to the mid 1970s, at which time the population began to rapidly increase in size, reaching a peak in the early 1980s. From the mid 1980s to early 2000s, the stock declined steadily, with some signs of 'rebuilding' (on an increasing limb of a historical distribution say) observed recently. However, as noted previously, recent estimates of stock size are necessarily related to assumptions regarding the dynamics of the fish (biology) and fishery (operations) over the last several years, which generally confounds long-term (abundance) forecasts for this species (e.g., SS model *AA* and model *AB* are generally similar historically, but diverge in the mid 2000s, based on different assumptions surrounding both selectivity and catchability (see Model selection and evaluation above).

Results from a retrospective analysis are presented in Figure 20, i.e., data associated with terminal years 2008 to 2004 were omitted (sequentially) from the model. As observed in all past assessments, a retrospective pattern exists with this assessment model as well (albeit only moderate in severity), i.e., a tendency to overestimate stock abundance (*B*) in any current year, with future assessments based on additional data producing estimates lower in magnitude. However, given this model (SS model *AA*) is structured substantially different from past models used for the ongoing stock assessment, the usefulness of a retrospective evaluation at this time should be interpreted accordingly.

Finally, for comparative purposes, final estimated B time series for the historical assessment period (1994-09) are presented in Figure 21. It is important to note that in 2007, estimated *B* scaled upwards substantially, based largely on assumptions regarding variability surrounding estimated recruitment, i.e., since 2005, σ-*R* has increased from 0.25 to 0.7 to the current level of assumed variability of 1.0, which is more in line with internal estimation of recruitment uncertainty associated with assessment models developed recently for this species (also, see Harvest Control Rule for USA Management in 2009-10 below).

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

Specificially, in addition to lacking ongoing data exchange with Mexico regarding catch, biology, and survey information associated with this species, a primary area of uncertainty in the overall assessment is assumptions and associated parameterization surrounding both selectivity for the fisheries, as well as catchability for the CPFV index of relative abundance. That is, the degree to which changes have occurred across time in terms of 'probability of capture' associated with the commercial and recreational fisheries has not been definitively evaluated at this time, but rather, will need further examination as the Pacific mackerel assessment progresses in the future. However, in the interim, it is important to note that fishing pressure on this stock has been very low for the last several years and coupled with this species' biology, likely indicates the stock is not highly vulnerable to overfishing presently, but rather, should be monitored closely in terms of both magnitude of landings in coming years, as well as evaluated through ongoing (improved) assessment efforts. See Research and Data Needs below.

HARVEST CONTROL RULE FOR USA MANAGEMENT IN 2009-10

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

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

where Harvest is the harvest guideline (HG), Biomass is the estimated total stock biomass (age 1+) in 2009 (282,049 mt), Cutoff (18,200 mt) is the lowest level of estimated biomass at which harvest is allowed, Fraction (30%) is the proportion of biomass above the Cutoff that can be harvested by fisheries, and Distribution (70%) is the average fraction of total biomass assumed in USA waters (PFMC 1998). The HGs under the federal FMP are applied to a July-June fishing 'year.' Landings and associated HGs since 1992 are presented in Figure 22A.

The HG for the 2009-10 fishing year is 55,408 mt:

B **(Age 1+, mt)**	**Cutoff (mt)**	**Fraction**	**Distribution**	**HG (mt)**
282,049	18,200	30%	70%	**55,408**

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. From 2001-06, HGs averaged roughly 20,000 mt. In 2007, the HG was increased substantially to over 100,000 mt based largely on assumptions regarding variability surrounding estimated recruitment and has remained at an elevated level since then (Figure 22A). It is important to note that since the 2001 fishing year, from a management context, the fishery has failed to fully utilize HGs, with average yields since this time of roughly 5,000 mt. Finally, 'hypothetical' quotas and total landings, based on omission of the USA 'Distribution' parameter in the harvest control rule are presented in Figure 22B.

RESEARCH AND DATA NEEDS

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

Second, fishery-independent survey data for measuring (relative) changes in mackerel spawning (or total) biomass are currently lacking. Further, at this time, a single index of relative abundance is used in the assessment, which is developed from a marine recreational fishery

(CPFV fleet) that typically does not (directly) target the species. In this context, it is imperative that future research funds be focused on improvement of the current CPFV survey, with emphasis on a long-term horizon, which will necessarily rely on cooperative efforts between the industry, research, and management bodies. Additionally, we strongly support development of a well-designed logbook monitoring program associated with the current commercial (purse-seine) fishery, which has been long overdue.

Third, given the importance of age (and length) distribution time series to developing a sound understanding of this species' population dynamics, it is critical that data collection programs at the federal and particularly, the state-level continue to be supported adequately. In particular, CDFG/NOAA funding should be bolstered to ensure ongoing ageing-related laboratory work is not interrupted, as well as providing necessary funds for related biological research that is long overdue. For example, maturity-related time series currently relied upon in the assessment model are based on data collected over twenty years ago during a period of high spawning biomass that does not reflect current levels. Also, further work is needed to obtain more timely error estimates from production ageing efforts in the laboratory, i.e., accurate interpretation of age-distribution data used in the ongoing assessment necessarily requires a reliable ageing error time series. Finally, examinations of sex-specific age distributions will allow hypotheses regarding natural mortality/selectivity (i.e., absence of older animals in sex-combined age distributions) to be more fully evaluated.

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

ACKNOWLEDGEMENTS

Thanks to all individuals involved in the data collection- and laboratory-related programs surrounding this species, inclusive … in particular, those individuals from the California Department of Fish and Game—this information is critical to obtaining an accurate assessment of the status of an exploited fish population, period. Additionally, the industry and CPSMT have provided a concerted forum for communicating the critical need for better sample data for inclusion in assessment modeling efforts. Also, the STAR panel generated important discourse and subsequent recommendations that improved upon the ongoing stock assessment, including, Alec (MacCall), Owen (Hamel), Ken (Burnham), Gary (Melvin), and in particular, Andre (Punt) who provided good guidance at pivotal times in the overall review.

Regarding the overall analysis, thanks are extended to Kevin (Piner), Alex (Aires-da-Silva), HuiHua (Lee), Rick (Methot), Ian (Taylor), Ian (Stewart), the STAR panel, and in particular, Mark (Maunder), who provided invaluable insight in terms of both theoretical concepts underlying animal population dynamics in general, as well as explicit model-related advice regarding a parameterization or two … the support's appreciated—big time.

REFERENCES

Allen, M. J., R. J. Wolotira, Jr., T. M. Sample, S. F. Noel, and C. R. Iten. 1990. West coast of North America coastal and oceanic zones strategic assessment: Data Atlas. NOAA. Seattle, WA. Invertebrate and fish 145:

Beverton, R. J. H. 1963. Maturation, growth and mortality of clupeid and engraulid stocks in relation to fishing. Rapp. P.-V. Reun. Cons. Perm. Int. Explor. Mer, 154: 44-67.

Beverton, R. J. H. and S. J. Holt. 1959. A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. In: Wolstenholme, G.E.W. and M. O'Connor. CIBA Foundation Colloquia on Ageing, Vol. 5, The Lifespan of Animals. J. and A. Churchill Ltd. London. 324 p.

Cannon, R. 1967. How to fish the Pacific Coast. 3rd edition. Lane Books, Menlo Park, CA. 160 p.

Clemmens, W. A., and G. V. Wilby. 1961. Fishes of the Pacific coast of Canada. Fish. Res. Board Can., Bull. 68. 443 p.

Collette, B. B., and C. E. Nauen. 1983. Scombrids of the world. FAO Fish. Synop. 125. 137 p.

Cota-V., A., R. Troncoso-G., and F. Javier-Sanchez. 2006. Análisis de la pesqueria de pelágicos menores para la costa occidental de Baja California durante la temporada del 2005.(Abstract) In: Memorias del XIV Taller de Pelágicos Menores, La Paz, Baja California Sur, 21-23 Junio de 2006.

Croker, R. S. 1933. The California mackerel fishery. Calif. Div. Fish Game. Fish Bull. 40. 149 p.

Croker, R. S. 1938. Historical account of the Los Angeles mackerel fishery. Calif. Div. Fish Game. Fish Bull. 52. 62 p.

Crone, P. R., K. T. Hill, and J. D. McDaniel. 2006. Pacific mackerel (*Scomber japonicus*) stock assessment for U.S. Management in the 2006-07 fishing year. Pacific Fishery Management Council, June-2006 Briefing Book-Agenda Item C1A-Attachment 1.

Dickerson, T. L., B. J. Macewicz and J. R. Hunter. 1992. Spawning frequency and batch fecundity of chub mackerel, *Scomber japonicus*, during 1995. Calif. Coop. Oceanic Fish. Invest. Rep. 33:130-140.

Dorval, E., K. T. Hill, N. C. H. Lo, and J. D. McDaniel. 2008. Assessment of Pacific mackerel (*Scomber japonicus*) stock for the U.S. management in the 2008-09 fishing season. PFMC June 2007 Briefing Book, Exhibit G.1b. Appendix 2. Pacific Fishery Management Council, Foster City California. 78 p.

Fitch, J. E. 1951. Age composition of the southern California catch of Pacific mackerel 1939-40 through 1950-51. Calif. Dept. Fish and Game, Fish. Bull., 83: 1-73.

Fitch, J. E. 1969. Offshore fishes of California. 4th revision. Calif. Dep. Fish and Game, Sacramento, CA. 79 p.

Fitch, J. E., and R. J. Lavenberg. 1971. Marine food and game fishes of California. Univ. Calif. Press, Berkeley, CA. 179 p.

Frey, H. W. [ed.] 1971. California's living marine resources and their utilization. Calif. Dept. Fish and Game 148 p.

Fritzsche, R. A. 1978. Development of fishes in the Mid-Atlantic Bight, Vol. 5. Chaetodontidae through Ophdiidae. U.S. Fish Wildl. Serv., Washington, D.C. FWS/OBS-78/12. 340 p.

Fry, D. H. Jr. and P. M. Roedel. 1949. Tagging experiments on the Pacific mackerel (*Pneumatophorus diego*). Calif. Div. Fish Game. Fish Bull. 73. 64 p.

García F. W. and Sánchez R. F. J. 2003. Análisis de la pesquería de pelágicos menores de la costa occidental de Baja California durante la temporada del 2002. Boletín Anual 2003. Secretaria de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. Instituto Nacional de la Pesca. Centro Regional de Investigación Pesquera de Ensenada, Cámara Nacional de la Industria Pesquera y Acuícola, Delegación Baja California. 15 p.

Hargreaves, N. B. and R. M. Hungar. 1995. Robertson creek chinook assessment and forecast for 1994 and 1995. Part B: early marine mortality. PSARC Report S95-03. 55 p.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. 180. 740 p.

Hill, K. T. 1999. Age composition and growth of coastal pelagic species in northern California, Oregon, and Washington coastal waters. Pacific States Marine Fisheries Commission, Gladstone, Oregon. Final Report for Project #1-IJ-9, Sub-task 2A. 48 p.

Hill, K. T., and J. T. Barnes. 1998. Historical catch data from California's commercial passenger fishing vessel fleet: status and comparisons of two sources. Calif. Dep. Fish Game, Marine Region Tech. Rep. No. 60. 44 p.

Hill, K. T. and N. Schneider. 1999. Historical logbook databases from California’s commercial passenger fishing vessel (partyboat) fishery, 1936-1997. SIO Ref. Ser. 99-19. 64 p.

Hill, K. T. and P. R. Crone. 2004a. Stock assessment of Pacific mackerel (*Scomber japonicus*) with recommendations for the 2004-2005 management season (Executive Summary). Pacific Fishery Management Council, June 2004. 16 p.

Hill, K. T. and P. R. Crone. 2004b. Stock assessment of Pacific mackerel (Scomber japonicus) in 2004: Draft document for STAR Panel review. Pacific Fishery Management Council, June 2004. 140 p.

Hill, K. T. and P. R. Crone. 2005. Assessment of the Pacific Mackerel (*Scomber japonicus*) stock for U.S. management in the 2005-2006 season. Pacific Fishery Management Council June 2005 Briefing Book, Agenda Item F.1.b, Attachment 1. 167 p.

Jacobson, L. D. 1993. ADEPT: Software for VPA analysis using Gavaris's procedure. National Marine Fisheries Service, Southwest Fisheries Science Center. Admin. Rep. LJ-93-02: 71p.

Jacobson, L. D., E. Konno, and J. P. Pertierra. 1994a. Status of Pacific mackerel and trends in abundance during 1978-1993 (with data tables). National Marine Fisheries Service, SWFSC Admin. Rep. LJ-94-08, 33p.

Jacobson, L. D., E. S. Konno, and J. P. Pertierra. 1994b. Status of Pacific mackerel and trends in biomass, 1978-1993. Calif. Coop. Oceanic Fish. Invest. Rep. 35: 36-39.

Klingbeil, R. A. 1983. Pacific mackerel: a resurgent resource and fishery of the California Current. Calif. Coop. Oceanic Fish. Invest. Rep. 24:35-45.

Klingbeil, R. A. and P. Wolf. 1986. Status of the Pacific mackerel population, 1985 and 1986. Calif. Dept. Fish and Game, Report to the Legislature, 23 pp.

Kramer, D. 1969. Synopsis of the biological data on the Pacific mackerel, *Scomber japonicus* Houttuyn (northeast Pacific). FAO (Food and Agri. Org.), U.N., Fish. Synopsis 40: 1-18.

Legault, C. M., and V. R. Restrepo. 1998. A flexible forward age-structured assessment program. ICCAT Working Document SCRS/98/58. 15 p.

MacCall, A. D., R. A. Klingbeil, and R. D. Methot. 1985. Recent increased abundance and potential productivity of Pacific mackerel (*Scomber japonicus*). Calif. Coop. Oceanic Fish. Invest. Rep. 26: 119-129.

Mallicoate, D. L. and R. H. Parrish. 1981. Seasonal growth patterns of California stocks of northern anchovy, *Engraulis mordax*, Pacific mackerel, *Scomber japonicus*, and jack mackerel, *Trachurus symmetricus*. Calif. Coop. Oceanic Fish. Invest. Rep. 22: 69-81.

Maunder, M. N., and A. E. Punt. 2004. Standardizing catch and effort data: a review of recent approaches. Fisheries Research, 70: 141-159

MBC Applied Environmental Sciences. 1987. Ecology of important fisheries species offshore California. OCS-Study, MMS 86-0093. 252 p.

Methot, R. 2005. Technical description of the stock synthesis II assessment program. Version 1.17-March 2005.

Methot, R. 2009. User manual for Stock Synthesis: Model Version 3.02C. January 29, 2009.

Moser, H. G., R. L. Charter, P. E. Smith, D. A. Ambrose, S. R. Charter, C. A. Meyer, E. M. Sandknop, and W. Watson. 1993. Distributional atlas of fish larvae and eggs in the California Current region: taxa with 1000 or more total larvae, 1951 through 1984. CalCOFI Atlas 31. 233 p.

Otter Research Ltd. 2001. An introduction to AD Model Builder (Version 6.0.2) for use in nonlinear modeling and statistics. Otter Research Ltd., Sidney, B.C., Canada. 202 p.

Pacific Fisheries Environmental Laboratory (PFEL). 2005. Live Access Server for California Fish Landings. [http://las.pfeg.noaa.gov:8080/las_fish1/servlets/dataset].

Pacific Fishery Management Council (PFMC). 1998. Amendment 8: (To the northern anchovy fishery management plan) incorporating a name change to: The coastal pelagic species fishery management plan. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, OR, 97220.

Pacific Fishery Management Council (PFMC). 2009. Terms of reference for a Coastal Pelagic Species Stock Assessment Review Process. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, OR, 97220.

Parrish, R.H. 1974. Exploitation and recruitment of Pacific Mackerel, *Scomber japonicas,* in the northeastern Pacific. Calif. Coop. Oceanic Fish. Invest. Rep. 17:136-140-101.

Parrish, R. H., and A. D. MacCall. 1978. Climatic variation and exploitation in the Pacific mackerel fishery. Calif. Dep. Fish Game Fish Bull. 167, 110 p.

Roedel, P. 1938. Record-size mackerel in Santa Monica Bay. Calif. Fish Game 24: 423.

Roedel, P. M. 1949. Movements of Pacific mackerel as demonstrated by tag recoveries. Calif. Fish and Game 35(4): 281-291.

Roedel, P. M. 1952. A review of the Pacific mackerel (*Pneumatophorus diego*) fishery of the Los Angeles region with special reference to the years 1939-1951. Calif. Fish and Game 38(2): 253-273.

Schaefer, K. M. 1980. Synopsis of biological data on the chub mackerel, *Scomber japonicus* Houtuyn, 1782, in the Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Spec. Rep., 2: 395-446.

Soutar, A., and J. D. Isaacs. 1974. Abundance of pelagic fish during the 19th and 20th centuries as recorded in anaerobic sediment off the Californias. Fish. Bull. 72: 257-273.

Stock Assessment Review (STAR). 2009. Pacific mackerel STAR panel meeting report. A. Punt (chair) and members O. Hamel, A. MacCall, G. Melvin, and K. Burnham. NOAA Fisheries, Southwest Fisheries Science Center, La Jolla CA, May 4-8, 2009. 18 p.

Stefansson, G. 1996. Analysis of groundfish survey abundance data: combining the GLM and delta approaches. ICES J. Mar. Sci., 53: 577-588.

Turner, C. H. and J. C. Sexsmith. 1967. Marine baits of California. First revision. Calif. Dep. Fish Game, Sacramento, CA. 70 p.

Ware, D. M. and N. B. Hargreaves. 1993. Occurrence of Pacific (chub) mackerel off the B.C. coast in 1993. PICES Press 2(1):12-13.

Wolf, P. and K. R. Worcester. 1988. Status of the Pacific mackerel population, 1987 and 1988. Calif. Dept. Fish and Game, Report to the Legislature, 15 pp.

Young, P. H. 1969. The California partyboat fishery 1947-1967. Calif. Dept. Fish Game, Fish Bull. 145. 91 p

Table 1. Sample sizes associated with CDFG data collection program for Pacific mackerel (1962-08).

Fishing Year	Landings (mt)	# Fish Sampled	Fish per 1,000 mt
62	23,758	205	9
63	23,483	205	9
64	19,901	268	13
65	11,057	111	10
66	7,138	1,944	272
67	1,567	720	459
68	1,599	2,145	1,342
69	1,010	498	493
70	677	150	222
71	590	344	583
72	228	223	978
73	152	239	1,568
74	514	179	348
75	1,950	1,326	680
76	3,925	2,202	561
77	12,914	1,943	150
78	25,818	3,810	148
79	33,905	3,491	103
80	32,518	6,711	206
81	45,562	5,067	111
82	34,955	4,764	136
83	40,573	2,694	66
84	45,001	2,394	53
85	45,812	2,607	57
86	53,263	3,000	56
87	46,958	4,150	88
88	48,576	4,479	92
89	48,788	3,583	73
90	70,935	2,121	30
91	64,825	1,689	26
92	31,754	2,015	63
93	20,311	2,740	135
94	22,674	4,357	192
95	10,982	2,718	247
96	23,877	2,222	93
97	50,272	2,722	54
98	62,393	2,261	36
99	15,757	1,674	106
00	27,467	1,919	70
01	12,439	2,114	170
02	13,869	2,150	155
03	8,590	1,599	186
04	7,029	2,547	362
05	7,079	2,300	325
06	10,437	2,424	232
07	9,123	1,609	176
08	6,513	425	65

Table 2. Landings (mt) of Pacific mackerel by fishery (1962-2008).

Fishing year	USA Commercial (mt)	Mexico Commercial (mt)	Recreational CPFV (mt)	Recreational non-CPFV (mt)	Total (mt)
62	20,527	3,231	58	85	23,901
63	15,517	7,966	86	134	23,703
64	11,283	8,618	33	54	19,988
65	3,442	7,615	84	138	11,279
66	1,848	5,290	97	169	7,405
67	619	948	56	90	1,713
68	1,492	107	37	60	1,695
69	809	201	58	100	1,168
70	277	400	61	98	835
71	90	500	118	203	911
72	28	200	118	186	532
73	52	100	95	154	401
74	43	471	47	73	634
75	141	1,809	75	124	2,149
76	2,654	1,271	69	97	4,092
77	7,748	5,165	314	524	13,751
78	18,446	7,372	501	854	27,173
79	28,755	5,150	804	1149	35,858
80	27,972	4,546	1,277	1409	35,203
81	38,407	7,155	665	757	46,985
82	30,626	4,329	693	723	36,371
83	36,309	4,264	700	844	42,118
84	39,240	5,761	612	855	46,468
85	37,615	8,197	524	492	46,828
86	44,298	8,965	386	474	54,123
87	44,838	2,120	245	1020	48,223
88	41,968	6,608	181	507	49,265
89	25,063	23,724	167	451	49,406
90	39,974	30,961	230	386	71,551
91	30,268	34,557	252	429	65,505
92	25,584	6,170	135	329	32,217
93	10,787	9,524	196	413	20,920
94	9,372	13,302	226	837	23,737
95	7,615	3,368	439	574	11,996
96	9,788	14,089	320	366	24,563
97	23,413	26,860	104	700	51,076
98	19,578	42,815	108	322	62,823
99	7,170	8,587	55	97	15,910
00	20,936	6,530	78	248	27,792
01	8,436	4,003	51	520	13,010
02	3,541	10,328	22	232	14,123
03	5,972	2,618	28	295	8,913
04	5,012	2,017	23	510	7,562
05	4,572	2,507	21	375	7,475
06	7,870	2,567	15	356	10,808
07	6,208	2,914	18	289	9,429
08	3,599	2,914	19	272	6,803

Table 3. Normalized net fecundity calculations for Pacific mackerel, which in effect, represented the maturity schedule (ogive) used in all model scenarios[a].

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

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

Table 4. Summary of SS model scenarios developed for the Pacific mackerel (2009) assessment, including: (A) new data sources and critical parameterizations; and (B) likelihood component estimates and derived quantities of importance.

(A)

	Model scenarios [a]						
Time series	***AA***	***AB***	***H2***	***N***	***Q***	***P***	***U***
Landings - USA/Mexico commerical (1962-08) - Fishery 1	X	X	X	X	X	X	X
Landings - USA recreational (1962-08) - Fishery 2	X	X	X	X	X	X	X
Age distributions (1962-08) - USA/Mexico commercial	X	X	X	X	X	X	X
Length distributions (1992-08) - USA recreational	X	X		X	X	X	X
Mean length-at-age distributions (1962-08) - USA/Mexico commercial	X		X	X	X	X	X
CPFV survey (1962-08) - Survey 1 [b]	X	X	X	X	X		
CPFV survey (1962-99) and (2000-08) - Surveys 2 and 3, respectively		X				X	X
CalCOFI survey (1978-08) - daily larv. prod. ('super years') - Survey 4 [c]						X	
Parameterization	***AA***	***AB***	***H2***	***N***	***Q***	***P***	***U***
Model structure							
Time period	1962-08	1962-08	1962-08	1962-08	1962-08	1962-08	1962-08
Number of fisheries	2	2	2	2	2	2	2
Number of surveys	1	2	2	1	2	3	1
Genders	1	1	1	1	1	1	1
Time-step	Annual	Annual	Annual	Annual	Annual	Annual	Annual
Biology							
Maturity-at-age	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Length-at-age	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated
Weight-length	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Weight-at-age	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated
Natural mortality (M)	Fixed - all ages (M=0.5)	Fixed - all ages (M=0.5)	Fixed - all ages (M=0.5)	Fixed - all ages (M=0.5)	Fixed - all ages (M=0.5)	Fixed - all ages (M=0.5)	Fixed - all ages (M=0.5)
Stock-recruitment							
$\ln(R_0)$	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated
Offset for initial equilibrium R_1	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated
Steepness (h)	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated
σ-R	Fixed (σ-R=1.0)	Fixed (σ-R=1.0)	Fixed (σ-R=1.0)	Fixed (σ-R=0.7)	Fixed (σ-R=0.7)	Fixed (σ-R=0.7)	Fixed (σ-R=1.0)
Initial conditions for population dynamics							
Age distribution	Non-equilibrium	Non-equilibrium	Non-equilibrium	Non-equilibrium	Non-equilibrium	Non-equilibrium	Non-equilibrium
Fishing mortality (F) - Fishery 1[d]	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated
Fishing mortality (F) - Fishery 2	Fixed (F_{init}=0.001)	Fixed (F_{init}=0.001)	Fixed (F_{init}=0.001)	Fixed (F_{init}=0.001)	Fixed (F_{init}=0.001)	Fixed (F_{init}=0.001)	Fixed (F_{init}=0.001)
Selectivity							
Fisheries							
Parameterization	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated	Estimated
Time block	Fishery 1=3 blocks Fishery 2=single	Fishery 1=4 blocks Fishery 2=2 blocks	Fishery 1=3 blocks Fishery 2=single	Fishery 1=3 blocks Fishery 2=single	Fishery 1=3 blocks Fishery 2=single	Fishery 1=4 blocks Fishery 2=2 blocks	Fishery 1=4 blocks Fishery 2=2 blocks
Shape	Dome-shaped	Dome-shaped	Dome-shaped	Dome-shaped	Dome-shaped	Dome-shaped	Dome-shaped
Surveys							
Parameterization	Fixed (mirrors Fishery 2)	Fixed (mirrors Fishery 2)	Fixed (mirrors Fishery 2)	Fixed (mirrors Fishery 2)	Fixed (mirrors Fishery 2)	Fixed (mirrors Fishery 2)	Fixed (mirrors Fishery 2)
Time block	Single	2 blocks	Single	Single	Single	2 blocks	2 blocks
Shape	Dome-shaped	Dome-shaped	Dome-shaped	Dome-shaped	Dome-shaped	Dome-shaped	Dome-shaped
Catchability							
q - Surveys	Est. (median unbiased)	Est. (median unbiased)	Est. (median unbiased)	Est. (median unbiased)	Est. (median unbiased)	Est. (median unbiased)	Est. (median unbiased)
Variance adjustment factors							
Biological distributions - Fishery 2 (ESS for length distributions)[e]	Doubled weight	Doubled weight	No additional weighting	No additional weighting	No additional weighting	No additional weighting	No additional weighting

Table 4. Continued.

(B)

Likelihood component	*AA*	*AB*	*H2*	*N*	*Q*	*P*	*U*
Biological distributions							
Age distributions							
USA/Mexico commercial - Fishery 1	700.4	673.9	673.3	695.5	687.6	670.5	657.5
Length distributions							
USA recreational - Fishery 2	201.4	183.8	117.0	117.1	114.2	104.6	110.1
Length-at-age distributions							
USA/Mexico commercial - Fishery 1	540.4	535.9	538.9	534.1	535.6	526.1	530.4
Surveys							
CPFV - Survey 1	-18.3	Na	-18.0	-15.7	-16.0	Na	Na
CPFV - Survey 2	Na	-10.0	Na	Na	Na	-11.0	-15.0
CPFV - Survey 3	Na	-6.0	Na	Na	Na	-8.6	-7.8
CalCOFI - Survey 4	Na	Na	Na	Na	Na	2.5	Na
Sub-total	-18.3	-16.0	-18.0	-15.7	-16.0	-17.2	-22.8
Recruitment							
Model time period (1958-08)	34.7	33.7	36.0	39.9	40.1	38.1	34.6
Forecast (2009)	0.016	0.006	0.002	0.038	0.005	0.102	0.009
Global							
Likelihood (L)	1,458.6	1,411.3	1,347.2	1,370.9	1,361.5	1,322.3	1,309.9
Number of estimated parameters	84	97	85	82	85	98	97
Key estimated parameters and derived quantities							
Biology							
Length-at-age (k)	0.22	0.28	0.28	0.28	0.28	0.30	0.29
$\ln(R_0)$	13.5	13.6	13.5	13.1	13.3	13.8	13.5
Offset for initial equilibrium R_1	0.2473	0.2916	0.2581	0.1510	0.1924	0.2743	0.2766
Steepness (h)	0.47	0.40	0.49	0.48	0.43	0.33	0.42
Initial conditions for population dynamics							
Fishing mortality (F) - Fishery 1[d]	0.65	0.51	1.22	1.30	0.74	0.89	1.09
Population time series							
SSB - 1962	47,534	61,882	52,485	35,085	41,234	93,908	60,595
SSB - 2008	76,441	17,264	80,540	76,441	76,453	134,186	26,235
B (1+) - 1962	171,865	196,629	181,367	129,586	154,541	307,827	198,645
B (1+) - 2009	282,049	55,003	293,719	229,556	274,032	329,342	81,637
HG - 2009	55,408	7,729	57,859	44,385	53,725	65,340	13,322

[a] Further parameterization details regarding model scenarios presented here can be found in STAR (2009).
[b] CPFV survey included two alternive formulations: Survey 1 (1962-08); and a split index that spanned 1962-99 (Survey 2) and 2000-08 (Survey 3).
[c] Initial sensitivity analysis regarding the CalCOFI survey presented at the onset of the STAR was based on three alternative indices (see Appendix 3B-C); however, a revised index (Survey 4) was used in subsequent sensitivity analysis conducted during the STAR, see STAR (2009).
[d] Estimated initial fishing mortality was not fit to 'equilibrium' catch, but rather, implemented for purposes of providing a more robust initial non-equilibrium age composition.
[e] Variance adjustments reflect doubled input sample sizes, i.e., in effect, reweighted effective sample sizes reflect total number of fish divided by 12.5 (vs. 25 as used for initial (baseline) sample sizes).

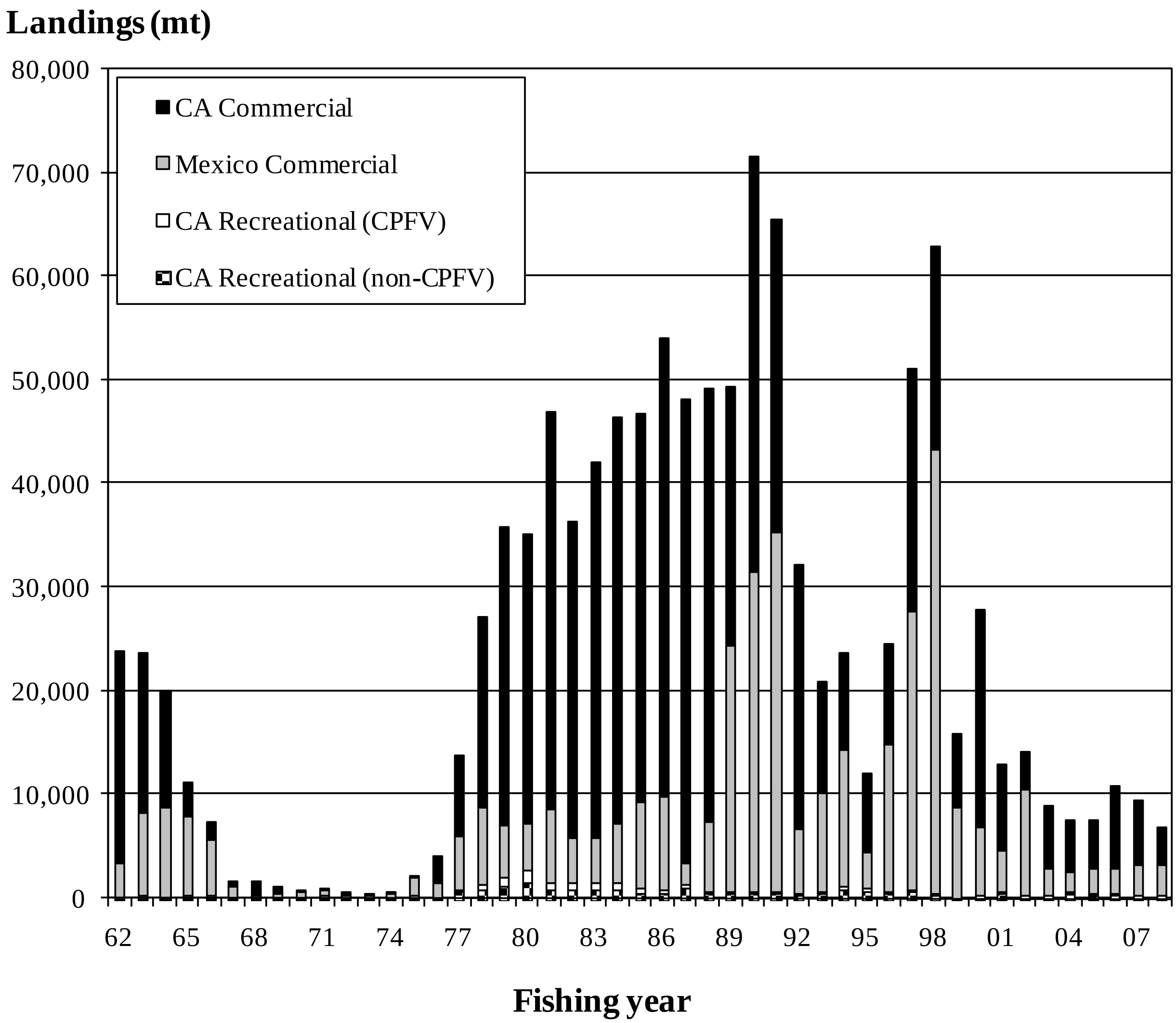


Figure 1. Commercial and recreational landings (mt) of Pacific mackerel in the USA (CA commercial, recreational-CPFV, and recreational-non-CPFV) and Mexico (commercial), (1962-08).

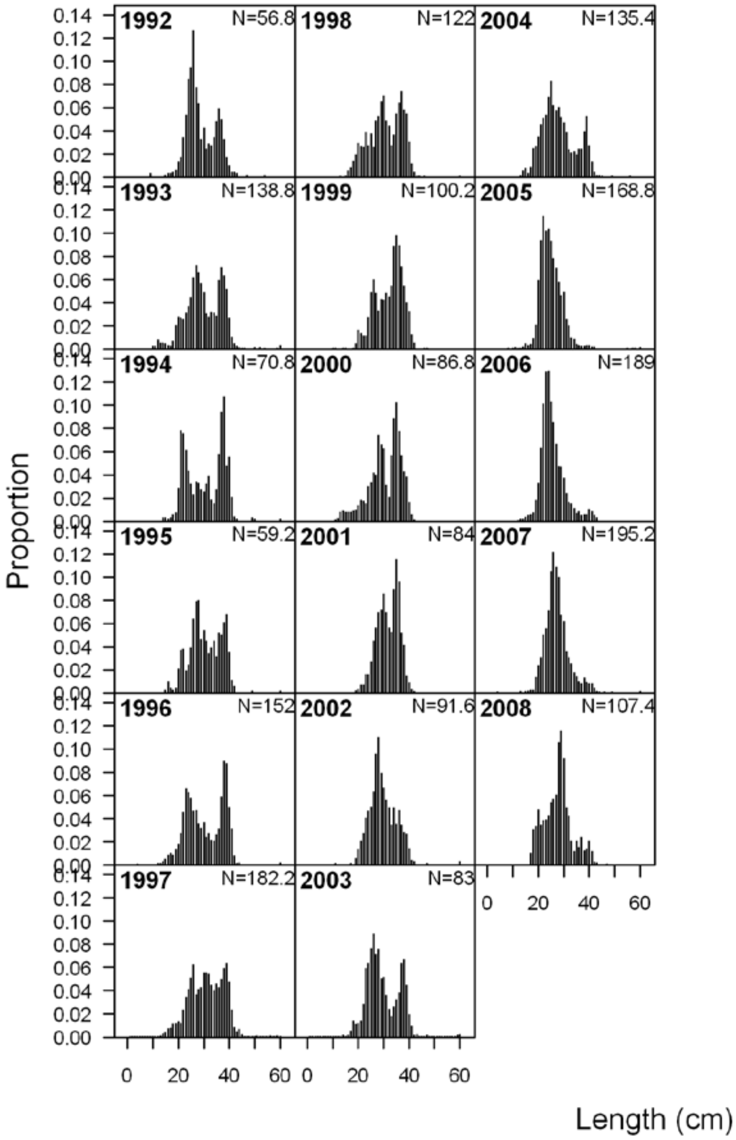


Figure 2. Length distributions of Pacific mackerel from RecFIN data base associated with the CPFV fishery (1992-08).

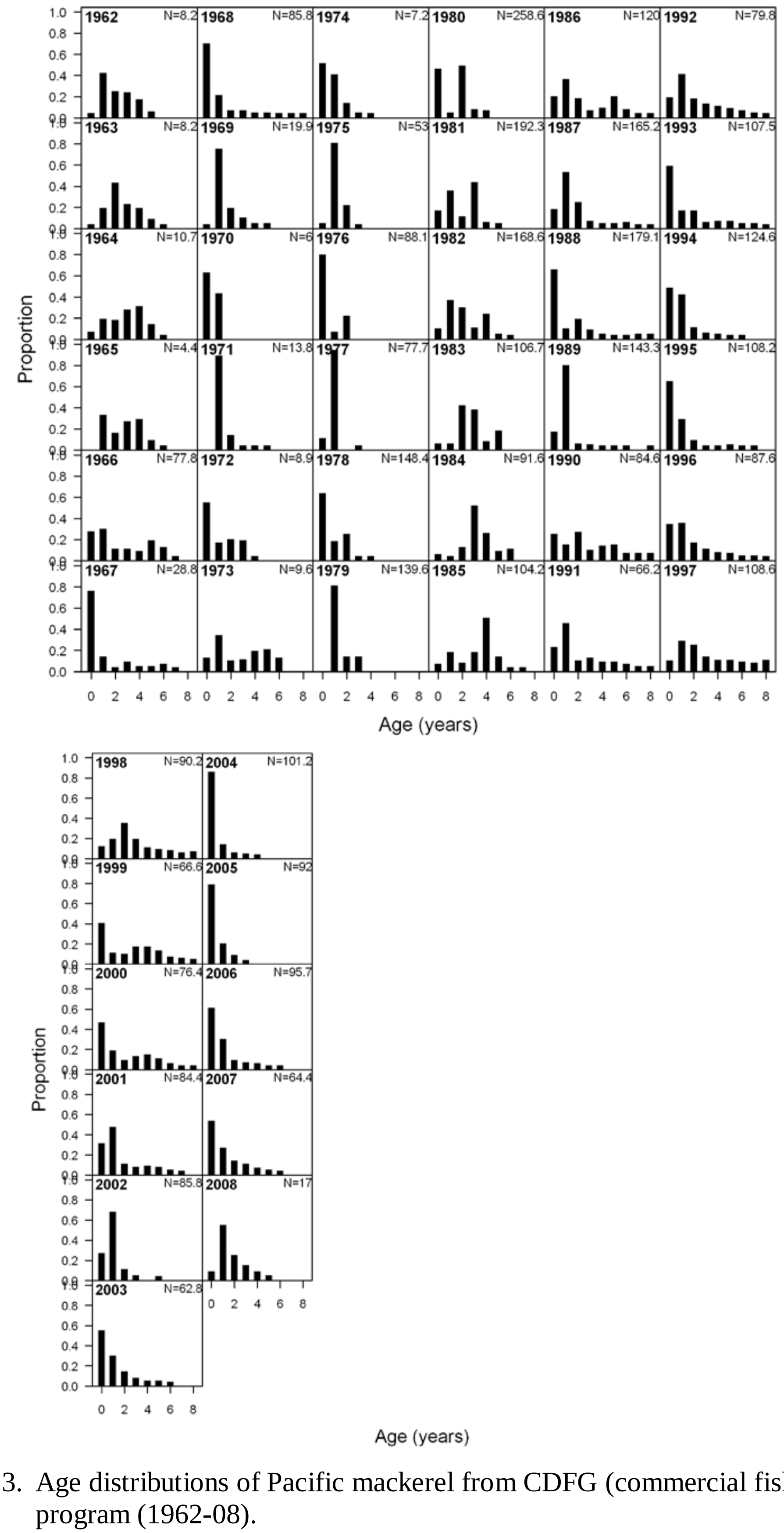


Figure 3. Age distributions of Pacific mackerel from CDFG (commercial fishery) port sampling program (1962-08).

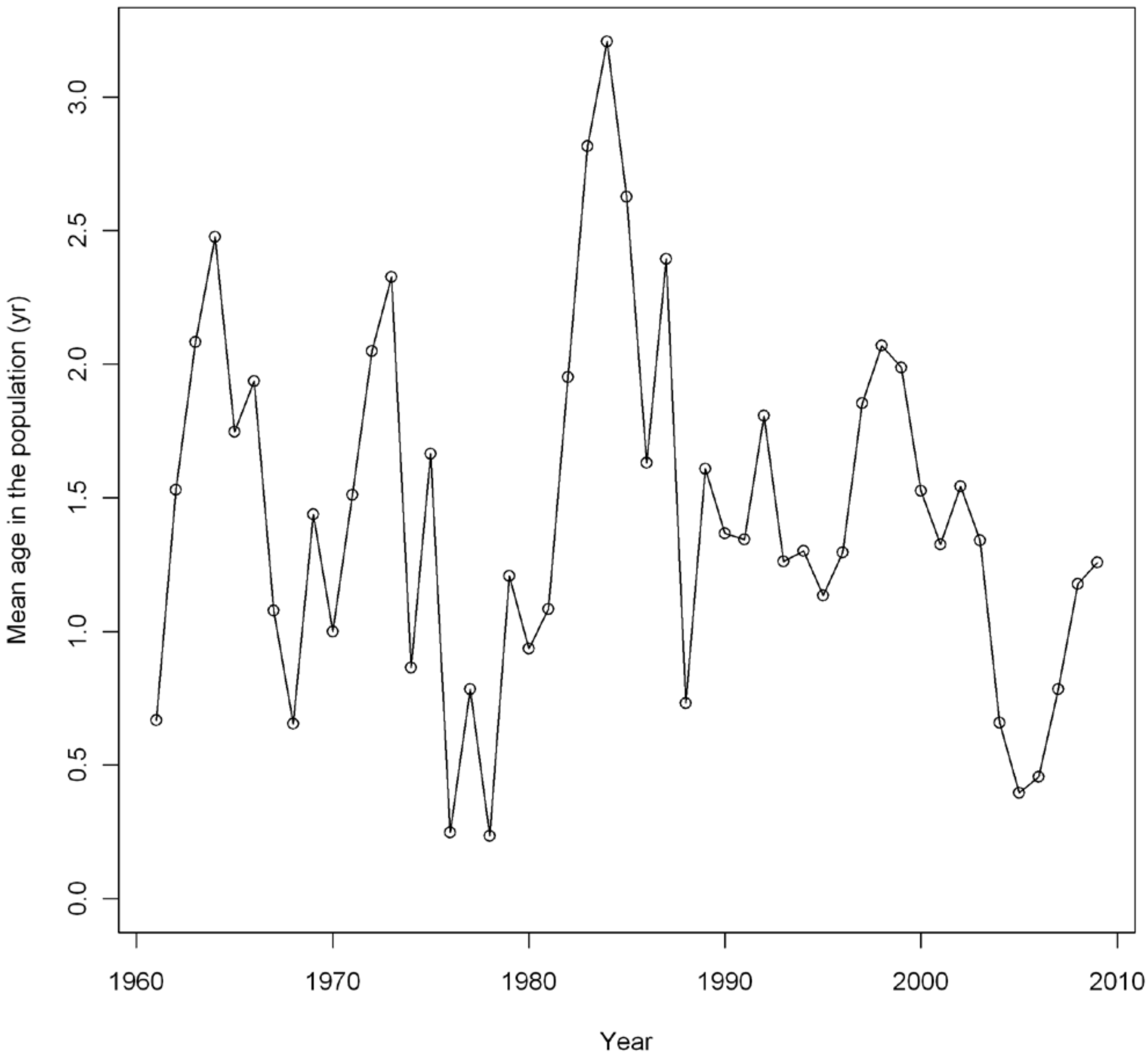


Figure 4. Estimated mean age time series of Pacific mackerel from CDFG (commercial fishery) port sampling program (1962-08).

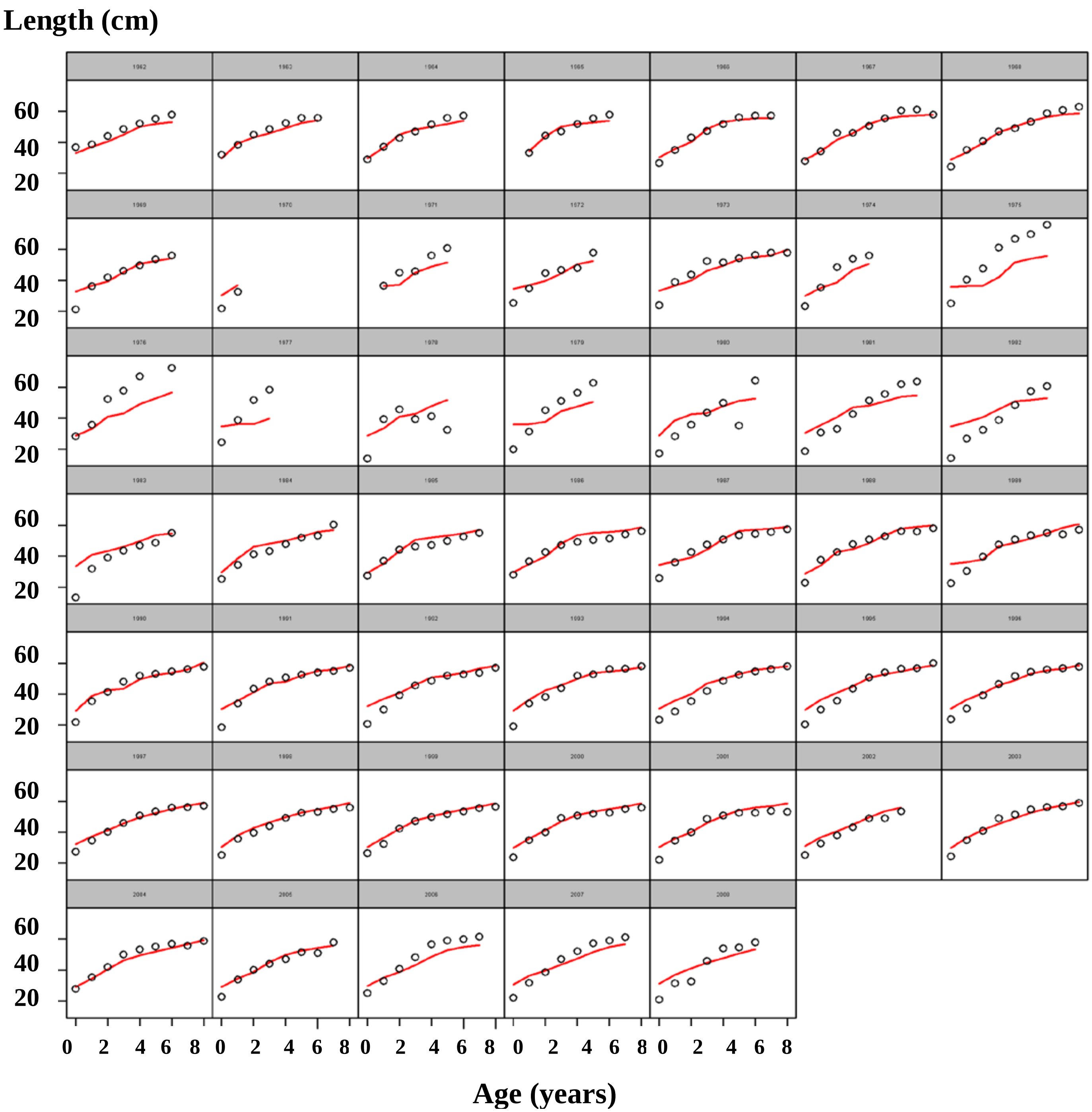


Figure 5. Estimated mean length-at-age (cm/yr, open circles) time series of Pacific mackerel from CDFG (commercial fishery) port sampling program (1962-08). Also, model fits to this time series are also presented (curved line in each display).

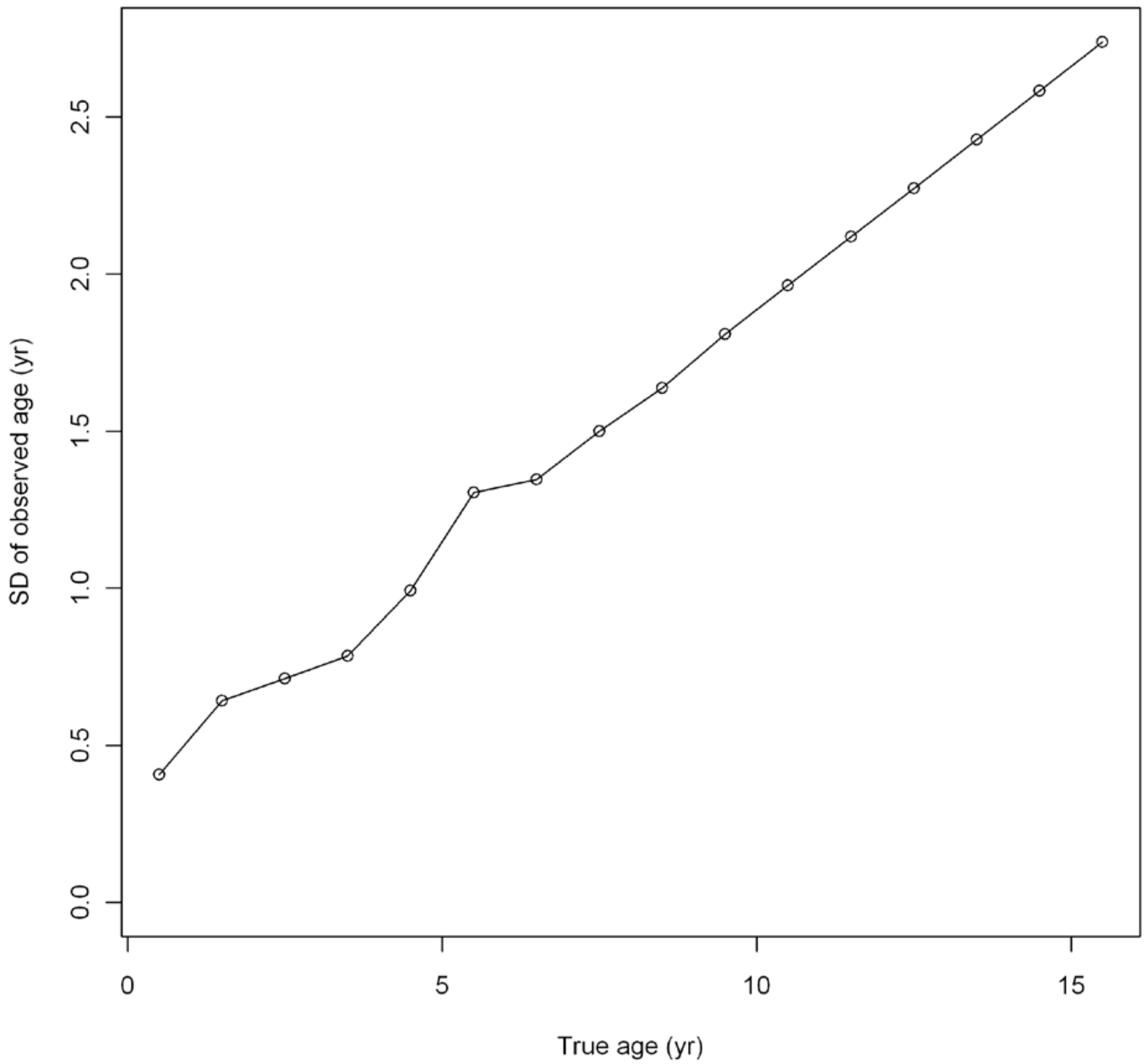


Figure 6. Ageing error vector (SD by age) from CDFG age production laboratory based on double-read analysis.

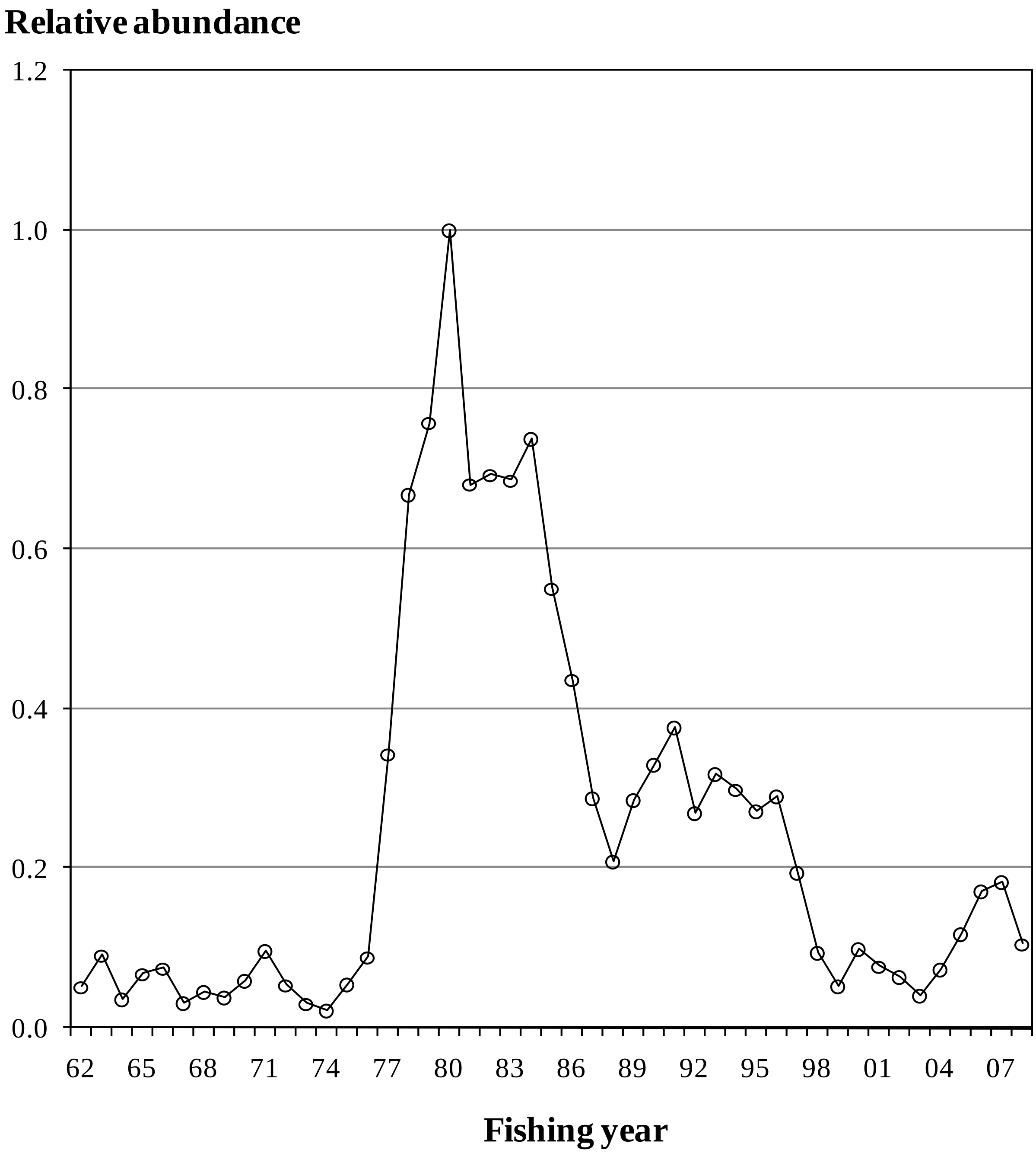


Figure 7. The CPFV index of relative abundance (CPUE) time series for Pacific mackerel (1962-08). Index is presented as a rescaled (normalized) time series.

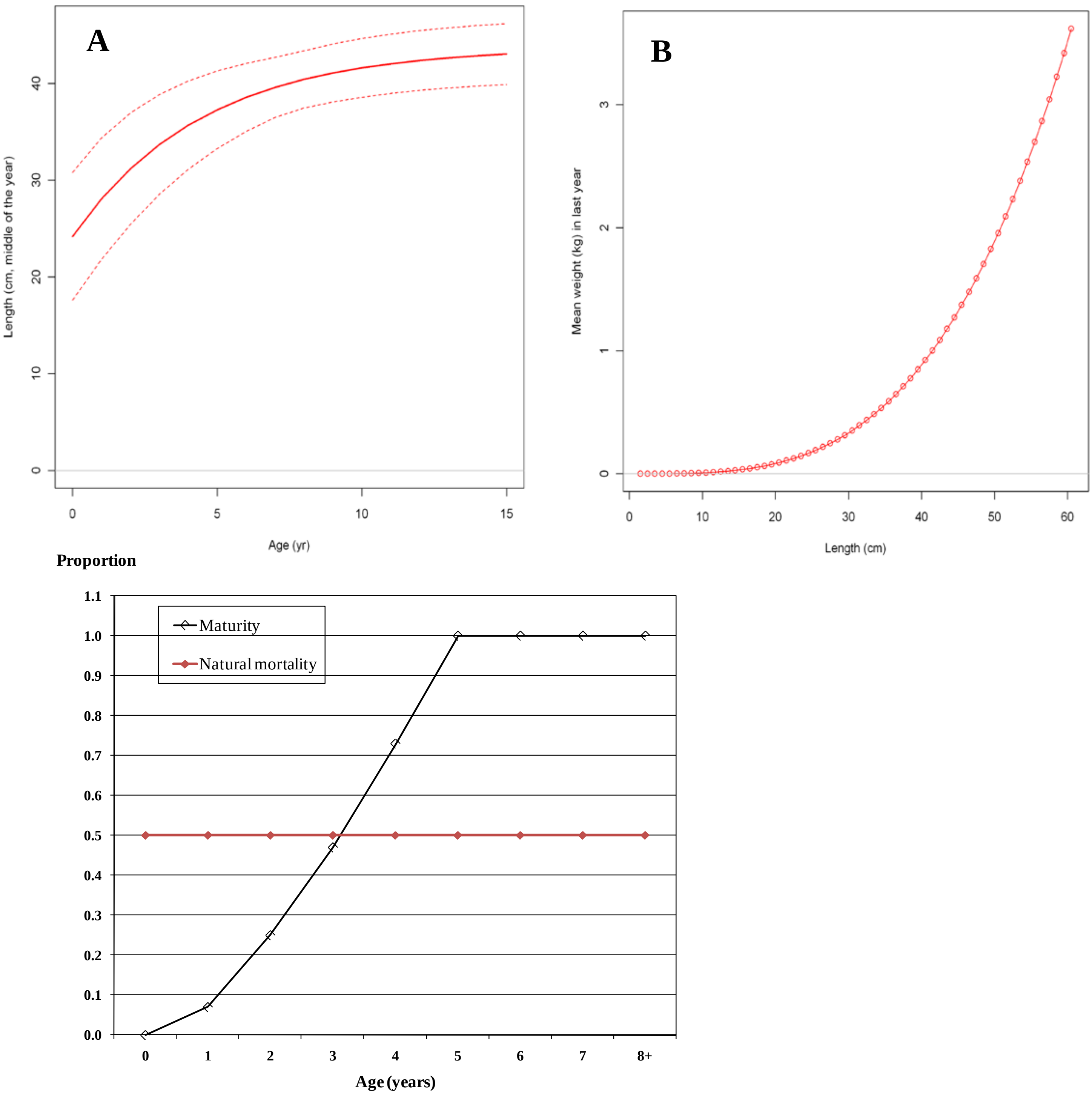


Figure 8. Biological parameters for Pacific mackerel either assumed or estimated in the assessment models: (A) weight-length relationship; (B) length (cm)-at-age (yr); and (C) maturity (also, see Table 3) and natural mortality (*M*).

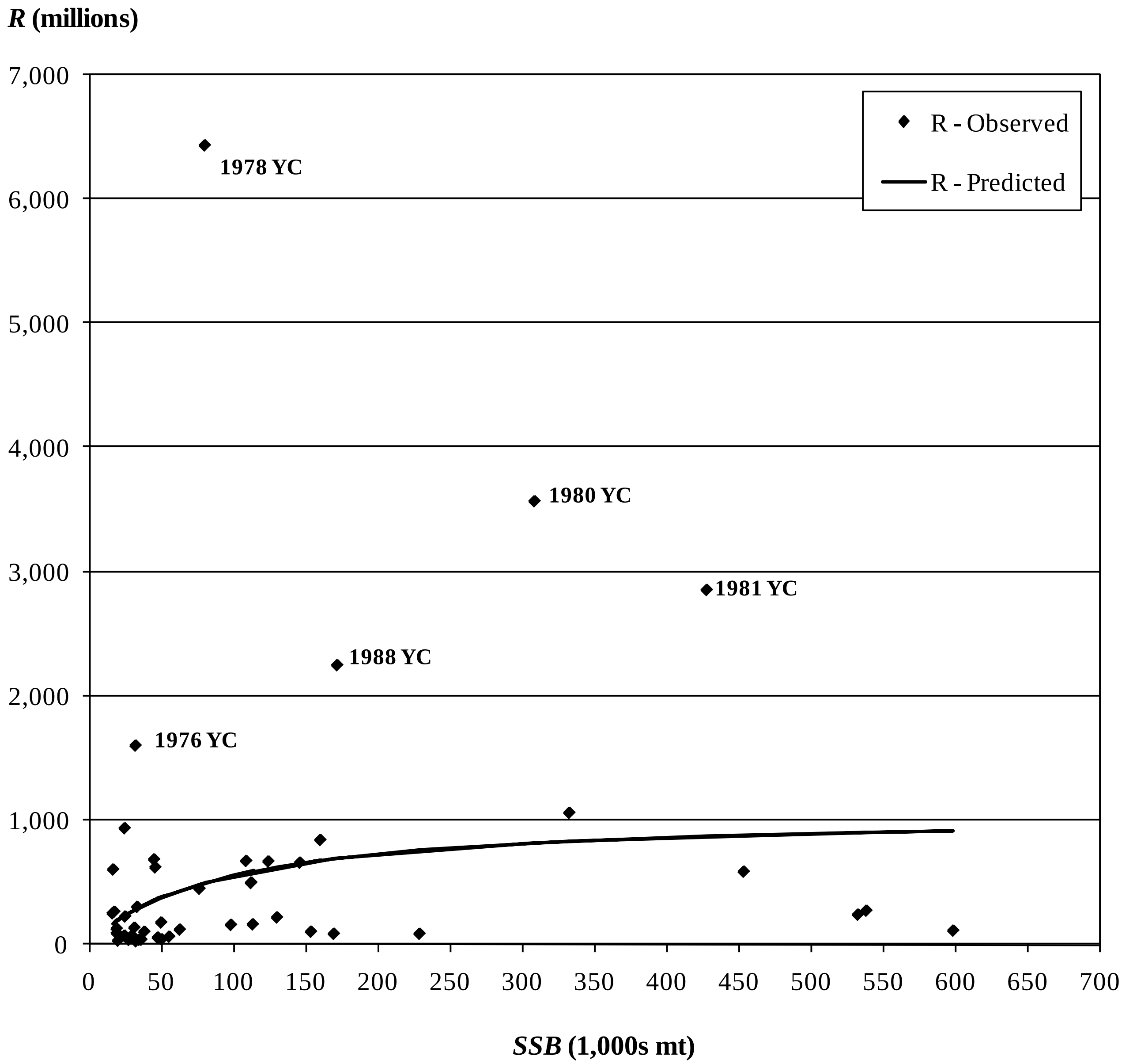
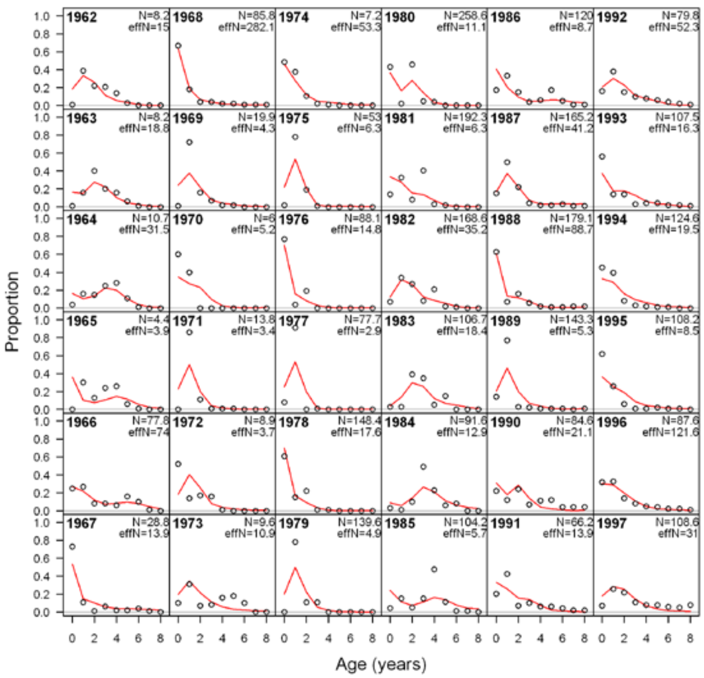


Figure 9. Beverton-Holt stock (*SSB* in 1000s mt)-recruitment (*R* in millions of fish) relationship for Pacific mackerel estimated in the final SS model *AA* (2009). Recruitment estimates are presented as (year+1) values. Strong year classes are highlighted. Steepness=0.47.

A



A

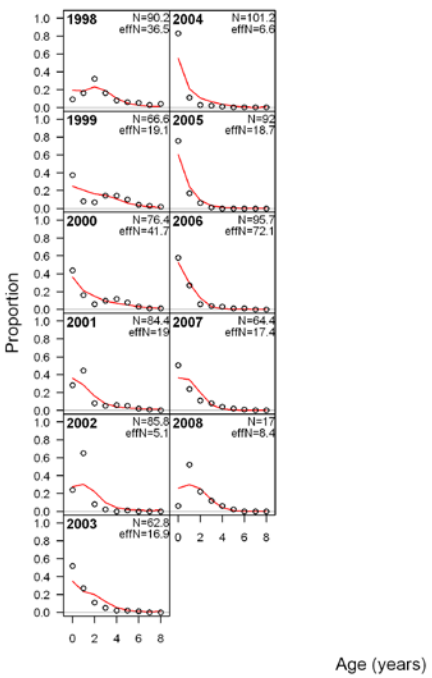
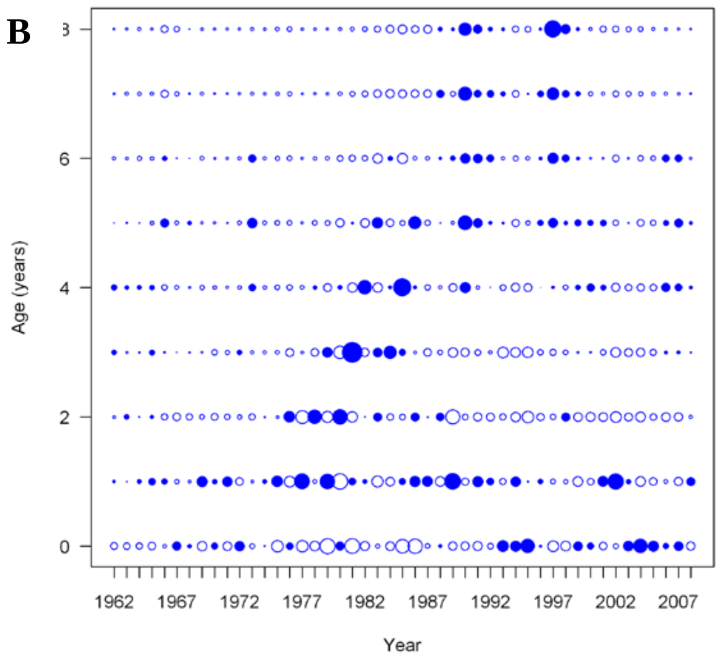


Figure 10. Model (SS model *AA*) fit diagnostics associated with the commercial fishery age distribution time series (1962-08): (A) observed (open circles) vs. predicted (line) estimates; (B) Pearson standardized residuals (observed – predicted; maximum bubble size = 10.94; dark circles represent positive values); and (C) effective vs. observed (input) sample sizes for the commercial fishery age distribution time series. Solid line represents a 1:1 relationship and the dashed line reflects a loess smoother.

B



C

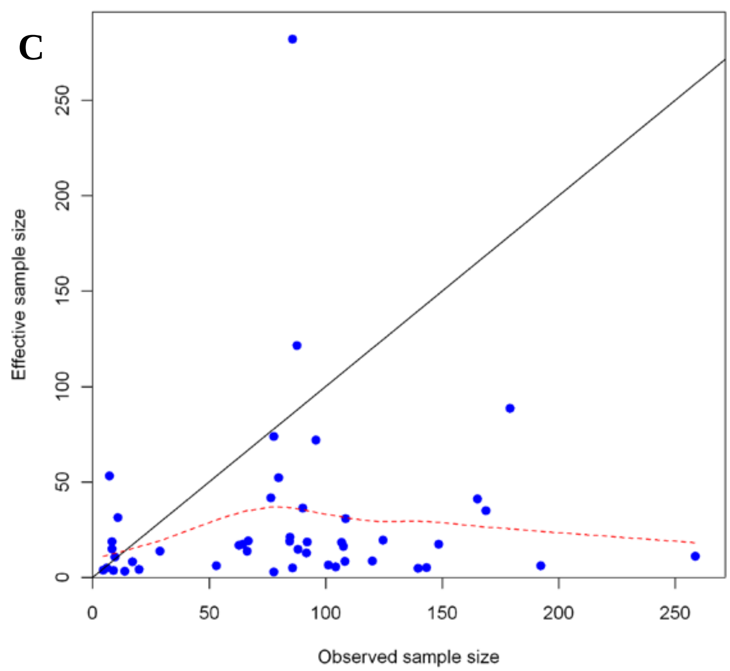


Figure 10. Continued.

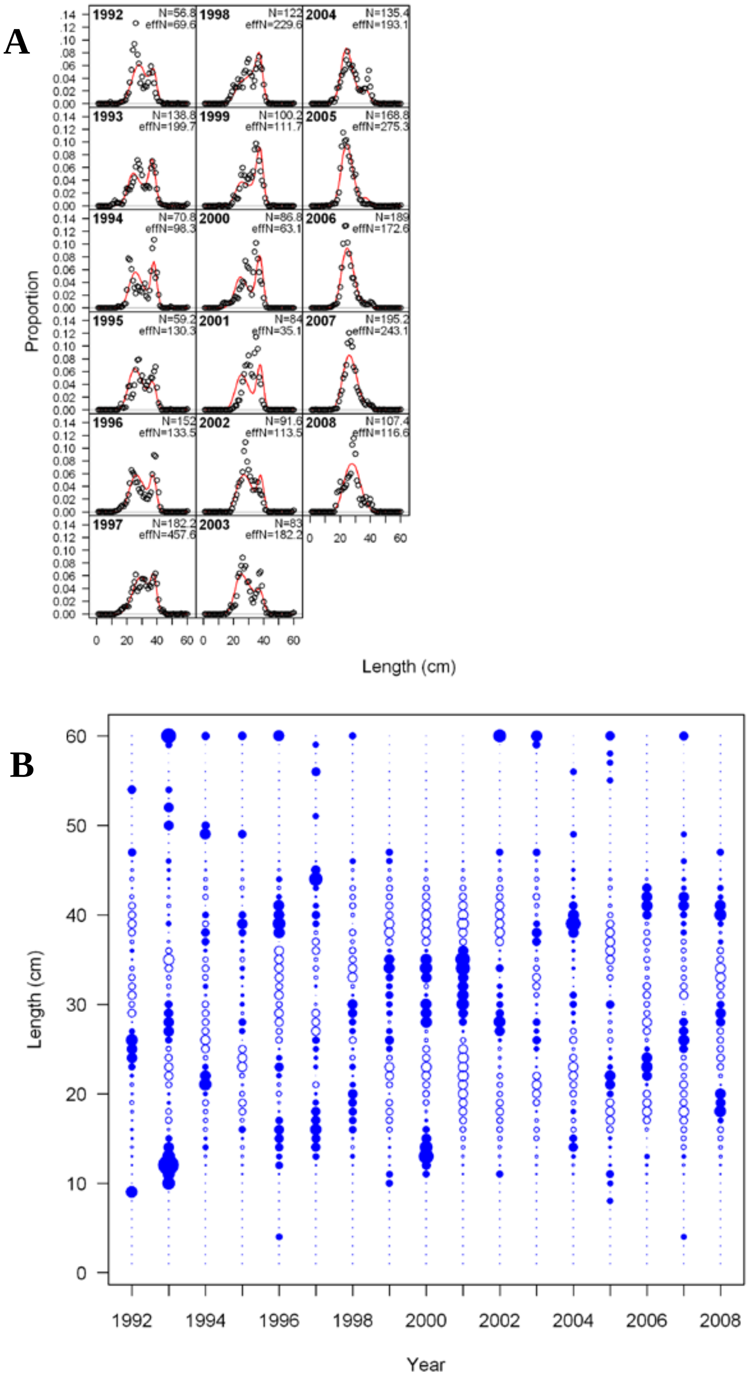


Figure 11. Model (SS model *AA*) fit diagnostics associated with the recreational (CPFV) fishery length distribution time series (1992-08): (A) observed (open circles) vs. predicted (line) estimates; (B) Pearson standardized residuals (observed – predicted; maximum bubble size = 6.38; dark circles represent positive values); and (C) effective vs. observed (input) sample sizes for the commercial fishery age distribution time series. Solid line represents a 1:1 relationship and the dashed line reflects a loess smoother.

C

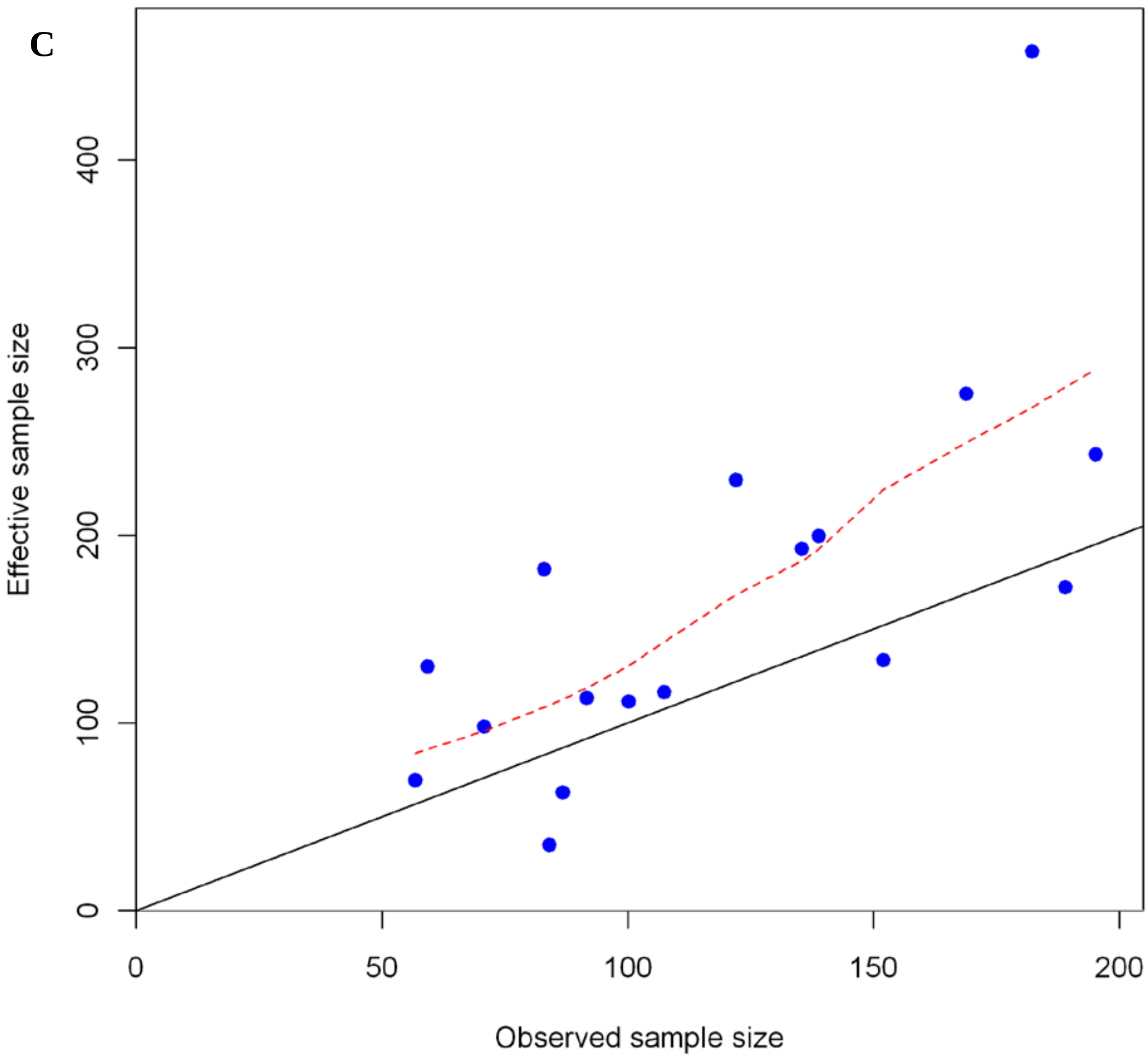


Figure 11. Continued.

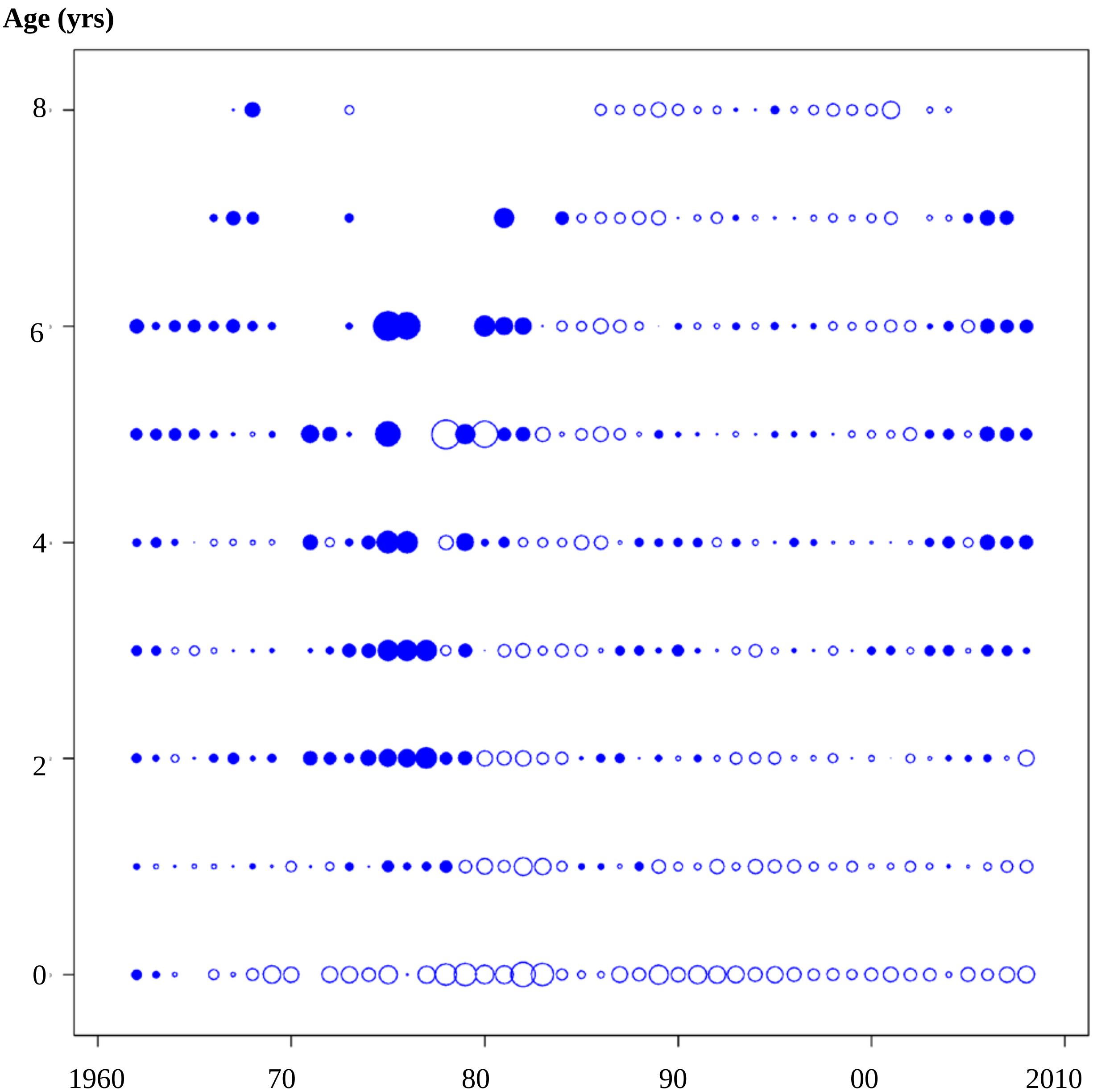
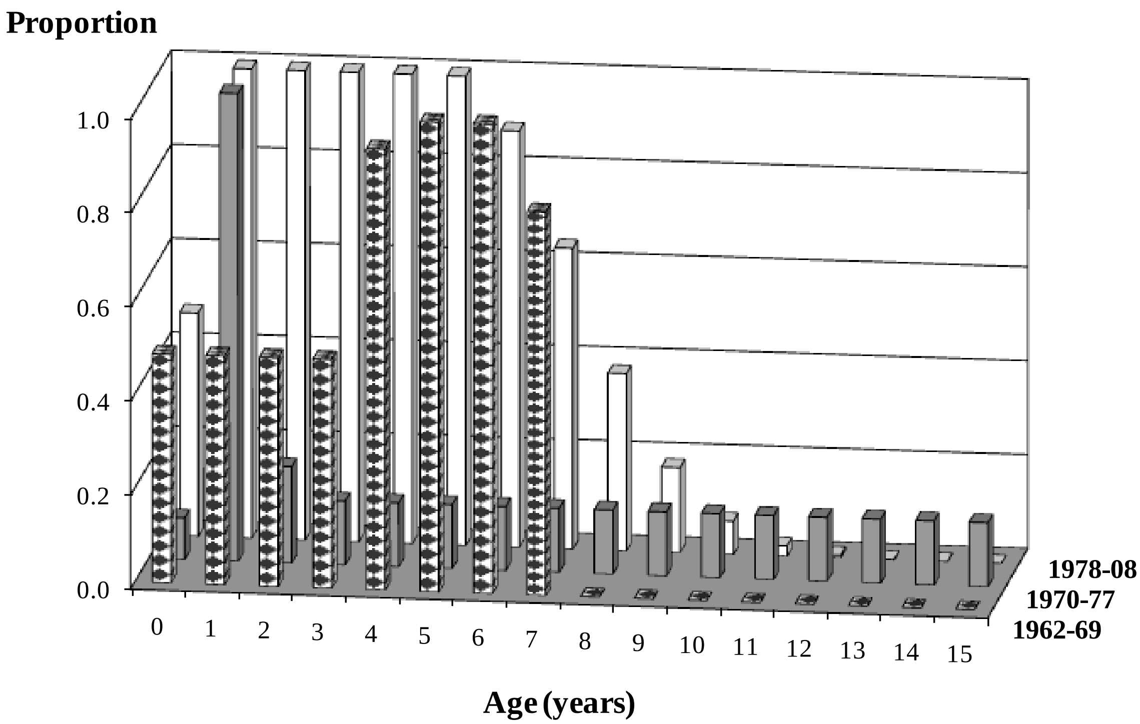


Figure 12. Model (SS model *AA*) fit diagnostics associated with the commercial fishery mean length-at-age (cm/yr, open circles) time series (1962-08), i.e., see Figure 5 for observed (open circles) vs. predicted (line) estimates and the associated Pearson standardized residuals plot (observed – predicted; maximum bubble size = 4.33; dark circles represent positive values) is presented here.

A



B

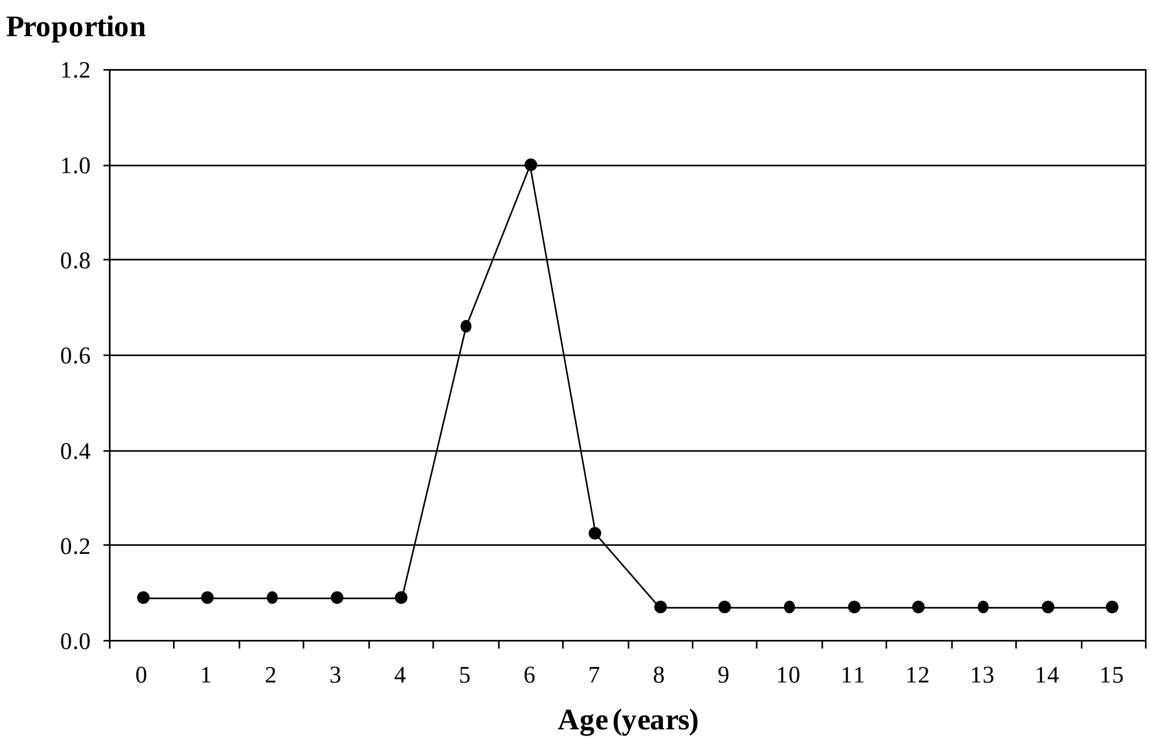


Figure 13. Estimated selectivity schedules associated with SS model *AA*: (A) time-varying for the commercial fishery (1962-69, 1970-77, 1978-08); and constant for recreational fishery (1962-08). Note that selectivity associated with the CPFV index mirrored the recreational fishery.

A

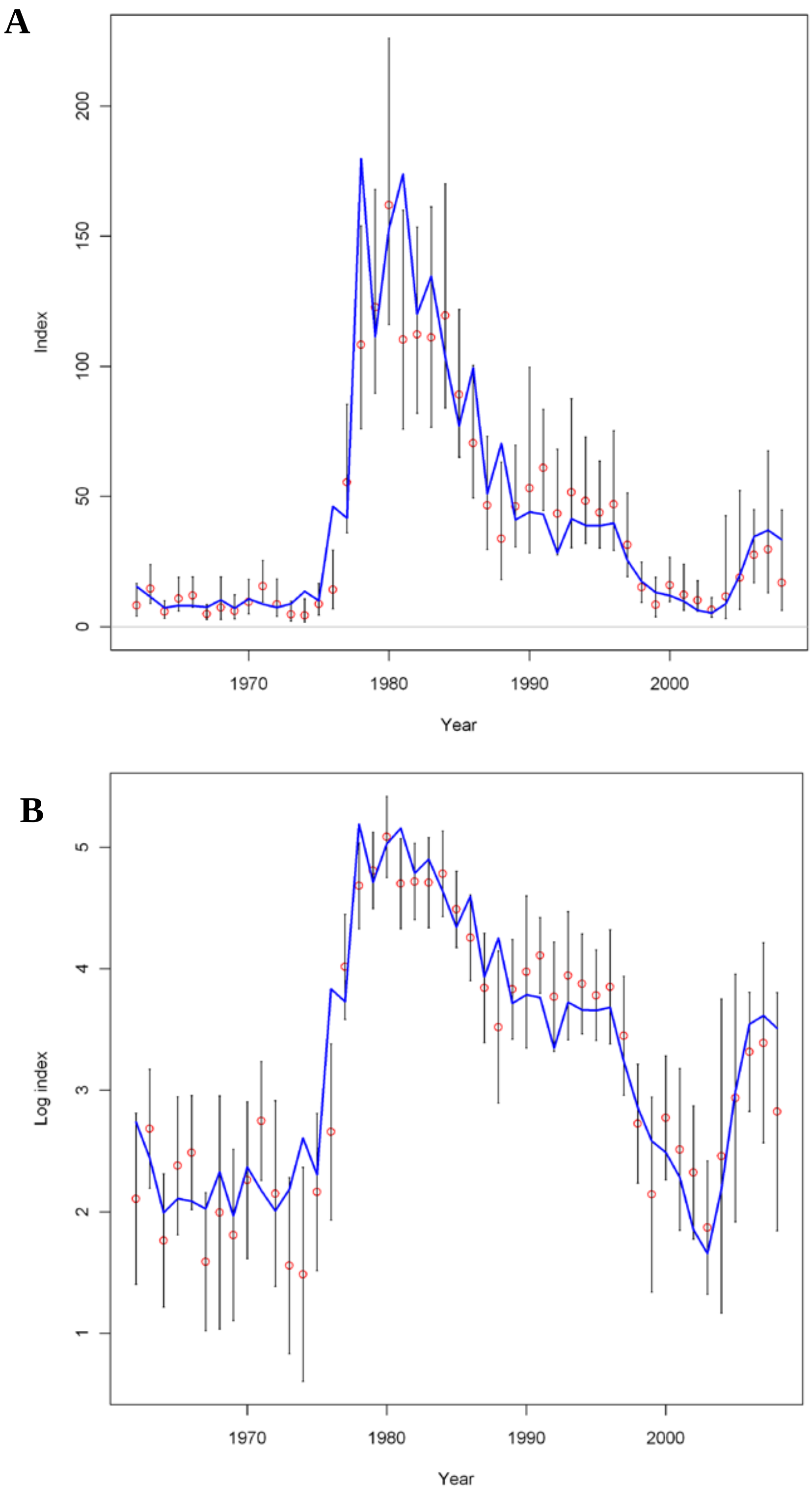


Figure 14. Model (SS model *AA*) fits to the CPFV index of relative abundance: (A) normal space; and (B) log space.

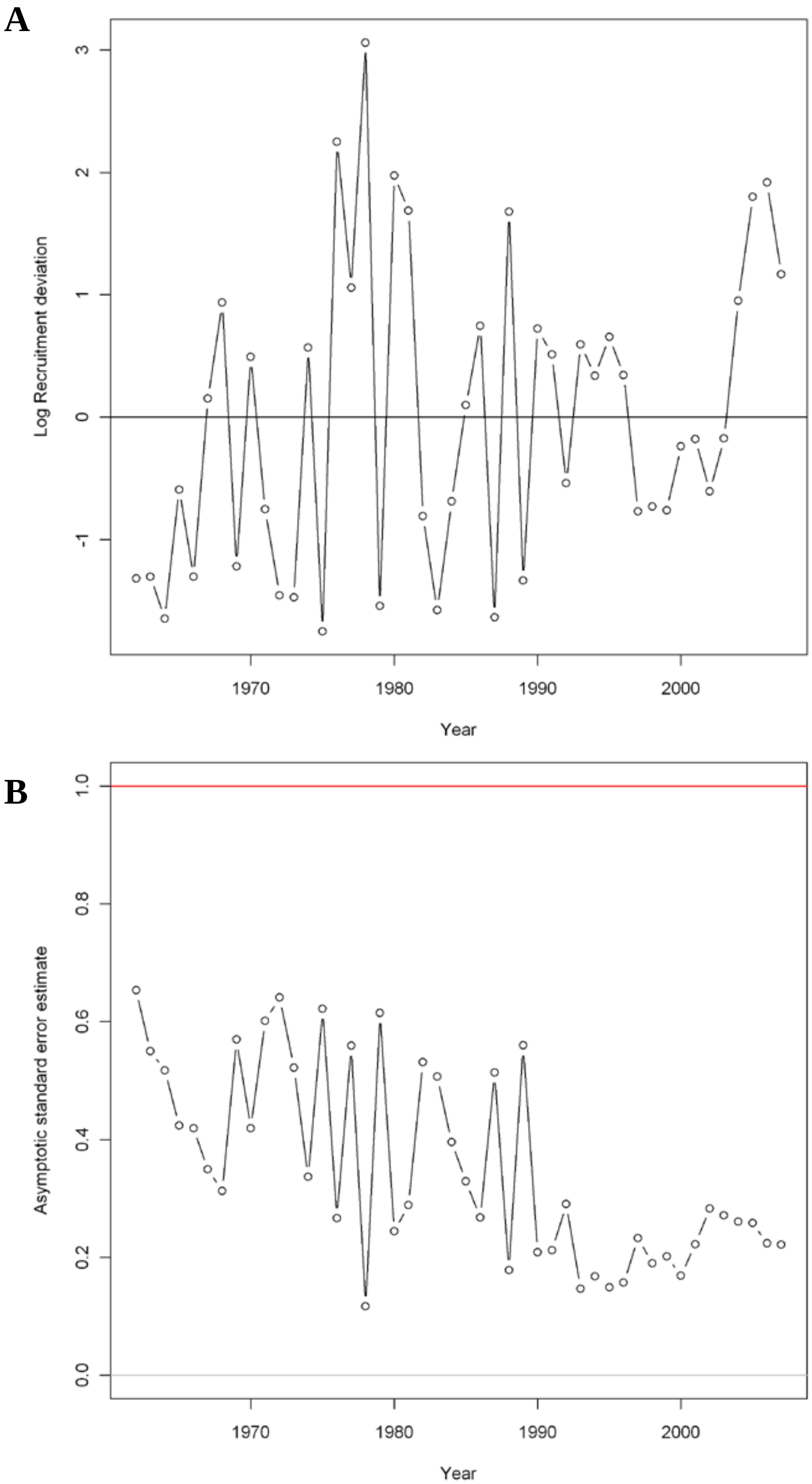


Figure 15. Recruitment-related estimates from SS model *AA*: (A) recruitment deviations; and (B) SEs associated with the deviations (horizontal line indicates the estimate of the standard deviation of log recruitment deviations, i.e., fixed σ-*R* =1.0).

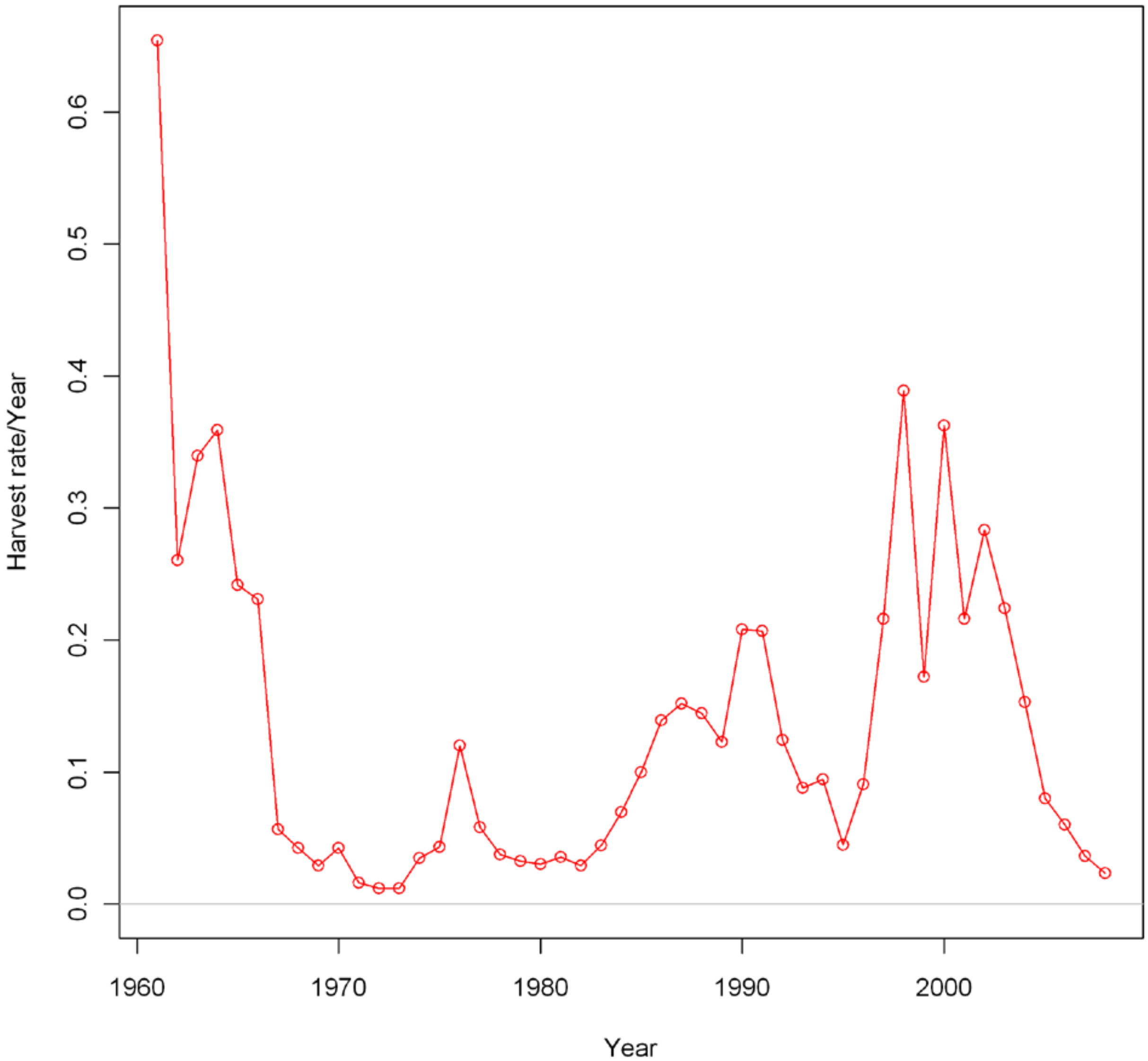


Figure 16. Estimated harvest rate (fishing mortality, *F*) time series from SS model *AA* (1962-08).

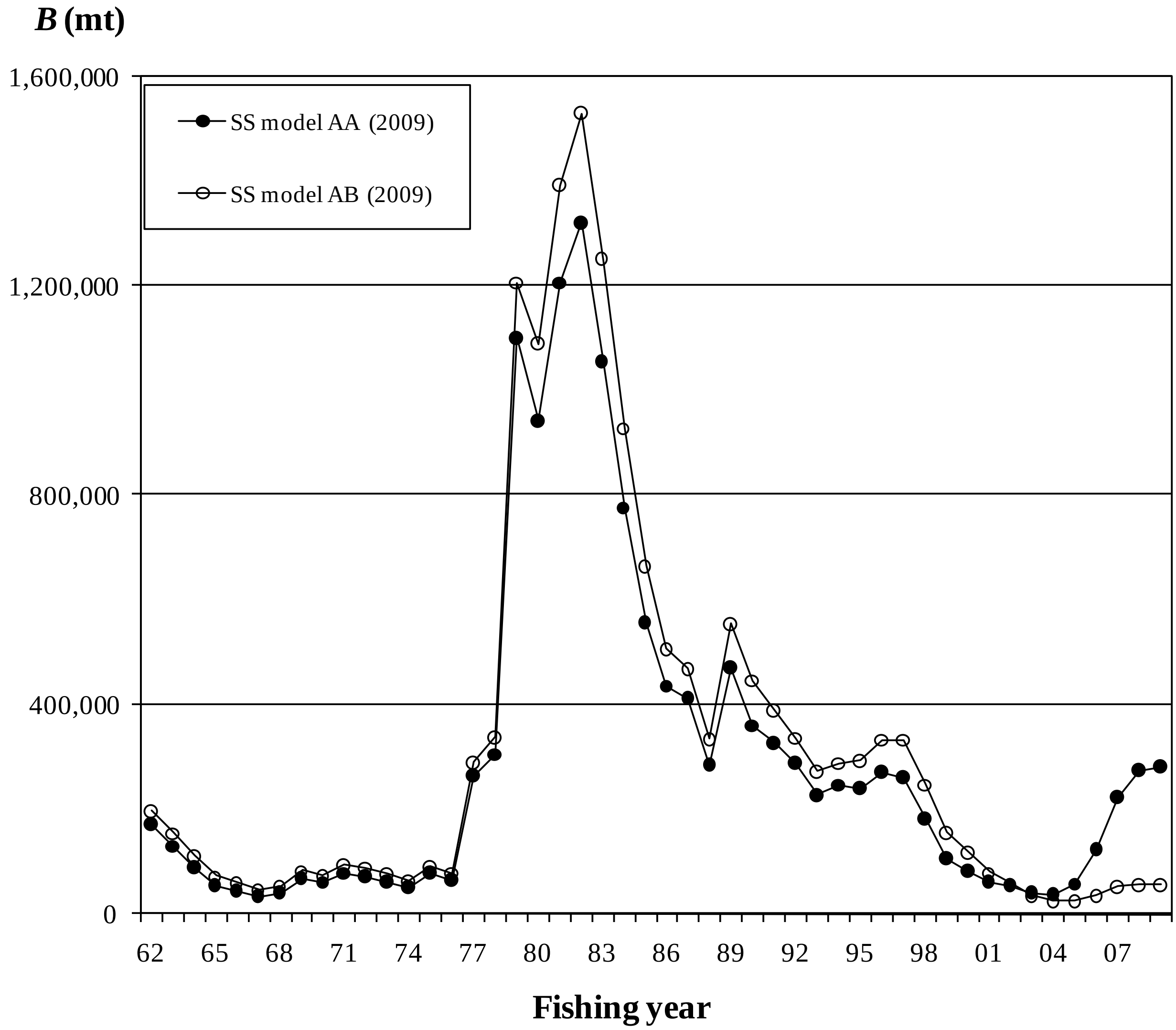


Figure 17. Estimated total stock biomass (age 1+ fish in mt, *B*) of Pacific mackerel based on the final SS model *AA* and alternative model *AB* (1962-09).

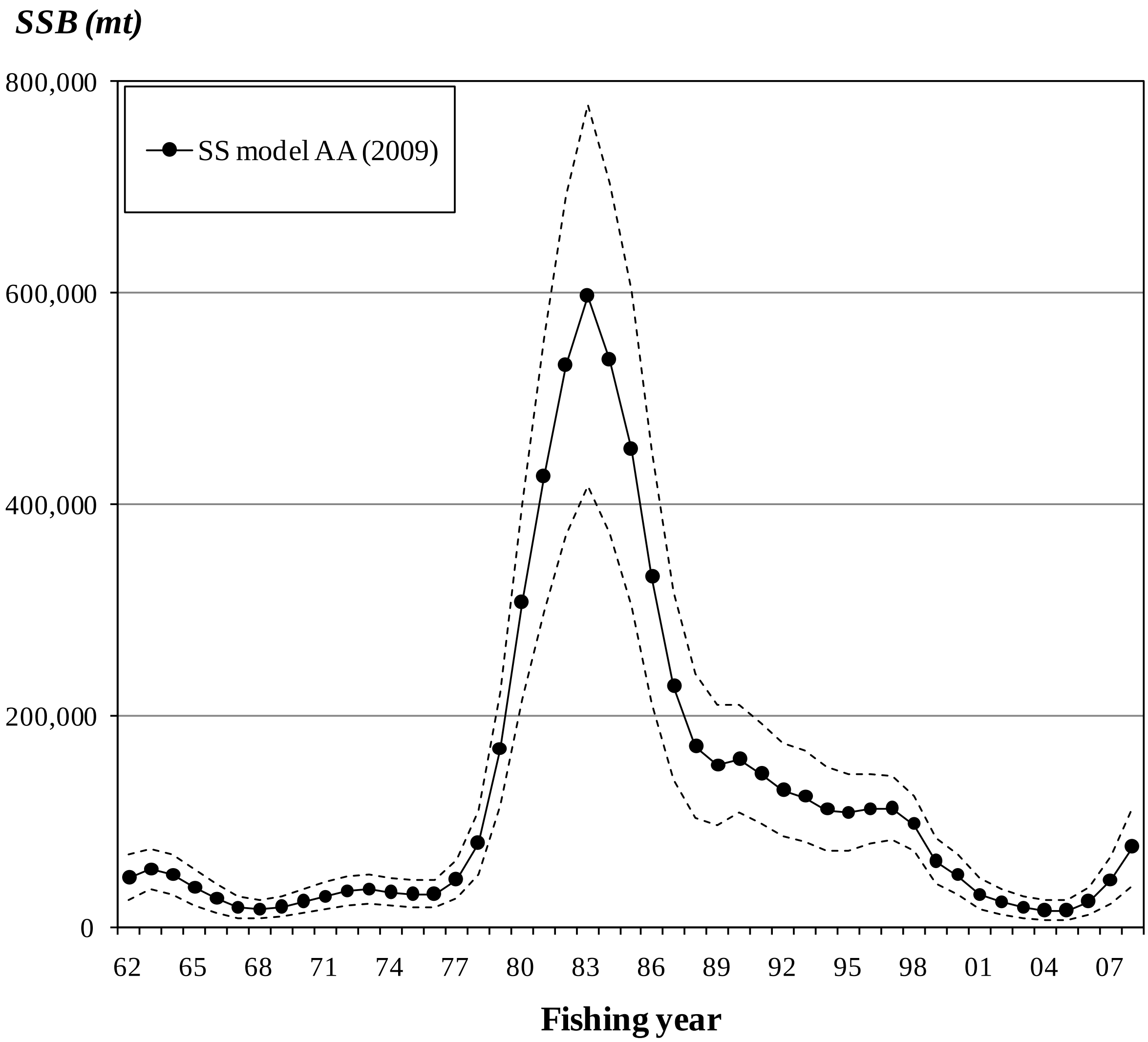


Figure 18. Estimated spawning stock biomass (*SSB*) of Pacific mackerel based on SS model *AA* (1962-08). Confidence interval (± 2 SD) is also presented as dashed lines.

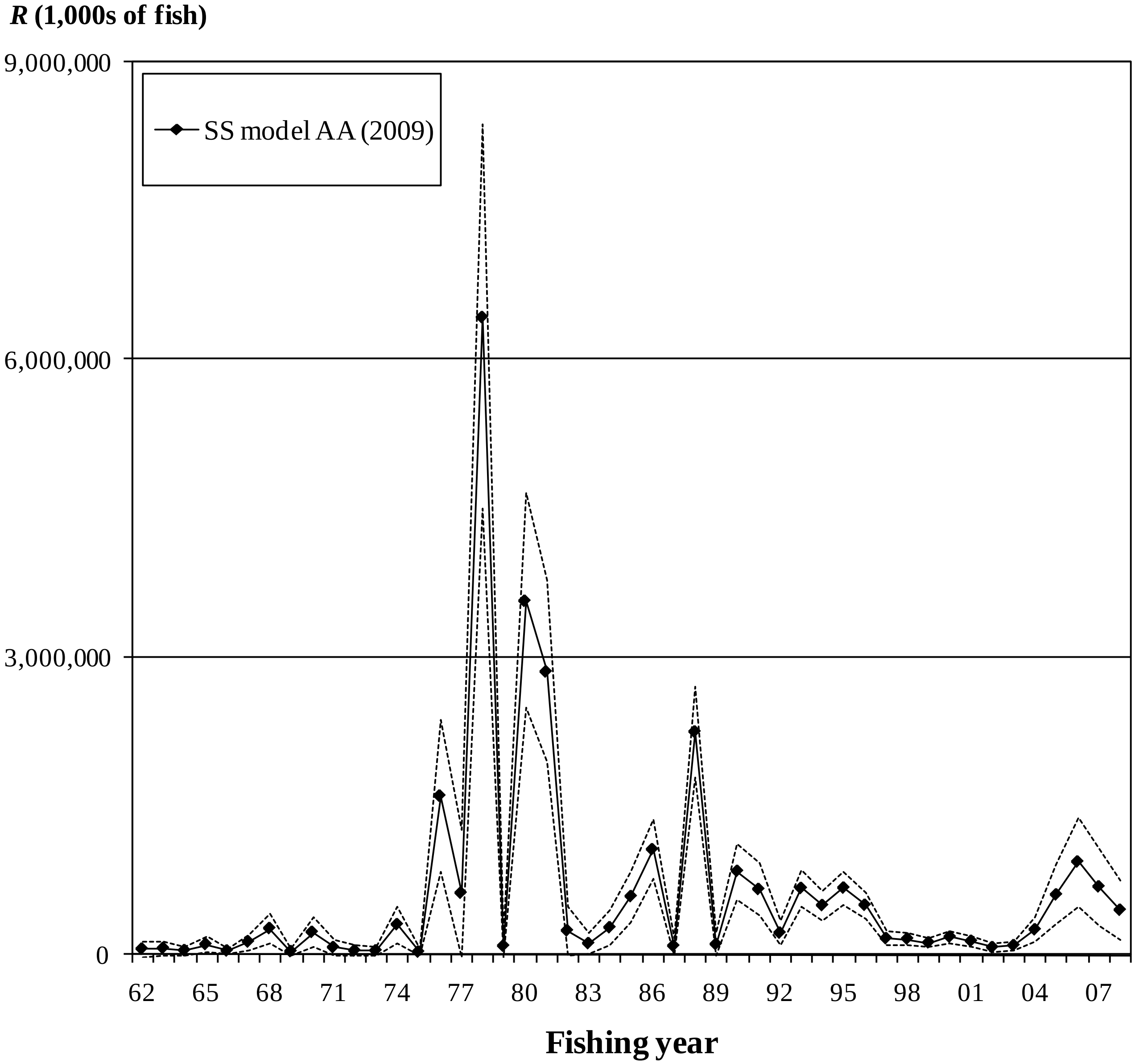


Figure 19. Estimated recruitment (age-0 fish in 1,000s, *R)* of Pacific mackerel based on SS model *AA* (1962-08). Confidence interval (± 2 SD) is also presented as dashed lines.

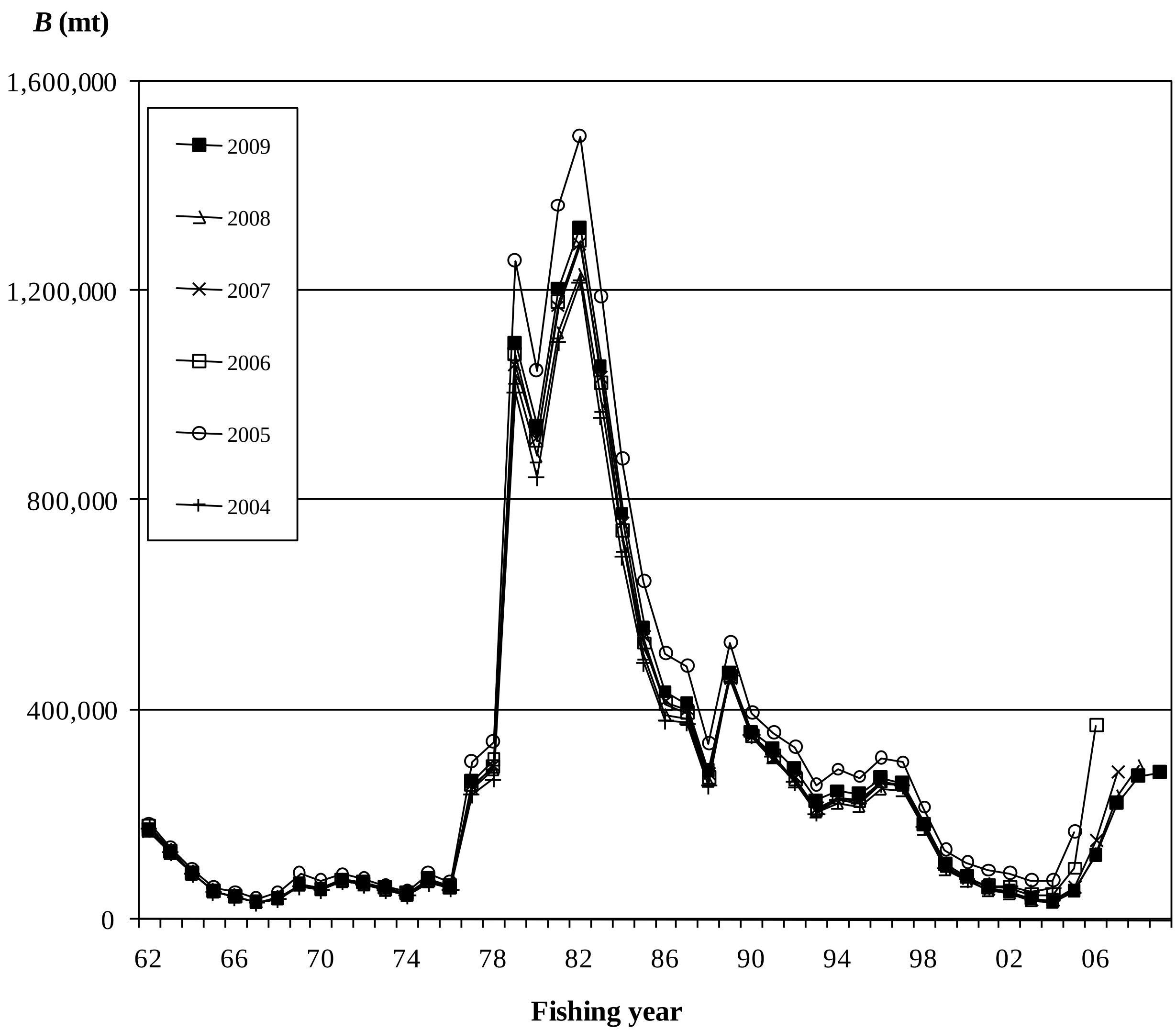


Figure 20. Estimated total stock biomass (age 1+ fish in mt, *B*) of Pacific mackerel based on retrospective analysis that omitted one year of data in chronological order (2004-09), i.e., 2009 time series represents final SS model *AA*.

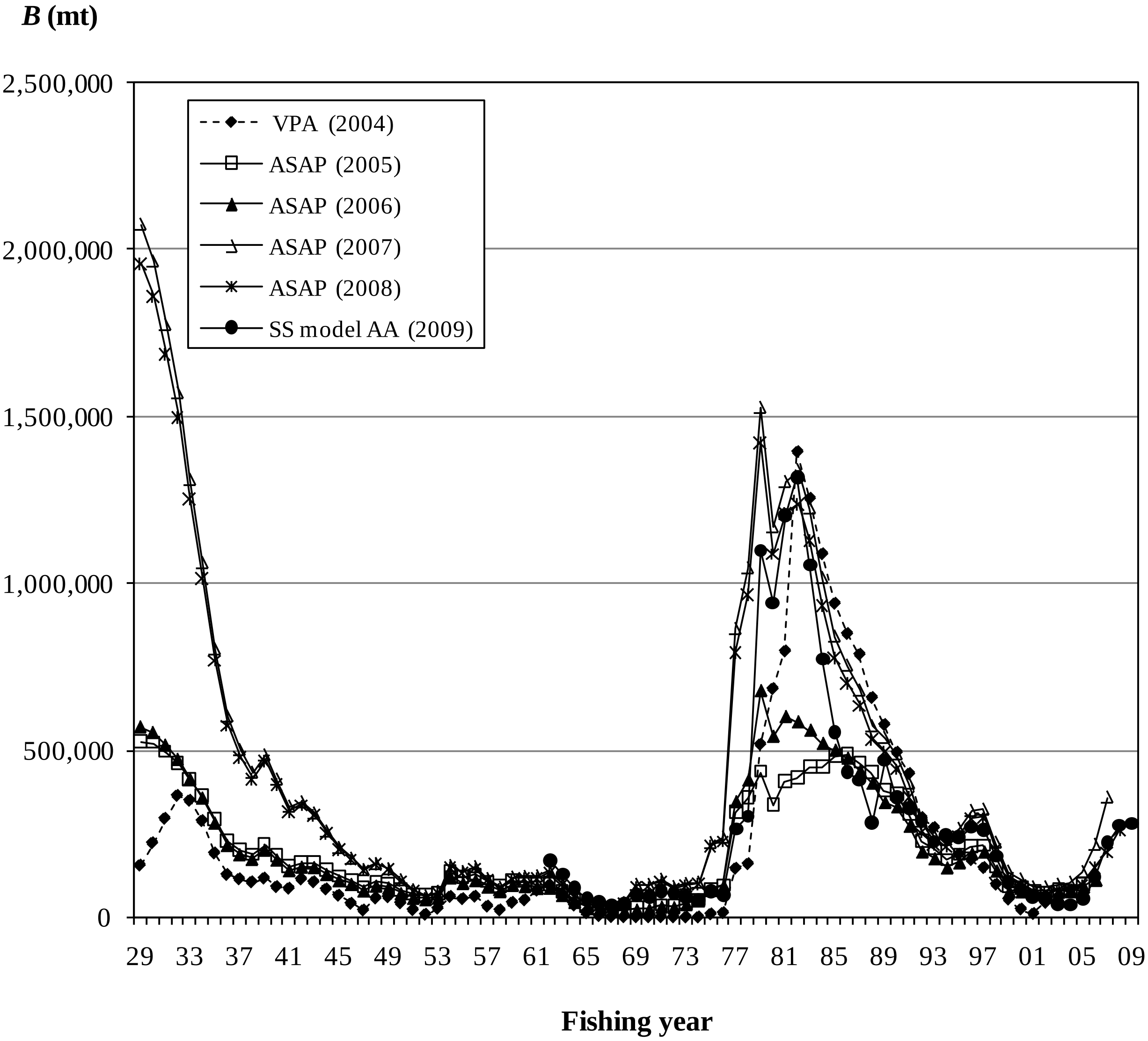


Figure 21. Estimated total stock biomass (*B* age 1+ fish in mt) of Pacific mackerel for historical assessment period (1994-09): VPA model-based assessments from 1994-04; ASAP model-based from 2005-08; and SS model-based currently (2009).

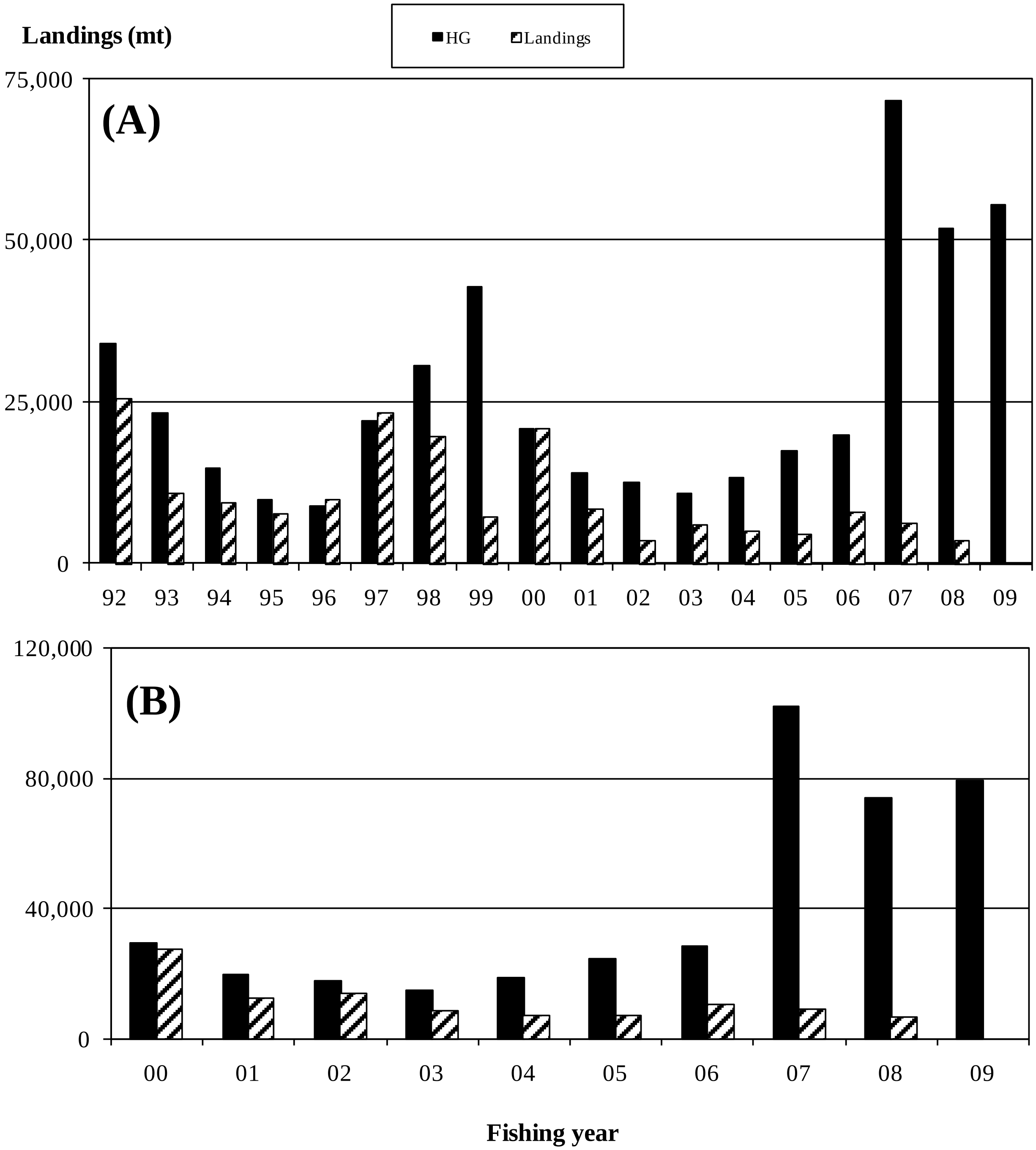


Figure 22. Harvest guideline statistics for Pacific mackerel: (A) commercial landings (California directed fishery in mt) and quotas (HGs in mt), (1992-09); and (B) total landings (mt) and hypothetical quotas based on no USA 'Distribution' parameter in the harvest control rule. Incidental landings from Pacific Northwest fisheries are not included, but typically are limited, ranging 100 to 300 mt per year.

Appendix 1

SS model *AA* (2009) files

```
###############################################################################

# P. mackerel stock assessment (1962-08)
# P. R. Crone (March 2009)
# Stock Synthesis 3 (v. 3.0.12) - R. Methot
# Model AA: number of fisheries = 2 / surveys = 1 / time-step = annual /
biological distributions = age, length, and mean size-at-age / selectivity =
age-based
#
# NOTES: ** ... ** = Pending questions and/or comments
#
```

 # STARTER FILE

```
#
AA.dat # Data file
AA.ctl # Control file
0 # Read initial values from 'par' file: 0 = no, 1 = yes
1 # DOS display detail: 0, 1, 2
1 # Report file detail: 0, 1, 2
0 # Detailed checkup.sso file: 0 = no, 1 = yes
0 # Write parameter iteration trace file during minimization
1 # Write cumulative report: 0 = skip, 1 = short, 2 = full
0 # Include prior likelihood for non-estimated parameters
1 # Use soft boundaries to aid convergence: 0 = no, 1 = yes
0 # Number of bootstrap data files to produce
20 # Last phase for estimation
1 # MCMC burn-in interval
1 # 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)
-1 # 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
1 # Fraction for depletion denominator (e.g., 0.4)
1 # (1-SPR) reporting: 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 SD reporting: 0 = skip, 1 = exploitation(Bio), 2 = exploitation(Num), 3
    = sum(F_rates)
0 # F reporting: 0 = raw, 1 = F/Fspr, 2 = F/Fmsy, 3 = F/Fbtgt
999 # End of file
```

```
##############################################################################
# P. mackerel stock assessment (1962-08)
# P. R. Crone (March 2009)
# Stock Synthesis 3 (v. 3.0.12) - R. Methot
# Model AA: number of fisheries = 2 / surveys = 1 / time-step = annual /
  biological distributions = age, length, and mean size-at-age / selectivity =
  age-based
#
# NOTES: ** ... ** = Pending questions and/or comments
#
```

FORECAST FILE

```
#
1 # Forecast: 0 = none, 1 = F_SPR, 2 = F_MSY, 3 = F_btgt, 4 = F_endyr, 5 =
  Avg_F (enter yrs), 6 = read F_mult
2008 # First year for averaging selectivity to use in forecast (e.g., 2004 or
  use -x to be relative endyr)
2008 # Last year for averaging selectivity to use in forecast
1 # Benchmarks: 0 = skip, 1 = calculate (F_SPR, F_btgt, F_MSY)
2 # MSY: 0 = none, 1 = set to F_SPR, 2 = calculate F_MSY, 3 = set to F_Btgt,
  4 = set to F(endyr)
0.3 # SPR target (e.g., 0.40)
0.4 # Biomass target (e.g., 0.40)
1 # Number of forecast years
#
0 # Read 10 advanced forecast options: (0/1) ** Placeholders **
# Do West Coast groundfish rebuilder output: (0/1)
# Rebuilder: first year catch could have been set to zero
# Rebuilder: year for current age structure (Yinit)
# Control rule method: 1 = West Coast adjust catch, 2 = adjust F
# Control rule biomass level for constant F (as fraction of B_0, e.g., 0.40)
# Control rule Biomass level for no F (as fraction of B_0, e.g., 0.10)
# Control rule fraction of F_limit (e.g., 0.75)
# Maximum annual catch during forecast ** Placeholder **
# Implementation error: 1 = use implementation error in forecast **
  Placeholder **
# SD of log(realized F/target F) in forecast ** Placeholder **
#
1 # Fleet allocation (in terms of F): 1 = use endyr pattern (no read), 2 =
  read below
# Rows = seasons and columns = fisheries
# 0 0 # Relative F for forecast when based on F, seasons, fleets within
  seasons
2 # Number of forecast catch levels to input (for additional years, catch
  estimates based on forecasted F)
1 # Basis for input forecasted catch: 1 = retained catch, 2 = total dead
  catch
# Columns: Year Season Fishery Catch
2009 1 1 6513
2009 1 2 290
999 # End of file
```

```
################################################################################
# P. mackerel stock assessment (1962-08)
# P. R. Crone (March 2009)
# Stock Synthesis 3 (v. 3.0.12) - R. Methot
# Model AA: number of fisheries = 2 / surveys = 1 / time-step = annual /
  biological distributions = age, length, and mean size-at-age / selectivity =
  age-based

# NOTES: ** ... ** = Pending questions and/or comments
```

CONTROL FILE

```
# MODEL DIMENSION PARAMETERS
================================================================================

# Morph parameterization

1 # Number of growth patterns (morphs)
1 # Number of sub-morhps within morphs

# Note: 'conditional' (8) lines follow, based on above morp/season/area
  parameterization

# Time block parameterization (time-varying parameterization)
1 # Number of block designs
3 # Blocks in design 1: Selectivity (Fishery 1)

1962 1969 1970 1977 1978 2008 # Blocks - design 1

# BIOLOGICAL PARAMETERS
================================================================================

0.5 # Fraction = female (at birth)
# Natural mortality (M)
0 # Natural mortality type: 0 = 1 parameter, 1 = N_breakpoints, 2 = Lorenzen,
    3 = age-specific, 4 = age-specific with season interpolation
# Placeholder for number of M breakpoints (if M type option >0)
# Placeholder for Age (real) at M breakpoints
# Growth
1 # Growth model: 1 = VB with L1 and L2, 2 = VB with A0 and Linf, 3 =
    Richards, 4 = readvector
0.5 # Growth_age at L1 (L_min): Age_min for growth
8 # Growth_age at L2 (L_max) - (to use L_inf = 999): Age_max for growth
0 # SD constant added to length-at-age (LAA)
0 # Variability of growth: 0 = CV_f(LAA), 1 = CV_f(A), 2 = SD_f(LAA), 3 =
    SD_f(A)
# Maturity
3 # Maturity option: 1 = logistic (length), 2 = logistic (age), 3 = fixed
    (vector of proportion-at-age), 4 = read age fecundity
# Maturity-at-age (if maturity option = 3) ** based on 'accumulator age'+1 **
0 0.07 0.25 0.47 0.73 1 1 1 1 1 1 1 1 1 1 # Maturity-at-age (proportion)
0 # 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)
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 (fixed) all ages **
# Growth parameterization
# Length-at-age
4 35 15 0 -1 0 3 0 0 0 0 0 0 0 # VB_L_Amin ** Length at age = 0.5 **
30 80 45 0 -1 0 3 0 0 0 0 0 0 0 # VB_L_Amax  ** Length at age = 8 **
0.1 0.7 0.35 0 -1 0 3 0 0 0 0 0 0 0 # VB_K
0.01 0.5 0.1 0 -1 0 3 0 0 0 0 0 0 0 # CV_young
0.01 0.5 0.1 0 -1 0 3 0 0 0 0 0 0 0 # CV_old
# Weight-length
-1 5 3.12e-006 0 -1 0 -3 0 0 0 0 0 0 0 # W-L_a
1 5 3.40352 0 -1 0 -3 0 0 0 0 0 0 0 # W-L_b
# Maturity parameterization ** fixed vector for maturity-at-age **
-3 3 3 0 -1 0 -3 0 0 0 0 0 0 0 # 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) ** Placeholders **
-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
#
# Custom environment (MG) parameterization: (0/1)
#
# Custom block (MG) parameterization: (0/1)
#
# Seasonal effects on biology parameters
0 0 0 0 0 0 0 0 0 0 # ** Placeholder **
#
# Stock-recruit (S-R)
3 # S-R function: 1 = B-H w/flat top, 2 = Ricker, 3 = standard B-H, 4 = no
    steepness or bias adjustment
# Low High Initial Prior_mean Prior_type SD Phase
1 30 10 0 -1 0 1 # ln(R0)
0.1 1 0.9 0 1 0 5 # Steepness
0 2 1.0 0 -1 0 -3 # Sigma_R
-5 5 0 0 -1 0 -3 # Env link coefficient
-15 15 0 0 -1 0 1 # Initial eqilibrium recruitment offset
0 2 0 0 -1 0 -3 # Autocorrelation in recruitment devs
0 # Index for environment variable to be used
0 # Environment target
#
# Recruitment residual (recruitment devs) parameterization
1 # Recruitment dev type: 0 = none, 1 = dev_vector, 2 = simple
1958 # Start year for recruitment devs
2007 # Last year for recruitment devs
1 # Phase for recruitment devs
0 # Read 11 advanced recruitment options: 0 = off, 1 = on - ** Placeholders
    **
```

```
# Start year for (early) recruitment devs
# Phase for (early) recruitment devs
# Phase for forecast recruitment devs
# Lambda for forecast recruitment devs (before endyr+1)
# Last recruitment dev with no bias adjustment
# First year of full bias correction adjustment
# Last year for full bias correction adjustment in MPD
# First recent year no bias adjustment in MPD
# Lower bound for recruitment devs
# Upper bound for recruitment devs
# Read initial values for recruitment devs
#
# FISHING MORTALITY PARAMETERS
=============================================================================
#
# Fishing mortality (F) parameterization
0.1 # F ballpark for tuning early phases
-2000 # F ballpark year (negative value = off)
1 # F method: 1 = Pope, 2 = instantaneous F, 3 = hybrid
0.9 # F or Harvest rate (depends on F method)
# No additional F input needed for F method = 1 - ** Placeholders **
# Read overall start F value, overall phase, N detailed inputs to read for F
  method = 2
# Read N iterations for tuning for F method = 3 (recommend 3 to 7)

# Initial F parameters ** non-equilibrium initial age distribution
  implemented **
# Low High Initial Prior_mean Prior_type SD Phase
0.01 5 0.1 0 -1 0 1 # Initial F (Fishery 1)
0.0001 5 0.001 0 -1 0 -1 # Initial F (Fishery 2)

# CATCHABILITY (q) PARAMETERS
=============================================================================

# Catchability (q) parameterization
# Column definitions follow
# A = do power: 0 = off (survey is proportional to abundance), 1 = add
  parameter for non-linearity
# B = env link: 0 = off, 1 = add parameter for env effect on q
# C = extra SD: 0 = off, 1 = add parameter for additive constant to input SE
  (ln space)
# D = dev 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, 4 = ln(q)+set of devs about q for indexyr-1
# E = units: 0 = numbers, 1 = biomass
# F = error type: 0 = lognormal, >0 = t-dist. (df = input value)
# A B C D E F
# Create one parameter for each entry >0 (by row, in columns A-D)
0 0 0 0 1 0 # F1 = COM (USA commercial and Mexico commercial)
0 0 0 0 1 0 # F2 = REC (USA recreational)
0 0 0 0 0 0 # S1 = CPFV
# Placeholder line: 0 = read one parameter for each fleet with random q, 1 =
  read a parameter for each year of index
# q parameters
# Low High Initial Prior_mean Prior_type SD Phase
# -10 10 1.99024e-06 0 -1 0 -1 # ln(q) - CPFV (S1)
```

```
#
# SELECTIVITY (S) PARAMETERS
=============================================================================

# Selectivity/retention parameterization
# Size (length) parameterization
# A = selectivity option: 1 - 24
# B = do retention: 0 = no, 1 = yes
# C = male offset to female: 0 = no, 1 = yes
# D = mirror selectivity (fishery/survey)
# A B C D
# Size selectivity (S) - ** No size-based S **
0 0 0 0 # F1
0 0 0 0 # F2
0 0 0 0 # S1
#
# Age selectivity (S) - ** Age-based S is implemented **
20 0 0 0 # F1 (double-normal distribution)
20 0 0 0 # F2 (double-normal distribution)
15 0 0 2 # S1 (mirror F2)
#
# S (age) parameters
# Low High Initial Prior_mean Prior_type SD Phase Env_var Use_dev Dev_minyr
  Dev_maxyr Dev_stddev Block_def Block_type
# F1 (double-normal) ** selectivity = 3 time blocks: 1962-69, 1970-77, 1978-
  08 **
-10 10 3.98 0 -1 0 -4 0 0 0 0 0 1 2 # P_1 (1978-08, peak size)
-10 10 -4.12 0 -1 0 -4 0 0 0 0 0 1 2 # P_2 (1978-08, top logistic)
-10 10 3.22 0 -1 0 -4 0 0 0 0 0 1 2 # P_3 (1978-08, ascending limb width -
  exp)
-10 10 -0.01 0 -1 0 -4 0 0 0 0 0 1 2 # P_4 (1978-08, descending limb width -
  exp)
-10 10 -0.38 0 -1 0 -4 0 0 0 0 0 1 2 # P_5 (1978-08, initial S - at first age
  bin)
-10 10 -0.46 0 -1 0 -4 0 0 0 0 0 1 2 # P_6 (1978-08, final S - at last age
  bin)
#
# F2 (double-normal)
-10 20 4.47 0 -1 0 4 0 0 0 0 0 0 0 # P_1 (peak size)
-10 10 -4.01 0 -1 0 4 0 0 0 0 0 0 0 # P_2 (top logistic)
-10 20 2.64 0 -1 0 4 0 0 0 0 0 0 0 # P_3 (ascending limb width - exp)
-20 10 -1.50 0 -1 0 4 0 0 0 0 0 0 0 # P_4 (descending limb width - exp)
-10 10 -2.38 0 -1 0 4 0 0 0 0 0 0 0 # P_5 (initial S - at first age bin)
-10 10 -2.35 0 -1 0 4 0 0 0 0 0 0 0 # P_6 (final S - at last age bin)
#
# S1 (mirror F2) ** no additional parameter lines needed **
#
# Custom S-env parameterization: (0/1) - ** Placeholder **
# Low High Initial Prior_mean Prior_type SD Phase
#
1 # Custom S-block parameterization: (0/1)
#
# F1 S time blocks (design 1) ** For age-based S **
# Low High Initial Prior_mean Prior_type SD Phase
# F1 (double-normal)
-10 20 4.47 0 -1 0 4 # P_1 (1962-69, peak size)
-10 10 0.16 0 -1 0 4 # P_1 (1970-77, peak size)
```

```
-10 20 3.98 0 -1 0 4 # P_1 (1978-08, peak size)
#
-10 10 -4.01 0 -1 0 4 # P_2 (1962-69, top logistic)
-10 10 -4.32 0 -1 0 4 # P_2 (1970-77, top logistic)
-10 10 -4.12 0 -1 0 4 # P_2 (1978-08, top logistic)
#
-20 10 2.64 0 -1 0 4 # P_3 (1962-69, ascending limb width - exp)
-10 10 2.64 0 -1 0 4 # P_3 (1970-77, ascending limb width - exp)
-20 10 3.92 0 -1 0 4 # P_3 (1978-08, ascending limb width - exp)
#
-20 10 -1.50 0 -1 0 4 # P_4 (1962-69, descending limb width - exp)
-20 10 -1.38 0 -1 0 4 # P_4 (1970-77, descending limb width - exp)
-20 10 -0.01 0 -1 0 4 # P_4 (1978-08, descending limb width - exp)
#
-10 10 -2.38 0 -1 0 4 # P_5 (1962-69, initial S - at first age bin)
-10 10 -1.28 0 -1 0 4 # P_5 (1970-77, initial S - at first age bin)
-10 10 -0.38 0 -1 0 4 # P_5 (1978-08, initial S - at first age bin)
#
-10 10 -2.35 0 -1 0 4 # P_6 (1962-69, final S - at last age bin)
-10 10 -1.24 0 -1 0 4 # P_6 (1970-77, final S - at last age bin)
-10 10 -10 0 -1 0 -4 # P_6 (1978-08, final S - at last age bin)
#
# Custom selectivity_env_dev (phase) parameterization - ** Placeholder **
1 # Block adjust method: 1 = standard, 2 = logistic transition to keep in
  base parameter bounds
0 # Tagging flag: 0 = no tagging parameters, 1 = read tagging parameters
#
# LIKELIHOOD COMPONENT PARAMETERS
============================================================================

1 # Variance and sample size/effective sample size adjustments (by
  fleet/survey): (0/1)
# F1 F2 S1
0 0 0 # constant (added) to survey CV
0 0 0 # constant (added) to discard SD
0 0 0 # constant (added) to body weight SD
1 2 1 # scalar (multiplied) to length distribution sample size (effective ss)
1 1 1 # scalar (multipled) to age distribution sample size (effective ss)
0 0 0 # scalar (multiplied) to size-at-age distribution sample size
  (effective ss)
#
0 # Discard observations df
0 #_Mean body weight observations df
1 # Maximum lambda phase: 1 = none
1 # SD offset: 1 = include
#
# Likelihood component (lambda) parameterization
# Likelihood component codes:
# 1 = survey, 2 = discard, 3 = mean body weight, 4 = length distribution, 5 =
  age distribution, 6 = weight distribution, 7 = size-at-age distribution,
# 8 = catch, 9 = initial equilibrium catch, 10 = recruitment devs, 11 =
  parameter priors, 12 = parameter devs, 13 = crash penalty, 14 = morph
  composition
# 15 = tag composition, 16 = tag neg_bin
#
4 # Number of changes to likelihood components
```

```
# Columns: Likelihood_comp Fishery/Survey Phase Lambda_value
  Size_distribtuion_method
# Priors
11 1 1 0 1 # All priors = off
#
# Equilibrium catch
9 1 1 0 1 # Equilibrium catch F1
9 2 1 0 1 # Equilibrium catch F2
#
# Length distribution sensitivity analysis
# Omit length distributions (annual)
4 1 1 0 1 # Omit F1
# 4 2 1 0 1 # Omit F2
#
# Age distribution sensitivity analysis
# Omit age distributions (annual and age-at-length)
# 5 1 1 0 1 # Omit F1
#
# Mean size-at-age distribution sensitivity analysis
# Omit mean size-at-age distributions
# 7 1 1 0 1 # Omit F1
#
0 # SD reporting option: (0/1)
999 # End of file

###############################################################################
```

INPUT DATA FILE

```
# P. mackerel stock assessment (1962-08)
# P. R. Crone (March 2009)
# Stock Synthesis 3 (v. 3.0.12) - R. Methot
# Model AA: number of fisheries = 2 / surveys = 1 / time-step = annual /
biological distributions = age, length, and mean size-at-age / selectivity =
age-based
#
# NOTES: ** ... ** = Pending questions and/or comments
#
# INPUT DATA FILE
#
1962 # Start year
2008 # End year
1 # Number of 'seasons' (quarters)
12 # Number of months per season
1 # Spawning season
2 # Number of fishing 'fleets' (fisheries)
# F1 = COM (USA commercial and Mexico commercial)
# F2 = REC (USA recreational)
1 # Number of 'surveys' (CPUE Indices: annual-based)
# S1 = CPFV
#
1 # Number of areas (populations)
COM%REC%CPFV
0.5 0.5 0.5 # Fishery/survey timing within time block
1 1 1 # Area assignment for each fishery/survey
#
```

```
1 1 # Catch units: 1=biomass, 2=numbers
0.01 0.01 # SE of ln(catch), i.e., equals CV in ln space
#
1 # Number of genders
15 # Number of ages (accumulator age)
# Catch: initial (annual) 'equilibrium' catch (mt)
10022 167
# Number of catch records (lines)
47
# Catch time series (biomass in mt): Columns=fisheries, year, season
23758.11    142.87      1962  1
23482.86    220.14      1963  1
19900.64    87.29 1964  1
11057.20    222.24      1965  1
7138.22     266.96      1966  1
1567.16     146.16      1967  1
1598.71     96.32 1968  1
1009.75     158.46      1969  1
677.04      158.45      1970  1
589.76      321.49      1971  1
228.00      304.00      1972  1
152.43      248.50      1973  1
513.94      119.87      1974  1
1950.41     198.88      1975  1
3925.07     166.58      1976  1
12913.81    837.45      1977  1
25817.57    1355.06     1978  1
33905.12    1952.97     1979  1
32517.89    2685.18     1980  1
45561.92    1422.63     1981  1
34955.38    1416.01     1982  1
40573.39    1544.12     1983  1
45001.01    1467.32     1984  1
45811.90    1015.90     1985  1
53263.39    859.20      1986  1
46958.31    1264.46     1987  1
48576.06    688.56      1988  1
48787.53    618.27      1989  1
70934.59    616.06      1990  1
64824.75    680.14      1991  1
31753.59    463.87      1992  1
20311.09    608.80      1993  1
22674.40    1062.65     1994  1
10982.43    1013.40     1995  1
23877.14    685.54      1996  1
50272.33    803.99      1997  1
62393.05    429.61      1998  1
15757.21    152.65      1999  1
27466.58    325.32      2000  1
12439.36    571.05      2001  1
13868.67    254.10      2002  1
8589.59     323.26      2003  1
7028.76     533.46      2004  1
7079.24     395.84      2005  1
10436.81    371.42      2006  1
9122.65     306.35      2007  1
6512.89     290.47      2008  1
```

```
#
# Number of observations (lines) for all surveys (indices)
47
# Survey time series: Columns=year, season, survey, estimate, CV/SE
# CPFV survey
1962  1     3     8.22  0.36
1963  1     3     14.63 0.25
1964  1     3     5.83  0.28
1965  1     3     10.79 0.29
1966  1     3     12.00 0.24
1967  1     3     4.89  0.29
1968  1     3     7.34  0.49
1969  1     3     6.10  0.36
1970  1     3     9.58  0.33
1971  1     3     15.63 0.25
1972  1     3     8.58  0.39
1973  1     3     4.74  0.37
1974  1     3     4.41  0.45
1975  1     3     8.69  0.33
1976  1     3     14.26 0.37
1977  1     3     55.51 0.22
1978  1     3     108.24      0.18
1979  1     3     122.74      0.16
1980  1     3     161.94      0.17
1981  1     3     110.22      0.19
1982  1     3     112.20      0.16
1983  1     3     111.09      0.19
1984  1     3     119.53      0.18
1985  1     3     89.13 0.16
1986  1     3     70.52 0.18
1987  1     3     46.63 0.23
1988  1     3     33.79 0.32
1989  1     3     46.17 0.21
1990  1     3     53.25 0.32
1991  1     3     61.01 0.16
1992  1     3     43.43 0.23
1993  1     3     51.59 0.27
1994  1     3     48.31 0.21
1995  1     3     43.91 0.19
1996  1     3     47.03 0.24
1997  1     3     31.45 0.25
1998  1     3     15.25 0.25
1999  1     3     8.51  0.41
2000  1     3     16.03 0.26
2001  1     3     12.33 0.34
2002  1     3     10.20 0.28
2003  1     3     6.48  0.28
2004  1     3     11.69 0.66
2005  1     3     18.86 0.52
2006  1     3     27.60 0.25
2007  1     3     29.68 0.42
2008  1     3     16.86 0.50
#
1 # Discard type
0 # Number of discard observations (lines)
0 # Number of mean body weight observations (lines)
#
```

```
# Population size distributions
1 # Length bin method: 1 = use fishery length bins below, 2 = generate from
min/max/width below, 3 = read count and vector below
# Placeholder for number of population length bins
# Placeholder for vector of population length bins
#
#
-0.01 # 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/CPFV 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
#
64 # Number of fishery length distribution observations (lines) ** Length
distributions for Fishery 1 are not used (included for
provisional/comparative purposes only **
# Length distributions (1962-08) - annual (percent)
# Length distributions: Columns=year, season, fishery/survey, gender,
partition, sample size, length bin observations (in numbers)
1962  1     1     0     0     8.2   0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00488     0.01463     0.02439     0.03415
      0.05366     0.06829     0.12195     0.11220     0.10244     0.08780
      0.09756     0.10244     0.06341     0.06829     0.01951     0.02439
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
1963  1     1     0     0     8.2   0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00488     0.00000     0.00976     0.00488     0.00976
      0.03415     0.05854     0.06829     0.08780     0.11707     0.10244
      0.12683     0.12195     0.08780     0.08293     0.05366     0.02927
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
1964  1     1     0     0     10.7  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00373     0.00000     0.00000     0.00373
      0.00000     0.00746     0.00746     0.00373     0.00746     0.02612
      0.03731     0.06716     0.05597     0.06716     0.08582     0.09328
      0.08955     0.14925     0.08582     0.10448     0.05970     0.03358
      0.01119     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
```

```
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1965 1     1     0     0     4.4   0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00901     0.01802     0.03604     0.03604     0.05405     0.03604
     0.04505     0.03604     0.05405     0.06306     0.05405     0.09910
     0.09910     0.05405     0.10811     0.09009     0.06306     0.03604
     0.00901     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1966 1     1     0     0     77.8  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00051     0.00257     0.00566     0.01646     0.02469
     0.02726     0.05864     0.07510     0.07562     0.05864     0.04424
     0.03447     0.04475     0.03961     0.04064     0.04527     0.03909
     0.03858     0.02984     0.02006     0.06276     0.11060     0.07356
     0.02675     0.00412     0.00051     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1967 1     1     0     0     28.8  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00139     0.01806     0.05278     0.05972
     0.09722     0.08472     0.05556     0.14028     0.14722     0.10417
     0.05278     0.02222     0.00278     0.00278     0.00972     0.03472
     0.02083     0.01389     0.01111     0.00417     0.00556     0.01667
     0.01528     0.01944     0.00417     0.00139     0.00139     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1968 1     1     0     0     85.8  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00047     0.00140     0.00699     0.02937     0.07086     0.12587
     0.15338     0.16317     0.11002     0.03170     0.00886     0.03636
     0.05548     0.04802     0.02611     0.01072     0.00699     0.02145
     0.02284     0.01865     0.00886     0.00653     0.00746     0.00559
     0.00839     0.00979     0.00326     0.00140     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1969 1     1     0     0     19.9  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00201     0.00803     0.00000
     0.00803     0.00201     0.01004     0.02610     0.05020     0.11446
     0.21285     0.19277     0.13052     0.07229     0.05221     0.06225
     0.01406     0.01807     0.01205     0.00201     0.01004     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
```

```
1970  1     1     0     0     6.0   0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.03333     0.10667     0.33333
      0.12000     0.01333     0.03333     0.07333     0.09333     0.10000
      0.07333     0.01333     0.00667     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
1971  1     1     0     0     13.8  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00291
      0.00581     0.01163     0.01453     0.02326     0.04651     0.17442
      0.22674     0.16570     0.10174     0.05523     0.07558     0.07849
      0.00291     0.00000     0.00000     0.00291     0.00291     0.00291
      0.00291     0.00291     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
1972  1     1     0     0     8.9   0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00448     0.02242     0.04036     0.04036     0.05830
      0.10762     0.08969     0.03587     0.01345     0.06726     0.10314
      0.04933     0.01345     0.00448     0.03587     0.10314     0.13004
      0.05381     0.00897     0.00897     0.00448     0.00000     0.00448
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
1973  1     1     0     0     9.6   0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00418     0.04184
      0.03347     0.01255     0.00000     0.02092     0.02510     0.04184
      0.07531     0.05439     0.02510     0.00837     0.01674     0.02929
      0.09623     0.07950     0.08787     0.16736     0.12134     0.05439
      0.00418     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
1974  1     1     0     0     7.2   0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.04469     0.08380     0.02793     0.00559
      0.08939     0.18994     0.05587     0.00559     0.07821     0.07821
      0.08380     0.07821     0.04469     0.00559     0.00000     0.01676
      0.04469     0.02793     0.01117     0.02235     0.00559     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
1975  1     1     0     0     53.0  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
```

```
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00226    0.00830
     0.02338    0.02866    0.03394    0.02262    0.01433    0.01357
     0.01659    0.04148    0.09578    0.18552    0.18703    0.14253
     0.11463    0.04374    0.01207    0.00075    0.00302    0.00000
     0.00226    0.00000    0.00377    0.00000    0.00151    0.00075
     0.00075    0.00000    0.00075    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1976 1     1    0     0    88.1  0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00091    0.00045    0.00045    0.00000
     0.00318    0.00772    0.00681    0.01272    0.02361    0.03906
     0.06222    0.13306    0.14260    0.10536    0.09537    0.07266
     0.05540    0.03088    0.00999    0.00272    0.00500    0.01635
     0.02997    0.03270    0.02089    0.02679    0.02725    0.02407
     0.00772    0.00091    0.00091    0.00000    0.00045    0.00091
     0.00045    0.00000    0.00045    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1977 1     1    0     0    77.7  0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00051
     0.00000    0.00000    0.00772    0.00206    0.00412    0.01029
     0.01801    0.01801    0.02985    0.03345    0.04889    0.07566
     0.11786    0.19403    0.17293    0.11065    0.06536    0.04323
     0.02779    0.00823    0.00257    0.00154    0.00103    0.00257
     0.00257    0.00103    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1978 1     1    0     0    148.4 0.00000    0.00000    0.00000
     0.00000    0.01752    0.02156    0.04178    0.03100    0.01752
     0.00135    0.00135    0.00000    0.00000    0.00000    0.00000
     0.00027    0.03585    0.11159    0.15660    0.06900    0.01698
     0.01024    0.02318    0.02345    0.03181    0.01429    0.01914
     0.01887    0.03962    0.04609    0.05445    0.04636    0.04420
     0.04528    0.02237    0.01887    0.01024    0.00270    0.00216
     0.00350    0.00081    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1979 1     1    0     0    139.6 0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00057    0.00229
     0.02206    0.07648    0.15612    0.16987    0.12031    0.07935
     0.05357    0.03838    0.04239    0.03036    0.04239    0.03323
     0.03495    0.03266    0.02463    0.02263    0.00888    0.00315
     0.00172    0.00115    0.00229    0.00057    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1980 1     1    0     0    258.6 0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.01253    0.06542
     0.08212    0.03371    0.03387    0.05428    0.04841    0.06093
```

```
     0.03526     0.01268     0.01655     0.03078     0.07191     0.09527
     0.07393     0.05258     0.04655     0.04036     0.03433     0.03047
     0.01887     0.01469     0.01098     0.01036     0.00665     0.00387
     0.00124     0.00046     0.00046     0.00031     0.00015     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1981 1     1     0     0     192.3 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00083     0.00000
     0.00208     0.00499     0.00416     0.00208     0.00125     0.00749
     0.01082     0.00790     0.01019     0.02787     0.02933     0.03993
     0.05782     0.02787     0.02121     0.04451     0.06593     0.06094
     0.05761     0.08319     0.09859     0.08819     0.07051     0.05928
     0.03869     0.02933     0.01872     0.01352     0.00603     0.00582
     0.00146     0.00083     0.00042     0.00042     0.00021     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1982 1     1     0     0     168.6 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00190     0.00569
     0.00095     0.00498     0.00688     0.00095     0.00119     0.00119
     0.01803     0.01257     0.01874     0.04696     0.03771     0.04910
     0.09772     0.06618     0.04056     0.04649     0.03582     0.03250
     0.03534     0.04269     0.04246     0.05835     0.05432     0.05289
     0.04673     0.04317     0.03226     0.02894     0.01471     0.00996
     0.00735     0.00261     0.00142     0.00071     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1983 1     1     0     0     106.7 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00037     0.00225     0.00075     0.00300     0.00300
     0.00150     0.00450     0.00300     0.00150     0.00262     0.00300
     0.00000     0.00112     0.00525     0.00937     0.02211     0.03636
     0.06297     0.09370     0.12969     0.14355     0.14318     0.13718
     0.08883     0.05022     0.02849     0.01237     0.00600     0.00187
     0.00187     0.00037     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1984 1     1     0     0     91.6  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00044     0.00306     0.00480
     0.01135     0.00436     0.00567     0.00262     0.00262     0.00000
     0.01528     0.04845     0.10170     0.16194     0.16019     0.12353
     0.10214     0.08904     0.07071     0.04801     0.02750     0.01091
     0.00393     0.00175     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1985 1     1     0     0     104.2 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00038     0.00230
     0.00652     0.01266     0.00959     0.00767     0.01880     0.02916
     0.02533     0.04490     0.04029     0.07252     0.13315     0.17920
```

```
     0.16500     0.10860     0.07905     0.04068     0.01765     0.00422
     0.00153     0.00077     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1986 1     1     0     0     120.0 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00100     0.00967     0.01633     0.00400     0.00933
     0.00800     0.01133     0.01767     0.04000     0.06067     0.07867
     0.09633     0.09800     0.06600     0.05633     0.05700     0.06567
     0.09267     0.07833     0.06000     0.03867     0.01767     0.01000
     0.00433     0.00133     0.00067     0.00033     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1987 1     1     0     0     165.2 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00194     0.00509     0.01332     0.01502
     0.02349     0.03391     0.04384     0.06491     0.08695     0.08937
     0.07798     0.07145     0.09106     0.11940     0.08646     0.04626
     0.03197     0.02228     0.02180     0.02083     0.01502     0.01380
     0.00315     0.00048     0.00024     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1988 1     1     0     0     179.1 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00022     0.00156     0.01474     0.11660     0.20415
     0.16038     0.08979     0.02859     0.00960     0.00692     0.00893
     0.01631     0.02993     0.04333     0.04981     0.04646     0.03931
     0.03239     0.02792     0.01720     0.01273     0.01631     0.01407
     0.00871     0.00290     0.00089     0.00022     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1989 1     1     0     0     143.3 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00056     0.00112     0.02428     0.05833
     0.04996     0.09433     0.21100     0.19620     0.13536     0.07089
     0.03684     0.02623     0.01423     0.01144     0.00726     0.00977
     0.00893     0.00893     0.01144     0.00921     0.00670     0.00558
     0.00084     0.00056     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1990 1     1     0     0     84.6  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00095     0.01183     0.02933     0.03926     0.04494
     0.05771     0.02365     0.00473     0.00757     0.01892     0.02838
     0.04588     0.04730     0.07569     0.06575     0.04730     0.03453
     0.03974     0.06433     0.09413     0.10218     0.06575     0.02980
     0.01372     0.00520     0.00142     0.00000     0.00000     0.00000
```

```
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1991 1    1     0     0    66.2  0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00121    0.02236    0.05619    0.04592    0.02961    0.02840
     0.01873    0.01390    0.01873    0.04773    0.08520    0.09184
     0.08761    0.06767    0.03625    0.01269    0.02477    0.04230
     0.05438    0.04955    0.05015    0.04773    0.03565    0.01873
     0.00846    0.00363    0.00060    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1992 1    1     0     0    79.8  0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00100    0.00150    0.01153    0.02758    0.05065    0.03862
     0.02909    0.06620    0.09478    0.10782    0.08024    0.04965
     0.03009    0.02407    0.03410    0.03059    0.03661    0.03410
     0.05817    0.05918    0.05316    0.03912    0.02758    0.00903
     0.00401    0.00150    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1993 1    1     0     0    107.5 0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00446    0.04576    0.11942    0.12649    0.09710    0.08966
     0.04018    0.02493    0.01414    0.03460    0.03832    0.04167
     0.04799    0.05952    0.03720    0.02344    0.01079    0.00632
     0.00967    0.02121    0.02269    0.02902    0.02641    0.01860
     0.00670    0.00335    0.00000    0.00037    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1994 1    1     0     0    124.6 0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00032    0.00000    0.00417    0.01638    0.05845    0.12139
     0.13712    0.15125    0.16506    0.11689    0.05652    0.03565
     0.02408    0.01574    0.01991    0.01413    0.01060    0.00578
     0.00385    0.00417    0.00803    0.01509    0.00867    0.00450
     0.00161    0.00064    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000
1995 1    1     0     0    108.2 0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
     0.00000    0.00333    0.04361    0.14412    0.19586    0.13673
     0.09054    0.04435    0.05839    0.07095    0.06689    0.04028
     0.02772    0.00776    0.00665    0.00517    0.00665    0.00333
     0.00333    0.00296    0.00407    0.01109    0.01220    0.00739
     0.00333    0.00296    0.00037    0.00000    0.00000    0.00000
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
```

```
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1996 1     1     0     0     87.6  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00091     0.00183     0.00594     0.04523     0.09228
     0.10233     0.09274     0.09045     0.07766     0.06578     0.04888
     0.04797     0.03609     0.03518     0.02421     0.02101     0.02878
     0.02787     0.02969     0.02330     0.03563     0.02787     0.02604
     0.01005     0.00137     0.00046     0.00000     0.00046     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1997 1     1     0     0     108.6 0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00074     0.00074     0.00221     0.00626     0.00774
     0.00516     0.01363     0.02174     0.05232     0.06890     0.08364
     0.07148     0.06043     0.05453     0.05269     0.05748     0.03758
     0.04422     0.04937     0.05453     0.07443     0.08438     0.06190
     0.02763     0.00590     0.00037     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1998 1     1     0     0     90.2  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00044     0.00089     0.00576     0.00710     0.01330
     0.02217     0.02483     0.01729     0.01729     0.02483     0.03991
     0.07894     0.12772     0.11264     0.09534     0.06962     0.05366
     0.03503     0.05144     0.07317     0.06208     0.03503     0.01951
     0.01020     0.00177     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1999 1     1     0     0     66.6  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00060     0.00900     0.02821
     0.09364     0.09844     0.08884     0.06002     0.03241     0.02281
     0.01681     0.01801     0.02161     0.02641     0.03541     0.06002
     0.08643     0.08944     0.07263     0.06843     0.03902     0.01981
     0.00780     0.00180     0.00180     0.00060     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
2000 1     1     0     0     76.4  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00209     0.00524     0.00681     0.01728     0.05079     0.10419
     0.12094     0.09110     0.04764     0.02513     0.01675     0.01623
     0.03874     0.04607     0.03665     0.02094     0.01047     0.01990
     0.05445     0.09319     0.06702     0.05288     0.03665     0.00995
     0.00471     0.00366     0.00052     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
```

```
2001  1     1     0     0     84.4  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00284     0.01137     0.04121     0.06821     0.05590
      0.03932     0.03648     0.04074     0.05921     0.08764     0.09664
      0.10137     0.06490     0.03932     0.02795     0.02226     0.01611
      0.03316     0.04074     0.04500     0.03221     0.02416     0.00758
      0.00521     0.00047     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
2002  1     1     0     0     85.8  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00140     0.01119     0.02797     0.05035
      0.05221     0.06900     0.08159     0.11608     0.14592     0.15758
      0.14079     0.06247     0.03683     0.01772     0.00839     0.00420
      0.00373     0.00373     0.00186     0.00326     0.00233     0.00140
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
2003  1     1     0     0     62.8  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00255     0.01338     0.04777     0.11911
      0.13567     0.13376     0.04841     0.03822     0.05796     0.06943
      0.08025     0.06369     0.04013     0.02229     0.02102     0.01656
      0.01911     0.01529     0.01847     0.01656     0.01083     0.00573
      0.00191     0.00127     0.00064     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
2004  1     1     0     0     101.2 0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00119     0.00356     0.00514     0.01463     0.02847     0.05299
      0.11111     0.13642     0.14591     0.14037     0.11190     0.07078
      0.07038     0.03361     0.01423     0.01305     0.00989     0.00830
      0.00395     0.00751     0.00633     0.00237     0.00435     0.00237
      0.00079     0.00040     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
2005  1     1     0     0     92.0  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00043
      0.00304     0.01914     0.02305     0.06916     0.15485     0.17529
      0.13658     0.08830     0.04959     0.04045     0.04393     0.03045
      0.03871     0.03958     0.04002     0.02044     0.01305     0.00783
      0.00261     0.00000     0.00043     0.00130     0.00087     0.00087
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000
2006  1     1     0     0     95.7  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
```

```
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00084     0.00084     0.00919     0.01713     0.03886     0.09193
     0.13623     0.12996     0.11032     0.10155     0.06979     0.06728
     0.04931     0.03636     0.02591     0.01546     0.01379     0.01212
     0.01588     0.00501     0.00125     0.00669     0.01087     0.01421
     0.01045     0.00627     0.00125     0.00042     0.00042     0.00042
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
2007 1     1     0     0     64.4  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00062
     0.00808     0.03791     0.01740     0.02051     0.06464     0.13735
     0.11933     0.09136     0.07769     0.06588     0.05221     0.03294
     0.02548     0.03543     0.02735     0.02921     0.01927     0.02113
     0.01989     0.02610     0.02300     0.01429     0.01305     0.00622
     0.00808     0.00373     0.00186     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
2008 1     1     0     0     17.0  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00235     0.00000     0.00471     0.02118     0.02353     0.04706
     0.02824     0.06353     0.06353     0.06824     0.13176     0.13412
     0.15294     0.05412     0.01176     0.00471     0.01412     0.03059
     0.03059     0.04000     0.01882     0.01647     0.01176     0.01412
     0.00706     0.00471     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1992 1     2     0     0     28.4  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00282
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00141
     0.00282     0.00282     0.00423     0.00563     0.01268     0.01690
     0.03380     0.05352     0.08451     0.09437     0.12676     0.07746
     0.06338     0.03239     0.04225     0.02394     0.02817     0.02676
     0.03380     0.04789     0.05915     0.04930     0.03239     0.01690
     0.00986     0.00423     0.00423     0.00282     0.00000     0.00000
     0.00000     0.00141     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00141     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
1993 1     2     0     0     69.4  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00230     0.00230     0.00806     0.00461     0.00461     0.00403
     0.00288     0.00230     0.00691     0.02016     0.02765     0.02650
     0.02535     0.03111     0.03687     0.04435     0.06164     0.07200
     0.06624     0.05703     0.04839     0.03053     0.02765     0.03168
     0.03111     0.02823     0.05933     0.07028     0.06279     0.05184
     0.02650     0.00979     0.00403     0.00230     0.00115     0.00058
     0.00058     0.00000     0.00000     0.00000     0.00115     0.00000
     0.00115     0.00000     0.00058     0.00000     0.00000     0.00000
     0.00000     0.00058     0.00288
1994 1     2     0     0     35.4  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00226     0.00226
     0.00113     0.00226     0.00565     0.00678     0.02825     0.07797
```

```
      0.07571     0.06102     0.04294     0.03164     0.02260     0.03390
      0.03277     0.02712     0.02486     0.03164     0.03842     0.01808
      0.01469     0.02712     0.05763     0.09379     0.10734     0.04746
      0.05537     0.02034     0.00339     0.00113     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00226     0.00113     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00113
1995  1     2     0     0     29.6  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00271
      0.00947     0.00406     0.00271     0.00406     0.02030     0.03654
      0.03789     0.01894     0.02436     0.03924     0.06360     0.07848
      0.07984     0.04601     0.05413     0.04465     0.03383     0.03924
      0.04465     0.03112     0.05142     0.05007     0.06089     0.06766
      0.03518     0.01083     0.00541     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00135     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00135
1996  1     2     0     0     76.0  0.00000     0.00000     0.00000
      0.00053     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00105     0.00105     0.00263     0.00474
      0.00843     0.01001     0.00843     0.01316     0.01738     0.02686
      0.04529     0.06582     0.06214     0.05793     0.04634     0.04687
      0.03581     0.03160     0.03686     0.02370     0.02686     0.02106
      0.02001     0.02580     0.03107     0.05898     0.08952     0.08741
      0.04950     0.03107     0.00790     0.00105     0.00158     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00158
1997  1     2     0     0     91.1  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00088     0.00219     0.00307
      0.00702     0.00746     0.01097     0.01141     0.01317     0.01141
      0.02283     0.03424     0.04083     0.05048     0.06234     0.03600
      0.04083     0.04258     0.05531     0.05531     0.05443     0.04434
      0.03995     0.04565     0.04258     0.04960     0.05882     0.06365
      0.04741     0.02283     0.00790     0.00439     0.00658     0.00176
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00044
      0.00000     0.00000     0.00000     0.00000     0.00088     0.00000
      0.00000     0.00044     0.00000
1998  1     2     0     0     61.0  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00066     0.00000     0.00066
      0.00525     0.00787     0.01312     0.01903     0.02887     0.02625
      0.02559     0.03871     0.02690     0.03740     0.02559     0.04856
      0.05249     0.06496     0.07021     0.04856     0.04396     0.02690
      0.03609     0.05446     0.06365     0.07415     0.05774     0.05446
      0.03018     0.01115     0.00394     0.00066     0.00066     0.00000
      0.00066     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00000     0.00000     0.00066
1999  1     2     0     0     50.1  0.00000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
      0.00080     0.00080     0.00000     0.00000     0.00080     0.00080
      0.00000     0.00000     0.00080     0.00399     0.01596     0.01357
      0.01117     0.01117     0.02713     0.04868     0.05986     0.04789
      0.03272     0.04310     0.04230     0.04789     0.04469     0.05427
```

```
     0.08859     0.09816     0.08939     0.07103     0.05427     0.03990
     0.03192     0.01197     0.00479     0.00000     0.00000     0.00000
     0.00080     0.00080     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
2000 1     2     0     0     43.4  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00092     0.00185     0.00738     0.00830     0.00738
     0.00738     0.00738     0.00830     0.00923     0.01292     0.01753
     0.01661     0.01476     0.02952     0.03321     0.04151     0.03967
     0.07380     0.06550     0.06273     0.03044     0.02030     0.05627
     0.08856     0.10240     0.07749     0.05627     0.04244     0.03782
     0.01568     0.00554     0.00092     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
2001 1     2     0     0     42.0  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00190     0.00285     0.00666
     0.00666     0.01522     0.01522     0.02664     0.04472     0.05614
     0.06946     0.07136     0.08563     0.06946     0.05614     0.05233
     0.08944     0.11513     0.09610     0.05138     0.04091     0.01427
     0.00856     0.00285     0.00095     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
2002 1     2     0     0     45.8  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00087     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00087     0.00000     0.00524     0.01310     0.02009
     0.02707     0.04017     0.04629     0.04978     0.06288     0.09607
     0.11004     0.07948     0.06638     0.05590     0.04891     0.03406
     0.04891     0.03493     0.04716     0.03406     0.02795     0.02620
     0.01397     0.00349     0.00262     0.00000     0.00000     0.00000
     0.00000     0.00087     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00262
2003 1     2     0     0     41.5  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00096     0.00000
     0.00096     0.00482     0.01350     0.01061     0.01157     0.01350
     0.02797     0.05882     0.06365     0.07618     0.08872     0.07136
     0.07522     0.05014     0.05111     0.03568     0.02314     0.01736
     0.02604     0.03182     0.03761     0.06365     0.06654     0.04436
     0.01929     0.00868     0.00096     0.00193     0.00000     0.00000
     0.00000     0.00096     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00096     0.00193
2004 1     2     0     0     67.7  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00118     0.00532     0.00709
     0.00295     0.00827     0.02481     0.02599     0.03426     0.04548
     0.05021     0.05375     0.06911     0.08269     0.06202     0.05729
     0.06025     0.05139     0.04666     0.03839     0.02363     0.02067
     0.02185     0.01890     0.02422     0.02422     0.03898     0.05257
     0.02658     0.01299     0.00413     0.00118     0.00118     0.00059
```

```
     0.00000     0.00000     0.00000     0.00059     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00059     0.00000
     0.00000     0.00000     0.00000
2005 1     2     0     0     84.4  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00047     0.00000
     0.00047     0.00095     0.00047     0.00047     0.00190     0.00427
     0.00284     0.00379     0.00901     0.02086     0.05927     0.09388
     0.11522     0.10194     0.10384     0.09341     0.07824     0.06970
     0.05785     0.04599     0.04931     0.02560     0.01944     0.00948
     0.00853     0.00379     0.00284     0.00237     0.00237     0.00284
     0.00284     0.00190     0.00142     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00047     0.00000     0.00047
     0.00047     0.00000     0.00095
2006 1     2     0     0     94.5  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00042     0.00127     0.00127     0.00296
     0.00466     0.00550     0.00719     0.01777     0.03259     0.06306
     0.10114     0.12907     0.12950     0.10284     0.08548     0.06602
     0.04740     0.04655     0.03682     0.02328     0.01566     0.01481
     0.01058     0.00635     0.00804     0.00466     0.00550     0.00550
     0.00931     0.00804     0.00466     0.00212     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
2007 1     2     0     0     97.6  0.00000     0.00000     0.00000
     0.00041     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00082     0.00000     0.00082
     0.00164     0.00246     0.00246     0.01353     0.02378     0.03034
     0.05002     0.05576     0.07093     0.10496     0.12136     0.10865
     0.09963     0.06724     0.06191     0.03526     0.03034     0.02501
     0.01763     0.01394     0.00984     0.00779     0.01271     0.00902
     0.00738     0.00738     0.00410     0.00082     0.00041     0.00000
     0.00041     0.00000     0.00000     0.00041     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00082
2008 1     2     0     0     53.7  0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00968     0.03053     0.03276     0.04765     0.03425
     0.03797     0.03872     0.04244     0.05361     0.05659     0.06031
     0.10573     0.11616     0.09159     0.04914     0.04170     0.02010
     0.01117     0.02010     0.01489     0.02383     0.01191     0.01340
     0.02010     0.01117     0.00223     0.00149     0.00000     0.00000
     0.00000     0.00074     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.00000     0.00000     0.00000
#
# Fishery age distributions
9 # Number of age_bins
0 1 2 3 4 5 6 7 8
#
1 # Number of ageing error matrices (use 'accumulator age' above: (15) + 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 13.5 14.5 15.5 # 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
2.428 2.583 2.738 # Age bin SD
#
47 # 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
#
# Age distributions (1962-08) - 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)
1962  1     1     0     0     1     -1    -1    8.2   0.01  0.39  0.22  0.21
      0.14  0.03  0.00  0.00  0.00
1963  1     1     0     0     1     -1    -1    8.2   0.01  0.16  0.40  0.20
      0.16  0.06  0.01  0.00  0.00
1964  1     1     0     0     1     -1    -1    10.72 0.04  0.16  0.15  0.25
      0.28  0.11  0.01  0.00  0.00
1965  1     1     0     0     1     -1    -1    4.44  0.00  0.30  0.13  0.24
      0.26  0.06  0.01  0.00  0.00
1966  1     1     0     0     1     -1    -1    77.76 0.25  0.27  0.08  0.08
      0.06  0.16  0.10  0.01  0.00
1967  1     1     0     0     1     -1    -1    28.8  0.73  0.11  0.01  0.06
      0.02  0.02  0.04  0.01  0.00
1968  1     1     0     0     1     -1    -1    85.8  0.67  0.18  0.04  0.04
      0.02  0.02  0.01  0.01  0.01
1969  1     1     0     0     1     -1    -1    19.92 0.01  0.72  0.16  0.07
      0.02  0.02  0.00  0.00  0.00
1970  1     1     0     0     1     -1    -1    6     0.60  0.40  0.00  0.00
      0.00  0.00  0.00  0.00  0.00
1971  1     1     0     0     1     -1    -1    13.76 0.00  0.87  0.11  0.01
      0.01  0.01  0.00  0.00  0.00
1972  1     1     0     0     1     -1    -1    8.92  0.52  0.14  0.17  0.16
      0.01  0.00  0.00  0.00  0.00
1973  1     1     0     0     1     -1    -1    9.56  0.10  0.31  0.07  0.08
      0.16  0.18  0.10  0.00  0.00
1974  1     1     0     0     1     -1    -1    7.16  0.49  0.38  0.11  0.02
      0.01  0.00  0.00  0.00  0.00
1975  1     1     0     0     1     -1    -1    53.04 0.02  0.78  0.19  0.01
      0.00  0.00  0.00  0.00  0.00
1976  1     1     0     0     1     -1    -1    88.08 0.77  0.04  0.19  0.00
      0.00  0.00  0.00  0.00  0.00
1977  1     1     0     0     1     -1    -1    77.72 0.08  0.91  0.00  0.01
      0.00  0.00  0.00  0.00  0.00
1978  1     1     0     0     1     -1    -1    148.4 0.60  0.15  0.22  0.01
      0.01  0.00  0.00  0.00  0.00
1979  1     1     0     0     1     -1    -1    139.64      0.00  0.78  0.11
      0.11  0.00  0.00  0.00  0.00  0.00
1980  1     1     0     0     1     -1    -1    258.64      0.43  0.02  0.46
      0.05  0.04  0.00  0.00  0.00  0.00
1981  1     1     0     0     1     -1    -1    192.32      0.14  0.33  0.08
      0.41  0.03  0.02  0.00  0.00  0.00
1982  1     1     0     0     1     -1    -1    168.64      0.07  0.34  0.27
      0.08  0.21  0.02  0.01  0.00  0.00
1983  1     1     0     0     1     -1    -1    106.72      0.03  0.03  0.39
      0.35  0.05  0.15  0.00  0.00  0.00
```

```
1984  1     1     0     0     1     -1    -1    91.64 0.03  0.01  0.10  0.49
      0.23  0.06  0.08  0.00  0.00
1985  1     1     0     0     1     -1    -1    104.24      0.04  0.15  0.05
      0.15  0.47  0.11  0.01  0.01  0.00
1986  1     1     0     0     1     -1    -1    120   0.17  0.33  0.15  0.04
      0.06  0.17  0.05  0.01  0.01
1987  1     1     0     0     1     -1    -1    165.16      0.15  0.50  0.22
      0.04  0.02  0.02  0.03  0.01  0.01
1988  1     1     0     0     1     -1    -1    179.08      0.63  0.07  0.16
      0.06  0.02  0.01  0.01  0.02  0.02
1989  1     1     0     0     1     -1    -1    143.32      0.14  0.77  0.03
      0.02  0.01  0.01  0.01  0.00  0.01
1990  1     1     0     0     1     -1    -1    84.56 0.22  0.12  0.24  0.07
      0.11  0.12  0.04  0.04  0.04
1991  1     1     0     0     1     -1    -1    66.2  0.20  0.42  0.07  0.10
      0.06  0.06  0.04  0.02  0.02
1992  1     1     0     0     1     -1    -1    79.76 0.16  0.38  0.15  0.10
      0.08  0.06  0.04  0.02  0.01
1993  1     1     0     0     1     -1    -1    107.52      0.56  0.14  0.14
      0.03  0.04  0.04  0.02  0.02  0.01
1994  1     1     0     0     1     -1    -1    124.56      0.45  0.39  0.08
      0.03  0.02  0.01  0.01  0.00  0.00
1995  1     1     0     0     1     -1    -1    108.24      0.62  0.26  0.06
      0.01  0.01  0.02  0.01  0.01  0.00
1996  1     1     0     0     1     -1    -1    87.56 0.32  0.33  0.14  0.08
      0.05  0.04  0.02  0.02  0.01
1997  1     1     0     0     1     -1    -1    108.56      0.07  0.26  0.22
      0.11  0.08  0.08  0.06  0.05  0.08
1998  1     1     0     0     1     -1    -1    90.2  0.09  0.16  0.32  0.16
      0.08  0.06  0.05  0.03  0.04
1999  1     1     0     0     1     -1    -1    66.64 0.37  0.08  0.07  0.14
      0.14  0.10  0.04  0.03  0.02
2000  1     1     0     0     1     -1    -1    76.4  0.44  0.16  0.06  0.10
      0.12  0.08  0.03  0.01  0.01
2001  1     1     0     0     1     -1    -1    84.44 0.28  0.44  0.08  0.05
      0.06  0.05  0.02  0.01  0.00
2002  1     1     0     0     1     -1    -1    85.8  0.24  0.65  0.08  0.02
      0.00  0.01  0.00  0.00  0.00
2003  1     1     0     0     1     -1    -1    62.8  0.52  0.27  0.11  0.05
      0.02  0.02  0.01  0.00  0.00
2004  1     1     0     0     1     -1    -1    101.16      0.83  0.11  0.03
      0.02  0.01  0.00  0.00  0.00  0.00
2005  1     1     0     0     1     -1    -1    91.96 0.75  0.17  0.06  0.01
      0.00  0.00  0.00  0.00  0.00
2006  1     1     0     0     1     -1    -1    95.72 0.58  0.27  0.06  0.04
      0.03  0.01  0.01  0.00  0.00
2007  1     1     0     0     1     -1    -1    64.36 0.51  0.24  0.11  0.08
      0.04  0.02  0.01  0.00  0.00
2008  1     1     0     0     1     -1    -1    17    0.06  0.52  0.22  0.12
      0.06  0.02  0.00  0.00  0.00
#
# Fishery size-at-age distributions
47 # Number of mean size-at-age observations (lines)
# Mean size-at-age distributions (1962-08) - annual (cm)
# Mean size-at-age distributions: Columns=year, season, fishery/survey,
gender, partition, ageing error, sample size (nominal only), mean size-at-age
observations (in cm), mean size-at-age sample sizes
```

```
1962  1     1     0     0     1     1     28.50 29.43 32.07 34.37 36.14 37.67
      39.00 -1.00 -1.00 0.08000     3.20000     1.80000     1.72000
      1.12000     0.24000     0.04000     0.00000     0.00000
1963  1     1     0     0     1     1     26.00 29.16 32.47 34.36 36.24 38.00
      38.00 -1.00 -1.00 0.08000     1.28000     3.24000     1.68000
      1.32000     0.52000     0.08000     0.00000     0.00000
1964  1     1     0     0     1     1     24.50 28.63 31.40 33.59 35.87 37.90
      38.75 -1.00 -1.00 0.40000     1.72000     1.60000     2.64000
      3.04000     1.16000     0.16000     0.00000     0.00000
1965  1     1     0     0     1     1     -1.00 26.67 32.21 33.59 35.93 37.86
      39.00 -1.00 -1.00 0.00000     1.32000     0.56000     1.08000
      1.16000     0.28000     0.04000     0.00000     0.00000
1966  1     1     0     0     1     1     23.34 27.50 31.65 33.77 35.96 38.03
      38.75 38.67 -1.00 19.76000    21.28000    5.92000     6.12000
      4.36000     12.08000    7.64000     0.60000     0.00000
1967  1     1     0     0     1     1     23.99 27.03 33.17 33.14 35.33 37.87
      40.39 40.63 39.00 21.04000    3.12000     0.24000     1.72000
      0.60000     0.60000     1.12000     0.32000     0.04000
1968  1     1     0     0     1     1     22.08 27.48 30.47 33.57 34.68 36.68
      39.48 40.48 41.56 57.52000    15.28000    3.08000     3.72000
      1.76000     1.88000     1.08000     0.84000     0.64000
1969  1     1     0     0     1     1     20.57 28.11 31.06 33.15 34.90 36.80
      38.00 -1.00 -1.00 0.28000     14.28000    3.20000     1.32000
      0.40000     0.40000     0.04000     0.00000     0.00000
1970  1     1     0     0     1     1     20.93 26.38 -1.00 -1.00 -1.00 -1.00
      -1.00 -1.00 -1.00 3.60000     2.40000     0.00000     0.00000
      0.00000     0.00000     0.00000     0.00000     0.00000
1971  1     1     0     0     1     1     -1.00 28.22 32.56 33.00 38.00 40.50
      -1.00 -1.00 -1.00 0.00000     11.92000    1.56000     0.08000
      0.12000     0.08000     0.00000     0.00000     0.00000
1972  1     1     0     0     1     1     22.66 27.32 32.31 33.40 34.00 39.00
      -1.00 -1.00 -1.00 4.60000     1.24000     1.56000     1.40000
      0.08000     0.04000     0.00000     0.00000     0.00000
1973  1     1     0     0     1     1     22.00 29.51 31.88 36.22 35.79 37.21
      38.25 39.00 39.00 0.92000     2.96000     0.68000     0.72000
      1.52000     1.72000     0.96000     0.04000     0.04000
1974  1     1     0     0     1     1     21.72 27.65 34.32 37.00 38.00 -1.00
      -1.00 -1.00 -1.00 3.52000     2.72000     0.76000     0.12000
      0.04000     0.00000     0.00000     0.00000     0.00000
1975  1     1     0     0     1     1     22.55 30.30 33.84 40.67 43.50 45.00
      48.00 -1.00 -1.00 1.24000     41.20000    10.04000    0.36000
      0.08000     0.08000     0.04000     0.00000     0.00000
1976  1     1     0     0     1     1     24.23 27.95 36.21 39.00 43.67 -1.00
      46.33 -1.00 -1.00 67.72000    3.64000     16.40000    0.08000
      0.12000     0.00000     0.12000     0.00000     0.00000
1977  1     1     0     0     1     1     22.26 29.39 36.00 39.19 -1.00 -1.00
      -1.00 -1.00 -1.00 6.44000     70.48000    0.16000     0.64000
      0.00000     0.00000     0.00000     0.00000     0.00000
1978  1     1     0     0     1     1     16.95 29.79 32.93 29.82 30.68 26.33
      -1.00 -1.00 -1.00 89.56000    22.52000    31.96000    2.00000
      1.76000     0.60000     0.00000     0.00000     0.00000
1979  1     1     0     0     1     1     20.00 25.70 32.58 35.59 38.40 41.47
      -1.00 -1.00 -1.00 0.04000     108.48000   15.44000    14.88000
      0.20000     0.60000     0.00000     0.00000     0.00000
1980  1     1     0     0     1     1     18.67 24.20 27.95 31.83 35.05 27.63
      42.20 -1.00 -1.00 110.60000   5.04000     118.64000   12.56000
      10.84000    0.76000     0.20000     0.00000     0.00000
```

```
1981  1     1     0     0     1     1     19.42 25.34 26.67 31.49 35.72 37.95
      41.00 42.00 -1.00 26.20000    63.20000    15.32000    79.36000
      4.92000     3.12000     0.08000     0.12000     0.00000
1982  1     1     0     0     1     1     17.07 23.38 26.34 29.44 34.32 38.73
      40.44 -1.00 -1.00 11.52000    57.92000    45.32000    13.76000
      36.12000    3.00000     1.00000     0.00000     0.00000
1983  1     1     0     0     1     1     16.69 26.03 29.62 31.87 33.46 34.46
      37.50 -1.00 -1.00 2.68000     2.68000     41.96000    37.04000
      5.84000     16.28000    0.24000     0.00000     0.00000
1984  1     1     0     0     1     1     22.59 27.14 30.71 31.76 34.03 36.10
      36.64 40.25 -1.00 2.84000     0.56000     9.48000     45.04000
      21.20000    5.32000     7.04000     0.16000     0.00000
1985  1     1     0     0     1     1     23.66 28.55 32.11 33.15 33.61 35.06
      36.34 37.57 -1.00 4.24000     15.76000    5.28000     16.12000
      49.36000    10.96000    1.40000     1.12000     0.00000
1986  1     1     0     0     1     1     23.94 28.44 31.43 33.63 34.66 35.27
      35.76 37.13 38.17 20.96000    39.88000    17.88000    4.56000
      7.68000     20.96000    6.20000     0.96000     0.92000
1987  1     1     0     0     1     1     22.98 28.03 31.41 33.85 35.41 36.77
      37.24 37.92 38.77 25.04000    82.48000    36.76000    6.08000
      3.16000     3.88000     4.76000     2.12000     0.88000
1988  1     1     0     0     1     1     21.51 28.83 31.43 33.94 35.50 36.54
      38.16 38.08 39.10 112.00000   13.20000    28.44000    11.52000
      2.72000     1.84000     2.44000     3.80000     3.12000
1989  1     1     0     0     1     1     21.35 25.20 29.88 33.87 35.53 36.86
      37.50 37.08 38.61 19.36000    111.00000   4.76000     3.00000
      1.72000     1.16000     0.88000     0.52000     0.92000
1990  1     1     0     0     1     1     21.02 27.82 30.80 34.15 36.07 36.62
      37.47 38.08 38.93 18.20000    9.92000     20.48000    6.24000
      9.56000     9.84000     3.64000     3.20000     3.48000
1991  1     1     0     0     1     1     19.30 26.99 31.83 34.03 35.47 36.34
      37.12 37.54 38.61 13.56000    28.00000    4.88000     6.60000
      4.00000     4.00000     2.68000     1.04000     1.44000
1992  1     1     0     0     1     1     20.44 25.01 29.66 32.87 34.36 36.08
      36.49 37.00 38.63 12.80000    30.32000    11.68000    8.20000
      6.76000     4.80000     2.96000     1.60000     0.64000
1993  1     1     0     0     1     1     19.68 27.00 29.05 31.97 36.08 36.48
      38.08 38.24 39.06 60.44000    15.32000    14.84000    3.60000
      4.08000     3.80000     2.04000     2.04000     1.36000
1994  1     1     0     0     1     1     21.76 24.51 27.75 31.04 34.44 36.38
      37.36 38.21 39.00 55.60000    48.60000    10.08000    4.04000
      2.64000     1.36000     1.32000     0.56000     0.36000
1995  1     1     0     0     1     1     20.24 25.00 27.92 31.82 35.45 37.08
      38.32 38.38 40.10 67.16000    28.64000    6.36000     1.12000
      0.80000     1.92000     1.00000     0.84000     0.40000
1996  1     1     0     0     1     1     21.90 25.28 29.72 33.37 35.87 37.18
      37.96 38.41 38.96 27.64000    29.16000    11.88000    6.96000
      4.60000     3.16000     1.80000     1.36000     1.00000
1997  1     1     0     0     1     1     23.69 27.33 30.10 33.00 35.44 36.77
      38.01 38.16 38.56 7.28000     28.20000    23.92000    12.48000
      8.92000     8.52000     6.08000     5.00000     8.16000
1998  1     1     0     0     1     1     22.55 27.94 29.90 32.01 34.62 36.26
      36.59 37.45 37.98 8.52000     14.20000    28.84000    14.40000
      7.52000     5.76000     4.60000     2.92000     3.44000
1999  1     1     0     0     1     1     23.24 26.21 31.15 33.65 34.92 35.81
      36.71 37.87 38.24 24.80000    5.44000     4.68000     9.56000
      9.32000     6.88000     2.80000     1.80000     1.36000
```

```
2000  1     1     0     0     1     1     21.89 27.38 29.95 34.71 35.47 35.98
      36.37 37.50 38.00 33.28000    12.48000    4.32000     7.28000
      9.08000     5.80000     2.60000     0.96000     0.60000
2001  1     1     0     0     1     1     21.15 27.26 29.92 34.37 35.42 36.30
      36.31 36.95 36.60 23.68000    36.88000    6.88000     4.28000
      5.04000     4.32000     2.08000     0.88000     0.40000
2002  1     1     0     0     1     1     22.58 26.38 28.95 31.67 34.56 34.55
      36.71 -1.00 -1.00 20.52000    55.44000    7.04000     1.72000
      0.36000     0.44000     0.28000     0.00000     0.00000
2003  1     1     0     0     1     1     22.11 27.41 30.49 34.46 35.67 37.38
      38.13 38.40 39.50 32.60000    17.24000    7.12000     3.04000
      0.96000     0.96000     0.60000     0.20000     0.08000
2004  1     1     0     0     1     1     23.94 27.68 31.05 35.08 36.72 37.67
      38.50 38.00 39.50 84.00000    10.76000    3.28000     2.08000
      0.72000     0.12000     0.08000     0.04000     0.08000
2005  1     1     0     0     1     1     21.31 27.00 30.13 32.04 33.64 35.83
      35.50 39.00 -1.00 68.96000    15.36000    5.84000     1.00000
      0.44000     0.24000     0.08000     0.04000     0.00000
2006  1     1     0     0     1     1     22.55 26.51 30.47 34.16 38.46 39.68
      40.05 40.83 -1.00 55.60000    26.28000    5.88000     3.48000
      2.44000     1.00000     0.80000     0.24000     0.00000
2007  1     1     0     0     1     1     21.11 25.87 29.37 33.63 36.16 38.70
      39.64 40.67 -1.00 32.68000    15.52000    7.00000     5.20000
      2.32000     1.08000     0.44000     0.12000     0.00000
2008  1     1     0     0     1     1     20.40 25.77 26.30 33.02 37.04 37.29
      39.00 -1.00 -1.00 1.00000     8.84000     3.76000     2.04000
      1.00000     0.28000     0.08000     0.00000     0.00000
#
0 # Number of 'environmental' variables
0 # Number of 'environmental' observations
0 # Weight distributions
0 # Tag data
0 # Morph data
999 # End of file

################################################################
```

Appendix 2A

Preface

The following suites of displays (Appendix 2A: ASAP model (2009); and Appendix 2B: SS model *S1_aa*) are associated with objectives 1 and 2 (see Preface above). That is, results from these two model scenarios were presented in initial STAR discussions, reviewed accordingly, deemed satisfactory for meeting objectives 1 and 2, and are presented here.

ASAP model (2009) displays

Table A2A-1. Sample sizes associated with CDFG data collection program for Pacific mackerel 1939-08).

Fishing Year	Landings (mt)	# Fish Sampled	Fish per 1,000 mt	Fishing Year	Landings (mt)	# Fish Sampled	Fish per 1,000 mt
1939-40	45,341	1,524	34	**1974-75**	514	179	348
1940-41	48,786	2,258	46	**1975-76**	1,950	1,326	680
1941-42	32,547	2,445	75	**1976-77**	3,925	2,202	561
1942-43	21,872	1,287	59	**1977-78**	12,914	1,943	150
1943-44	35,291	2,250	64	**1978-79**	25,818	3,810	148
1944-45	36,644	1,520	41	**1979-80**	33,905	3,491	103
1945-46	23,588	2,088	89	**1980-81**	32,518	6,711	206
1946-47	27,566	2,637	96	**1981-82**	45,562	5,067	111
1947-48	19,237	1,397	73	**1982-83**	34,955	4,764	136
1948-49	17,843	631	35	**1983-84**	40,573	2,694	66
1949-50	24,059	1,835	76	**1984-85**	45,001	2,394	53
1950-51	17,401	1,019	59	**1985-86**	45,812	2,607	57
1951-52	15,792	911	58	**1986-87**	53,263	3,000	56
1952-53	10,223	397	39	**1987-88**	46,958	4,150	88
1953-54	5,182	447	86	**1988-89**	48,576	4,479	92
1954-55	18,023	811	45	**1989-90**	48,788	3,583	73
1955-56	21,998	572	26	**1990-91**	70,935	2,121	30
1956-57	36,663	1,011	28	**1991-92**	64,825	1,689	26
1957-58	27,544	931	34	**1992-93**	31,754	2,015	63
1958-59	11,687	903	77	**1993-94**	20,311	2,740	135
1959-60	19,221	755	39	**1994-95**	22,674	4,357	192
1960-61	20,705	488	24	**1995-96**	10,982	2,718	247
1961-62	26,059	422	16	**1996-97**	23,877	2,222	93
1962-63	23,758	205	9	**1997-98**	50,272	2,722	54
1963-64	23,483	205	9	**1998-99**	62,393	2,261	36
1964-65	19,901	268	13	**1999-00**	15,757	1,674	106
1965-66	11,057	111	10	**2000-01**	27,467	1,919	70
1966-67	7,138	1,944	272	**2001-02**	12,439	2,114	170
1967-68	1,567	720	459	**2002-03**	13,869	2,150	155
1968-69	1,599	2,145	1,342	**2003-04**	8,590	1,599	186
1969-70	1,010	498	493	**2004-05**	7,029	2,547	362
1970-71	677	150	222	**2005-06**	7,079	2,300	325
1971-72	590	344	583	**2006-07**	10,437	2,424	232
1972-73	228	223	978	**2007-08**	9,123	1,609	176
1973-74	152	239	1,568	**2008-09**	6,513	425	65

Table A2A-2. Landings (mt) of Pacific mackerel by fishery (1926-08).

Fishing year	USA Commercial (mt)	Mexico Commercial (mt)	Recreational CPFV (mt)	Recreational non-CPFV (mt)	Total (mt)
29	25,716	0	6	11	25,734
30	5,809	0	6	11	5,826
31	6,873	0	6	11	6,890
32	4,922	0	6	11	4,939
33	33,055	0	6	11	33,072
34	51,467	0	6	11	51,484
35	66,400	0	6	11	66,417
36	45,697	0	6	11	45,714
37	31,954	0	13	21	31,988
38	34,502	0	22	38	34,562
39	45,341	0	42	70	45,454
40	48,786	0	30	52	48,868
41	32,547	0	0	13	32,561
42	21,872	0	0	13	21,886
43	35,291	0	0	13	35,305
44	36,644	0	0	13	36,657
45	23,588	0	0	13	23,601
46	26,715	851	1	15	27,582
47	17,975	1,262	75	124	19,437
48	17,329	515	103	178	18,125
49	22,708	1,352	48	81	24,189
50	15,372	2,029	34	58	17,493
51	14,472	1,320	24	41	15,857
52	9,171	1,052	38	64	10,326
53	4,005	1,177	31	53	5,266
54	12,342	5,681	163	278	18,465
55	12,200	9,798	76	127	22,201
56	25,938	10,725	64	108	36,835
57	25,509	2,034	78	132	27,753
58	11,238	449	70	117	11,875
59	18,725	495	39	73	19,332
60	17,724	2,981	42	75	20,823
61	20,094	5,964	52	88	26,199
62	20,527	3,231	58	85	23,901
63	15,517	7,966	86	134	23,703
64	11,283	8,618	33	54	19,988
65	3,442	7,615	84	138	11,279
66	1,848	5,290	97	169	7,405
67	619	948	56	90	1,713
68	1,492	107	37	60	1,695
69	809	201	58	100	1,168
70	277	400	61	98	835
71	90	500	118	203	911
72	28	200	118	186	532
73	52	100	95	154	401
74	43	471	47	73	634
75	141	1,809	75	124	2,149
76	2,654	1,271	69	97	4,092
77	7,748	5,165	314	524	13,751
78	18,446	7,372	501	854	27,173
79	28,755	5,150	804	1149	35,858
80	27,972	4,546	1,277	1409	35,203
81	38,407	7,155	665	757	46,985
82	30,626	4,329	693	723	36,371
83	36,309	4,264	700	844	42,118
84	39,240	5,761	612	855	46,468
85	37,615	8,197	524	492	46,828
86	44,298	8,965	386	474	54,123
87	44,838	2,120	245	1020	48,223
88	41,968	6,608	181	507	49,265
89	25,063	23,724	167	451	49,406
90	39,974	30,961	230	386	71,551
91	30,268	34,557	252	429	65,505
92	25,584	6,170	135	329	32,217
93	10,787	9,524	196	413	20,920
94	9,372	13,302	226	837	23,737
95	7,615	3,368	439	574	11,996
96	9,788	14,089	320	366	24,563
97	23,413	26,860	104	700	51,076
98	19,578	42,815	108	322	62,823
99	7,170	8,587	55	97	15,910
00	20,936	6,530	78	248	27,792
01	8,436	4,003	51	520	13,010
02	3,541	10,328	22	232	14,123
03	5,972	2,618	28	295	8,913
04	5,012	2,017	23	510	7,562
05	4,572	2,507	21	375	7,475
06	7,870	2,567	15	356	10,808
07	6,208	2,914	18	289	9,429
08	3,599	2,914	19	272	6,803

Table A2A-3. Catch-at-age from ASAP (2009) model (1929-08).

Fishing Year	0	1	2	3	4	5	6	7	8+
29	9	12,434	22,467	20,819	5,208	3,875	3,198	1,273	507
30	0	1,393	7,164	4,838	1,916	670	44	17	7
31	0	957	9,991	6,190	1,307	753	371	148	59
32	0	144	3,222	5,845	1,394	940	489	195	77
33	0	4,620	19,017	31,887	23,363	8,277	2,731	1,087	433
34	0	4,894	53,354	35,598	40,808	15,508	5,669	2,257	898
35	0	10,872	12,737	61,704	63,820	33,633	6,206	2,470	983
36	0	2,248	20,404	17,399	33,062	35,159	5,252	2,091	832
37	129	1,476	2,592	8,035	15,910	26,039	7,865	3,131	1,246
38	772	11,577	31,967	16,528	4,309	10,884	6,608	2,631	1,047
39	1,803	23,228	23,713	33,698	11,094	6,310	3,744	1,525	485
40	3,199	18,453	59,415	27,594	17,025	2,514	686	114	0
41	638	18,397	31,228	28,818	6,522	922	71	71	0
42	0	28,455	10,343	15,109	6,149	1,096	143	48	0
43	426	14,144	62,073	10,523	7,413	1,022	170	85	0
44	0	20,800	20,685	35,320	8,873	1,613	230	0	58
45	2,034	15,337	12,076	8,920	8,320	4,825	1,930	600	391
46	3,290	16,673	20,262	11,041	6,704	4,287	1,819	1,097	548
47	7,427	4,646	10,460	9,228	6,068	3,508	1,896	695	221
48	2,723	37,273	9,107	3,662	4,037	1,408	657	282	94
49	566	21,983	36,329	9,173	3,071	1,980	808	121	81
50	44	6,588	17,066	17,154	3,183	531	398	44	44
51	1,031	4,005	6,860	11,816	11,301	674	238	79	79
52	510	324	1,992	1,992	8,709	4,679	93	46	0
53	11,077	2,069	1,339	1,380	568	812	771	0	0
54	694	47,800	10,177	2,159	1,234	0	308	154	0
55	15,608	17,731	25,097	10,738	1,124	125	250	125	375
56	420	54,867	22,555	19,093	8,812	315	0	0	0
57	1,996	7,915	30,079	10,875	8,535	3,029	1,308	344	0
58	11,505	2,666	4,595	7,401	3,157	1,438	912	0	0
59	1,690	46,897	7,774	3,633	2,450	1,014	254	0	0
60	1,629	12,726	17,002	10,181	5,091	1,731	1,324	0	0
61	7,345	28,680	15,564	14,690	5,771	1,224	525	0	0
62	739	23,299	12,554	10,472	7,072	1,421	187	0	0
63	284	6,843	18,432	10,339	8,843	2,842	425	0	0
64	1,389	7,716	6,521	9,629	10,969	4,240	715	0	0
65	13,074	1,265	767	1,701	5,525	8,677	1,563	0	0
66	3,689	8,093	1,458	1,168	992	2,240	1,220	91	0
67	4,530	1,003	88	632	228	163	192	45	4
68	7,418	499	221	353	89	86	68	52	37
69	46	2,354	606	221	71	61	9	0	0
70	1,405	3,004	0	0	0	0	0	0	0
71	0	2,853	224	10	12	8	0	0	0
72	1,319	197	293	318	9	7	0	0	0
73	50	547	153	33	75	88	49	2	2
74	2,154	769	244	39	13	0	0	0	0
75	130	6,335	90	66	2	4	2	0	0
76	13,974	164	1,763	1	23	0	27	0	0
77	11,071	36,734	78	287	0	0	0	0	0
78	73,773	18,837	28,598	1,166	1,006	257	0	0	0
79	27	102,762	14,944	15,204	222	675	0	0	0
80	63,978	3,376	77,514	8,221	7,379	407	126	0	0
81	19,073	45,822	10,974	69,210	4,792	3,067	76	123	0
82	16,129	36,225	33,231	9,921	31,045	2,318	768	0	0
83	2,841	2,812	44,336	40,174	6,319	17,770	251	0	0
84	2,875	533	9,589	48,965	25,204	6,271	7,986	198	0
85	3,251	17,478	5,189	16,256	50,114	10,704	1,389	1,047	0
86	18,857	44,528	23,016	5,276	9,002	25,599	7,435	1,024	1,085
87	18,059	71,920	32,698	5,326	2,862	3,517	4,718	2,064	849
88	104,977	15,168	36,143	13,133	2,849	1,943	2,574	4,155	3,178
89	21,821	161,291	8,376	6,715	4,513	2,718	2,543	867	1,677
90	29,559	19,434	43,284	11,974	16,878	19,588	8,229	6,546	8,187
91	27,181	91,782	21,912	21,684	10,412	9,327	6,709	3,023	4,448
92	11,121	30,147	12,343	9,853	10,637	8,100	5,594	2,629	1,025
93	51,845	9,383	10,677	3,440	3,366	5,043	2,885	2,893	1,651
94	25,604	38,016	9,946	4,530	5,751	3,022	1,869	1,485	606
95	46,200	21,302	5,281	983	552	1,417	759	529	336
96	28,944	43,914	12,554	6,006	3,741	2,567	1,368	1,073	756
97	24,318	49,846	32,822	12,959	8,404	7,622	4,901	4,166	6,853
98	13,603	19,878	38,777	23,702	15,523	13,343	10,668	6,472	7,980
99	11,997	2,949	2,680	6,120	5,834	4,447	1,946	1,330	966
00	29,467	15,355	5,178	8,769	10,300	6,638	2,845	1,141	630
01	14,207	20,422	3,517	1,951	2,408	2,134	984	555	299
02	7,247	51,289	5,176	1,192	228	365	253	0	0
03	21,539	10,745	3,701	1,342	518	449	249	55	65
04	36,128	3,915	1,147	755	276	41	28	15	28
05	41,331	6,563	2,595	445	181	108	40	17	0
06	31,524	17,158	3,649	1,682	709	269	188	97	0
07	22,924	10,607	4,575	3,125	1,197	594	189	70	0
08	14,385	7,130	3,684	2,837	1,309	527	207	31	0

Table A2A-4. Weight-at-age from the ASAP (2009) model (1929-08).

Fishing Year	0	1	2	3	4	5	6	7	8+
29	0.074	0.167	0.297	0	0.523	0.615	1	0.8	0.83
30	0.06	0.139	0.301	0	0.511	0.603	1	0.8	0.83
31	0.077	0.114	0.276	0	0.527	0.606	1	0.8	0.83
32	0.058	0.081	0.277	0	0.508	0.604	1	0.8	0.83
33	0.059	0.083	0.2	0	0.493	0.585	1	0.8	0.83
34	0.065	0.142	0.198	0	0.431	0.538	1	0.8	0.83
35	0.079	0.186	0.217	0	0.379	0.472	1	0.79	0.83
36	0.086	0.193	0.284	0	0.393	0.453	1	0.75	0.82
37	0.119	0.176	0.318	0	0.461	0.502	1	0.74	0.8
38	0.124	0.174	0.31	0	0.532	0.582	1	0.726	0.79
39	0.191	0.246	0.363	0	0.583	0.68	1	0.795	0.878
40	0.18	0.26	0.339	0	0.527	0.64	1	0.834	0.82
41	0.115	0.259	0.343	0	0.559	0.65	1	0.807	0.85
42	0.18	0.236	0.373	0	0.546	0.626	1	0.909	0.83
43	0.165	0.292	0.339	0	0.574	0.65	1	0.881	1
44	0.144	0.271	0.379	0	0.587	0.66	1	0.735	0.948
45	0.121	0.234	0.383	0	0.611	0.704	1	0.819	0.842
46	0.125	0.261	0.384	0	0.617	0.679	1	0.778	0.812
47	0.119	0.291	0.4	0	0.622	0.709	1	0.788	0.818
48	0.107	0.227	0.354	1	0.616	0.706	1	0.895	0.871
49	0.109	0.192	0.319	0	0.607	0.725	1	0.917	0.917
50	0.084	0.249	0.323	0	0.564	0.664	1	0.799	0.871
51	0.162	0.255	0.346	0	0.569	0.694	1	0.835	0.853
52	0.173	0.297	0.386	0	0.568	0.719	1	0.988	0.85
53	0.162	0.296	0.411	1	0.603	0.763	1	0.85	1.1
54	0.084	0.257	0.387	1	0.585	0.744	1	0.879	0.87
55	0.14	0.253	0.357	0	0.583	0.744	1	0.778	0.878
56	0.111	0.248	0.373	0	0.598	0.752	1	0.91	0.87
57	0.179	0.31	0.374	1	0.602	0.649	1	0.7	1
58	0.176	0.292	0.396	0	0.617	0.685	1	0.75	0.75
59	0.132	0.251	0.398	1	0.602	0.702	1	0.84	0.85
60	0.102	0.276	0.391	1	0.611	0.699	1	0.82	0.87
61	0.144	0.252	0.389	0	0.584	0.647	1	0.83	0.85
62	0.276	0.32	0.42	1	0.622	0.712	1	0.89	0.86
63	0.197	0.298	0.434	1	0.627	0.73	1	0.84	0.93
64	0.181	0.3	0.4	1	0.612	0.748	1	0.82	0.87
65	0.109	0.195	0.384	1	0.596	0.723	1	0.88	0.85
66	0.149	0.273	0.419	1	0.658	0.79	1	0.85	0.93
67	0.166	0.235	0.488	1	0.599	0.723	1	0.917	0.849
68	0.138	0.266	0.391	1	0.593	0.709	1	0.952	1.07
69	0.103	0.322	0.428	1	0.662	0.746	1	1	1.1
70	0.099	0.232	0.402	1	0.73	0.837	1	1	1.2
71	0.266	0.282	0.457	0	0.74	0.955	1	0.9	1.2
72	0.147	0.266	0.449	1	0.552	0.746	1	0.9	1.1
73	0.119	0.329	0.433	1	0.606	0.686	1	0.803	0.838
74	0.107	0.303	0.604	1	0.837	0.8	1	0.8	1
75	0.127	0.361	0.517	1	1.053	1.029	1	0.9	0.9
76	0.17	0.297	0.672	1	1.291	1.223	2	1.2	1
77	0.122	0.322	0.6	1	1.063	1.1	1	1.5	1.3
78	0.062	0.334	0.473	1	0.908	1.1	1	1.4	1.6
79	0.082	0.189	0.44	1	0.81	0.969	1	1.3	1.5
80	0.072	0.176	0.27	0	0.598	0.874	1	1.3	1.4
81	0.083	0.19	0.239	0	0.597	0.715	1	0.929	1.4
82	0.032	0.151	0.237	0	0.516	0.773	1	1	1.2
83	0.049	0.191	0.302	0	0.458	0.511	1	0.9	1.1
84	0.12	0.235	0.351	0	0.505	0.614	1	0.871	0.91
85	0.157	0.285	0.418	0	0.484	0.56	1	0.697	0.85
86	0.148	0.29	0.408	1	0.561	0.595	1	0.719	0.784
87	0.133	0.272	0.414	1	0.6	0.691	1	0.766	0.826
88	0.101	0.301	0.415	1	0.666	0.734	1	0.815	0.899
89	0.104	0.193	0.381	1	0.647	0.749	1	0.739	0.827
90	0.094	0.267	0.377	1	0.649	0.68	1	0.775	0.803
91	0.071	0.217	0.397	1	0.591	0.664	1	0.766	0.799
92	0.087	0.175	0.33	0	0.544	0.661	1	0.725	0.805
93	0.073	0.228	0.294	0	0.583	0.607	1	0.756	0.832
94	0.1	0.156	0.248	0	0.493	0.597	1	0.733	0.785
95	0.081	0.179	0.275	0	0.586	0.689	1	0.758	0.92
96	0.105	0.182	0.318	0	0.589	0.649	1	0.705	0.751
97	0.149	0.239	0.333	0	0.572	0.637	1	0.718	0.749
98	0.139	0.267	0.325	0	0.53	0.615	1	0.667	0.689
99	0.148	0.228	0.399	1	0.575	0.633	1	0.754	0.768
00	0.114	0.266	0.37	1	0.59	0.608	1	0.712	0.731
01	0.103	0.253	0.347	1	0.567	0.619	1	0.635	0.627
02	0.133	0.218	0.303	0	0.552	0.687	1	0.728	0.65
03	0.125	0.284	0.414	1	0.679	0.745	1	0.794	0.838
04	0.159	0.28	0.407	1	0.685	0.821	1	0.639	0.902
05	0.106	0.267	0.38	0	0.556	0.665	1	0.797	0.797
06	0.126	0.222	0.353	1	0.752	0.824	1	0.918	0.918
07	0.102	0.22	0.34	1	0.639	0.808	1	0.94	0.94
08	0.108	0.213	0.278	0	0.645	0.78	1	0.948	0.948

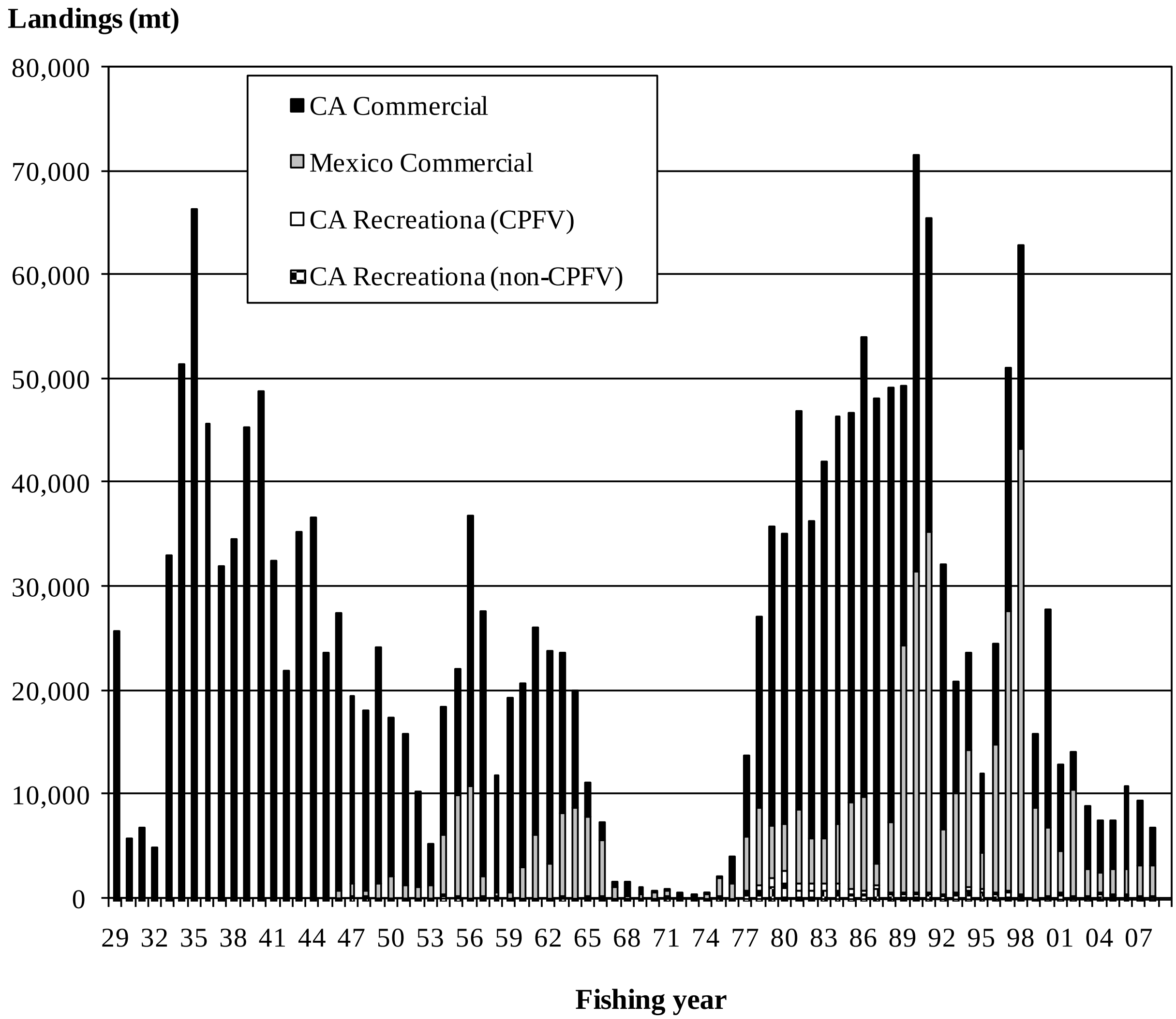


Figure A2A-1. Commercial and recreational landings (mt) of Pacific mackerel in the USA (CA commercial, recreational-CPFV, and recreational-non-CPFV) and Mexico (commercial), (1929-08).

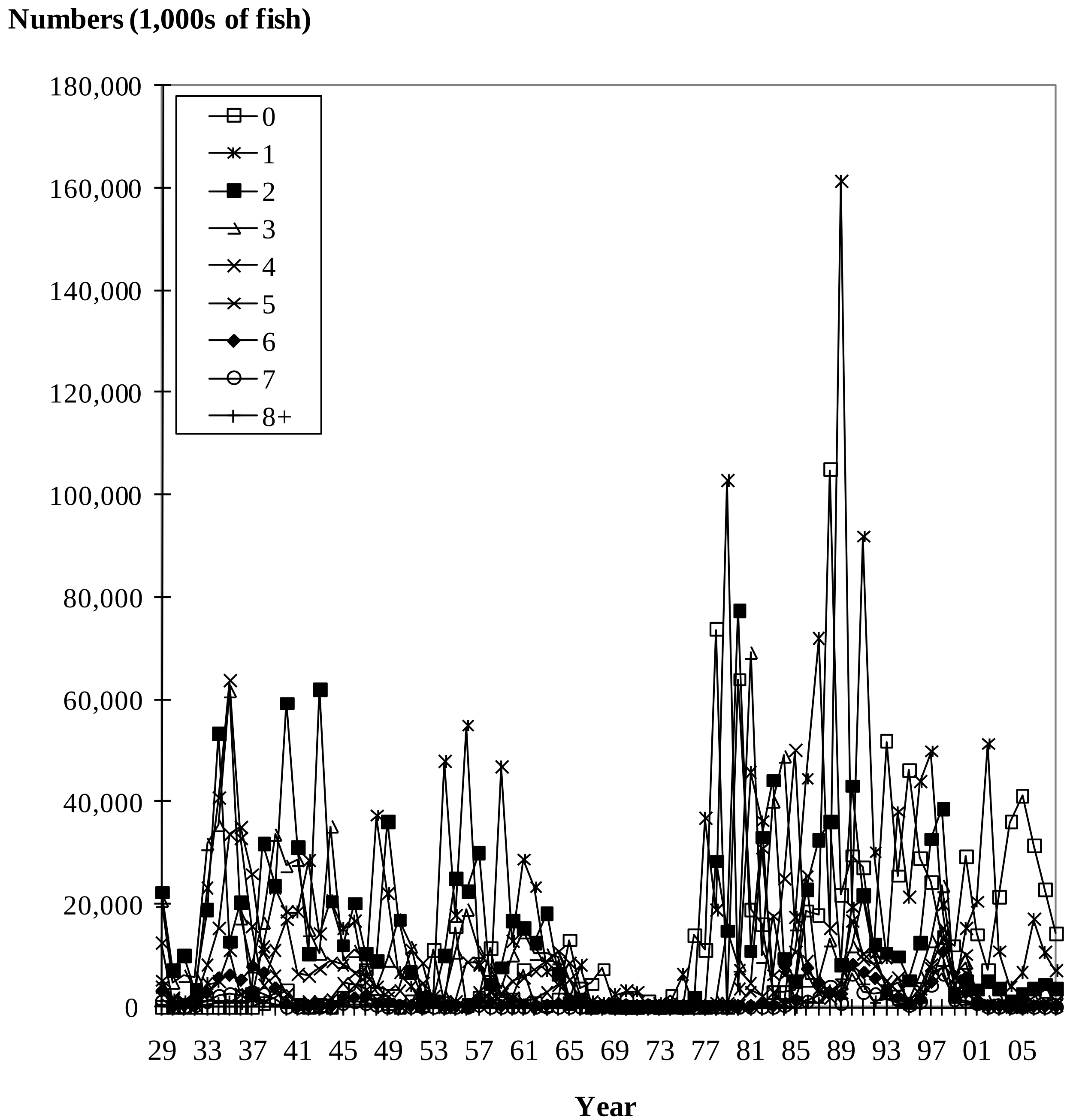


Figure A2A-2. Pacific mackerel catch-at-age (numbers of fish in 1,000s) estimates used in the ASAP (2009) model (1929-08).

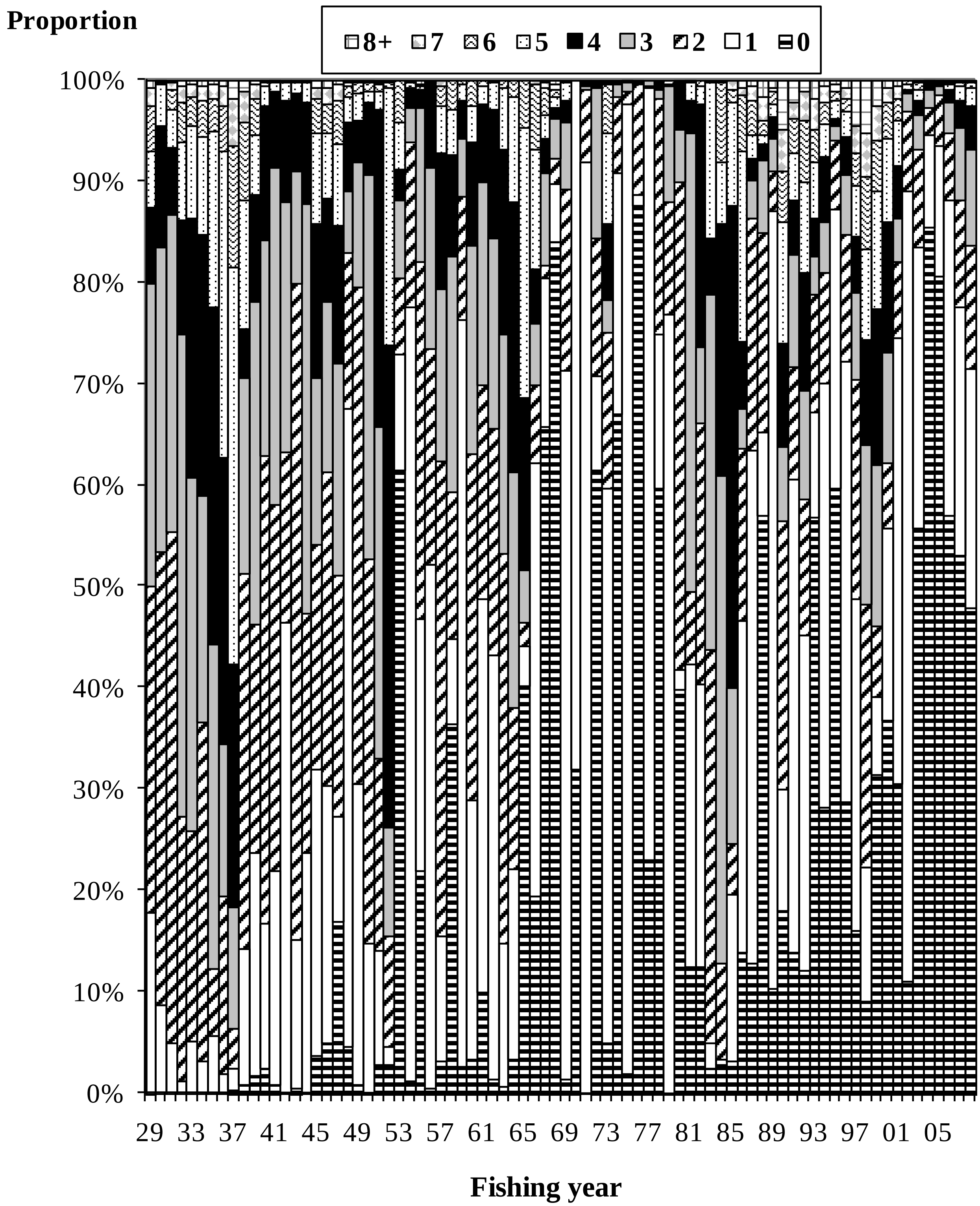


Figure A2A-3. Pacific mackerel catch-at-age (in proportion) estimates used in the ASAP (2009) model (1929-08).

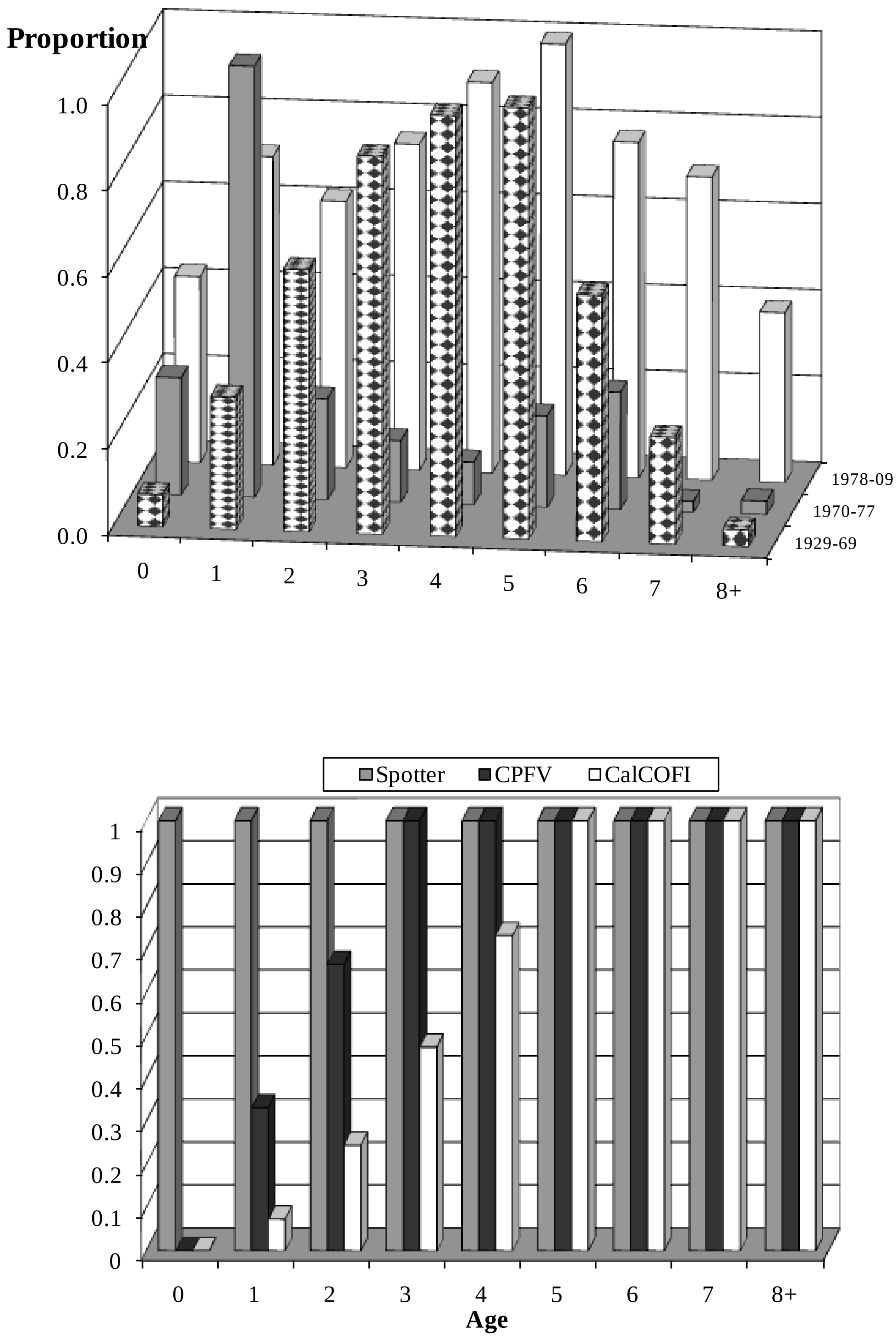


Figure A2A-4. Estimated selectivity schedule for fishery (catch-at-age) data (top display) and assumed selectivity ogives for survey-related indices of abundance (Spotter, CPFV, and CalCOFI) from the ASAP (2009) model. Note that CPFV ogive represents (1990-09), with ogive for 1929-89 parameterized with slightly different probabilities for ages 1 and 2.

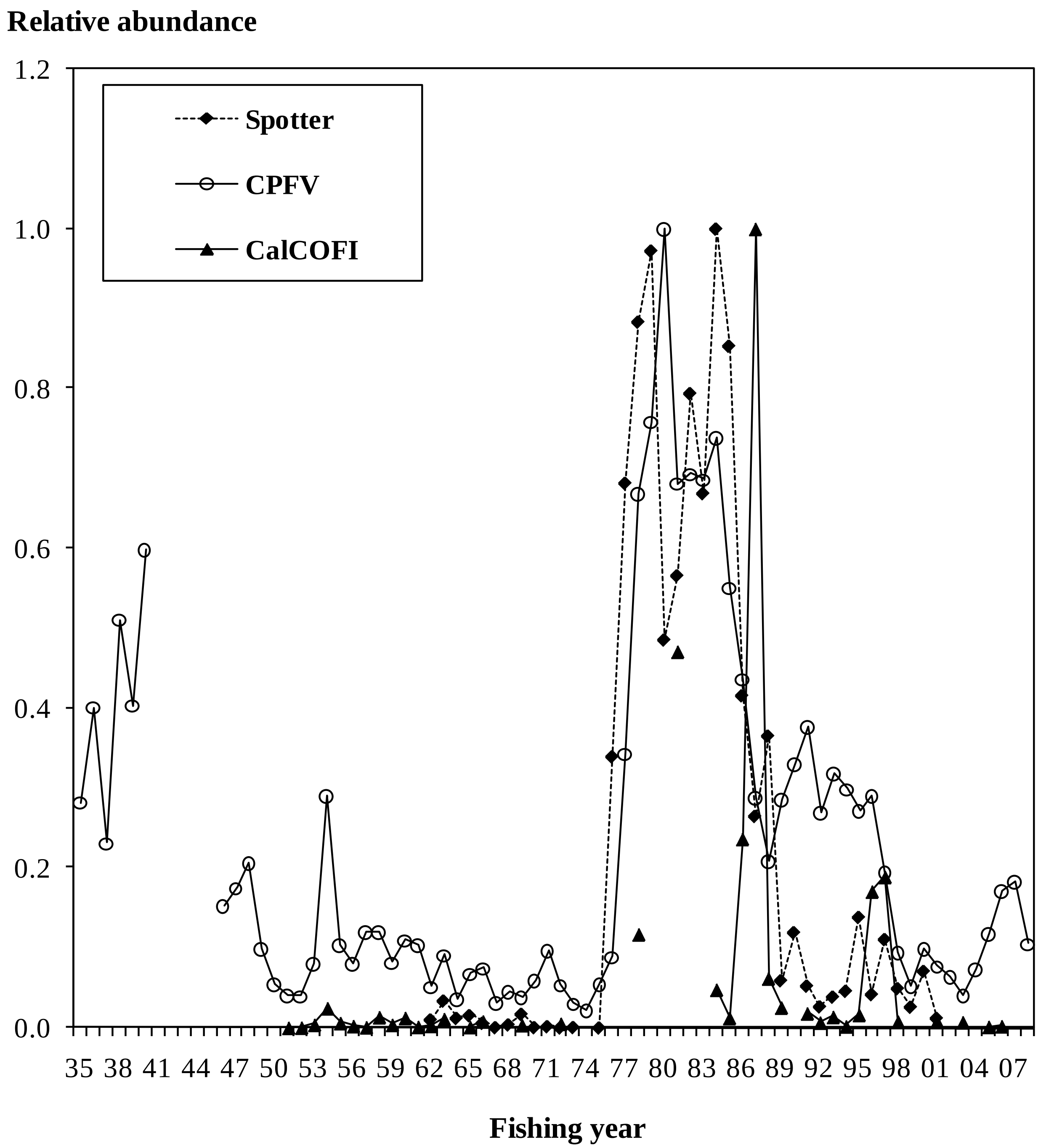


Figure A2A-5. Indices of abundance time series for Pacific mackerel used in the ASAP (2009) model (1929-08). Indices are rescaled (normalized).

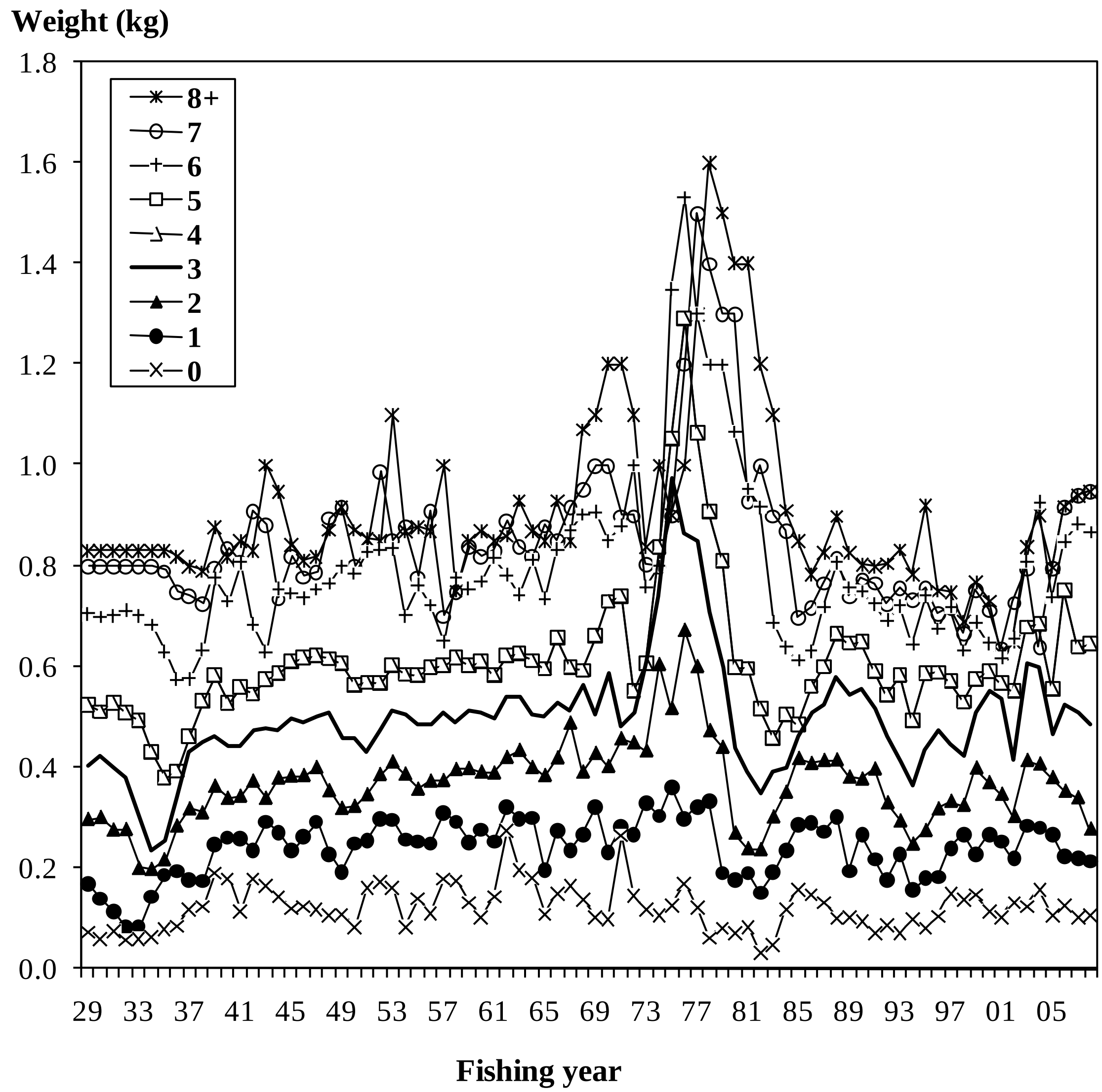


Figure A2A-6. Pacific mackerel weight-at-age (kg) estimates used in the ASAP (2009) model (1929-08).

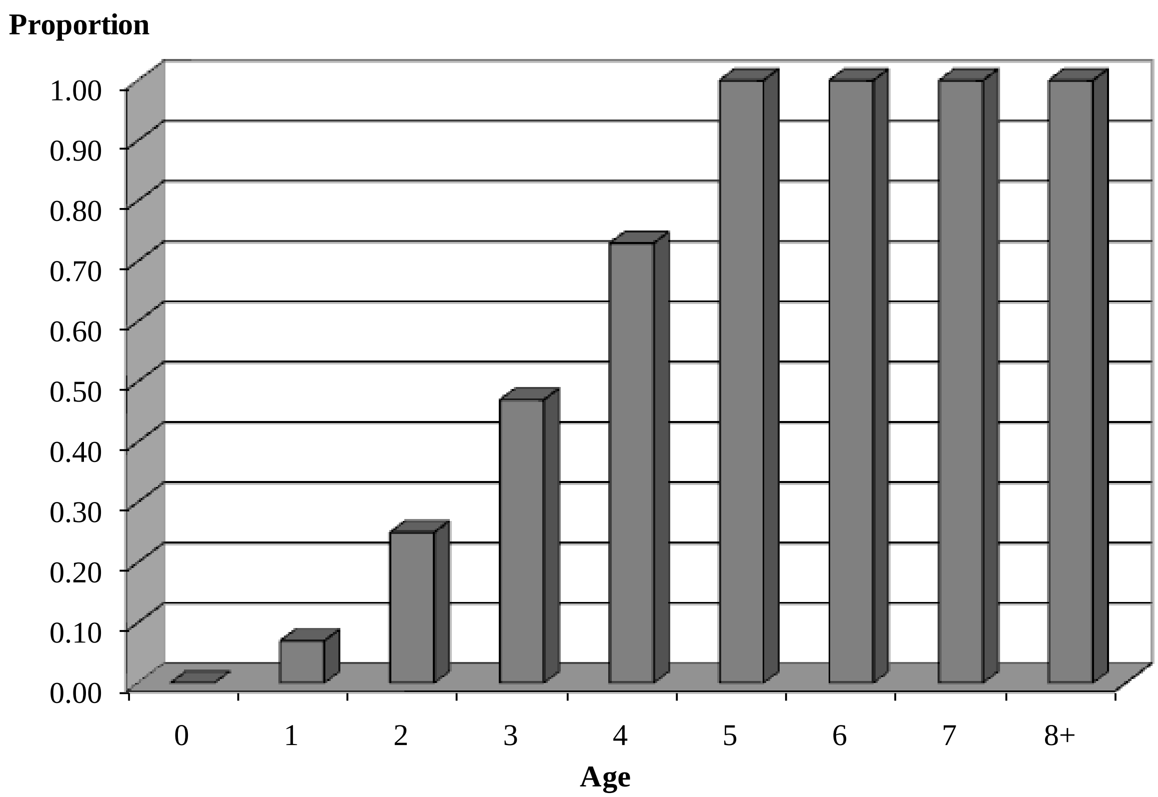


Figure A2A-7. Pacific mackerel maturity schedule used in the ASAP (2009) model.

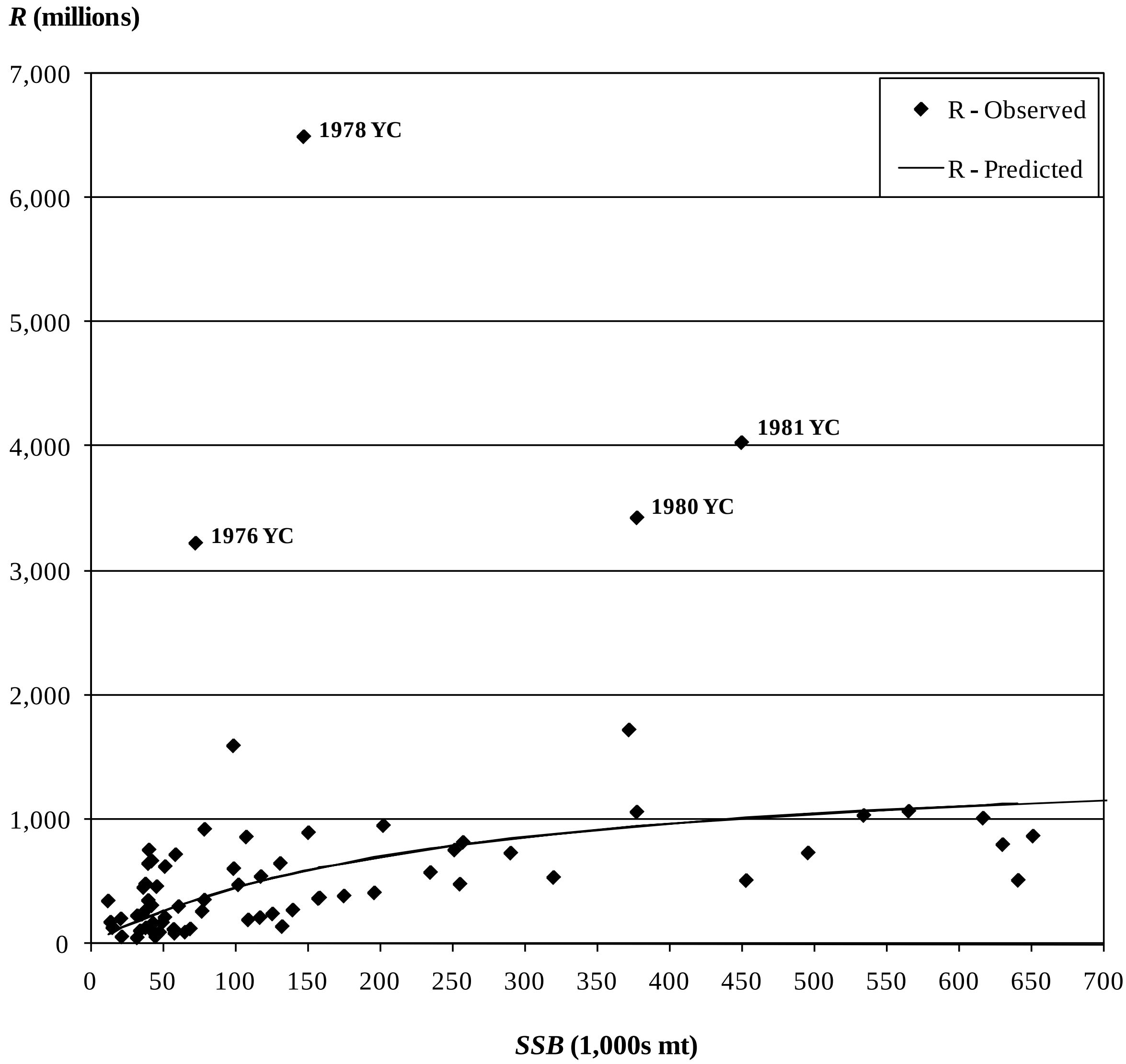


Figure A2A-8. Beverton-Holt stock (SSB in 1000s mt)-recruitment (R in millions of fish) relationship for Pacific mackerel estimated in the ASAP (2009) model (1929-09). Recruitment estimates are presented as (year+1) values. Strong year classes are highlighted. Steepness=0.31.

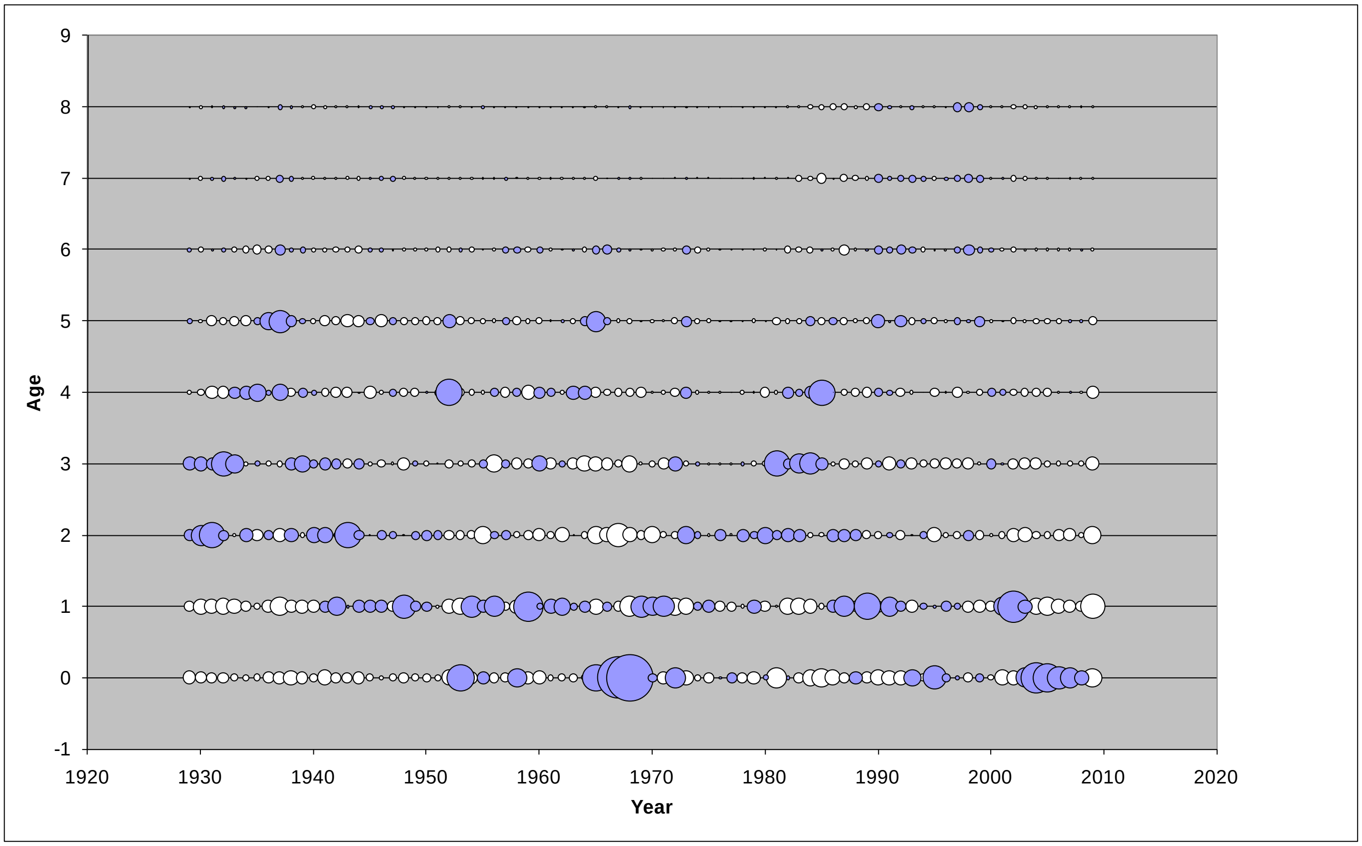


Figure A2A-9. Residual plot of catch-at-age fits associated with the ASAP (2009) model (1929-08). Grey-shaded bubbles indicate positive values and white bubbles indicate negative values.

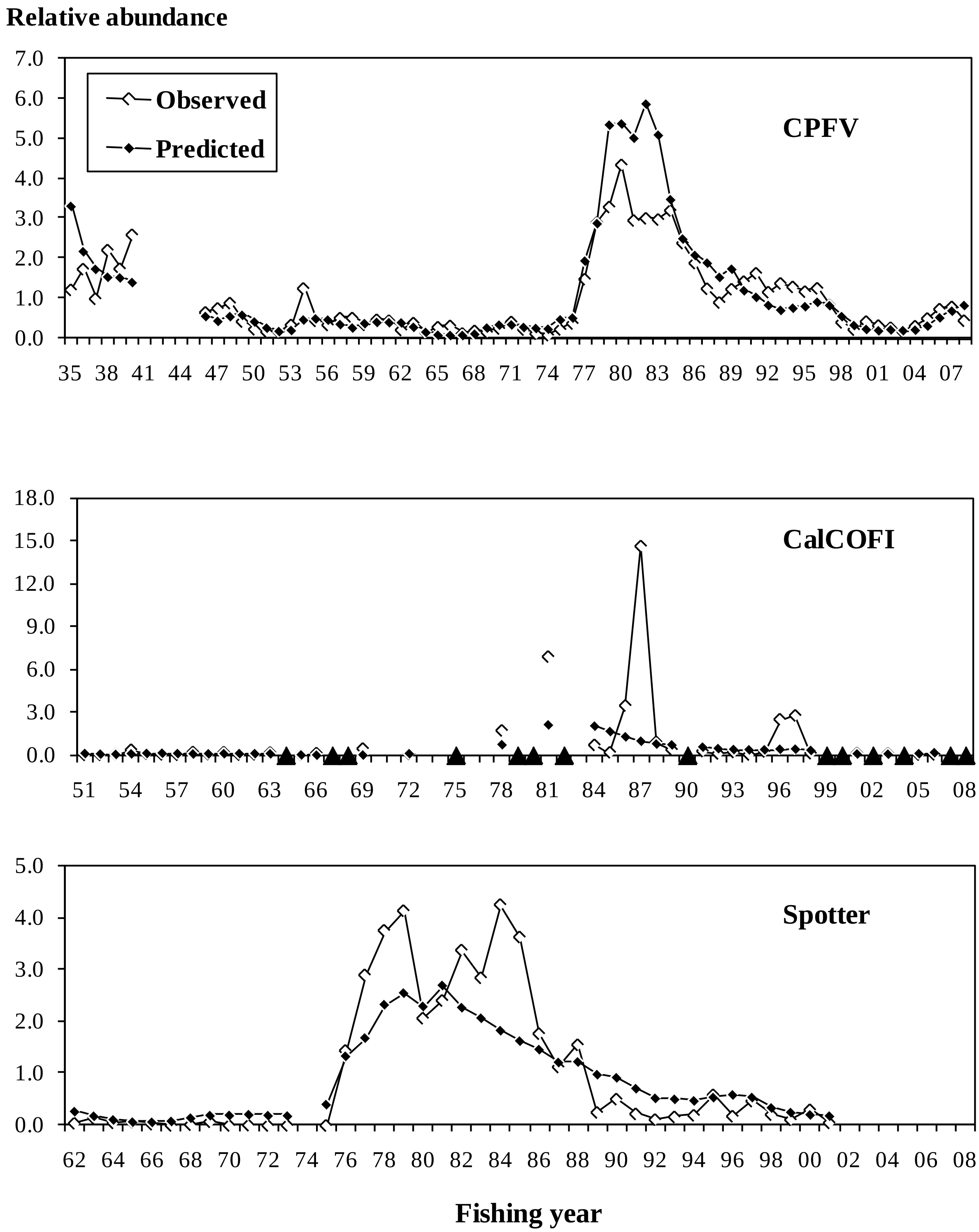


Figure A2A-10. Observed and predicted estimates from survey index fits generated from the ASAP (2009) model (1929-08): CPFV; CalCOFI (solid triangles reflect years that survey was conducted, but no observations); and Spotter.

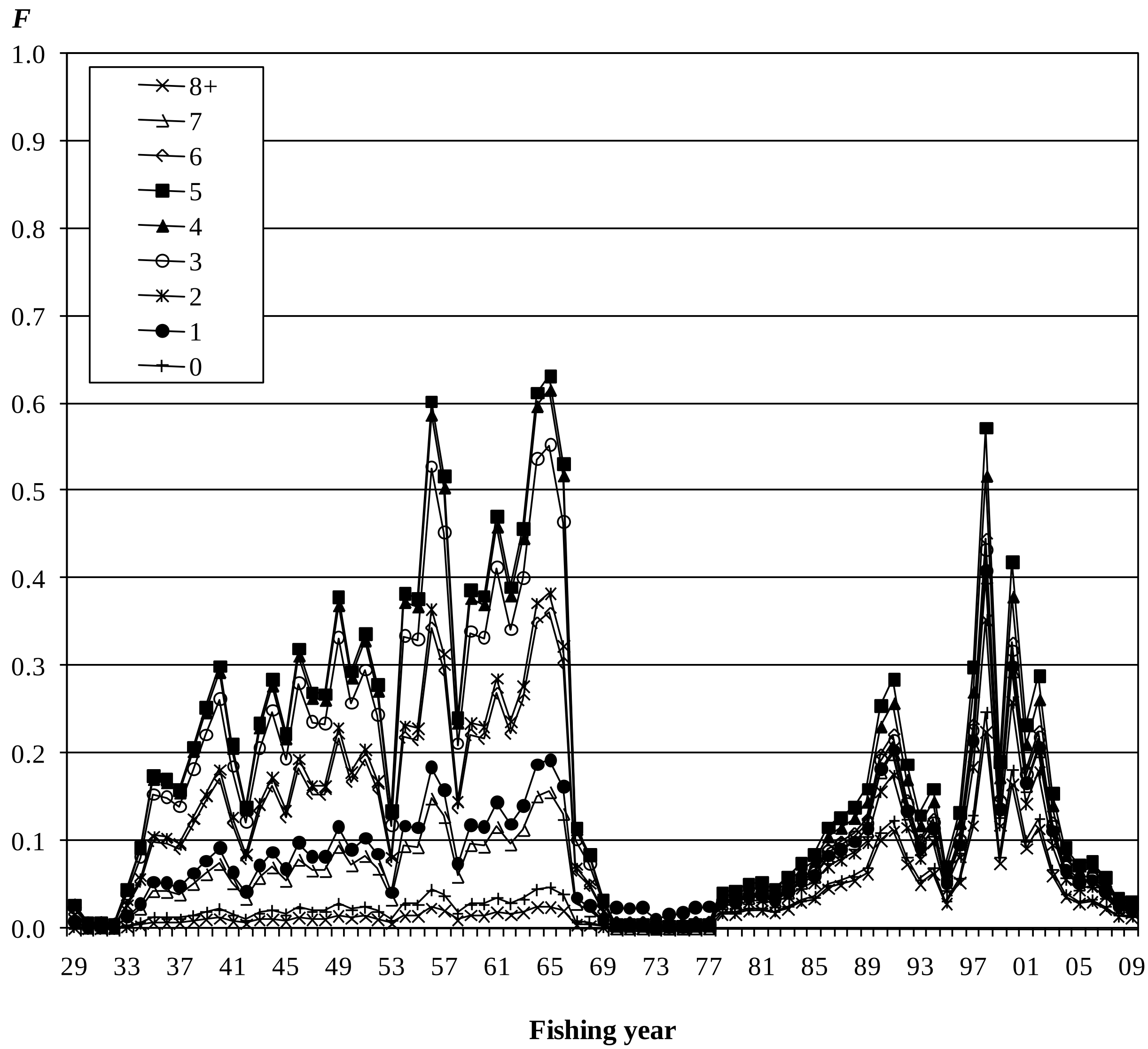


Figure A2A-11. Estimated (total) fishing mortality (*F*-at-age) for Pacific mackerel based on the ASAP (2009) model (1929-09).

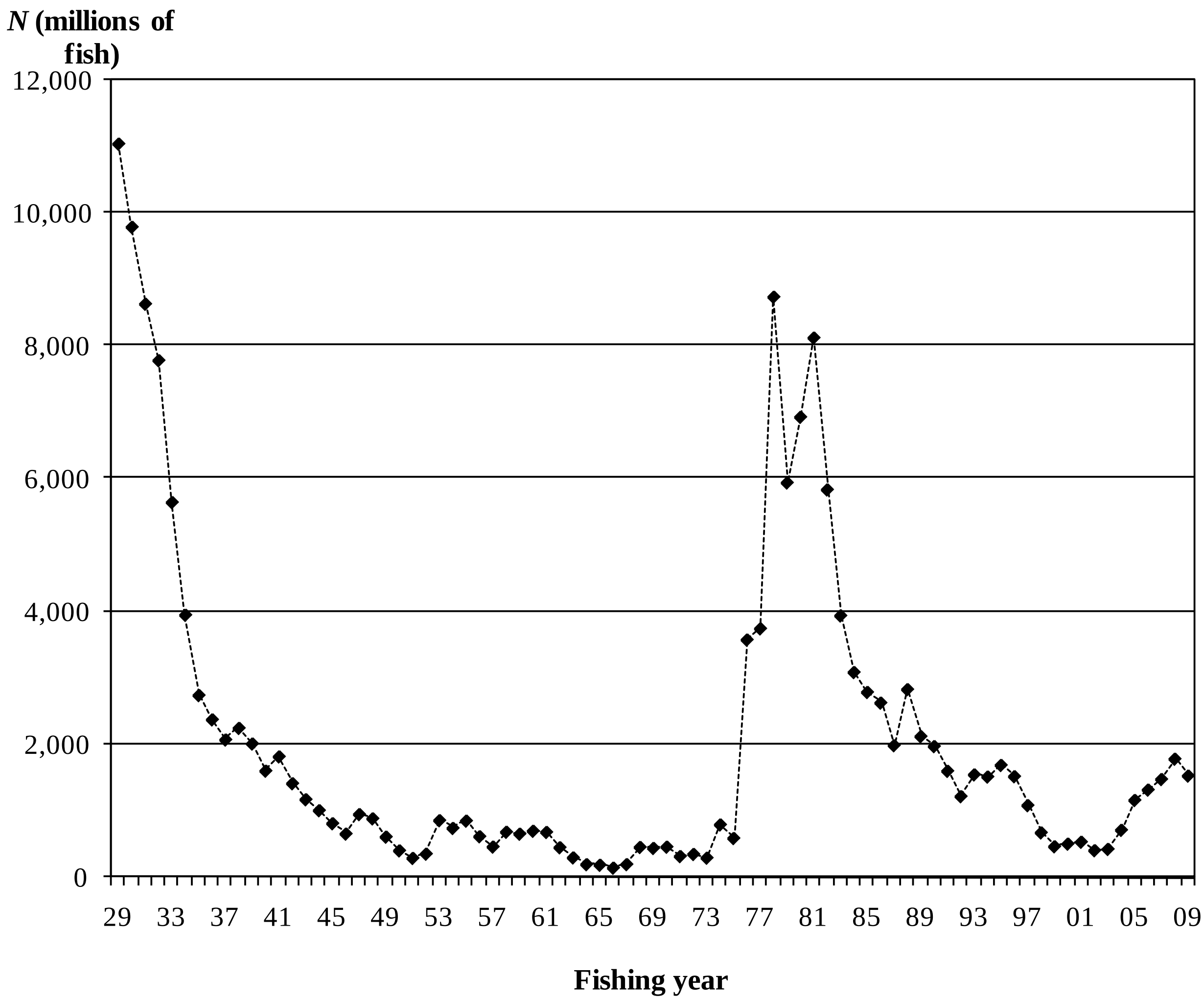


Figure A2A-12. Estimated total population abundance (*N* in millions of fish) of Pacific mackerel based on the ASAP (2009) model (1929-09).

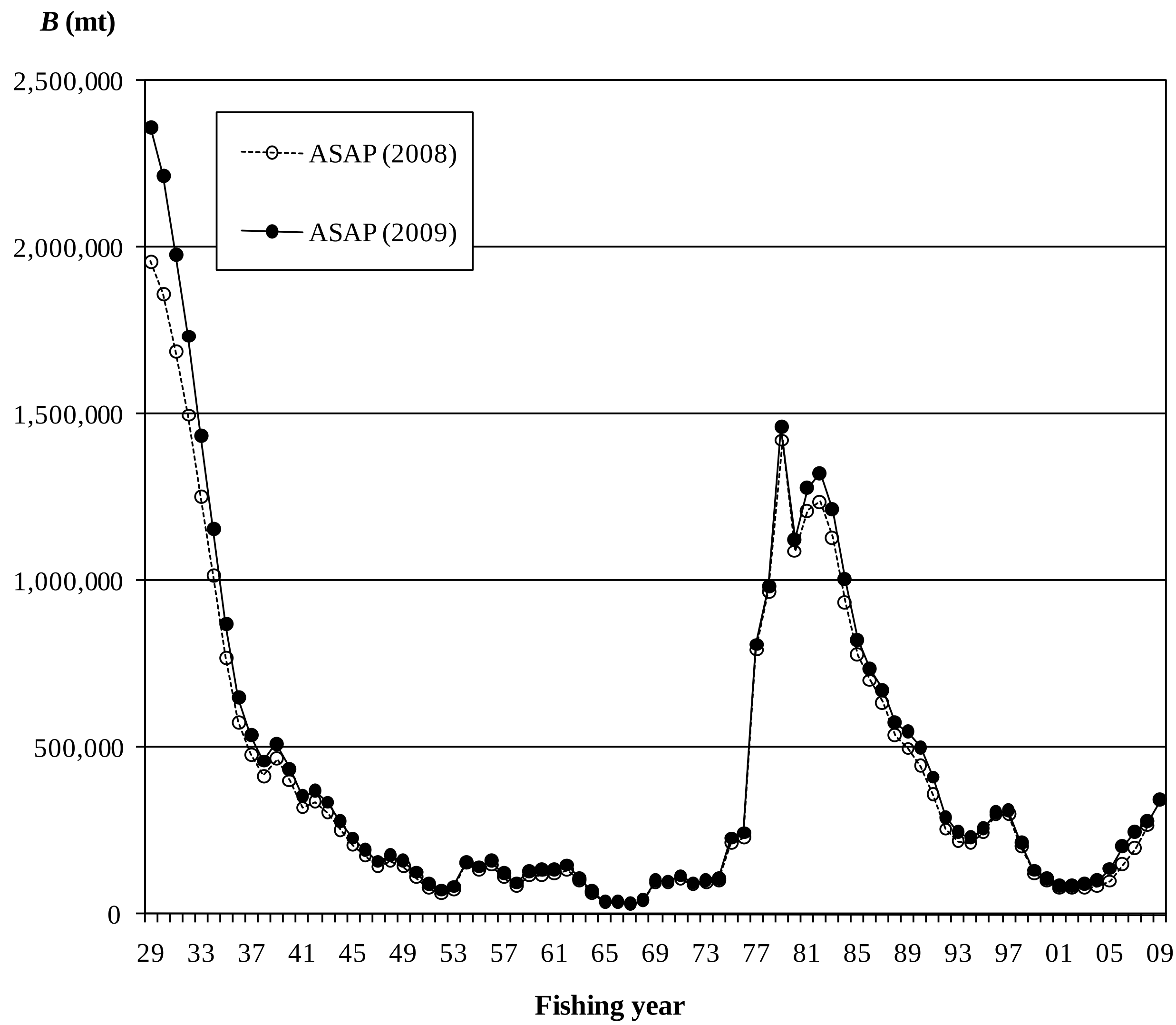


Figure A2A-13. Estimated total stock biomass (age 1+ fish in mt, *B*) of Pacific mackerel based on the ASAP (2009) model (1929-09). Estimated *B* for the ASAP (2008) final model is also presented.

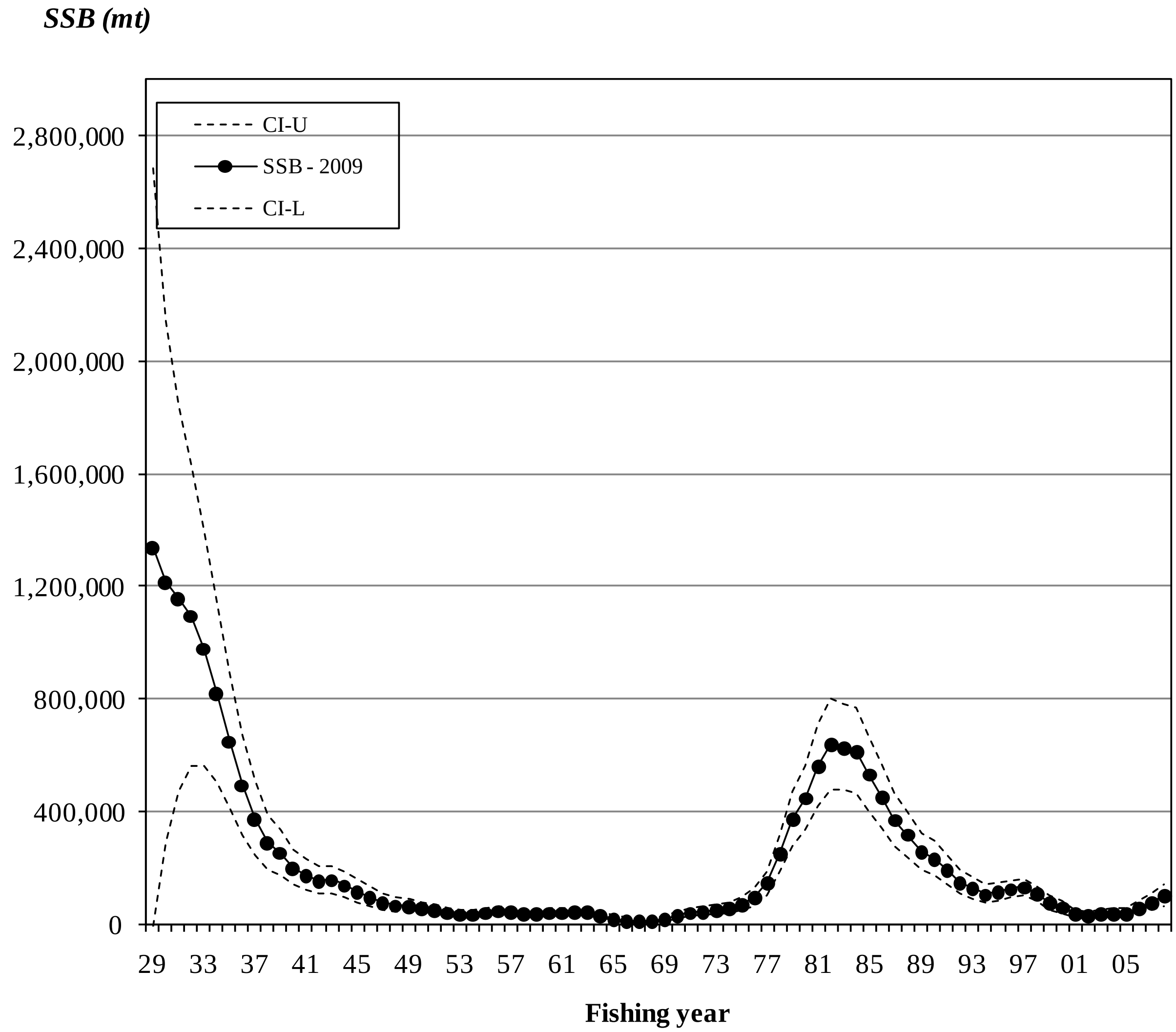


Figure A2A-14. Estimated spawning stock biomass of Pacific mackerel based on the ASAP (2009) model (1929-08). Confidence interval (± 2 SD) is also presented.

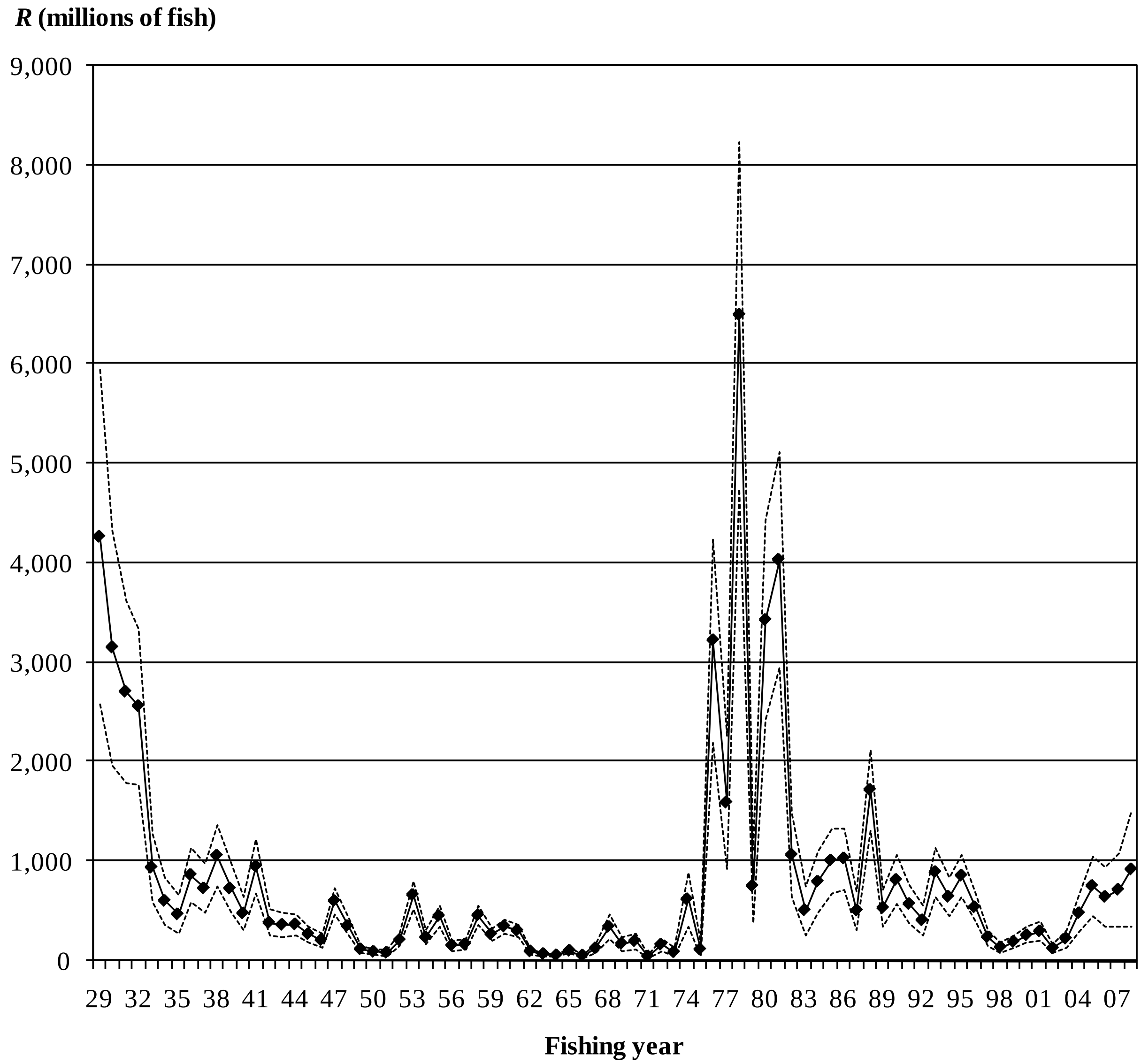


Figure A2A-15. Estimated recruitment (age-0 fish in millions, R) of Pacific mackerel based on the ASAP (2009) model (1929-08). Confidence interval (± 2 SD) is also presented.

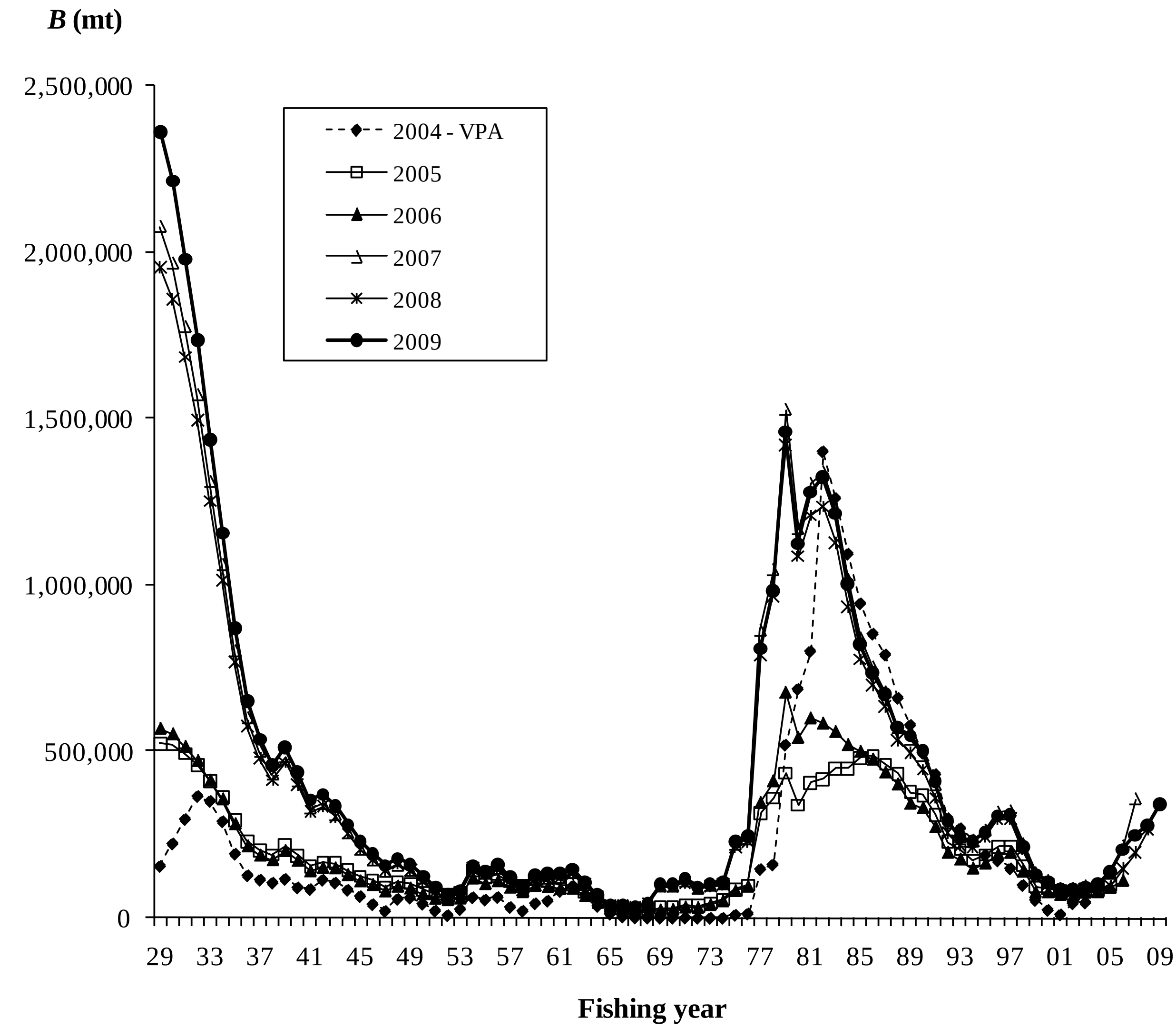


Figure A2A-16. Estimated total stock biomass (*B* age 1+ fish in mt) of Pacific mackerel for historical assessment period (1994-09): VPA model-based assessments from 1994-04; and ASAP model-based from 2005 to the present.

Appendix 2B

SS model (*S1_aa*) displays

Table A2B-1 Summary of model scenarios developed for the Pacific mackerel (2009) assessment, including: (A) new data sources and critical parameterizations for SS and ASAP; (B) likelihood component estimates for SS and and derived quantities of importance for SS and ASAP; and (C) likelihood component estimates for ASAP.

(A)

New Data	*ASAP*	*S1_aa*	*S1_qa*	*S1_qa1*	*S1_qa21*
Landings - USA/Mexico commerical (2003-08) - Fishery 1					
Landings - USA recreational (2008) - Fishery 2					
Age distributions (2008) - USA/Mexico commercial					
Length distributions (2008) - USA recreational					
Mean length-at-age distributions (1962-08) - USA/Mexico commercial					
Spotter survey - Survey 1 [1]					
CPFV survey (2008) - Survey 2					
CalCOFI survey (2008) - daily larval prod. ('missing' years) - Survey 3 [2]					
CalCOFI survey (2008) - daily larval prod. ('zero' years) - Survey 4					
CalCOFI survey (2008) - daily larval prod. (larval density - CA/MX) - Survey 5					
	Model scenarios				
Parameterization	***ASAP***	***S1_aa***	***S1_qa***	***S1_qa1***	***S1_qa21***
Model structure					
Time period	1929-08	1962-08	1962-08	1962-08	1962-08
Number of fisheries	1	2	2	2	2
Number of surveys	3	3	3	3	3
Genders	Combined	Combined	Combined	Combined	Combined
Time-step	Annual	Annual	Quarter	Quarter	Quarter
Biology					
Maturity-at-age	Fixed	Fixed	Fixed	Fixed	Fixed
Length-at-age	Na	Estimated	Estimated	Estimated	Estimated
Weight-length	Na	Fixed	Fixed	Fixed	Fixed
Weight-at-age	Fixed (annual blocks)	Estimated (constant)	Estimated (constant)	Estimated (constant)	Estimated (constant)
Mortality	Fixed (0.5)	Fixed (0.5)	Fixed (0.5)	Fixed (0.5)	Fixed (0.5)
Stock-recruitment					
$\ln(R_0)$	Estimated	Estimated	Estimated	Estimated	Estimated
Offset for initial equilibrium R_1	Na	Estimated	Estimated	Estimated	Estimated
Steepness (*h*)	Estimated	Estimated	Estimated	Estimated	Estimated
σ-*R*	Fixed (0.7)	Fixed (0.7)	Fixed (0.7)	Fixed (0.7)	Fixed (0.7)
Initial conditions for population dynamics					
Age distribution	Non-equilibrium	Non-equilibrium	Non-equilibrium	Non-equilibrium	Non-equilibrium
Fishing mortality (*F*) - Fishery 1[3]	Na	Estimated (F1) and fixed (F2=0.0001)	Estimated (F1) and fixed (F2=0.0001)	Estimated (F1) and fixed (F2=0.0001)	Fixed (F1=0.5 and F2=0.0001)
First year *R* bias adjustment	Na	1958	1958	1958	1958
Selectivity					
Fisheries					
Parameterization	Estimated	Fixed (similar to ASAP)	Fixed (similar to ASAP)	Estimated	Estimated
Time block	Time-varying (3 blocks)	Time-varying (3 blocks)	Time-varying (3 blocks)	Time-varying (3 blocks)	Time-varying (3 blocks)
Shape	Dome-shaped	Dome-shaped	Dome-shaped	Dome-shaped	Dome-shaped
Surveys					
Parameterization	Fixed	Fixed (similar to ASAP)	Fixed (similar to ASAP)	Fixed (S1, S3) and estimated (F1, F2, S2)	Fixed (S1, S4) and estimated (F1, F2, S2)
Time block	One	One	One	One	One
Shape	Asymptotic	Asymptotic	Asymptotic	Asymptotic	Asymptotic
Catchability					
q - Surveys	Median unbiased	Median unbiased	Median unbiased	Median unbiased	Median unbiased

[1] Spotter survey is included under 'New Data' for purposes of continuity only, i.e., survey has not been updated since 2001.

[2] CalCOFI surveys reflect current survey (Survey 3) used in assessment and two alternative surveys (Surveys 4-5) used in sensitivity analysis.

[3] In SS model scenarios, estimated initial fishing mortality is not fit to 'equilibrium' catch, but rather, implemented for purposes of providing a more realistic initial non-equilibrium age composition.

Table A2B-1 (A). Continued.

(A)

New Data	*S1_qa22*	*S1_qa23*	*S1_qa24*	*S1_qa25*	*S1_qa3*
Landings - USA/Mexico commerical (2003-08) - Fishery 1					
Landings - USA recreational (2008) - Fishery 2					
Age distributions (2008) - USA/Mexico commercial					
Length distributions (2008) - USA recreational					
Mean length-at-age distributions (1962-08) - USA/Mexico commercial					
Spotter survey - Survey 1 [1]					
CPFV survey (2008) - Survey 2					
CalCOFI survey (2008) - daily larval prod. ('missing' years) - Survey 3 [2]					
CalCOFI survey (2008) - daily larval prod. ('zero' years) - Survey 4					
CalCOFI survey (2008) - daily larval prod. (larval density - CA/MX) - Survey 5					
	Model scenarios				
Parameterization	***S1_qa22***	***S1_qa23***	***S1_qa24***	***S1_qa25***	***S1_qa3***
Model structure					
Time period	1962-08	1962-08	1962-08	1962-08	1962-08
Number of fisheries	2	2	2	2	2
Number of surveys	3	2	2	1	1
Genders	Combined	Combined	Combined	Combined	Combined
Time-step	Quarter	Quarter	Quarter	Quarter	Quarter
Biology					
Maturity-at-age	Fixed	Fixed	Fixed	Fixed	Fixed
Length-at-age	Estimated	Estimated	Estimated	Estimated	Estimated
Weight-length	Fixed	Fixed	Fixed	Fixed	Fixed (4 blocks)
Weight-at-age	Estimated (constant)	Estimated (constant)	Estimated (constant)	Estimated (constant)	Estimated (constant)
Mortality	Fixed (0.5)	Fixed (0.5)	Fixed (0.5)	Fixed (0.5)	Fixed (0.5)
Stock-recruitment					
$\ln(R_0)$	Estimated	Estimated	Estimated	Estimated	Estimated
Offset for initial equilibrium R_1	Estimated	Estimated	Estimated	Estimated	Estimated
Steepness (*h*)	Estimated	Estimated	Estimated	Estimated	Estimated
σ-*R*	Fixed (0.7)	Fixed (0.7)	Fixed (0.7)	Fixed (0.7)	Fixed (0.7)
Initial conditions for population dynamics					
Age distribution	Non-equilibrium	Non-equilibrium	Non-equilibrium	Non-equilibrium	Non-equilibrium
Fishing mortality (*F*) - Fishery 1[3]	ixed (F1=0.5 and F2=0.000	Estimated (F1) and fixed (F2=0.0001)	Fixed (F1=0.5 and F2=0.0001)	Estimated (F1) and fixed (F2=0.0001)	Estimated (F1) and fixed (F2=0.0001)
First year *R* bias adjustment	1958	1958	1958	1958	1958
Selectivity					
Fisheries					
Parameterization	Estimated	Estimated	Estimated	Estimated	Estimated
Time block	Time-varying (3 blocks)	Time-varying (3 blocks)	Time-varying (3 blocks)	Time-varying (3 blocks)	Time-varying (3 blocks)
Shape	Dome-shaped	Dome-shaped	Dome-shaped	Dome-shaped	Dome-shaped
Surveys					
Parameterization	S1, S5) and estimated (F1,	Fixed (S1) and estimated (F1, F2, S2)	Fixed (S4) and estimated (F1, F2, S2)	Estimated (F1, F2, S2)	Estimated (F1, F2, S2)
Time block	One	One	One	One	One
Shape	Asymptotic	Asymptotic	Asymptotic	Asymptotic	Asymptotic
Catchability					
q - Surveys	Median unbiased	Median unbiased	Median unbiased	Median unbiased	Median unbiased

[1] Spotter survey is included under 'New Data' for purposes of continuity only, i.e., survey has not been updated since 2001.

[2] CalCOFI surveys reflect current survey (Survey 3) used in assessment and two alternative surveys (Surveys 4-5) used in sensitivity analysis.

[3] In SS model scenarios, estimated initial fishing mortality is not fit to 'equilibrium' catch, but rather, implemented for purposes of providing a more realistic initial non-equilibrium age composition.

Table A2B-1 (B). Continued.

(B)

Likelihood component	*ASAP*	*S1_aa*	*S1_qa*	*S1_qa1*	*S1_qa21*	*S1_qa22*	*S1_qa23*	*S1_qa24*	*S1_qa25*	*S1_qa3*
Biological distributions										
Age distributions										
USA/Mexico commercial - Fishery 1		711.13	1,326.01	1,311.89	1,307.57	1,315.84	1,313.49	1,309.05	1,317.69	1,317.73
Length distributions										
USA recreational - Fishery 2		Na	Na	296.82	297.23	297.32	295.69	297.29	295.36	295.38
Length-at-age distributions										
USA/Mexico commercial - Fishery 1		519.81	1,738.41	1,744.80	1,746.96	1,742.57	1,742.78	1,742.77	1,740.08	1,740.13
Surveys										
Spotter - Survey 1		80.80	83.47	79.77	80.20	83.35	82.18	Na	Na	Na
CPFV - Survey 2		14.68	15.80	18.29	23.73	16.28	15.79	7.39	-2.00	-2.15
CalCOFI - Survey 3		73.78	72.93	74.10	Na	Na	Na	Na	Na	Na
CalCOFI - Survey 4		Na	Na	Na	205.42	Na	Na	209.09	Na	Na
CalCOFI - Survey 5		Na	Na	Na	Na	142.94	Na	Na	Na	Na
Sub-total		169.26	172.21	172.17	309.35	242.57	97.97	216.49	-2.00	-2.15
Recruitment										
Model time period (1958-08)		42.656	37.693	38.305	42.773	42.188	38.834	39.520	39.146	39.383
Forecast (2009)		0.220	0.341	0.443	0.522	0.450	0.422	0.517	0.427	0.422
Global										
Likelihood (*L*)		1,443.1	3,274.7	3,564.4	3,704.4	3,641.0	3,489.2	3,605.6	3,390.7	3,390.9
Number of estimated parameters		61	61	85	84	84	85	84	85	85
Key estimated parameters and derived quantities										
Biology										
Length-at-age (*k*)	Na	0.40	0.38	0.33	0.34	0.33	0.32	0.34	0.33	0.33
ln(R_0)	12.127	13.335	13.415	13.656	13.473	13.549	13.693	13.410	13.554	13.572
Offset for initial equilibrium R_1	Na	-0.1063	-0.1951	-0.1262	-0.9910	-0.6025	-0.1502	-0.3603	-0.0232	-0.0345
Steepness (*h*)	0.30	0.48	0.49	0.45	0.49	0.44	0.44	0.47	0.43	0.43
Initial conditions for population dynamics										
Fishing mortality (*F*) - Fishery 1[3]	Na	0.78	0.65	1.24	Na	Na	1.09	Na	0.79	0.80
Population time series										
SSB - 1962	46,001	22,789	28,778	38,189	54,792	88,273	44,133	47,252	54,449	55,212
SSB - 2008	101,999	97,040	86,497	96,513	59,547	89,840	115,412	47,094	94,645	94,471
B (1+) - 1962	147,838	98,251	105,640	118,588	117,684	162,916	126,759	122,850	146,719	150,297
B (1+) - 2009	343,180	304,886	278,944	326,163	207,456	294,465	381,251	166,308	314,526	313,764
HG - 2009	68,246	60,204	54,756	64,672	39,744	58,016	76,241	31,103	62,228	62,068

[1] Spotter survey is included under 'New Data' for purposes of continuity only, i.e., survey has not been updated since 2001.

[2] CalCOFI surveys reflect current survey (Survey 3) used in assessment and two alternative surveys (Surveys 4-5) used in sensitivity analysis.

[3] In SS model scenarios, estimated initial fishing mortality is not fit to 'equilibrium' catch, but rather, implemented for purposes of providing a more realistic initial non-equilibrium age composition.

Table A2B-1 (C). Continued.

(C)

Likelihood component[4]	***n***	***λ***	***RSS***	***L***	**% of Total**
Catch (weight) - fishery	81	150	0.005	0.789	<1%
Catch-at-age (proportions) - fishery	729	na	na	525.02	53.2%
Fits - Survey indices					
Spotter	39	1	168.67	123.93	12.5%
CPFV	69	1	15.56	90.21	9.1%
CalCOFI	37	1	82.04	133.24	13.5%
All	145	3	266.27	347.38	35.2%
Recruitment (deviations)	81	1	59.04	59.04	6.0%
Stock-recruit fit	81	1	59.04	55.41	5.6%
F penalty	729	0.001	2.22	0.002	<1%
Number of estimated parameters (Total)	202	Na	Na	Na	Na
Objective function (Total)	Na	Na	Na	987.6	100%

[4]ASAP model-related notation is as follows: *n* is number of observations; λ is lambda (weight value in overall fit); *RSS* is residula sum of squares; and *L* is likelihood value.

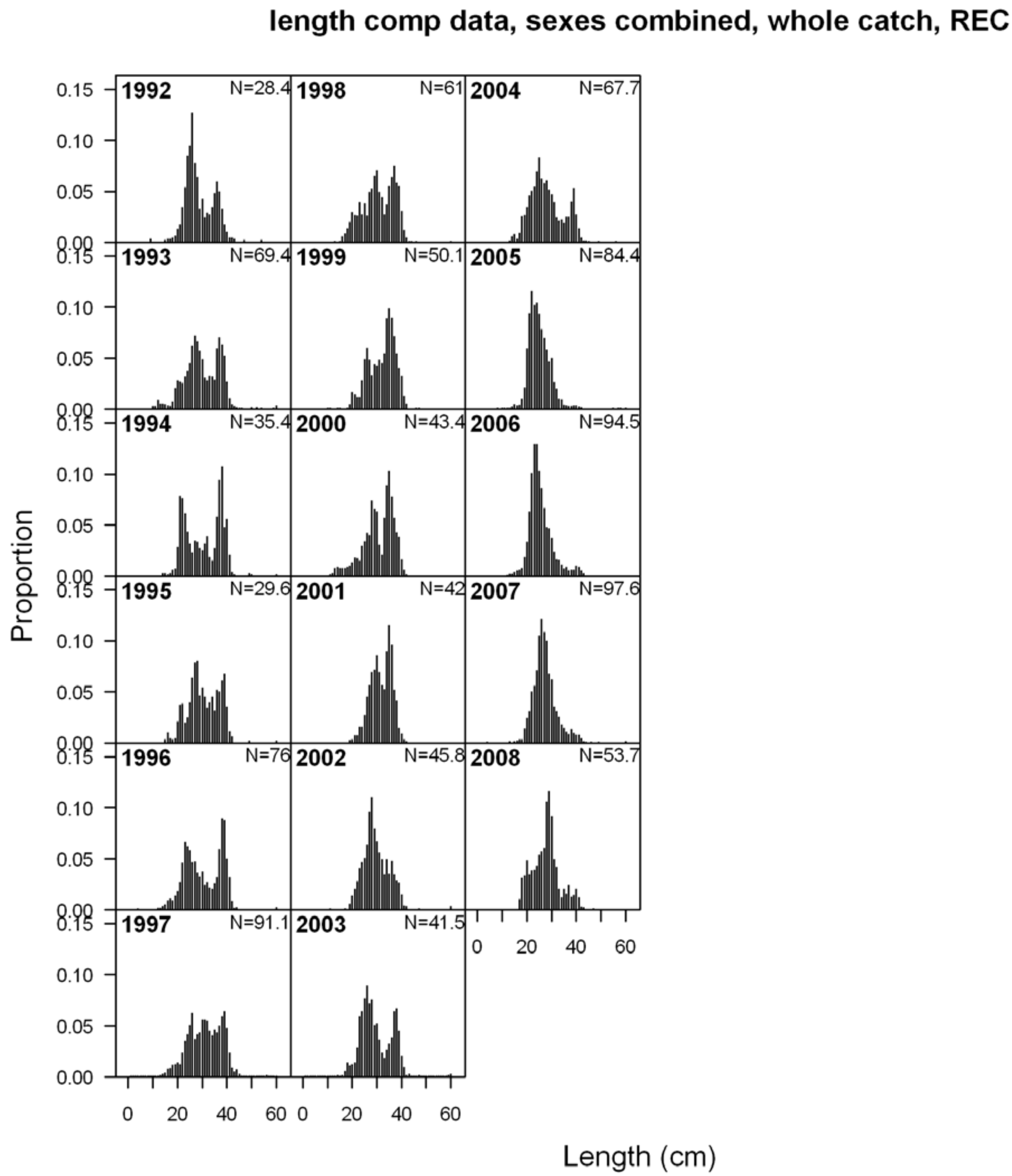
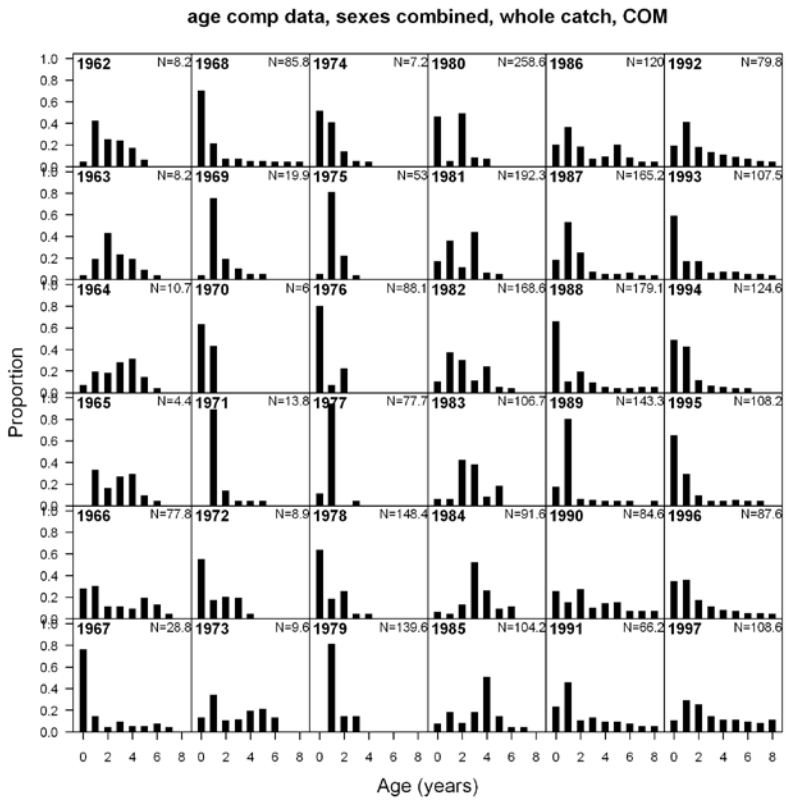


Figure A2B-1. Length distributions from RecFIN data base associated with CPFV fishery (1992-08).



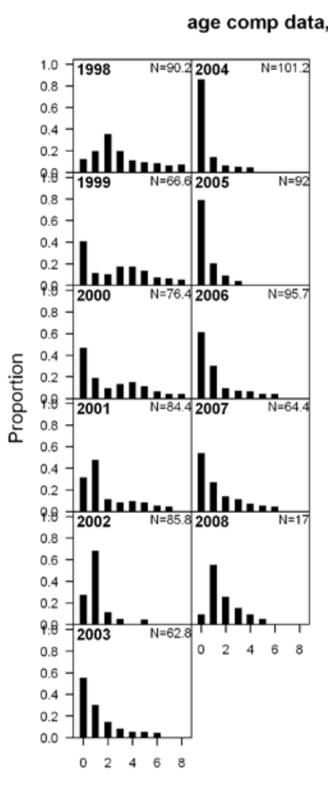


Figure A2B-2. Age distributions from CDFG port sampling program (1962-08).

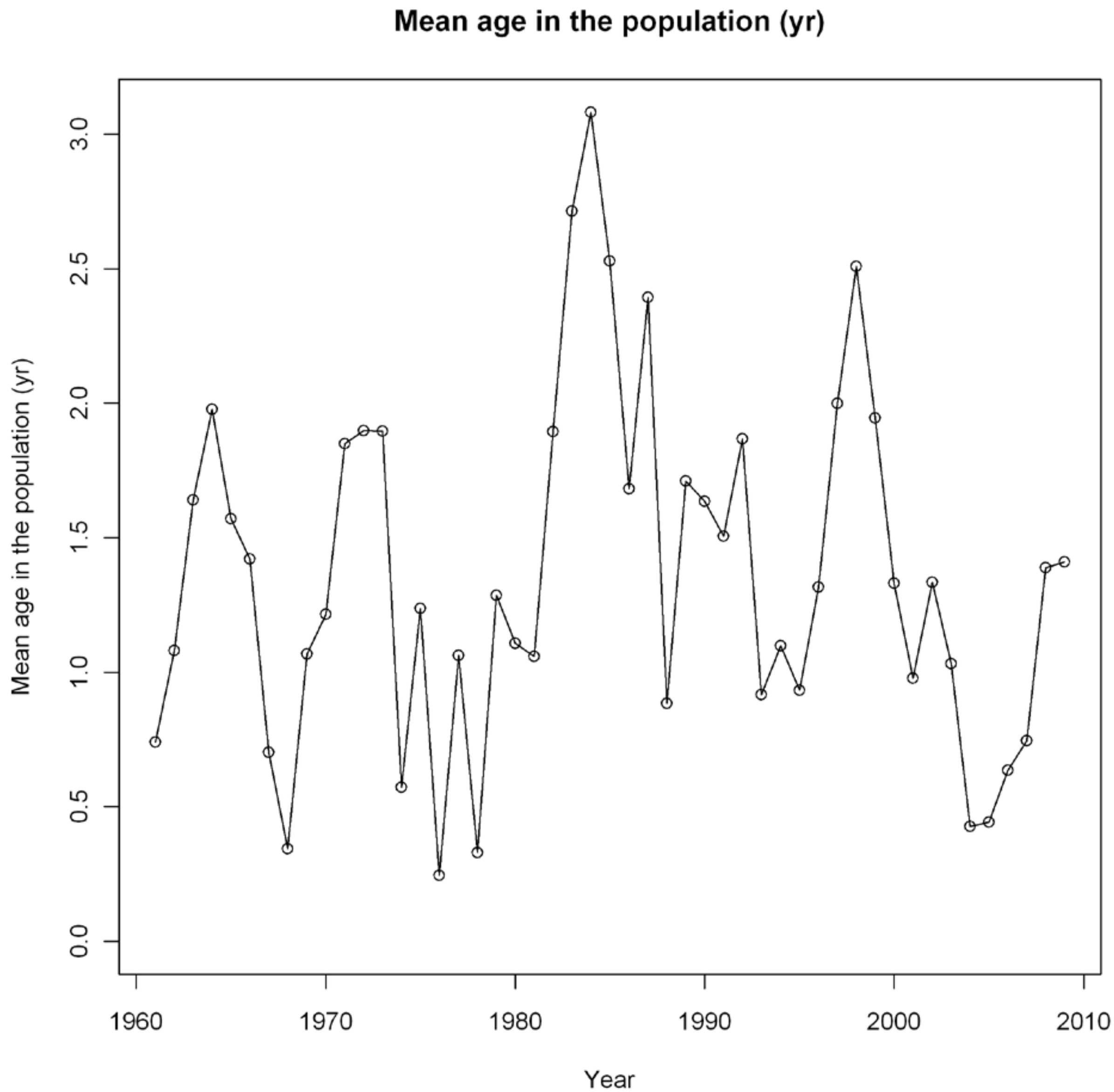


Figure A2B-3. Mean age estimated time series (1962-08).

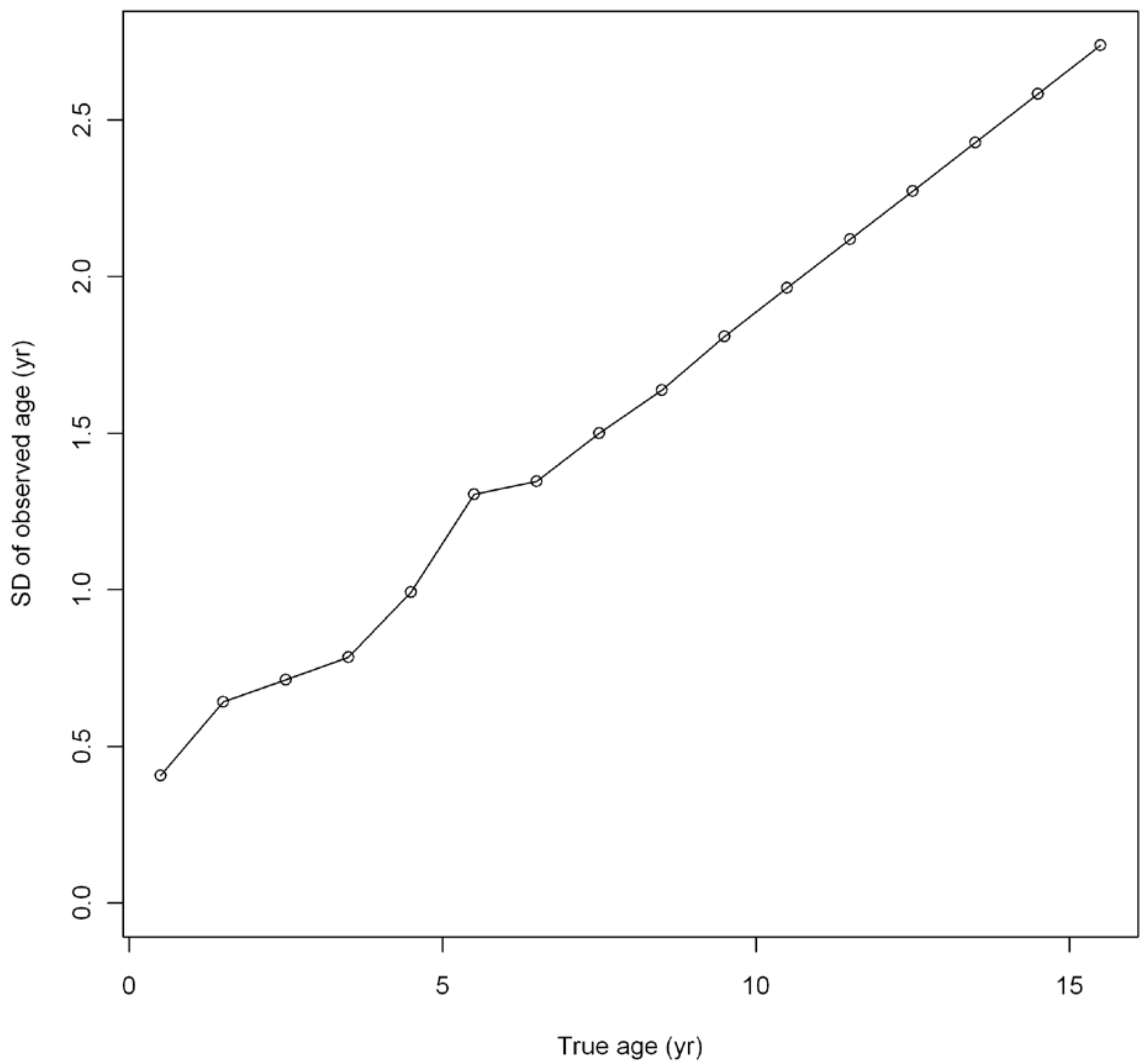


Figure A2B-4. Ageing error vector from CDFG age production laboratory based on doule read analysis.

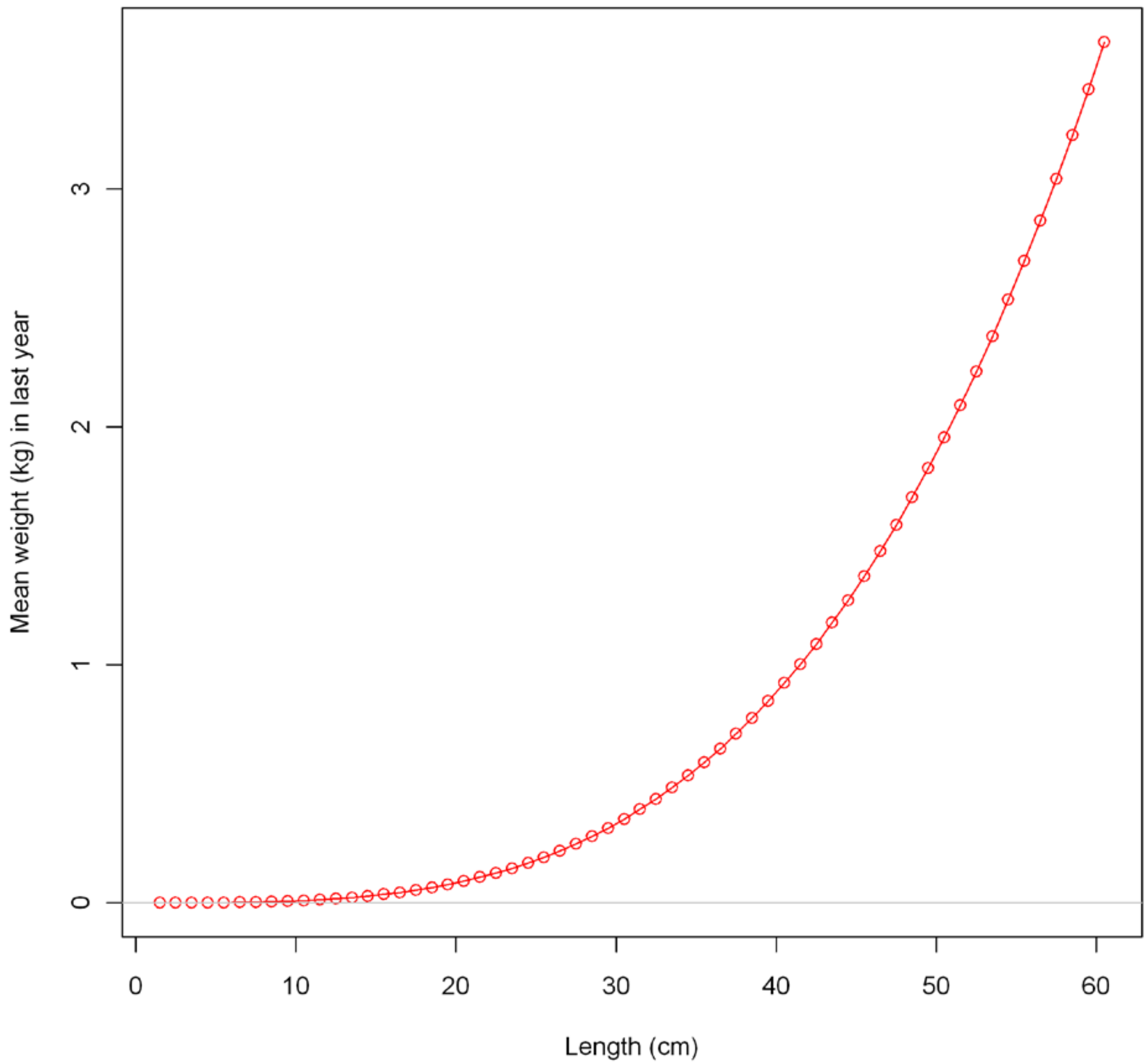
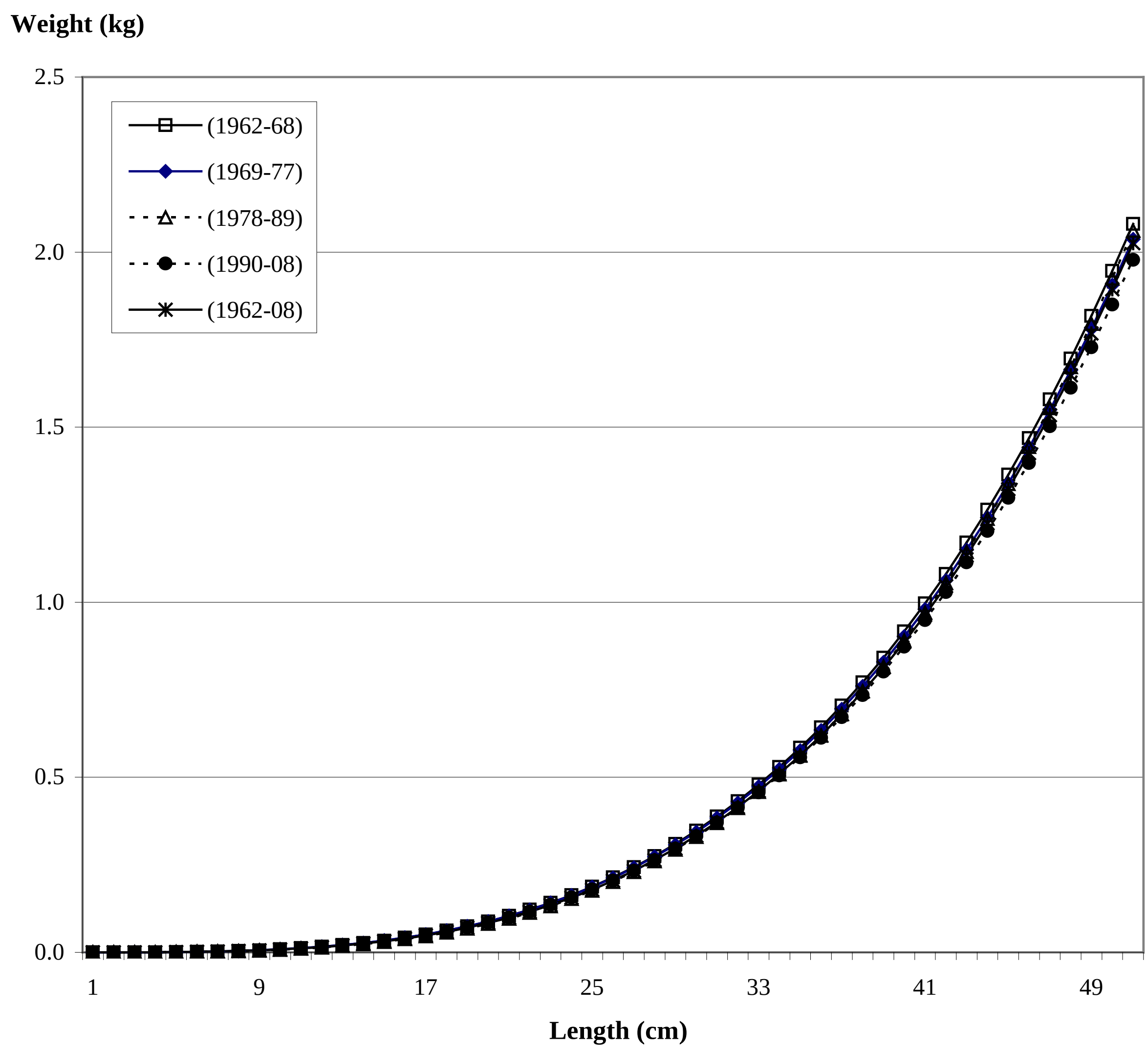


Figure A2B-5. Weight-length relationship.



Time block	*a*	*b*	*n*	R^2
1962-68	3.60340E-06	3.37410	5,598	0.984
1969-77	3.84101E-06	3.35245	7,104	0.967
1978-89	2.62897E-06	3.45186	45,957	0.971
1990-06	3.53906E-06	3.36574	37,102	0.971
1962-08	3.12517E-06	3.40352	95,761	0.971

Figure A2B-6. Weight-length (W-L) relationships used in time-varying growth model scenario S1_qa3 (see Table 1A-B).

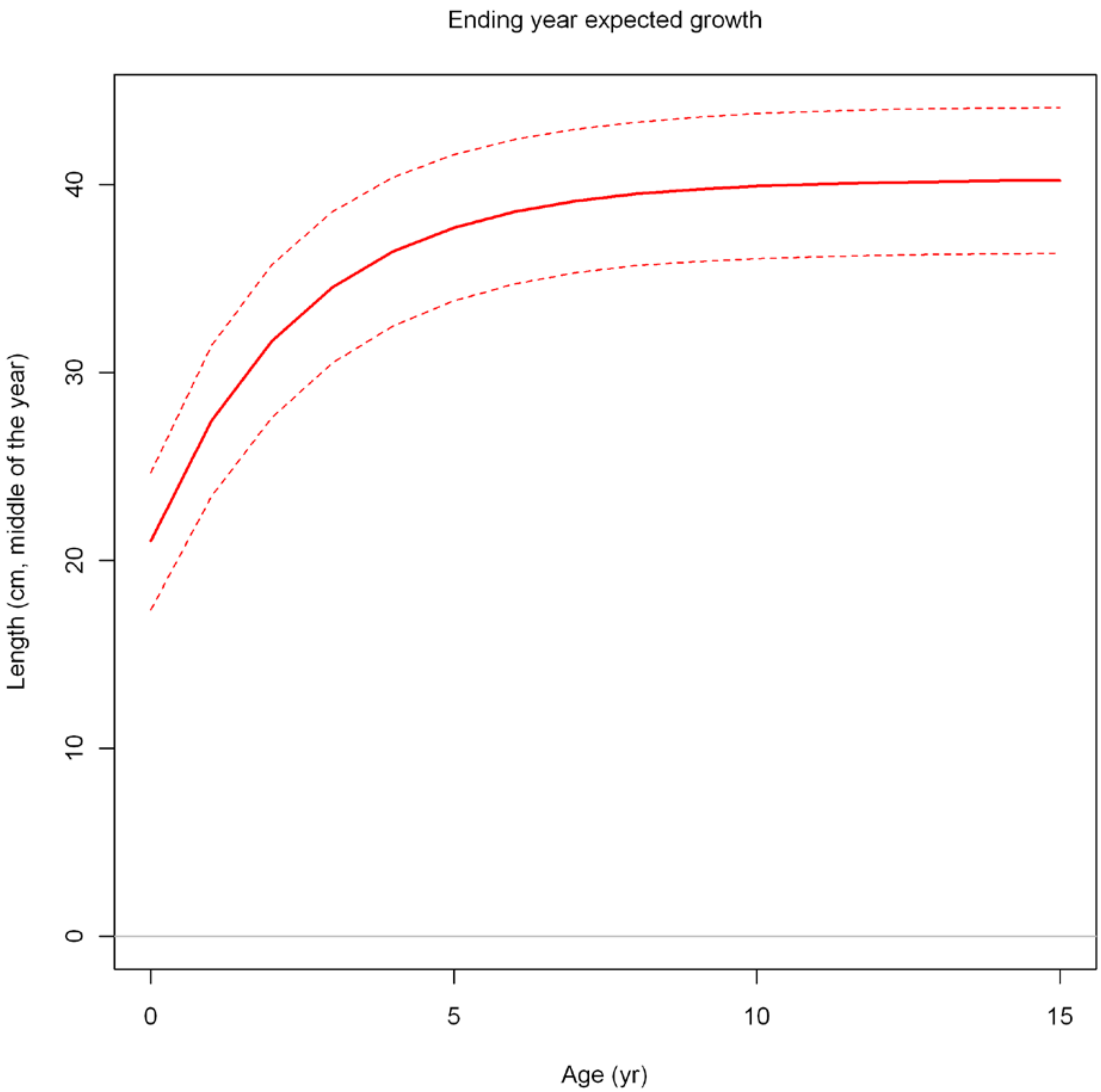


Figure A2B-7. Length-at-age relationship (K = 0.40).

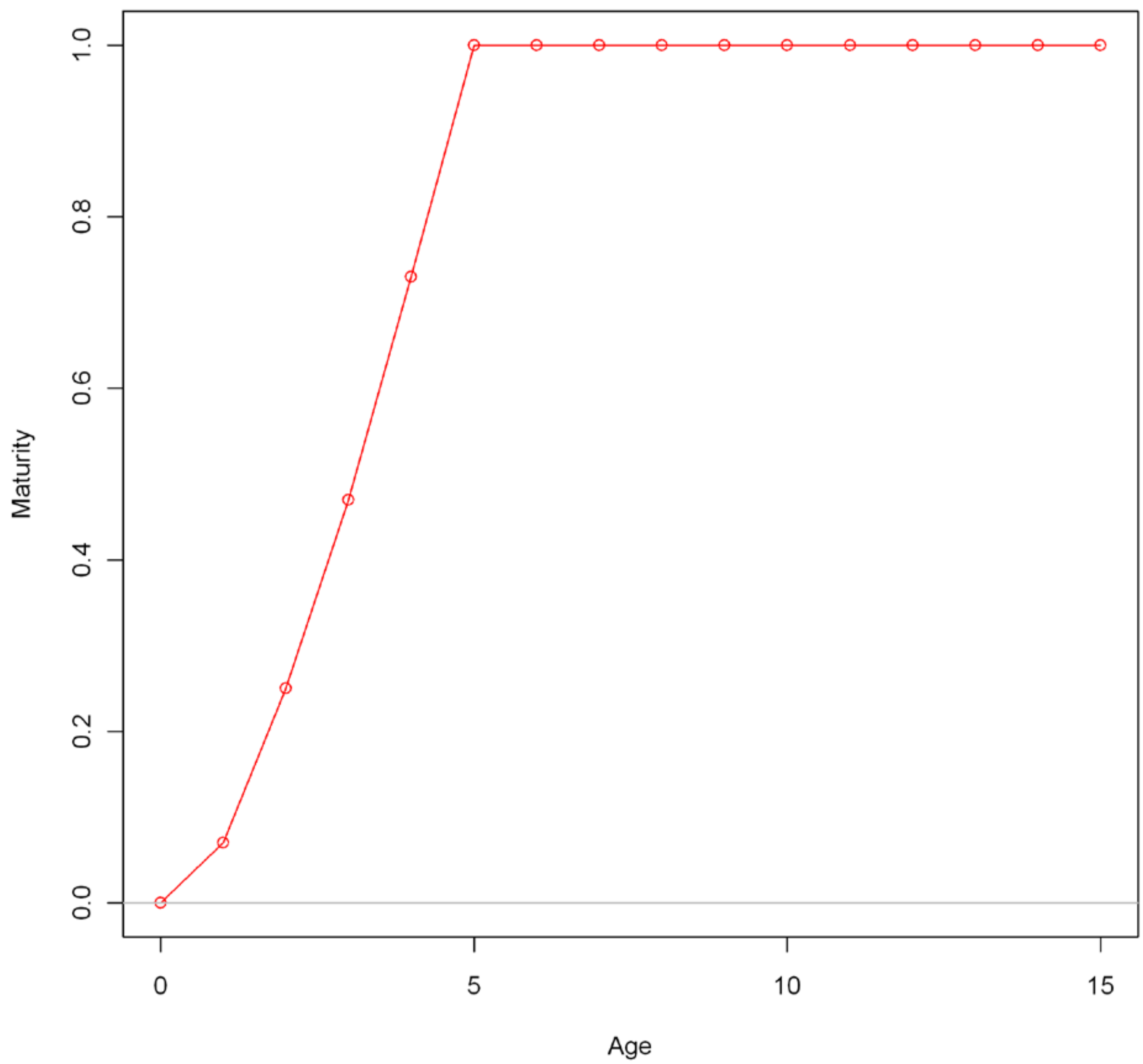


Figure A2B-8. Maturity-at-age schedule.

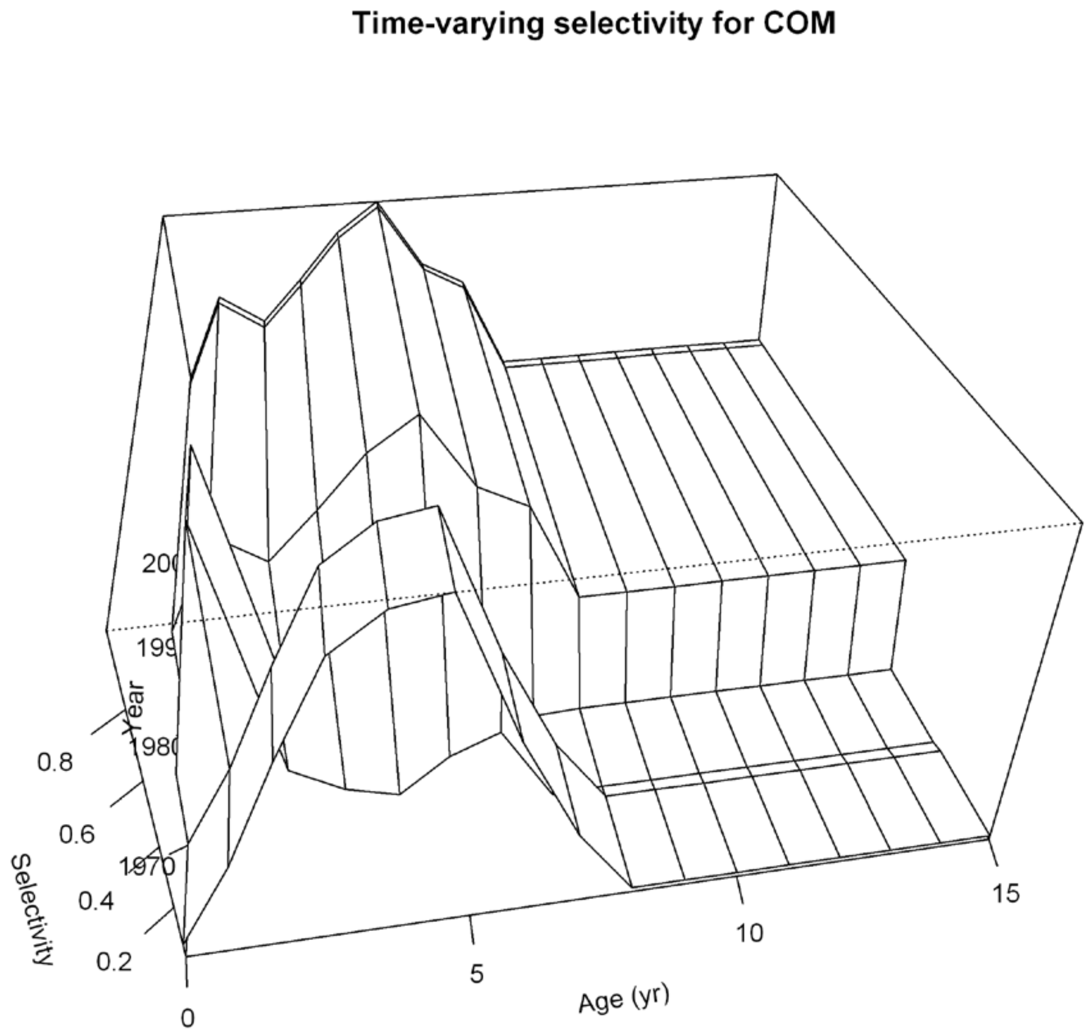


Figure A2B-9. Time-varying (fixed) selectivity associated with the commercial fishery (three blocks: 1962-69, 1970-77, and 1978-08).

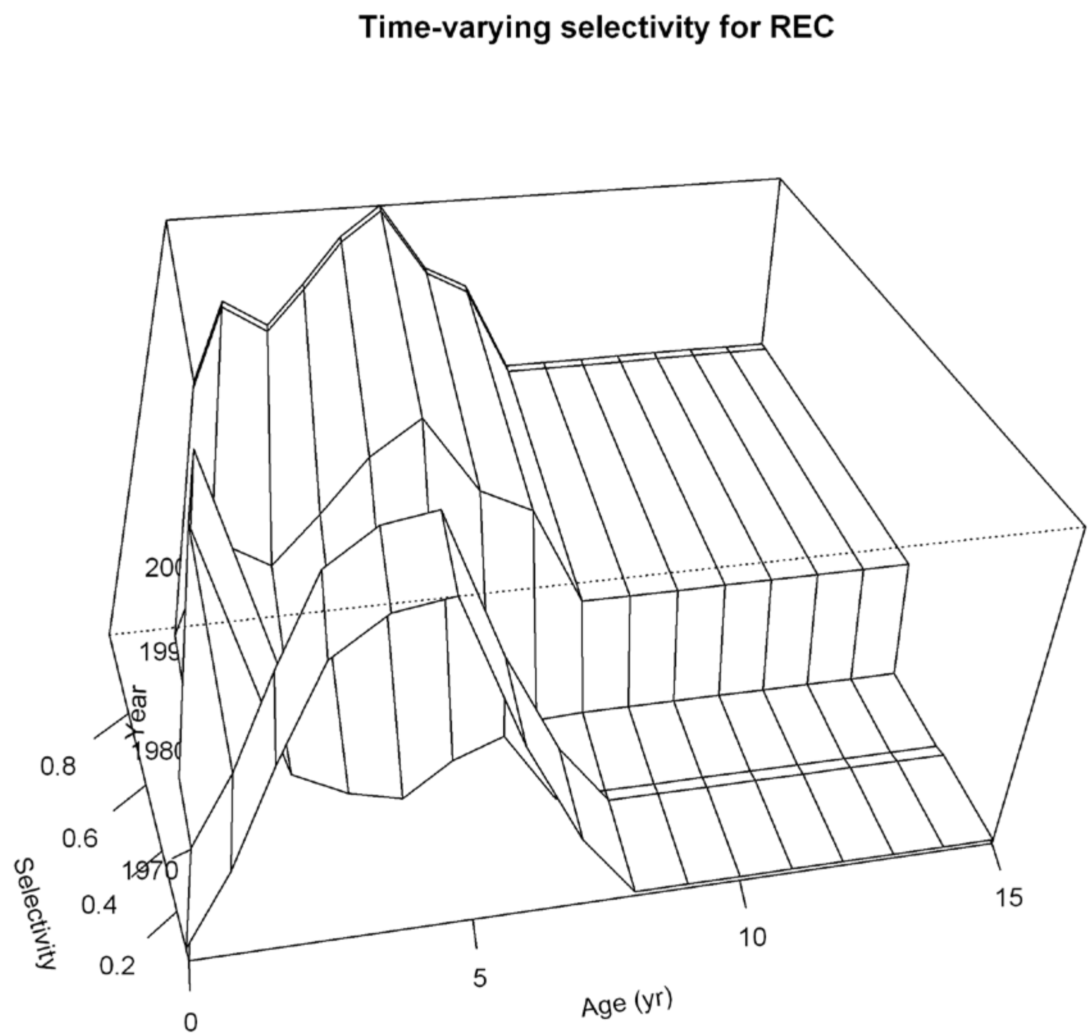


Figure A2B-10. Time-varying (fixed) selectivity associated with the recreational fishery, i.e., in Model S1_aa, mirrors commercial fishery.

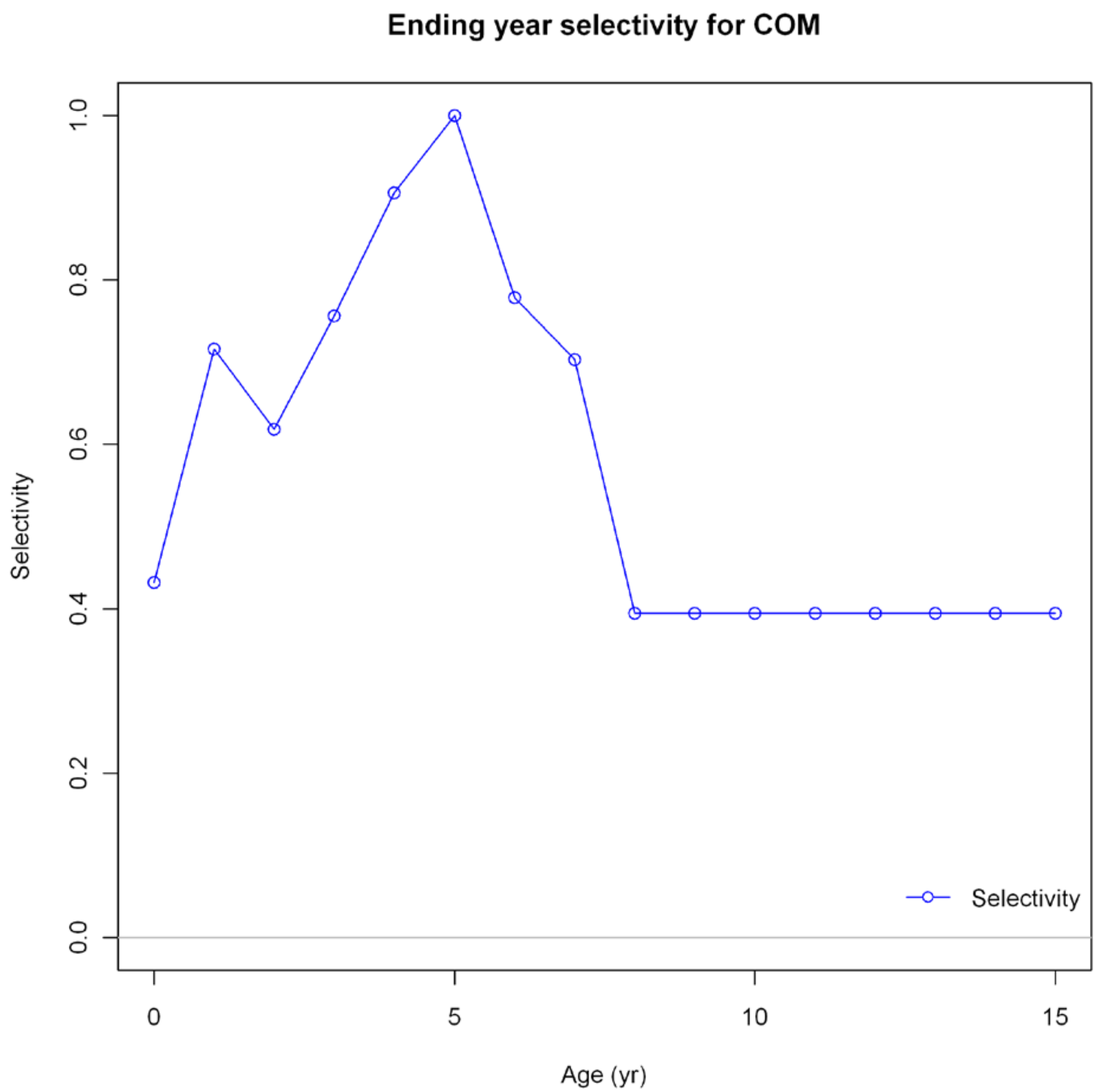


Figure A2B-11. Ending year (fixed) selectivity associated with the commercial fishery.

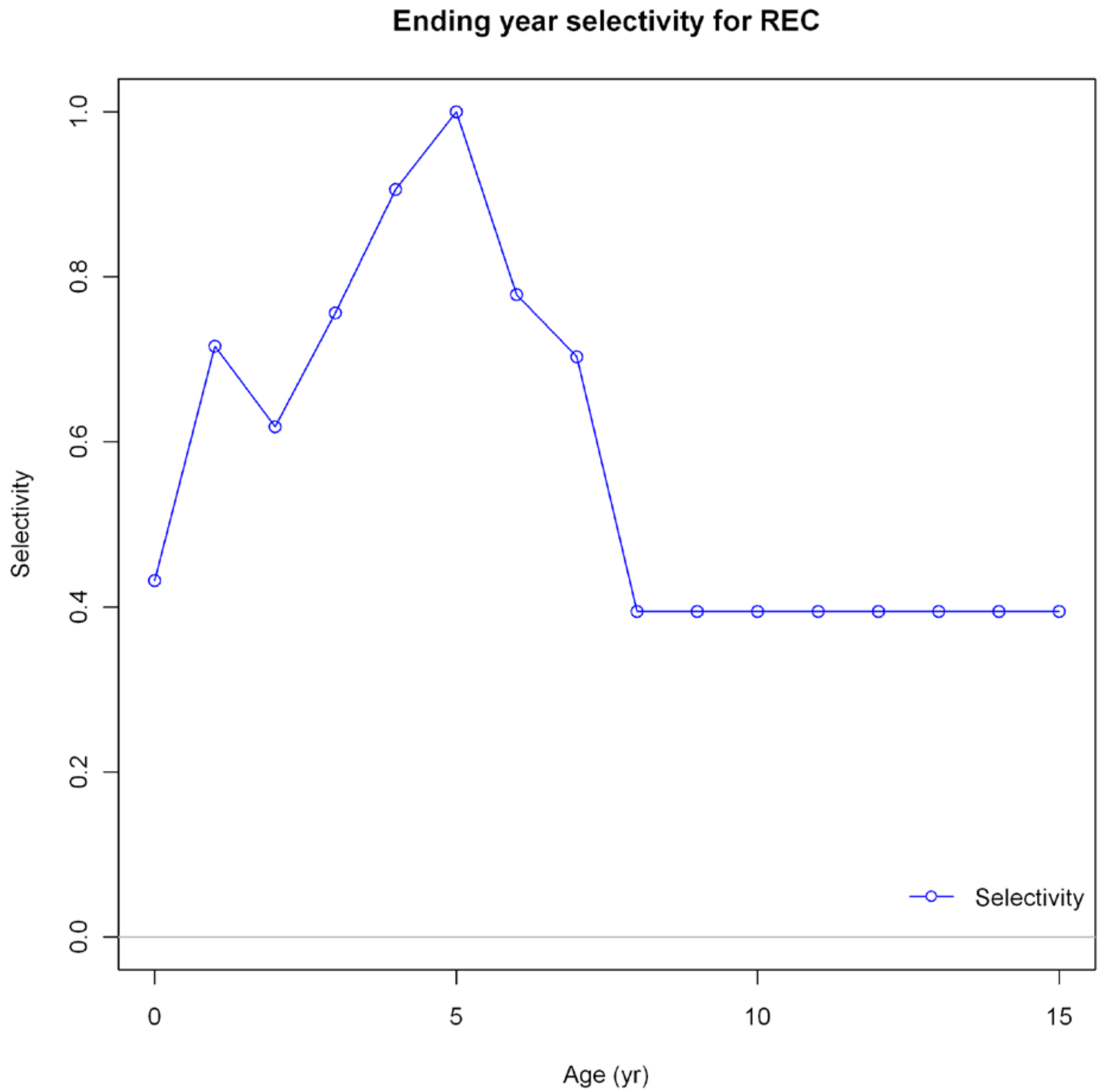


Figure A2B-12. Ending year (fixed) selectivity associated with the recreational fishery, i.e., mirrors commercial fishery.

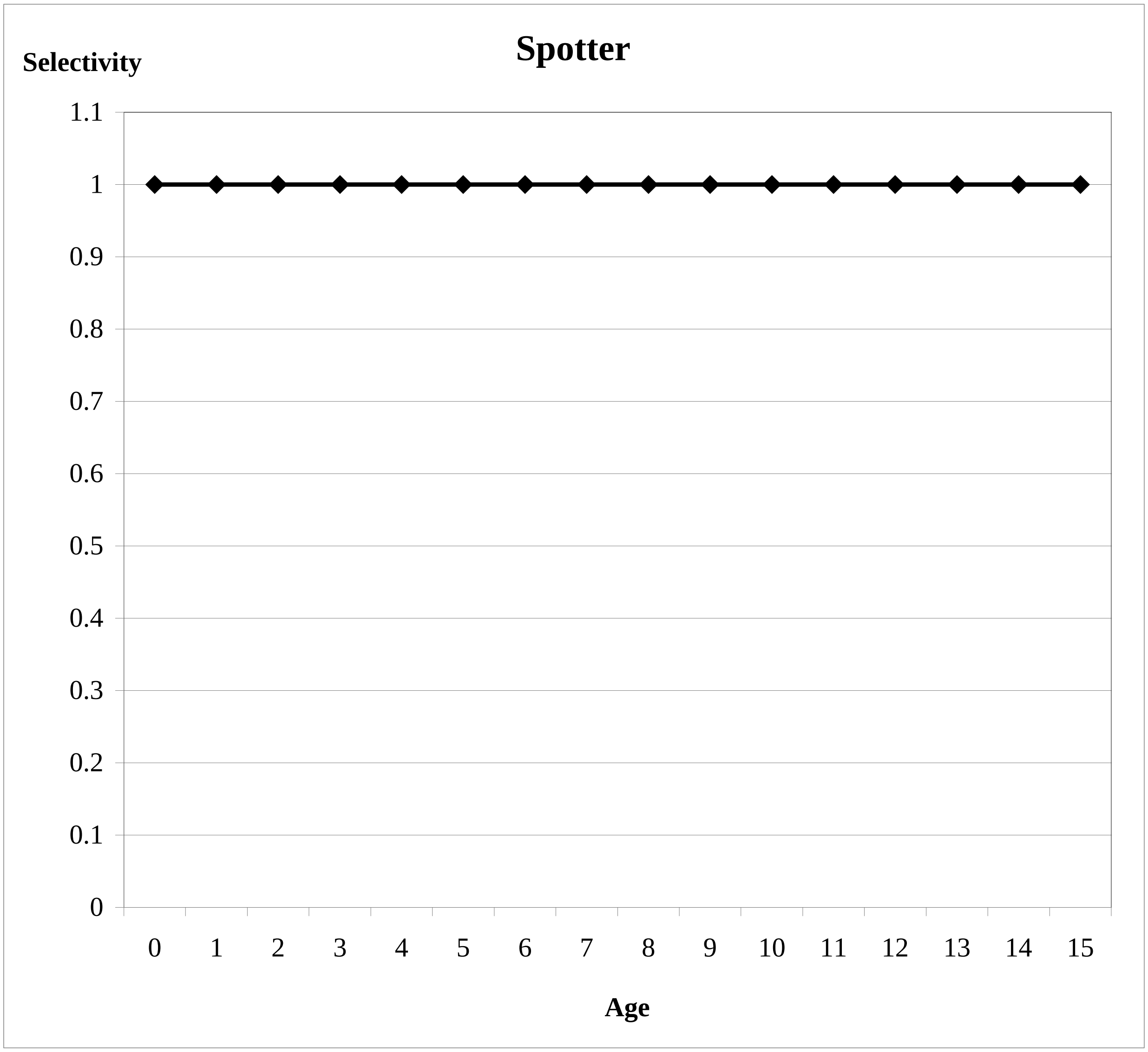


Figure A2B-13. Constant (fixed) selectivity, including ending year, associated with the Spotter index, i.e., all ages fully selectivity.

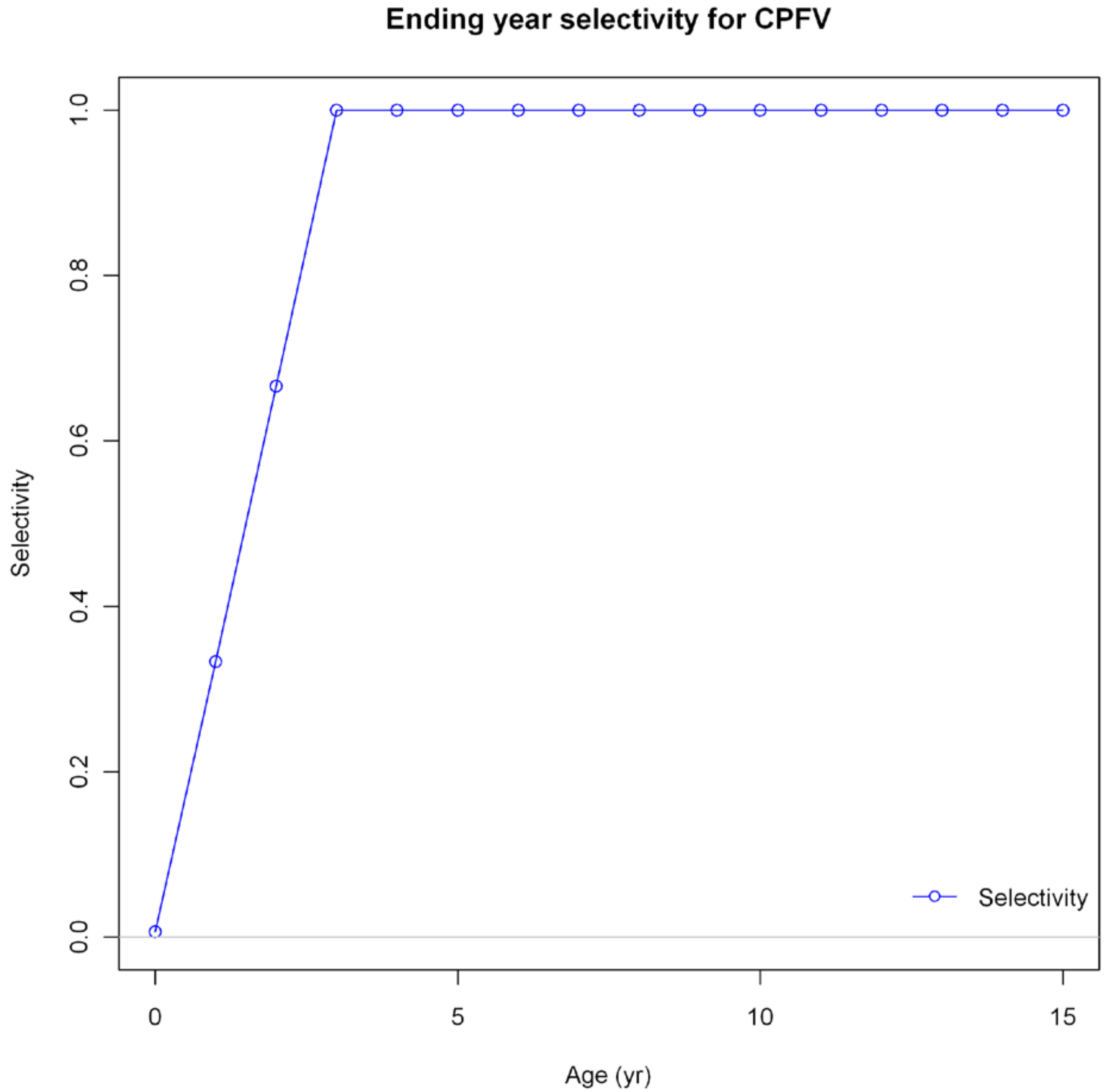


Figure A2B-14. Constant (fixed) selectivity, including ending year, associated with the CPFV index.

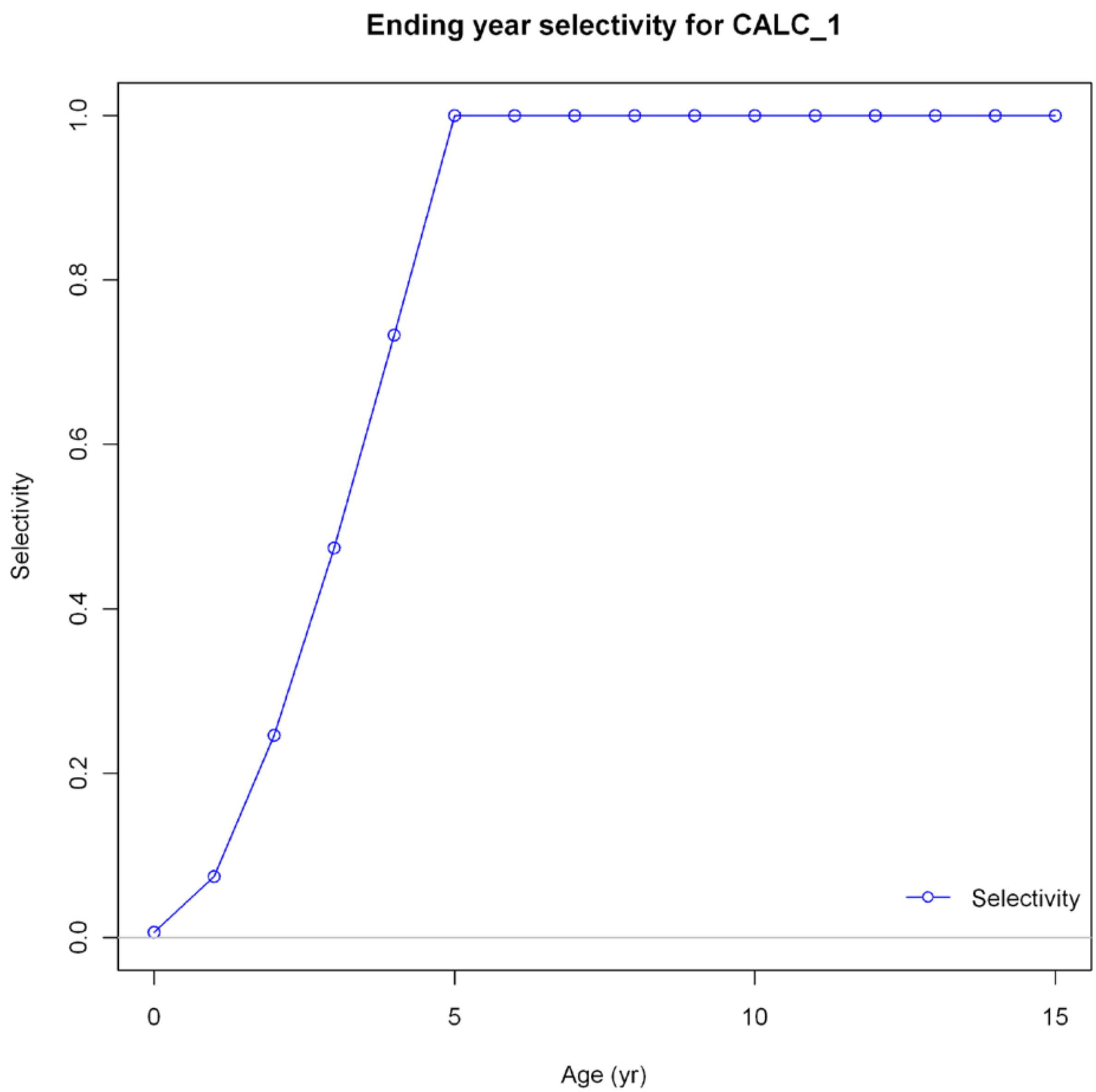


Figure A2B-15. Constant (fixed) selectivity, including ending year, associated with the CalCOFI index.

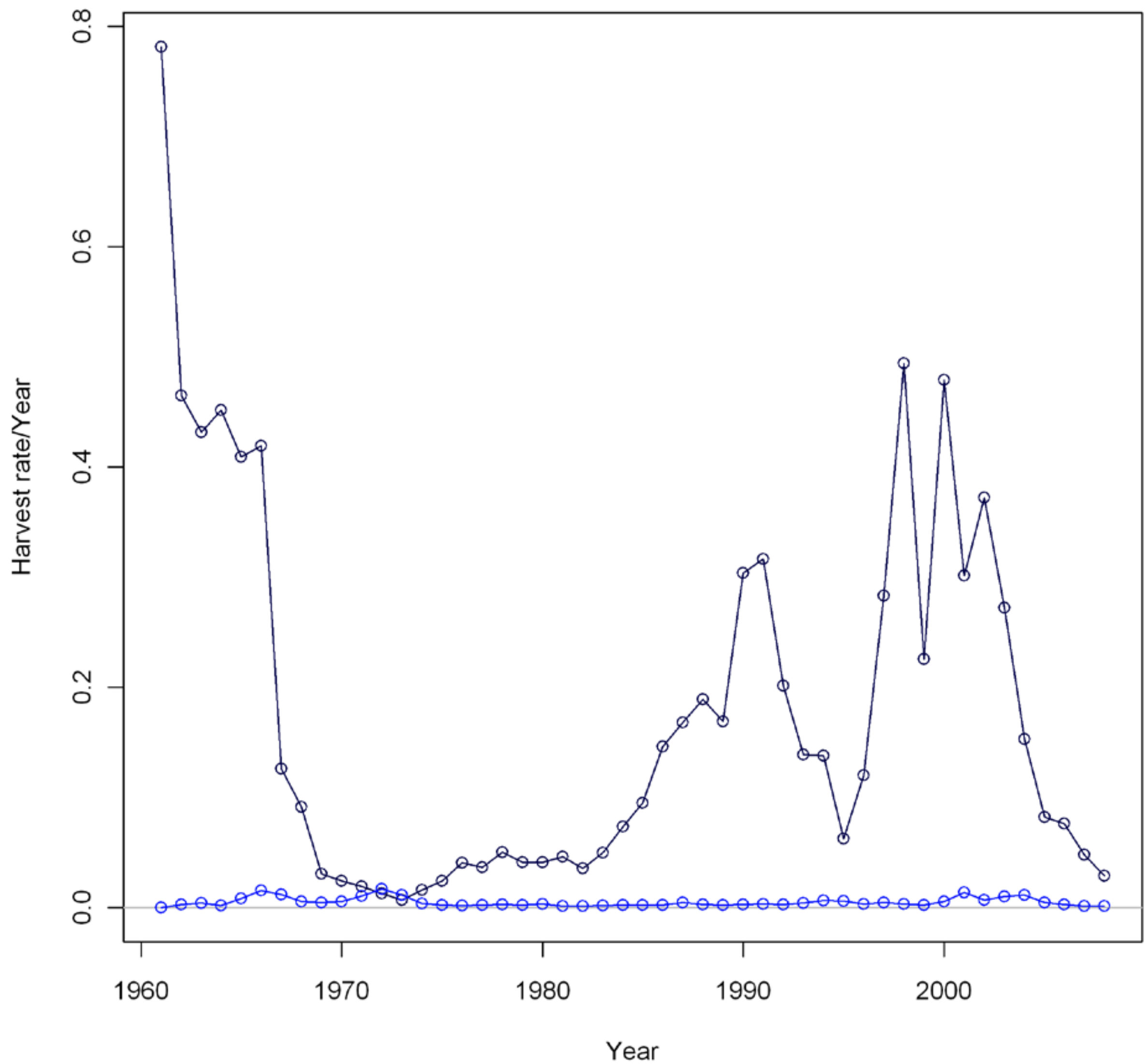


Figure A2B-16. Estimated harvest rate (1962-08). Disregard horizontal-like time series at bottom of display.

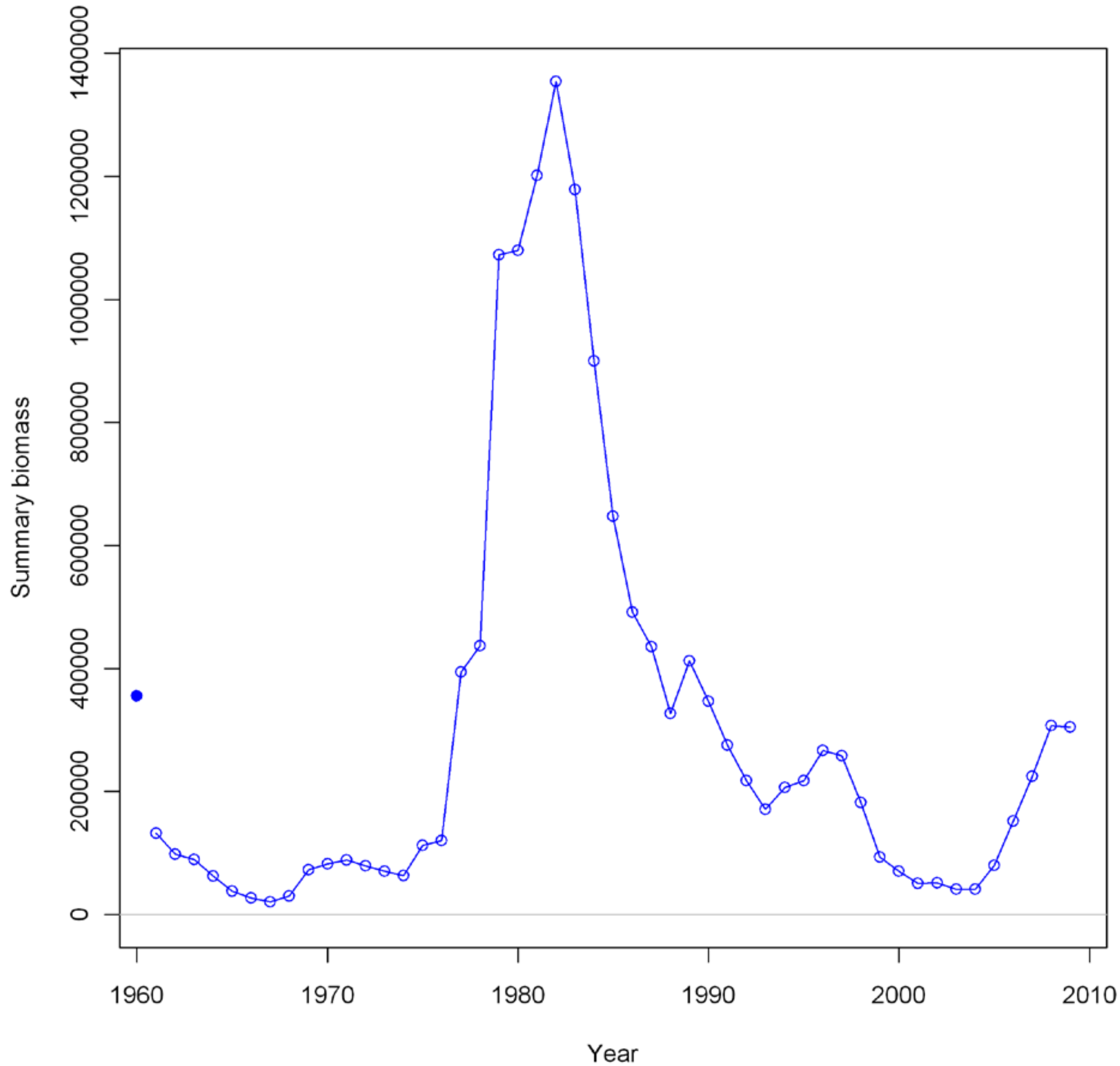


Figure A2B-17. Estimated total stock biomass (age 1+ fish in mt, *B*) of Pacific mackerel. Dark-shaded circle reflects estimated 'virgin' stock size.

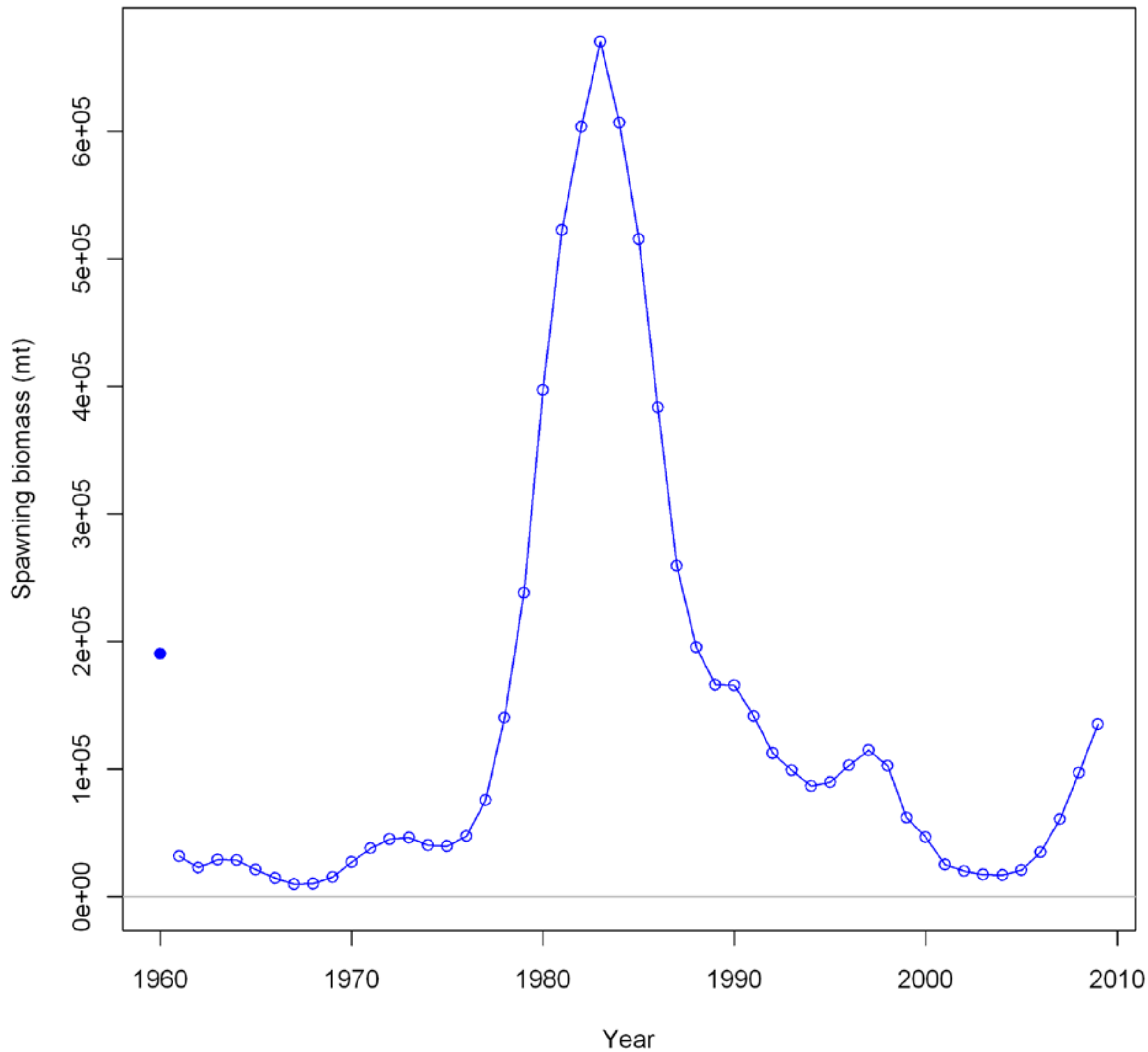


Figure A2B-18. Estimated spawning stock biomass (*SSB*) of Pacific mackerel. Dark-shaded circle reflects estimated 'virgin' level of *SSB*.

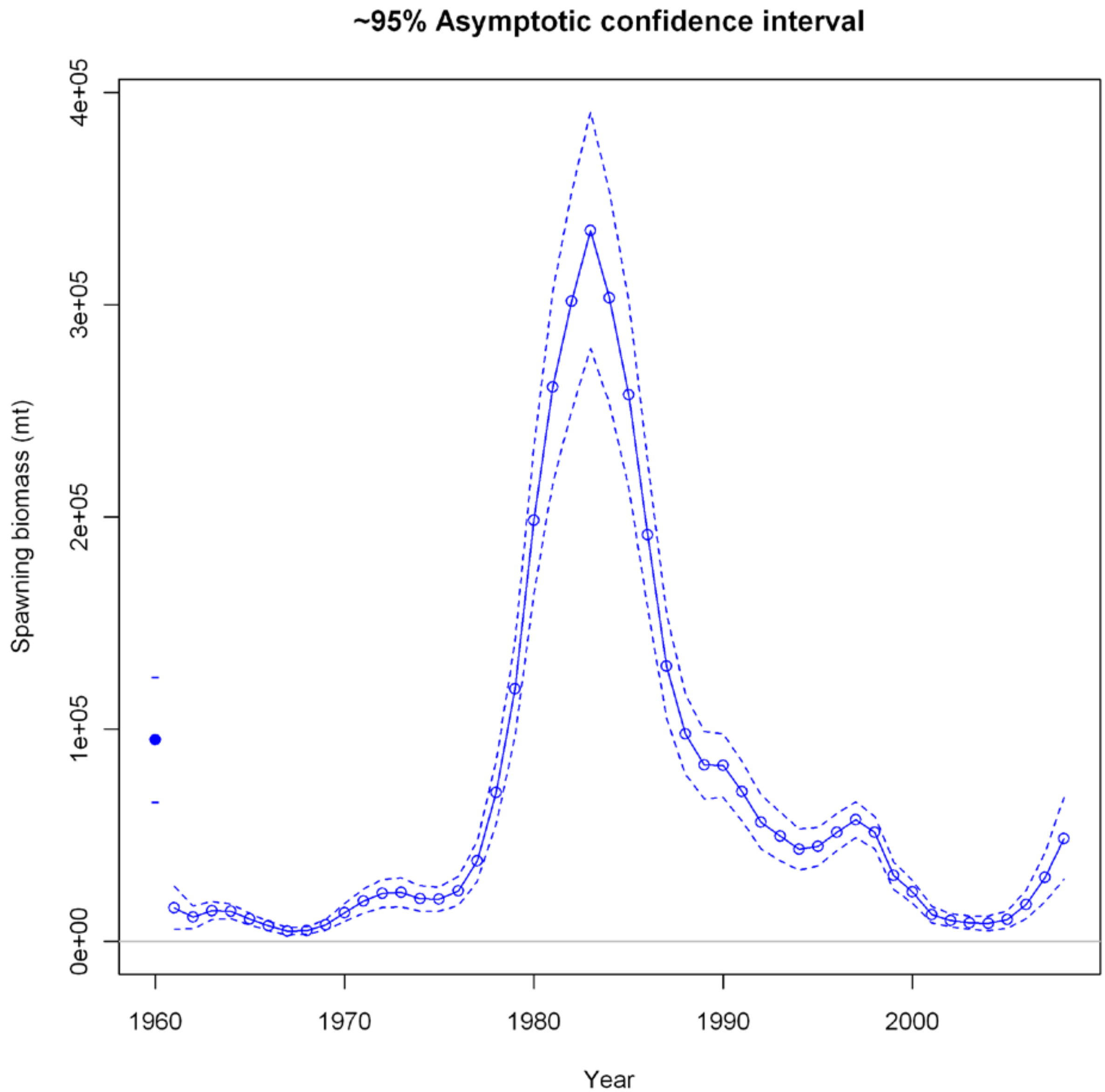


Figure A2B-19. Estimated spawning stock biomass (*SSB*) of Pacific mackerel with accompanying 95% CIs. Dark-shaded circle reflects estimated 'virgin' level of *SSB*, bounded by 95% CI. Note that Y-axis scale is incorrect, see previous display (Figure A4B-18) for correct interval notation, i.e., correct interval is: 0, 2e+05, 4e+05, 6e+05, 8e+05.

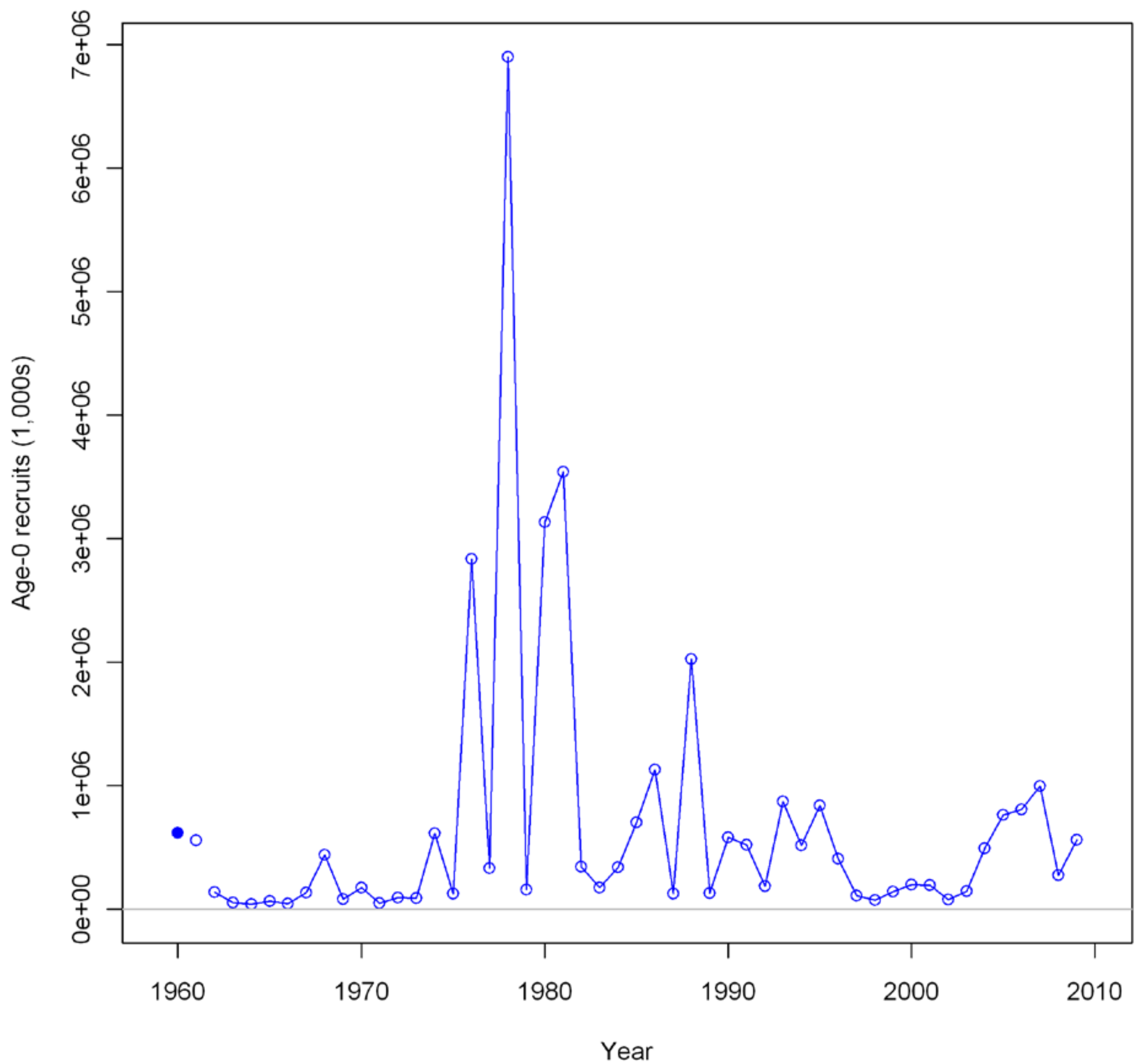


Figure A2B-20. Estimated recruitment (age 0 fish in 1,000s of fish, *R*) of Pacific mackerel. Dark-shaded circle reflects estimated 'virgin' level of *R*.

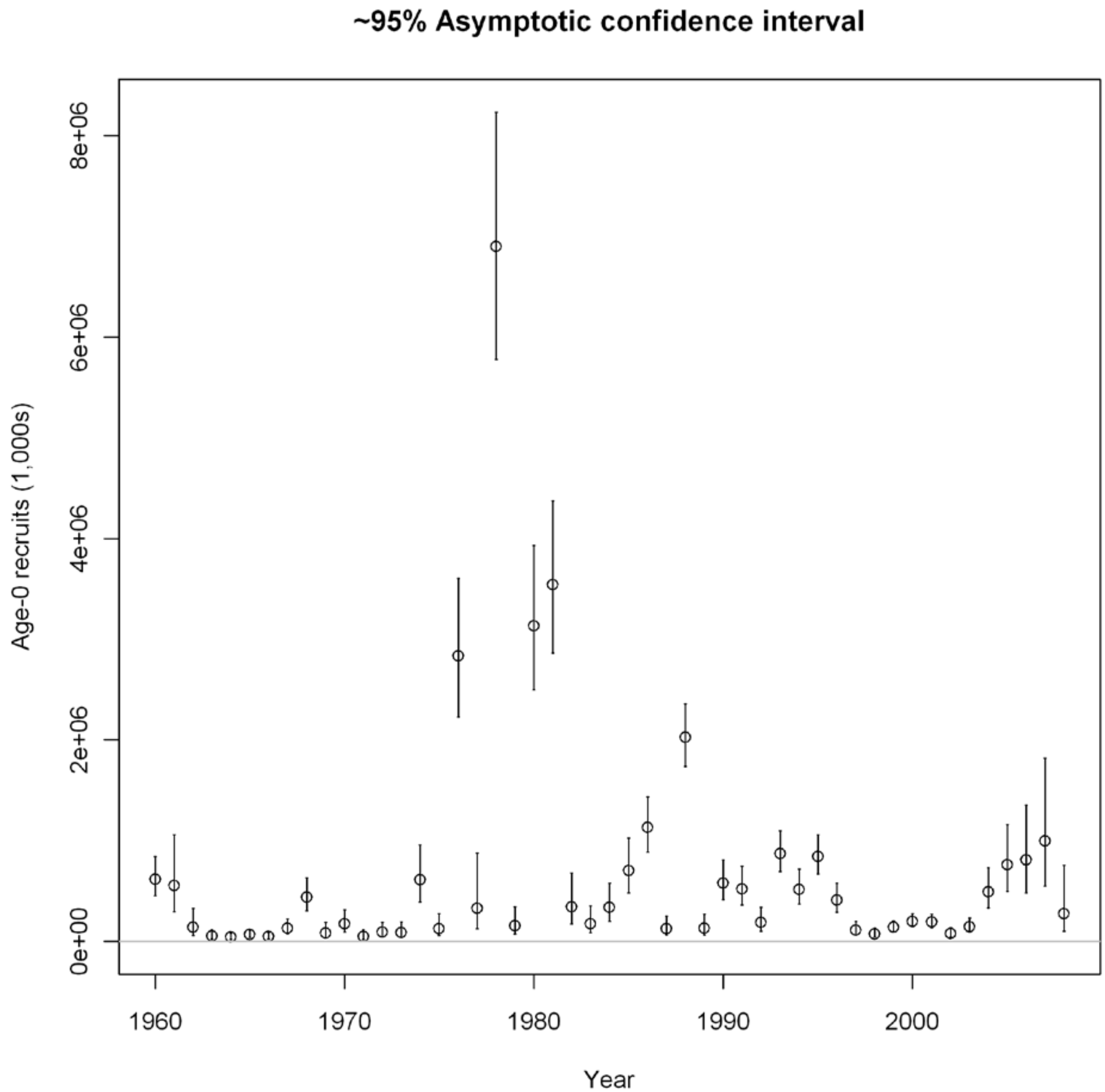


Figure A2B-21. Estimated recruitment (age 0 fish in 1,000s of fish, *R*) of Pacific mackerel, with accompanying 95% CIs.

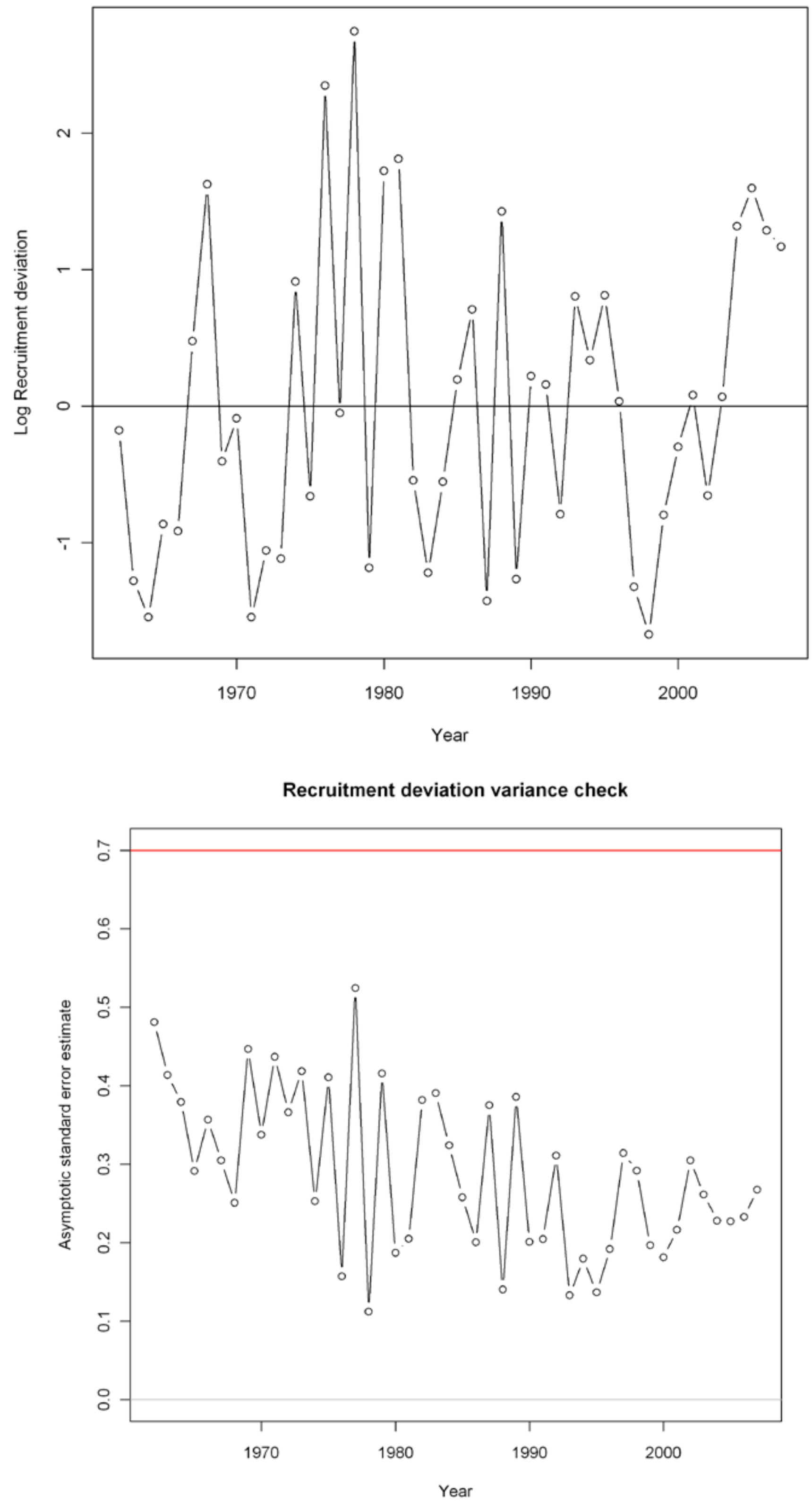


Figure A2B-22. Estimates of recruitment deviations (top panel), and SEs associated with the deviations (bottom panel). Horizontal line in bottom panel indicates the estimate of the standard deviation of log recruitment deviations, fixed σ-*R* = 0.7.

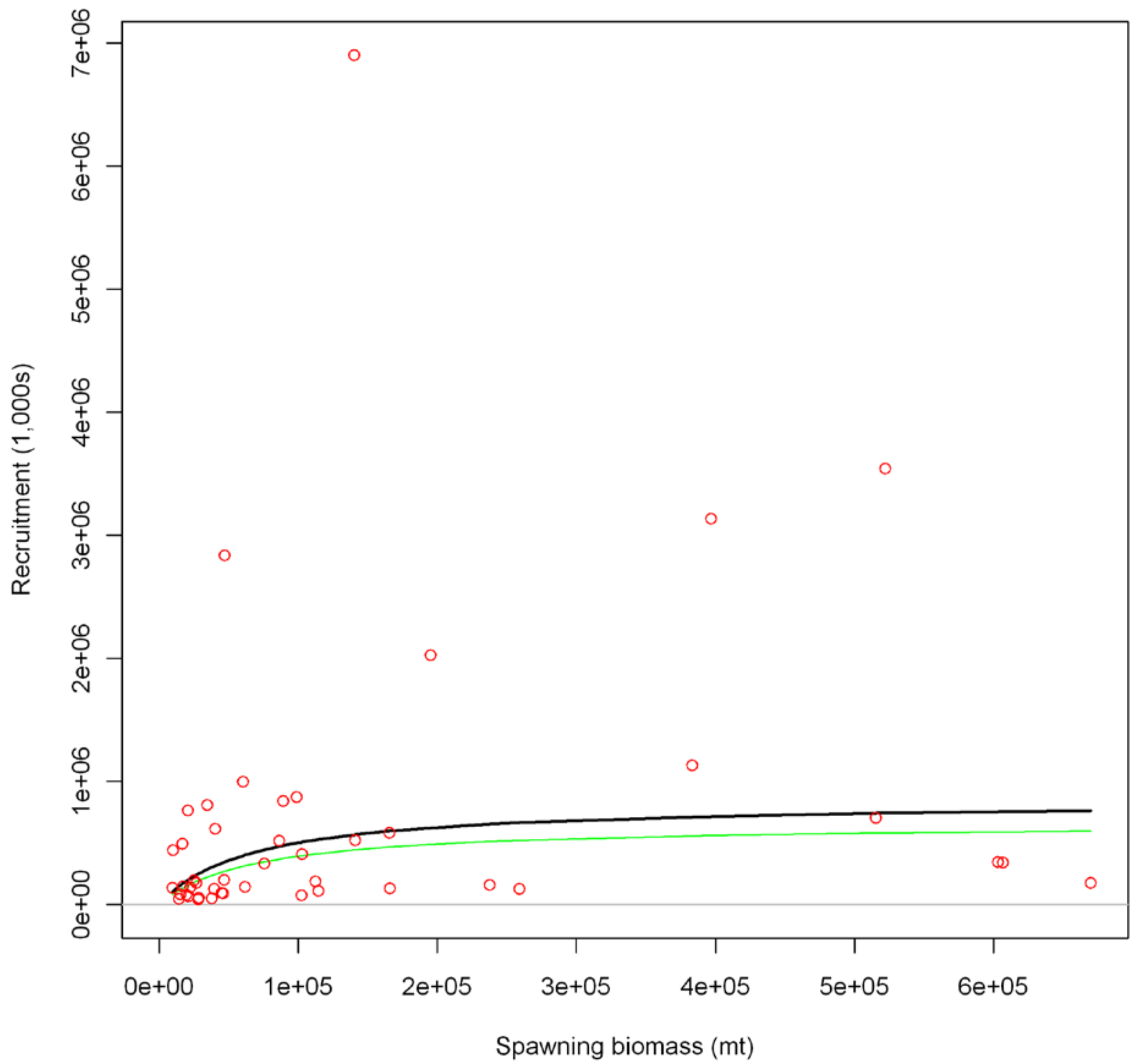


Figure A2B-23. Beverton-Holt stock (*SSB*)-recruitment (*R* in 1,000s of fish) relationship. Steepness=0.48.

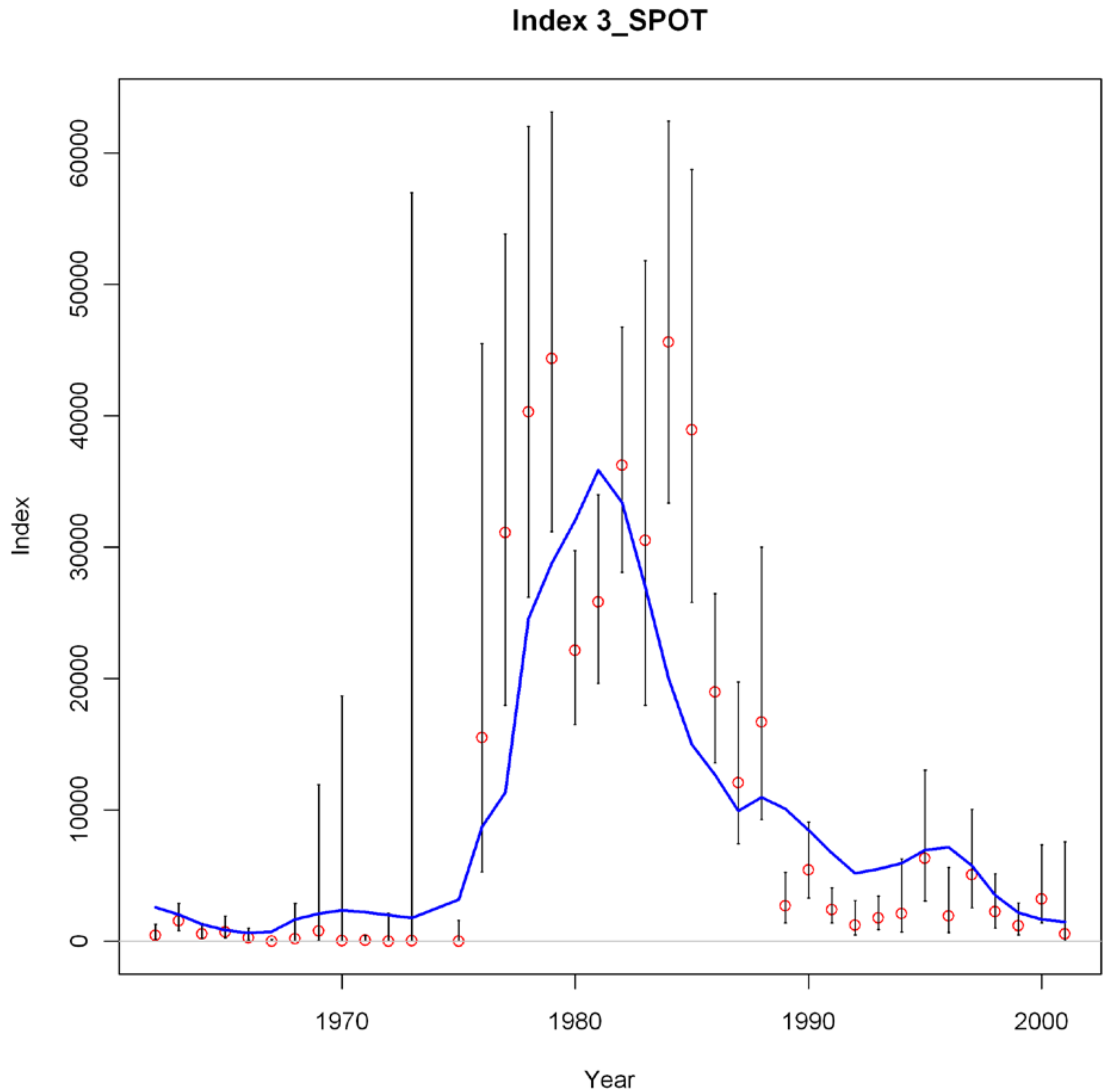


Figure A2B-24. Estimated fits (observed=red circles, with 95% CIs; predicted=line) associated with the Spotter index.

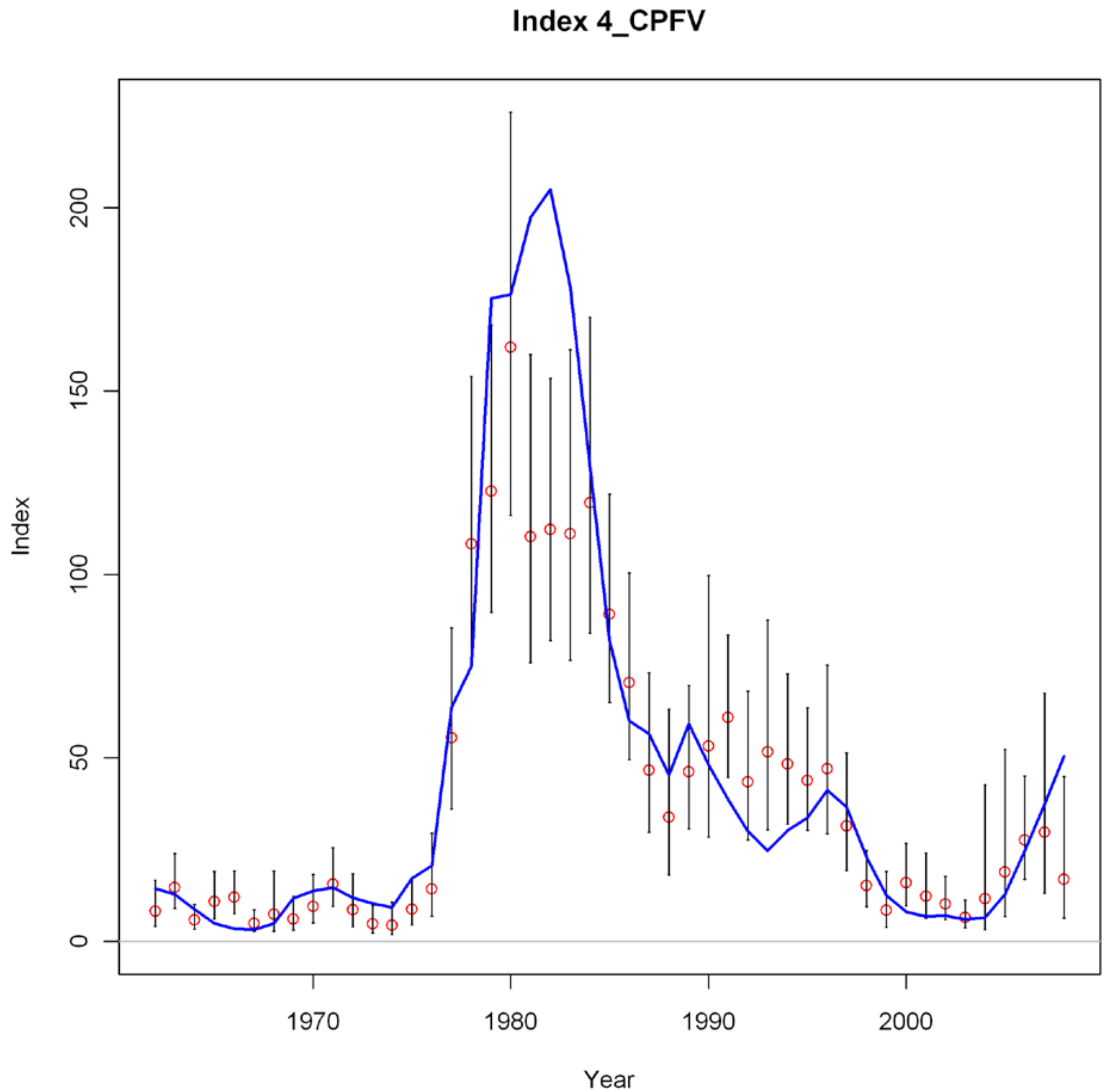


Figure A2B-25. Estimated fits (observed=red circles, with 95% CIs; predicted=line) associated with the CPFV index.

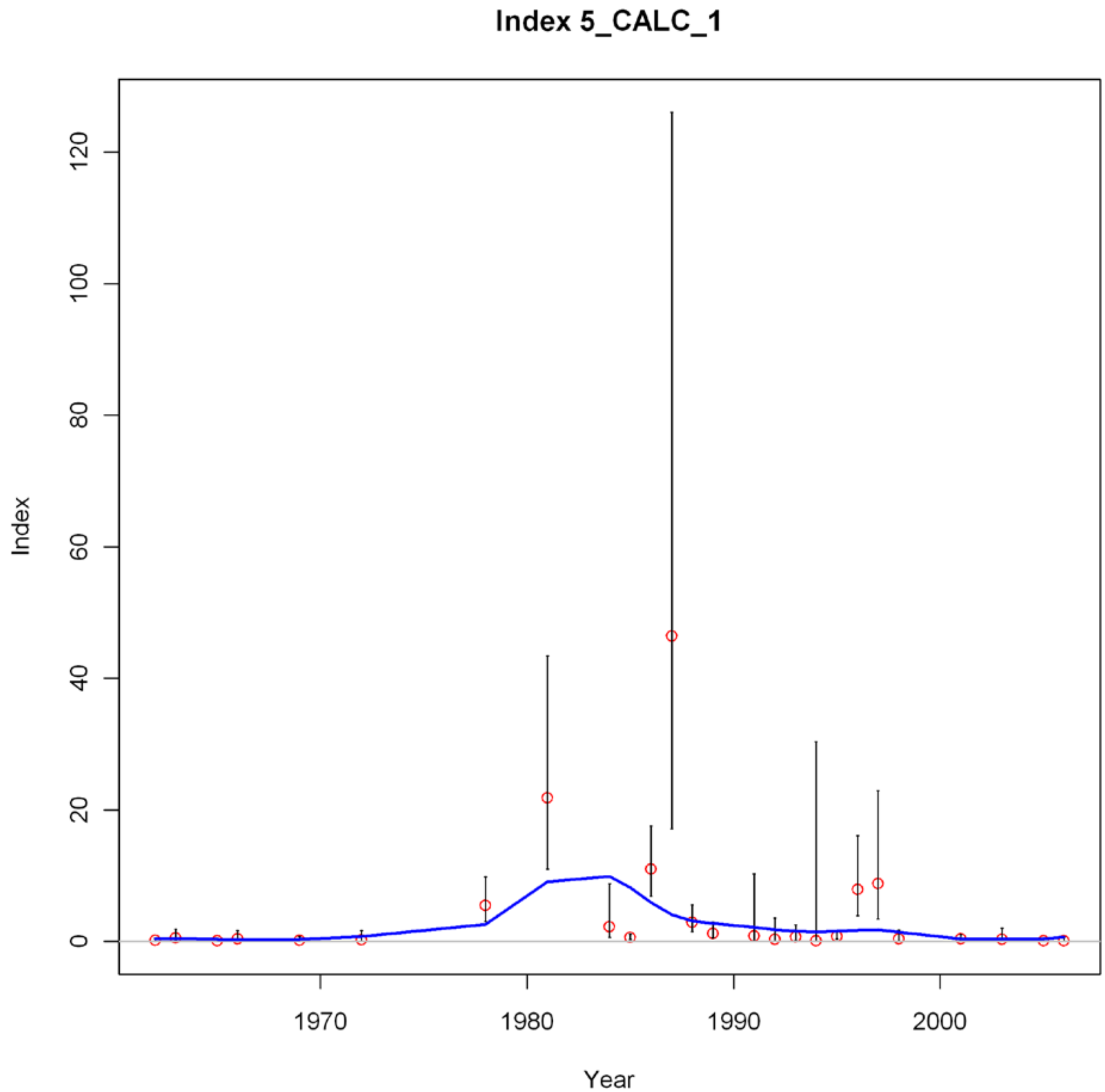


Figure A2B-26. Estimated fits (observed=red circles, with 95% CIs; predicted=line) associated with the CalCOFI index.

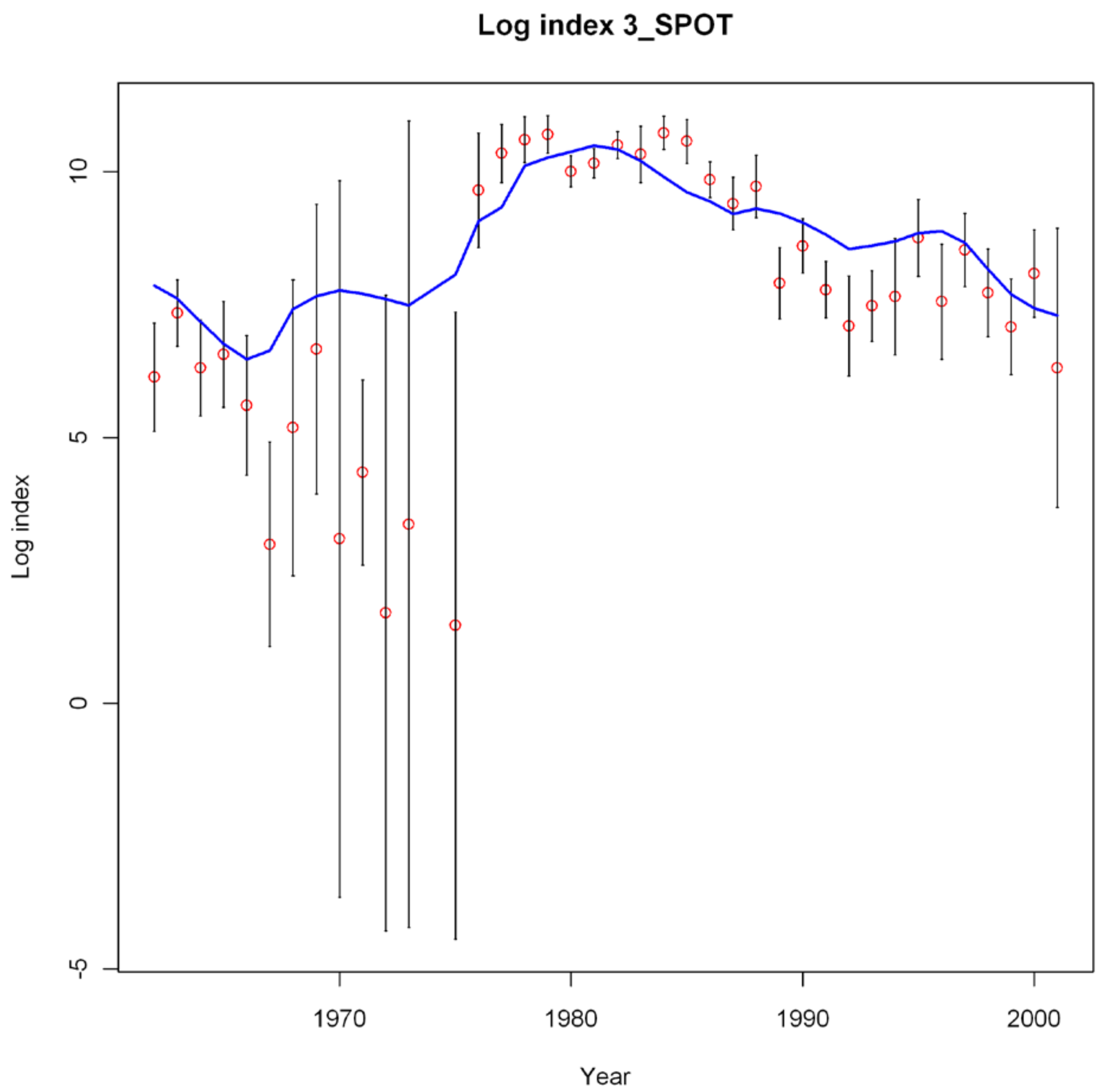


Figure A2B-27. Estimated fits (observed=red circles, with 95% CIs; predicted=line) in log space associated with the Spotter index.

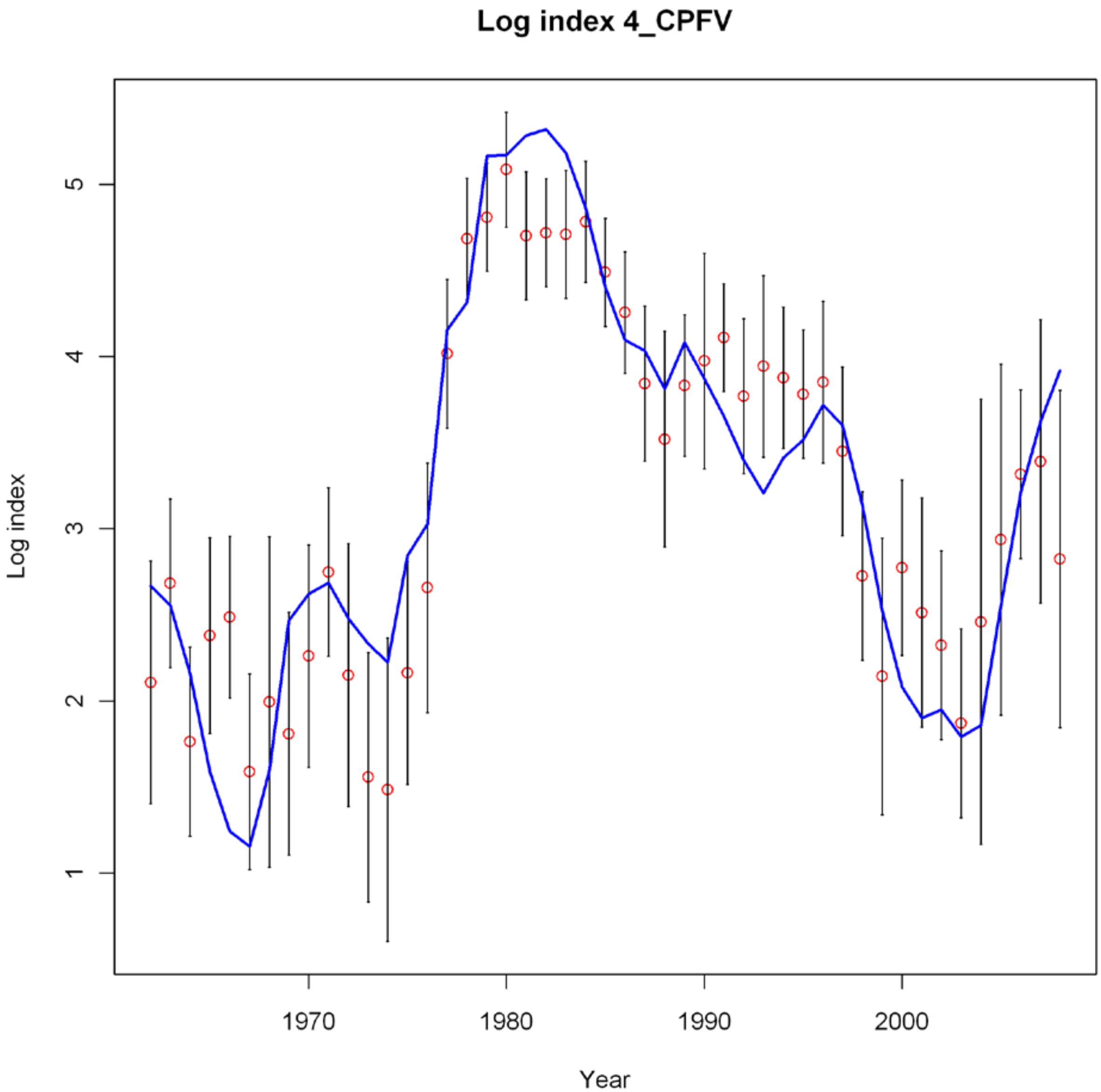


Figure A2B-28. Estimated fits (observed=red circles, with 95% CIs; predicted=line) in log space associated with the CPFV index.

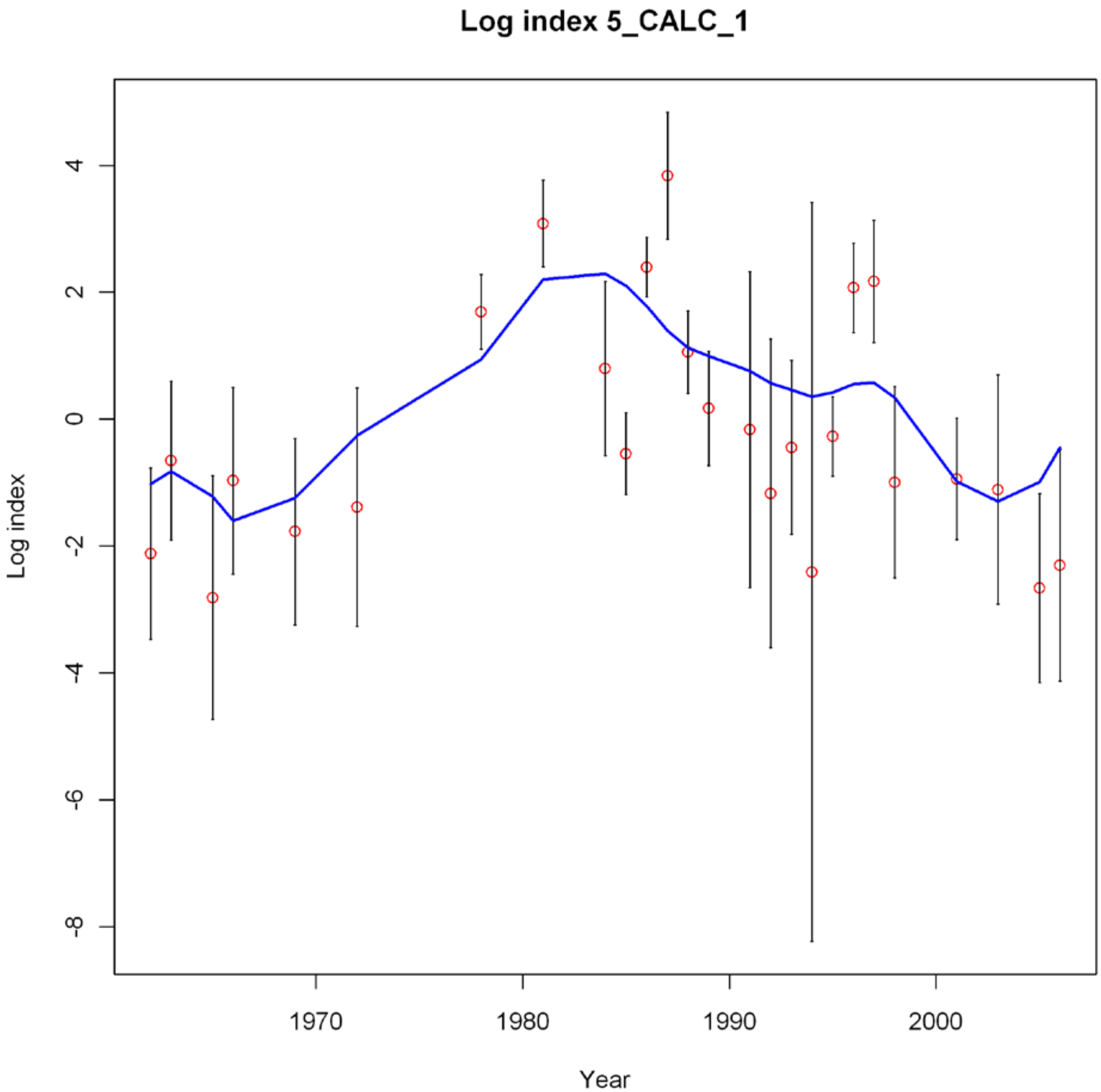


Figure A2B-28. Estimated fits (observed=red circles, with 95% CIs; predicted=line) in log space associated with the CalCOFI index.

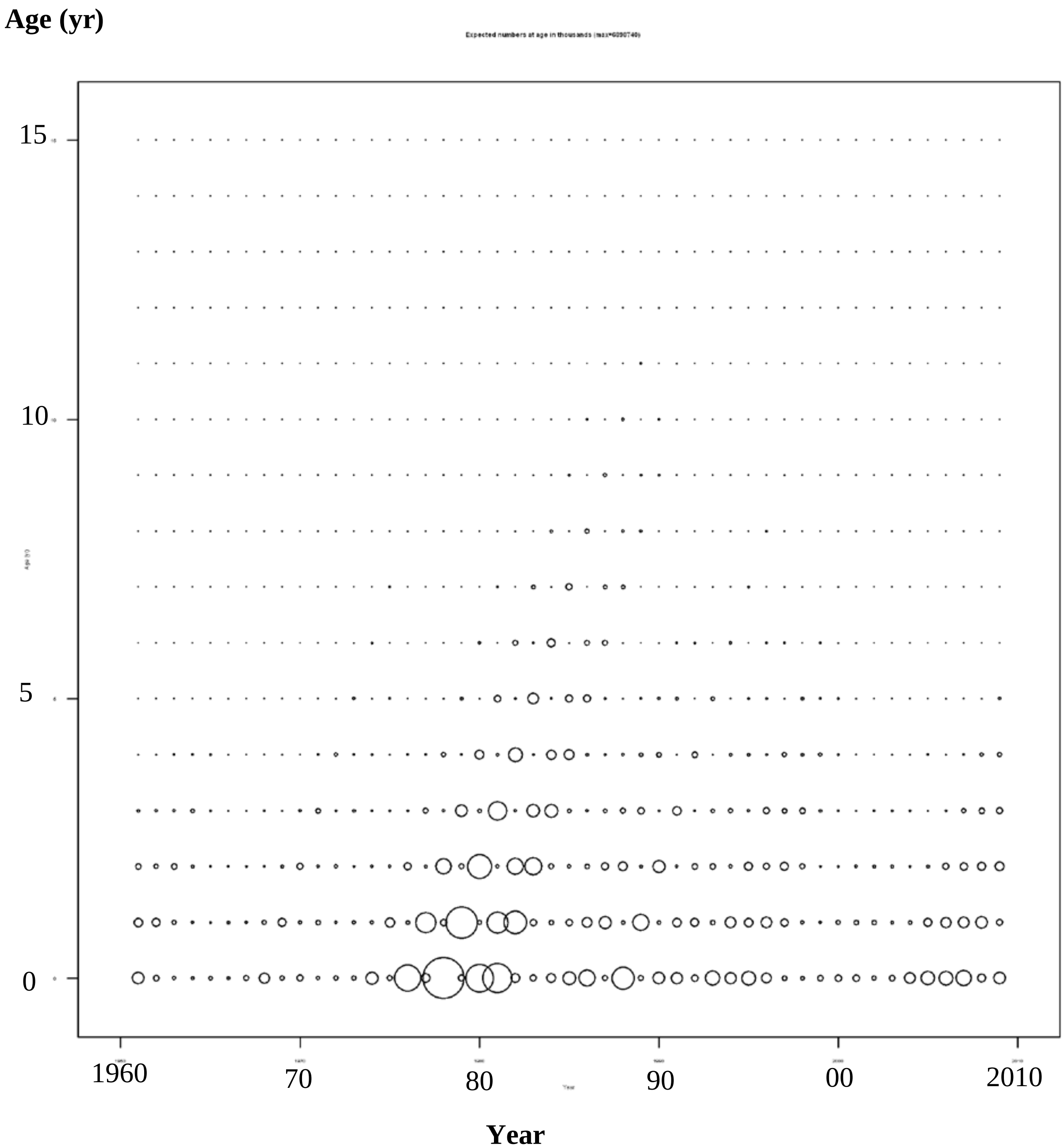


Figure A2B-29. Estimated population size (numbers-at-age), (1962-09).

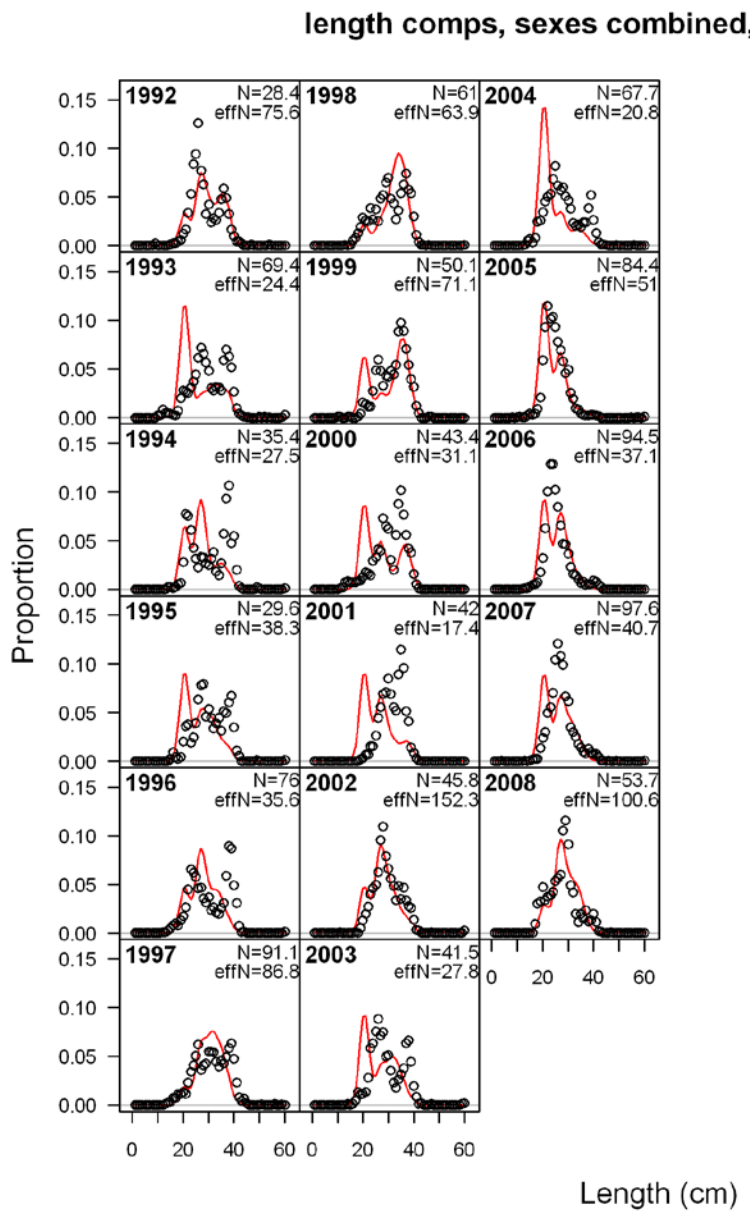


Figure A2B-30. Estimated fits (observed=black circles; predicted=line) associated with the recreational fishery length distribution time series.

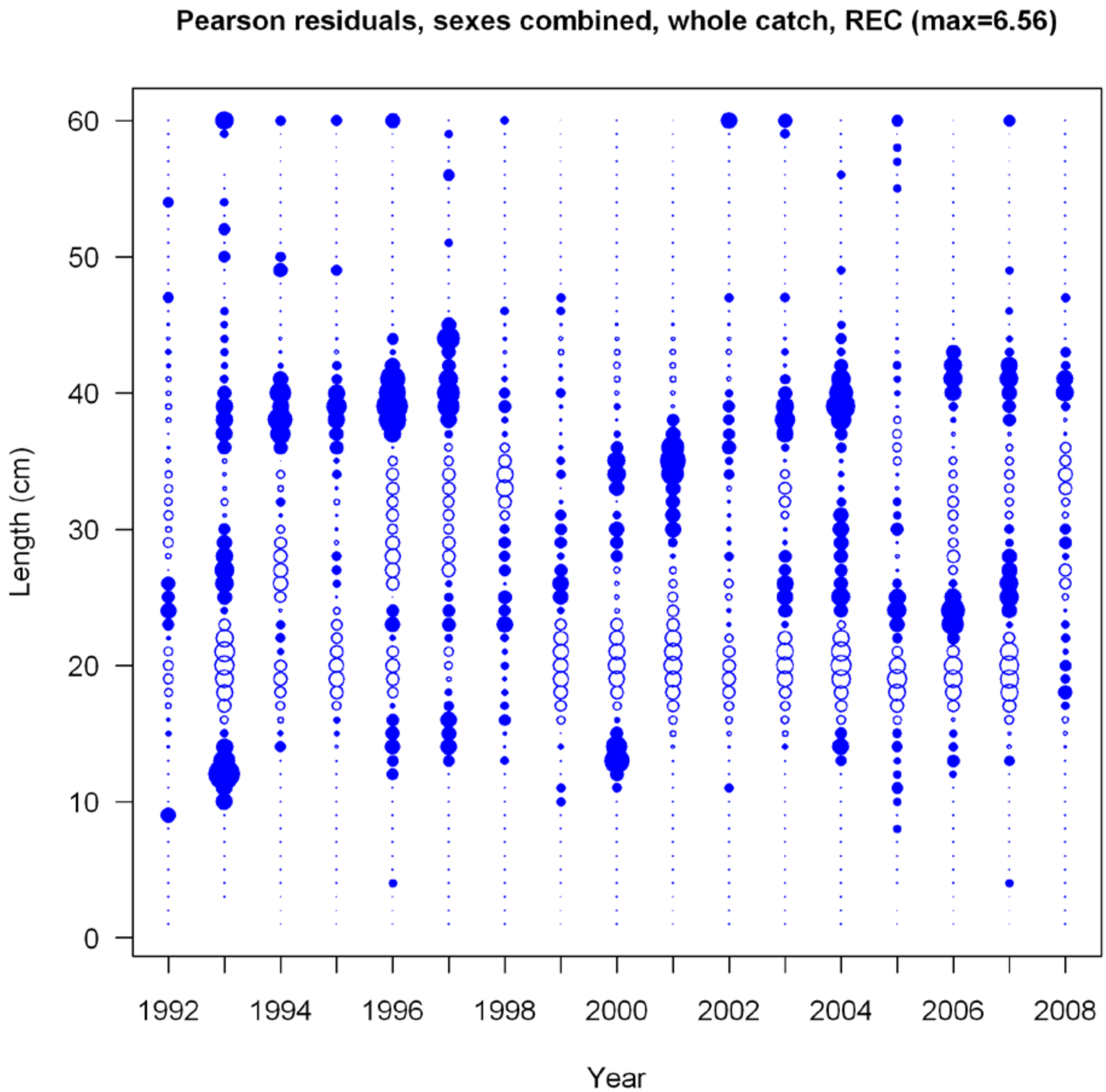


Figure A2B-31. Pearson standardized residuals (observed - predicted) for model fits to the recreational fishery length distribution time series (1992-08). Maximum bubble size = 6.56 (dark circles represent positive values).

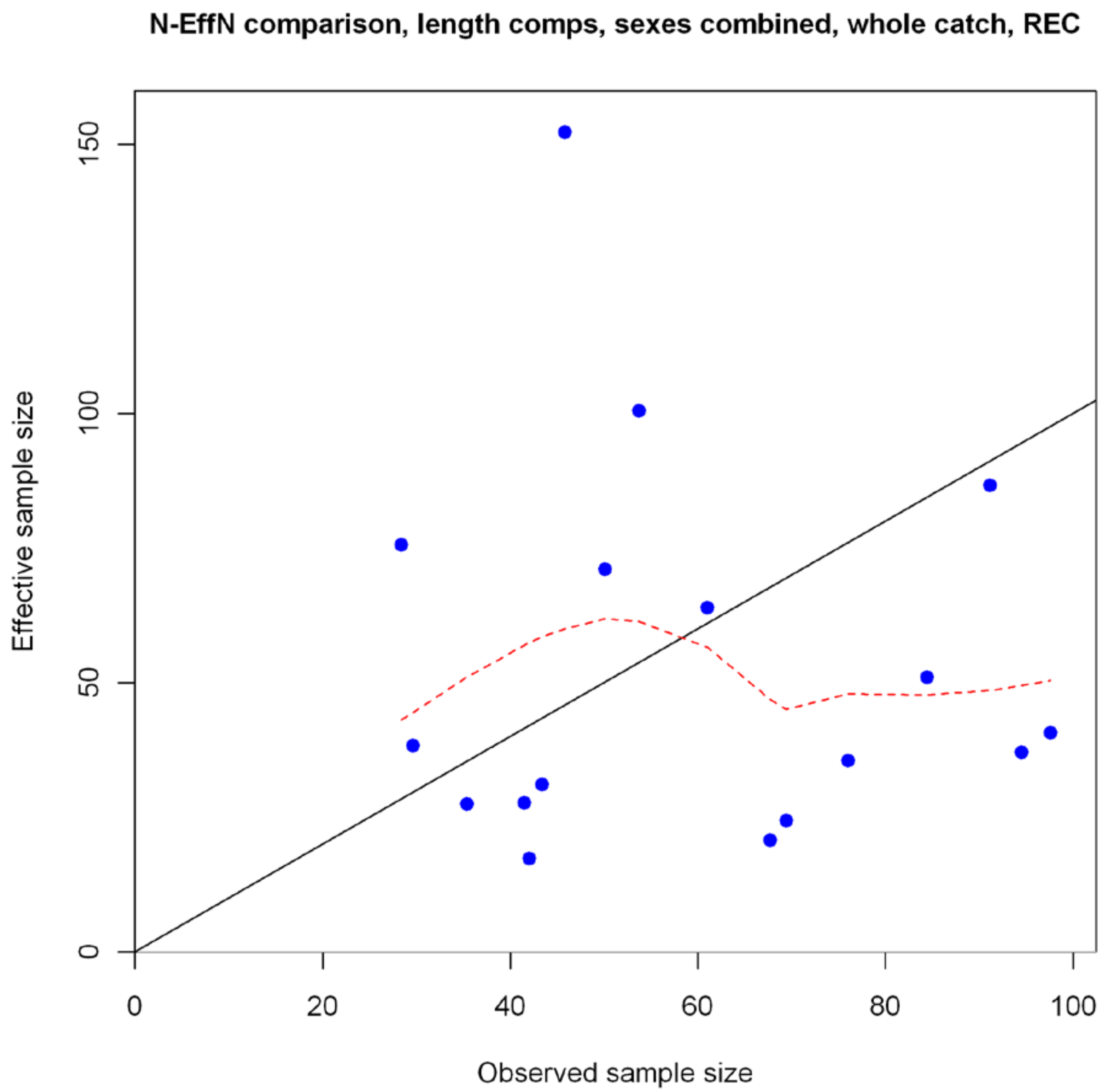


Figure A2B-32. Effective vs. observed (input) sample sizes for the recreational fishery length distribution time series. Solid line represents a 1:1 relationship and the dashed line reflects a loess smoother.

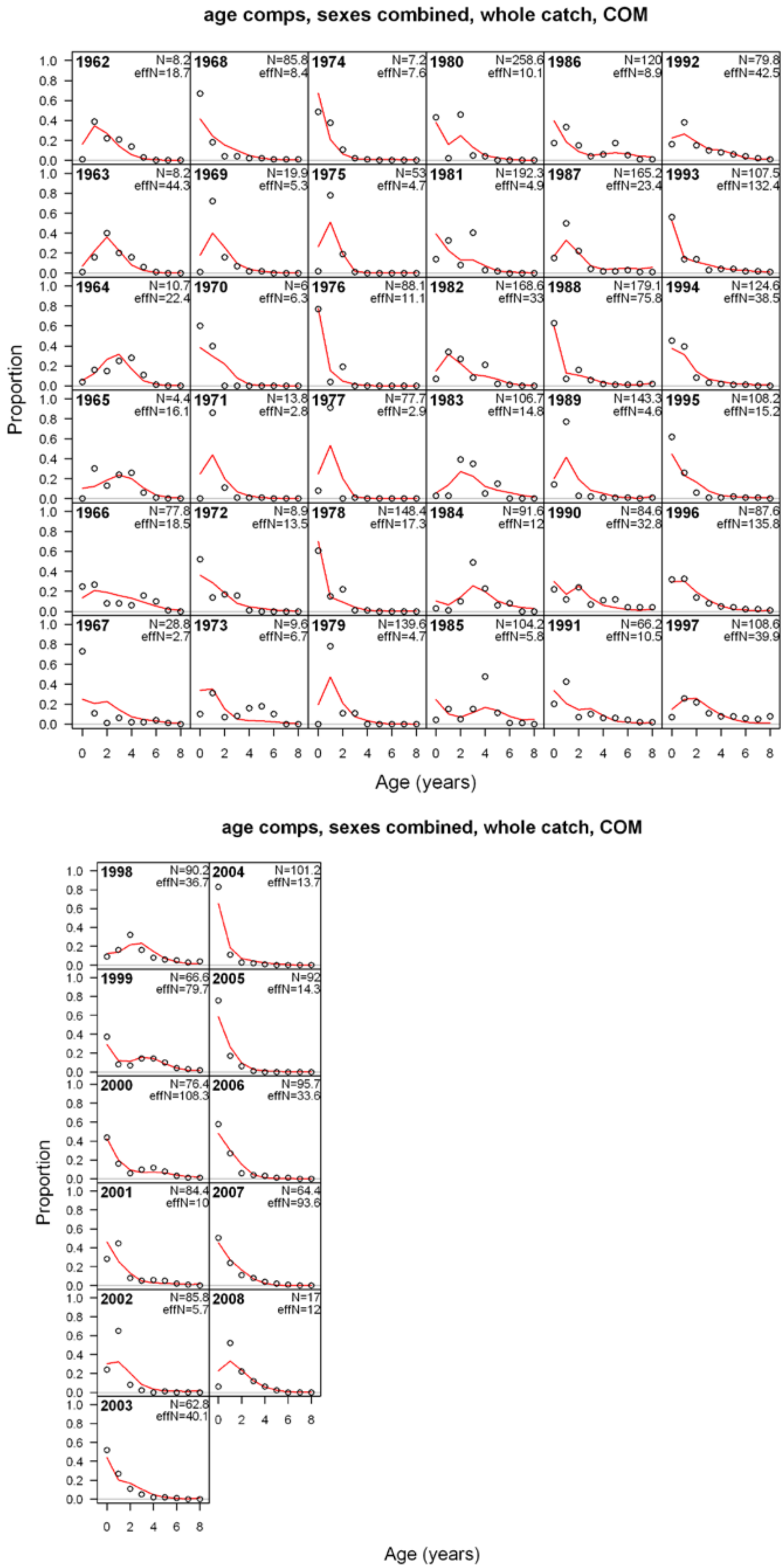


Figure A2B-33. Estimated fits (observed=black circles; predicted=line) associated with the commercial fishery age distribution time series.

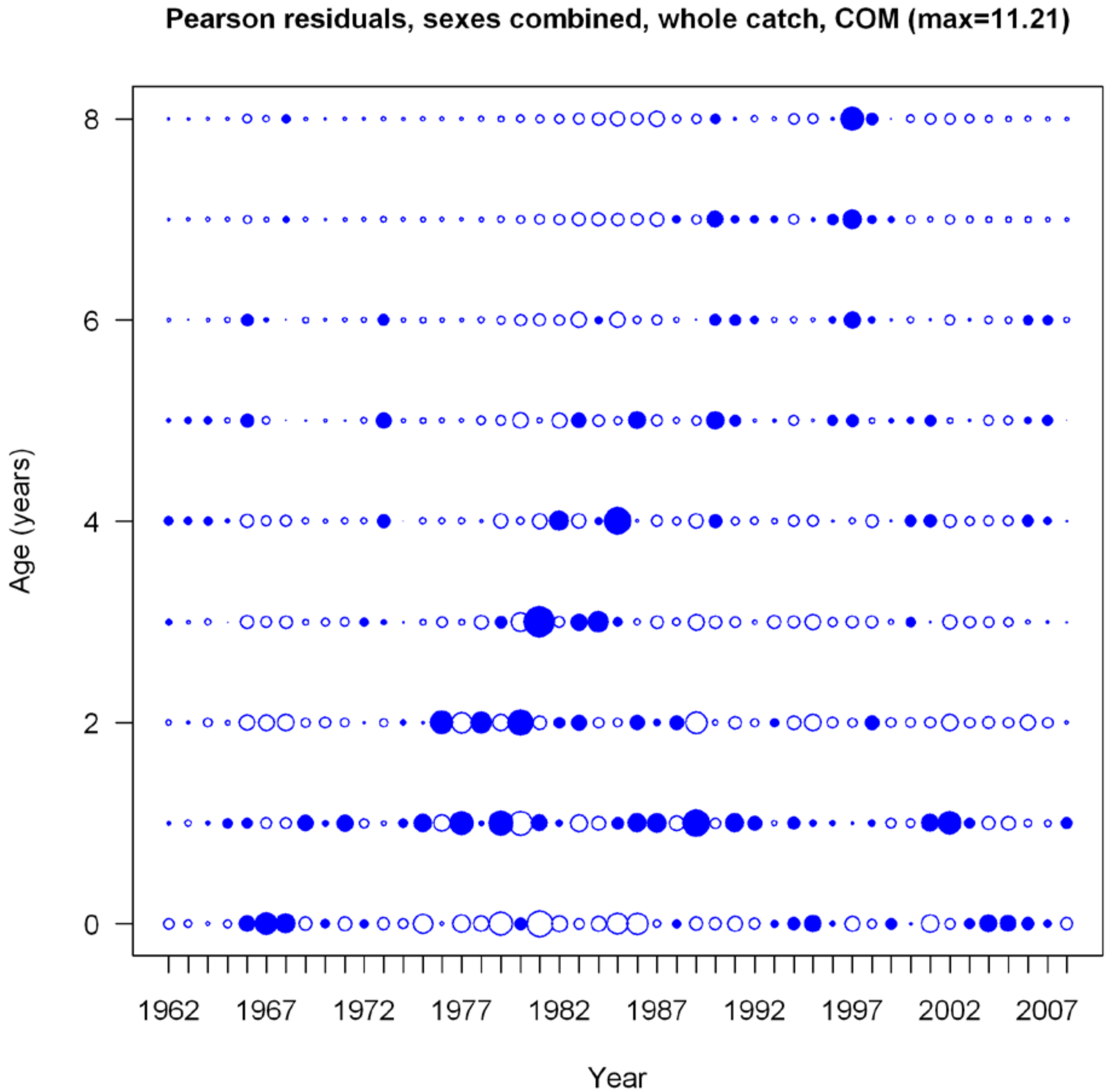


Figure A2B-34. Pearson standardized residuals (observed - predicted) for model fits to the commercial fishery age distribution time series (1962-08). Maximum bubble size = 11.21 (dark circles represent positive values).

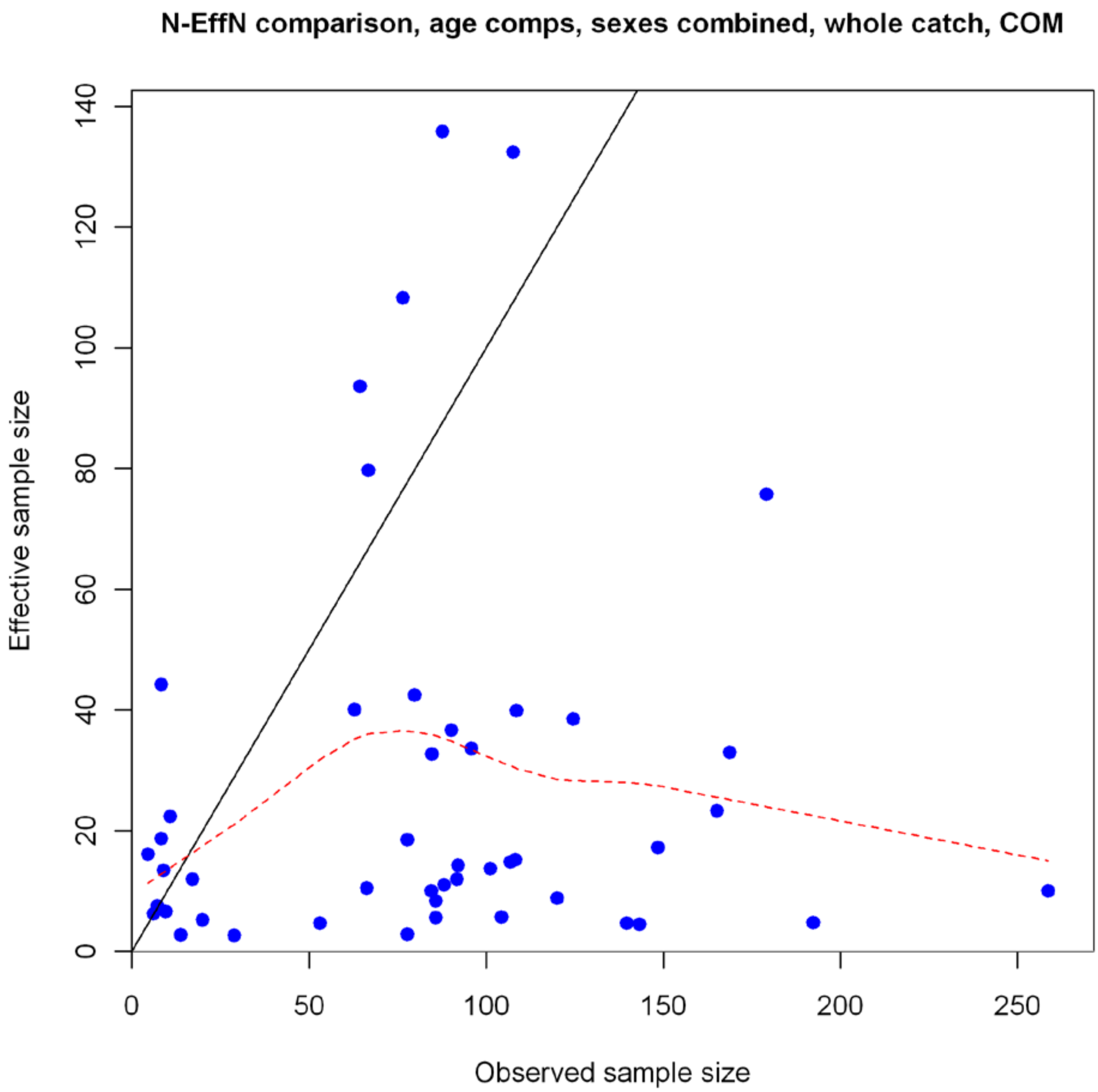


Figure A2B-35. Effective vs. observed (input) sample sizes for the commercial fishery age distribution time series. Solid line represents a 1:1 relationship and the dashed line reflects a loess smoother.

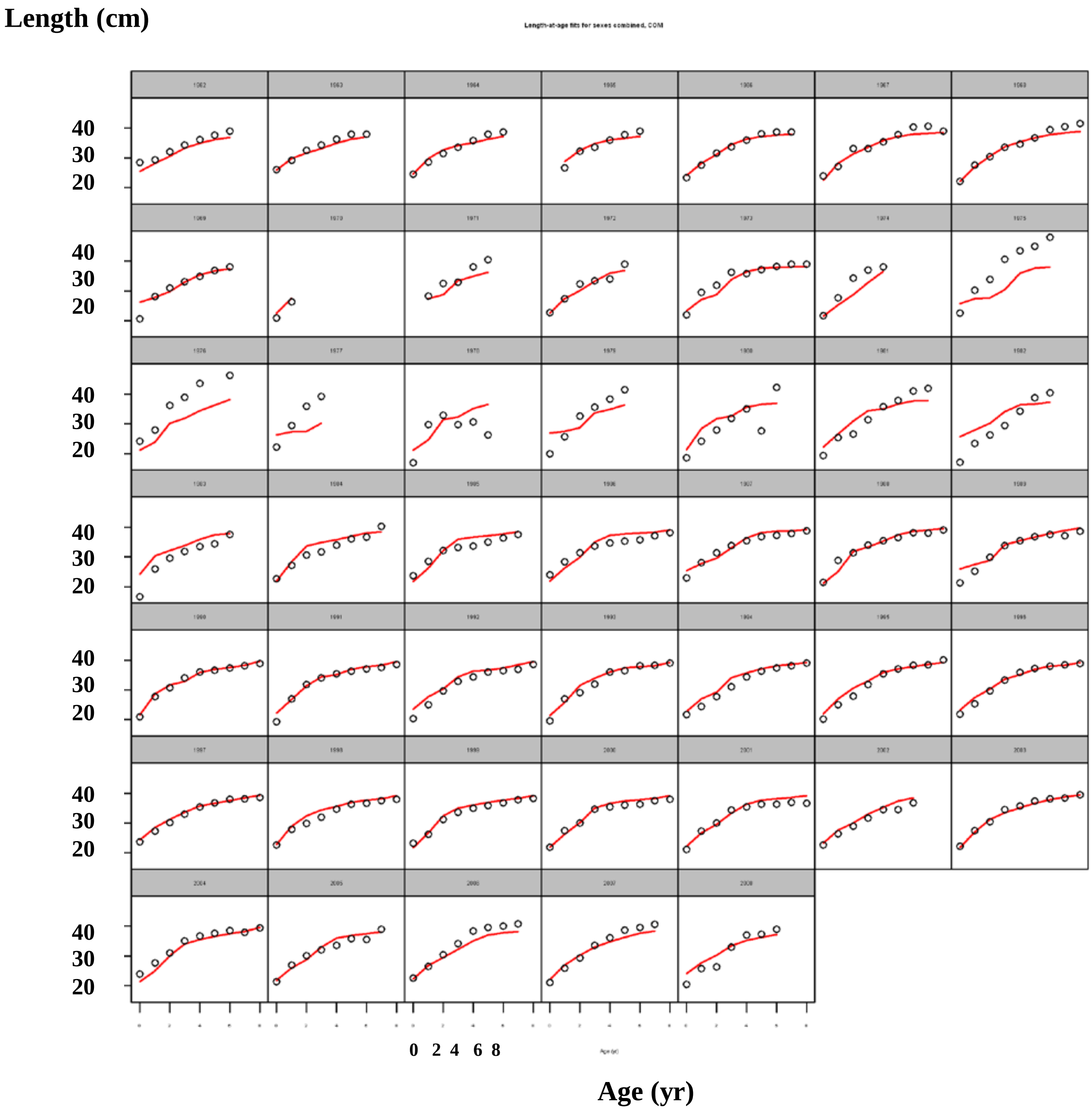


Figure A2B-36. Estimated fits (observed=black circles; predicted=line) associated with the commercial fishery mean size-at-age distribution time series.

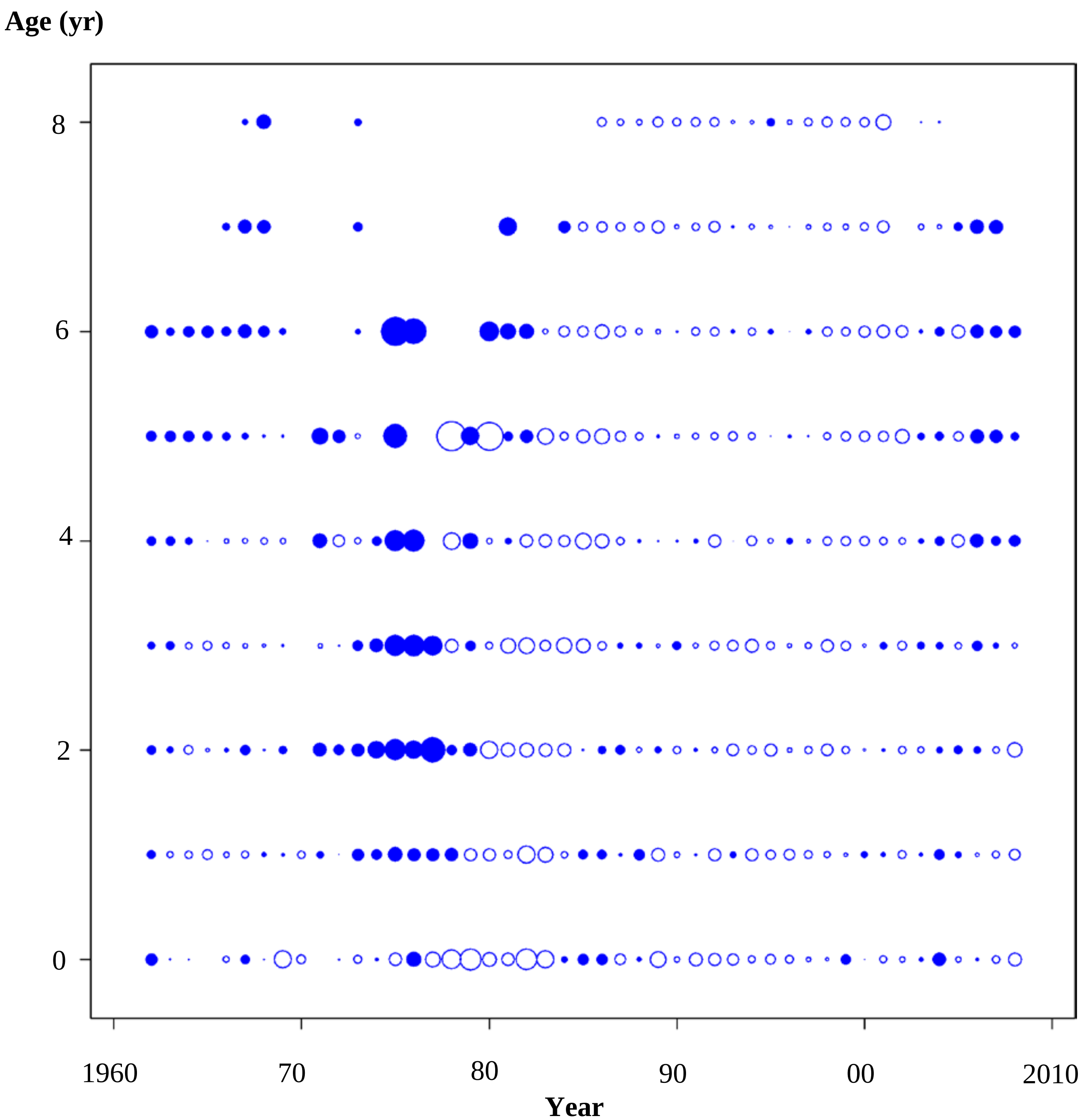


Figure A2B-37. Pearson standardized residuals (observed - predicted) for model fits to the commercial fishery mean size-at-age distribution time series (1962-08). Maximum bubble size = 4.79 (dark circles represent positive values).

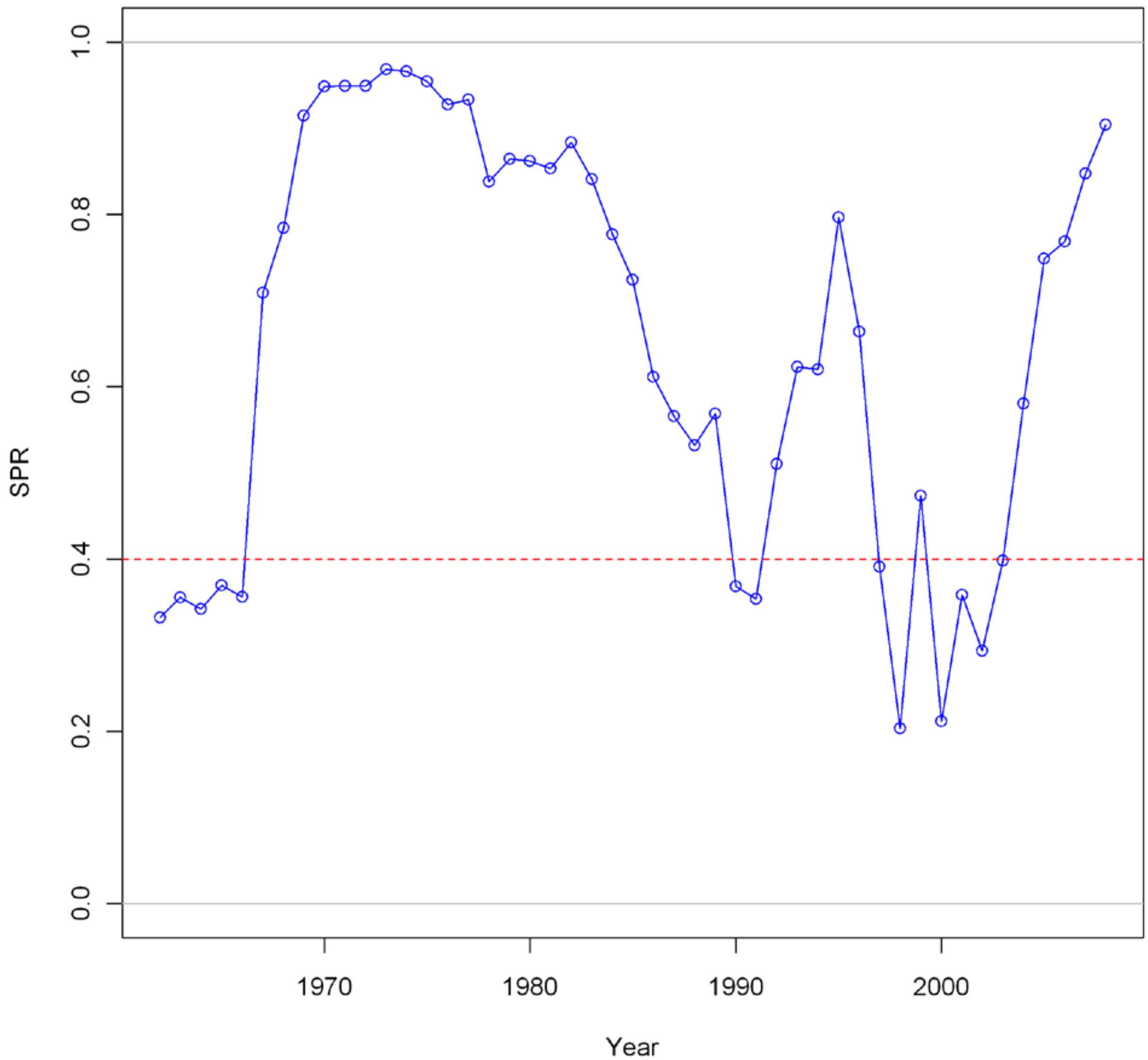


Figure A2B-38. Estimate spawning potential ratios (SPR), (1962-08). Dashed line represents reference SPR only.

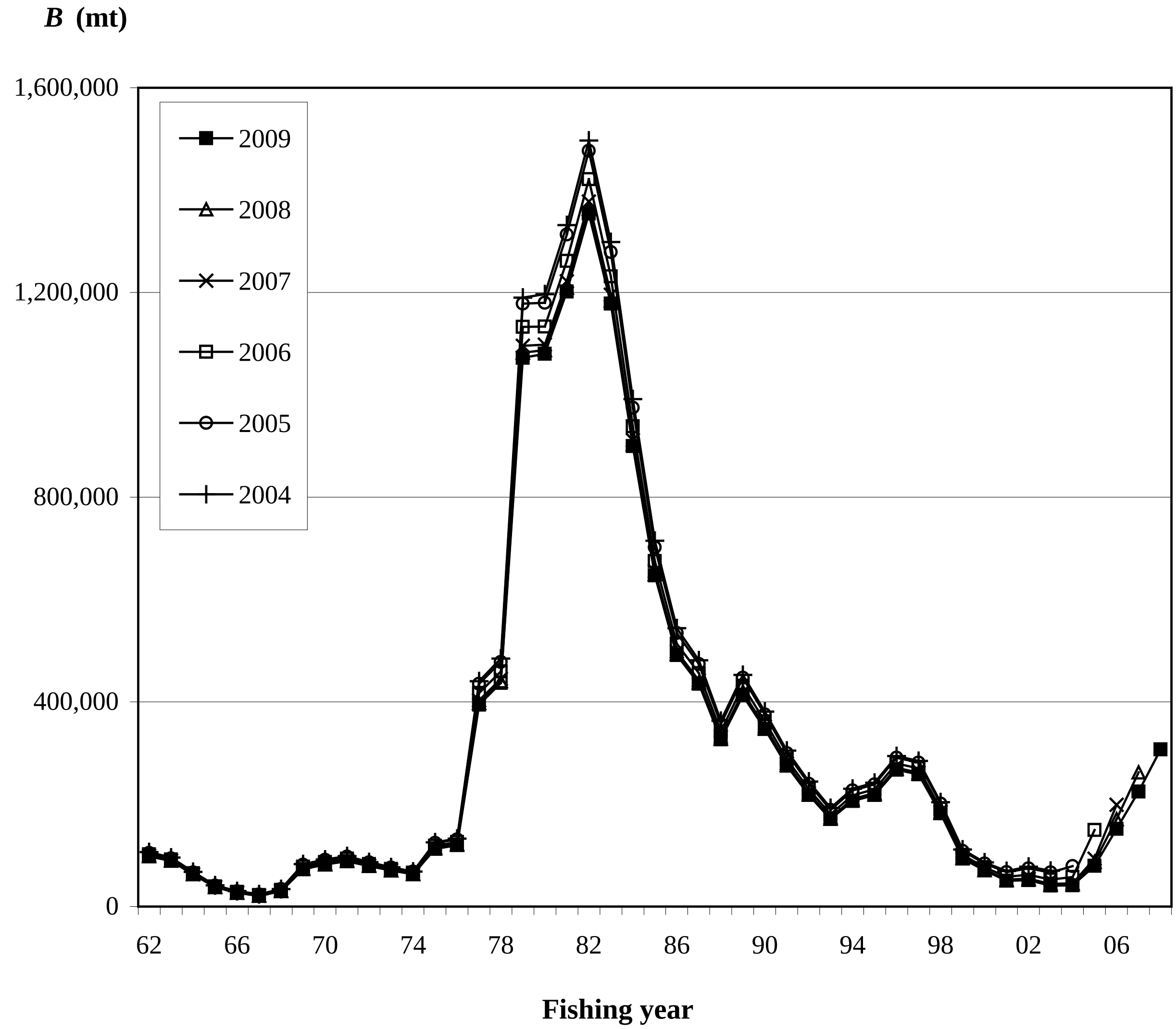


Figure A2B-39. Estimated total stock biomass (age 1+ fish in mt, B) of Pacific mackerel based on retrospective analysis that omitted one year of data in chronological order (1962-09).

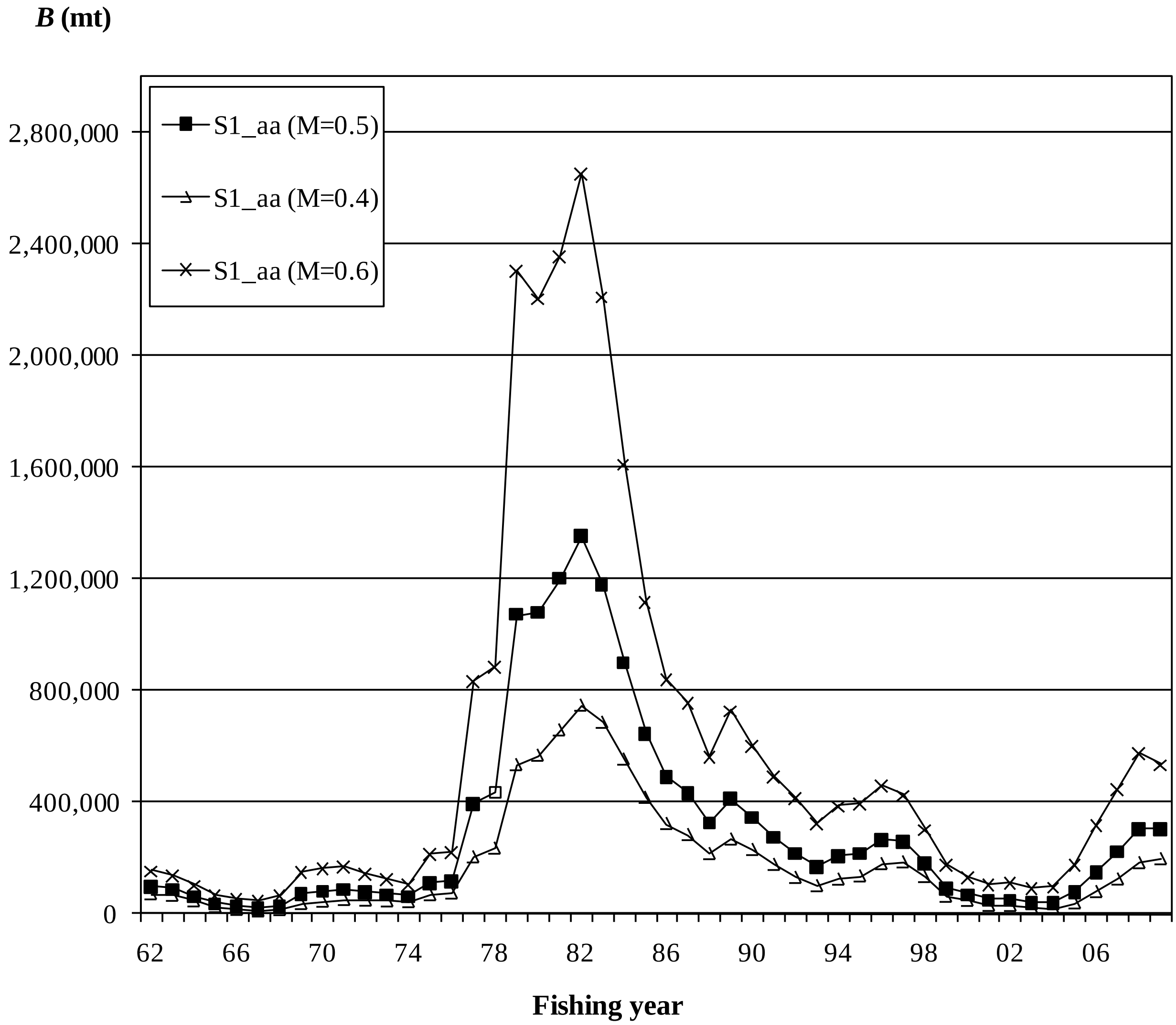


Figure A2B-40. Estimated total stock biomass (age 1+ fish in mt, B) of Pacific mackerel based on different assumptions concerning natural mortality (M), (1962-09).

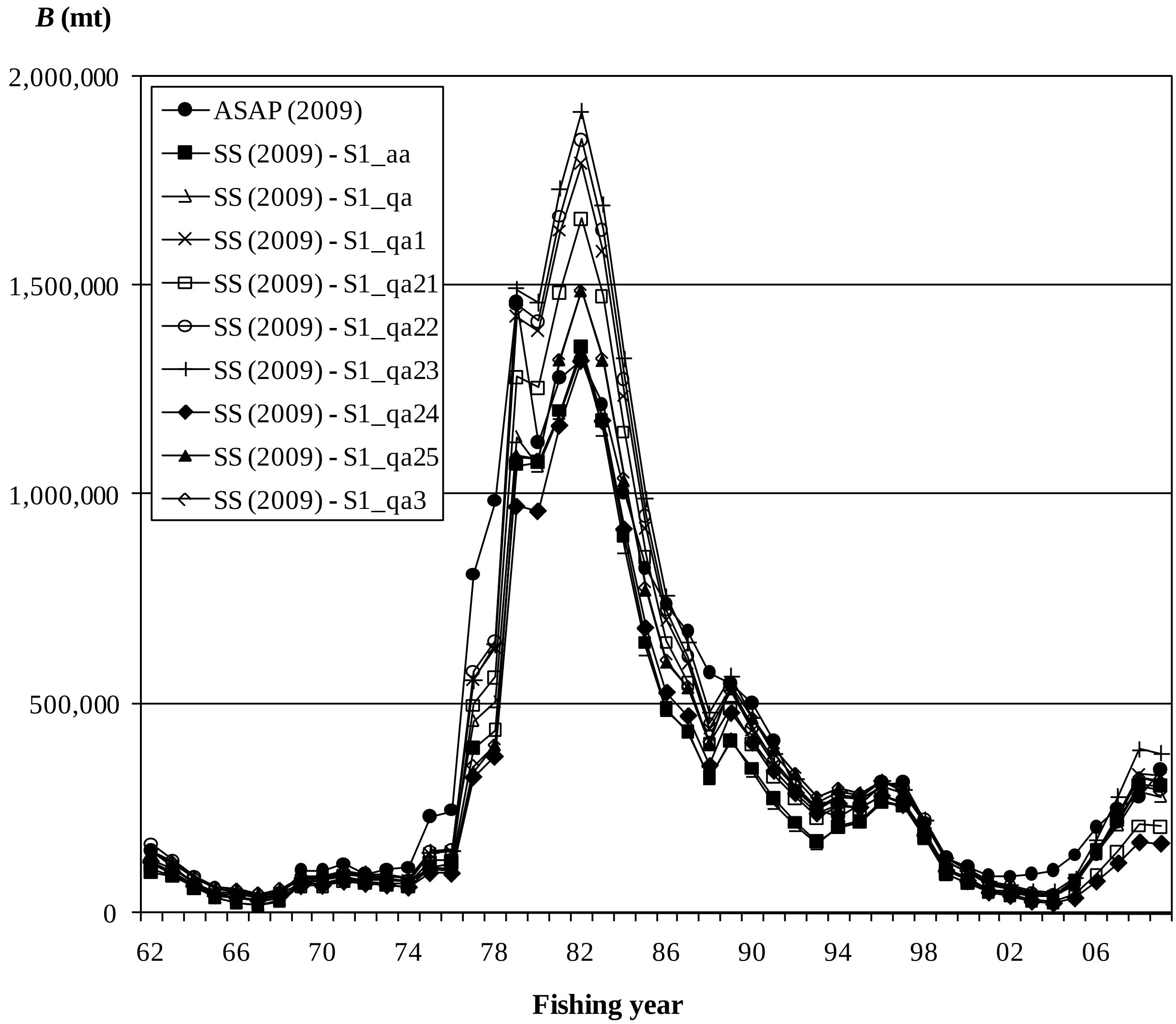


Figure A2B-41. Estimated total stock biomass (age 1+ fish in mt, *B*) of Pacific mackerel based on the ASAP (2009) model and SS model scenarios developed in sensitivity analysis (1962-09). Also, see Table A2B-1 (A-C).

Appendix 3A

Spotter Data Analysis for Pacific Mackerel From 1963-2005 Using a Delta GAM

Nancy C. H. Lo

NOAA Fisheries
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla CA 92037
USA

Introduction

From 1963 to 2003 pilots, employed by the fishing fleet to locate schools of pelagic fish, reported data for each flight on standardized logbooks and provided them to NOAA Fisheries for a fee per flying hour ($1.00-5.00). These data were used to derive Spotter-based indices of abundance for pelagic fish, such as anchovy and young sardine. These indices were calculated as year effects estimated using delta log-normal linear models (LLM; Lo et al. 1992). However, after the year 2000, there was rapid decline in both the number of active pilots and total logbooks returned (Tables 1 and 2), as well as a southward shift in effort to offshore areas around Baja California. To remedy this problem, NOAA Fisheries started to contract professional spotter pilots to survey the Southern California Bight region beginning in 2004 primarily for assessment of young sardine. Newly available data from this enhanced survey were incorporated into the index, and a new time series was calculated using a delta Generalized Linear Model (GLM) for young sardine. This paper presents estimates of the spotter survey index from 1963 to 2005 for Pacific mackerel (*Scomber japonicus*) However, due to the lower number of flights with positive sightings of Pacific mackerel in the spotter survey, I used a Generalized Additive Model (GAM) to obtain estimates of total tonnage as a relative index for the Pacific mackerel.

The old time series had an informal design. Pilots flew the year around at night and in the day, and in areas and seasons frequented by the fishery. The pilots' searching behavior, like most fishermen, might be characterized as "adaptive", meaning that searches for target species may be concentrated in areas where schools were previously sighted. There is no doubt that a formal fishery independent survey design would provide more precise and less biased estimates than the present indices. However, by altering the design, one would lose the most valuable property of the old aerial surveys, i.e., a time series that extends back to 43 years. Regardless of its merit, a new index will have little value in stock assessment until it extends over at least 5-10 years. Clearly, the time series that ended in 2000 needs to be extended, but it would also be valuable to develop a new, more precise index with less potential bias.

The new aerial survey was based on a line transect design with regular occupation of fixed grid lines spaced at regular intervals with random starting points. Concurrently, a "simulated old survey" was implemented by employing an adaptive design to simulate fishing conditions, where having found a school the fishermen will search the vicinity to find others. After searching the pilot returned to the transect line and continued along the line. In this way we could gather information appropriate to both old and new survey designs. Factors such as month, area and day/light in the new surveys are close to those standardized conditions used in the spotter index model developed by Lo et al. (1992):

Experienced pilots under contracts flew along the predetermined track lines in March and April from San Diego to San Francisco, at a maximum of 100 nm offshore(Figure 1). However, in reality, pilots were unable to conduct all assigned surveys in March and April due to weather conditions and their flying schedules. In addition, they only flew in the daytime and not in the nightime alone. As a result, flights in 2004 took place throughout the entire year, but during March and April in 2005. No surveys were conducted in 2006 due to unavailability of pilots during the pre-assigned survey months: March and April. This restriction will be relaxed to the first half of the year. In 2004, a total of 5 surveys by month (3,4,5,7, and 9) were accomplished from March-November, including two single-pilot flights in September and November. In 2005, we had two 3-pilot complete surveys, three 2-pilot surveys and one 1-pilot survey during March and April.

Statistical methods

Delta linear models

The relative abundance of pelagic species, like northern anchovy, or sardine can be expressed as the product of density and a measure of area:

$$(1)\ I = DA$$

where $\boldsymbol{I}$ is the index of relative abundance for a given year (tons). D is density of fish (tons per block) and A is the area (blocks 10' by 10' defined by California Department of Fish and Game (Caruso et al 1979) covered by fish spotters. In the original data analysis of the relative abundance of anchovy, it was reasonable to assume that fish spotters flew over an area that was at least as large as the area occupied by the anchovy stock in each year. This is not so for the entire population of other species like Pacific sardine and Pacific mackerel. For the case of sardine, it suffices to apply to young sardines (<=2 year old). In the current analysis for sardine, units for the index *(I)* are tons of young sardine, sighted by fish spotters.

Density of fish *(D)* for each year can be expressed as the product of d and P:

$$(2)\ D = dP$$

where d is a standardized measure of fish density (tons per block) for positive flights (flights during which fish of interest were seen) and P is a standardized measure of the proportion of blocks that were covered by positive flights (referred to as proportion positive) (Table 1). We used the product in order to avoid problems that arise from including a large number of zeros; therefore the distribution of D is Delta distribution.

Delta lognormal linear model (LLM)

In the original lognormal linear model, we assumed that the number of tons/block (y) or proportion positive (p) follows a lognormal distribution and varies with some covariates, i.e. log(y) or log(p+1) was a function of many covariates: year, region, season, pilot, night/day flights plus some interaction terms:

$$\log(y) \text{ or } \log(p+1) = x'B$$

The final estimates of standardized d and P were obtained by taking anti-log of the linear equations (x'B) plus correction terms. Thus, the relative abundance for each year is:

$$\hat{I} = \hat{d}\hat{P}A$$

Delta GAM model

To continue including spotter pilot data for the stock assessment, from the new datasets,we decided to switch from Delta lognormal linear model to a more flexible model, like GLM or GAM using S-Plus, to allow us to incorporate other possible distribution of tonnages/block (y) of sardine sighted by the pilots for the positive flights and the proportion of positive flights (p) with appropriate link functions for the expected values (d and P), respectively. As stated in Lo et al. (1992), although we used lognormal linear models for components of the delta distribution, other linear or nonlinear models based on other statistical distributions could be used instead.' The Delta GLM has been used for Pacific sardine. For Pacific mackerel, the GAM was chosen because it is more flexible than GLM due to the low sighting of Pacific mackerel and no sighting in 1974.

As done for the delta GLM, we chose a family of Poisson distribution and used log as the link function for the number of tons/block of positive flights (d), e.g., log (of the expected tonnage/block) = x'B; whereas a family of Binomial distribution and the logistic link function, for the proportion of positive flight (P), e.g. log(P/(1-P)) = x'B. In the GAM model, the year effect was modeled by a smoothing spline fit with d.f.=12 while other independent variables: day/night, season, region and survey type were treated as categorical data.

The estimate of density of Pacific mackerel is $\hat{D} = \hat{d}\hat{P}$, with variance estimated as (Goodman 1960):

$$\text{var}(\hat{D}) = \text{var}(\hat{d}\hat{P}) = \hat{P}^2\,\text{var}(\hat{d}) + \hat{d}^2\,\text{var}(\hat{P}) - \text{var}(\hat{d})\,\text{var}(\hat{P})$$

where the estimated variance of estimates of d and P came directly from S-Plus. No correction of *d* and *P* was included in the variance of *D* because the correlation from the data was not significant. The final estimate of the relative abundance (I) and its CV are simply as follows.

$$\hat{I} = \hat{D}A \text{ and}$$
$$CV(\hat{I}) = CV(\hat{D})$$

where A is total number of blocks within the traditional area covered by spotter pilots each year.

Results

The time series of the density (d=tonnage/block), the proportion of positives (p), the survey area (A=blocks) and the total tonnage (D) of Pacific mackerel were presented (Table 1). The estimates of density (d) and proportion of positives (p) were adjusted for night time, season 1(Jan-March), region 2,pilot number 17 and survey 1(traditional aerial survey prior to 2004). The adjusted relative tonnages serve as the relative abundance of Pacific mackerel from spotter data set were presented using the delta-GAM (Table 1). We also presented the time series of total number of flights with sightings of Pacific mackerel and number of blocks with Pacific mackerel (Figures 2 and 3).

Discussion

The relative abundance of Pacific mackerel peaked at the mid-1980 and has been decreased since 1985.The total number of flights decreased continuous since late 1990's(Figure 2). However total number of blocks covered has been similar except 2003 (Figure 3). So, the decrease of the relative abundance of Pacific mackerel could reflect the decline of the population rather than the coverage of the aerial survey in terms of time and space.

Because the effort has been reduced traumatically since 2001 off California, we compared the overall time (season) and space(region) between this two period by the total number of flights (Table 2). The overall distributions between these two periods are similar where most of the efforts were in regions 1-3 for all season and much of the efforts were shifted to regions 4-6 in second half of the year(Figure 1). Thus the reduced effort does not appear to introduce much bias in terms of time and space.

The LLM was used in the past prior to 2000. We compared time series of the relative abundance of Pacific mackerel based on the LLM and GAM (Figure 4). These two time series have similar shape except that the time series from LLM fluctuated more than that from Delta GAM. The CVs from LLM (Bradu and Munklak 1970) were higher than those from GAM (Figure 5) partially because the variances of the estimates from LLM included those of bias-correlation terms for the parameter estimates of lognormal distribution, which may not be so for the variance of estimates used in GAM(Lo et al. 1992, Chambers and Hastie 1992).

References

Aitchison. J. and J. A. C. Brown. 1957. The lognormal distribution Cambridge University Press, Cambridge. MA. 387 p.

Bradu. D. and Y. Munklak. 1970. Estimation in lognormal linear models J. Am. Stat. Assoc. 65: 198-211.

Chambers, J. M. and T. J. Hastie. 1992. Statistical models in S. Wadsworth & Brooks/Cole Advanced Books & Software, Pacific Grove, Ca. 608 p.

Caruso, J.D., C. A. Meyer and S. Iacometti. 1979. aerial marine resource monitoring system. Ad Southwest Fisheries Science Center, National Marine Fisheries Service, SWFSC Admin. Rpt JL-79-09. 208 p.

Goodman,L.A. 1960. On the exact variance of products. Jounral of American statistical Association,55(292):708-713.

Lo, N. C. H., L. D. Jacobson, and J. L. Squire. 1992. indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49: 2515-2526**.**

Pennington, M. 1983. Efficient estimators of abundance for fish and plankton surveys.Biometrics 39: 281-286.

Table 1: Summary of tonnage/block for positive flights (T/B+;d), and proportion of blocks covered by positive flights(%BLK;p), relative abundance(REL_ABN;I) and associated standard errors(SE) and coefficient of variation(CV), 1963-2005

YEAR	T/B+(d)	SE_T/B+(se(d))	%BLK(p)	SE_%BLK(se(p))	T/B(D)	SE_T/B(se(D)	BLOCKS: A	REL_ABN (I)	SE_RA(SE(I))	CV_RA(CV(I))
1963	10.9765	0.256	0.3948	0.126	4.334	1.386	180	780.1215	249.4857	0.3198
1964	9.1412	0.2097	0.2954	0.1009	2.7003	0.9246	206	556.2621	190.4636	0.3424
1965	7.9056	0.2247	0.2112	0.0846	1.6698	0.6701	208	347.3205	139.3901	0.4013
1966	7.2327	0.2471	0.1433	0.0674	1.0363	0.4881	224	232.1204	109.3434	0.4711
1967	7.0751	0.2736	0.0941	0.0513	0.666	0.3633	200	133.2097	72.6574	0.5454
1968	7.4065	0.3059	0.0641	0.0394	0.4748	0.2925	221	104.9266	64.644	0.6161
1969	8.263	0.3458	0.0457	0.0311	0.3777	0.2572	223	84.2257	57.3583	0.681
1970	9.7486	0.395	0.0351	0.0256	0.3417	0.2495	143	48.8633	35.6745	0.7301
1971	12.1586	0.4611	0.0288	0.0217	0.3504	0.2646	175	61.326	46.2968	0.7549
1972	16.4332	0.5719	0.0257	0.0194	0.4221	0.3194	184	77.6658	58.763	0.7566
1973	24.4208	0.761	0.0268	0.0195	0.6548	0.4756	320	209.5514	152.1861	0.7262
1974	39.512	0.3545	0.0368	0.024	1.4542	0.9487	303	440.6126	287.4576	0.6524
1975	68.2695	1.3696	0.0672	0.036	4.5882	2.4608	272	1247.999	669.3363	0.5363
1976	122.8261	1.6234	0.1425	0.0569	17.5023	6.9915	320	5600.725	2237.292	0.3995
1977	211.1617	1.8301	0.2805	0.0785	59.2229	16.5939	274	16227.06	4546.726	0.2802
1978	273.5644	2.1046	0.4336	0.0886	118.6293	24.2472	277	32860.31	6716.464	0.2044
1979	245.675	1.8841	0.5405	0.0886	132.7758	21.7868	279	37044.45	6078.508	0.1641
1980	207.3972	1.6878	0.5996	0.0854	124.3496	17.7401	196	24372.52	3477.056	0.1427
1981	175.8748	1.4067	0.6123	0.0821	107.6835	14.4608	232	24982.57	3354.899	0.1343
1982	163.2234	1.3314	0.5872	0.0816	95.8495	13.3451	249	23866.53	3322.929	0.1392
1983	158.6598	1.2833	0.5474	0.0829	86.8545	13.1711	363	31528.16	4781.096	0.1516
1984	201.1422	1.4698	0.5156	0.0823	103.7128	16.5765	390	40447.99	6464.815	0.1598
1985	230.6762	1.5536	0.4888	0.0802	112.7574	18.5052	382	43073.30	7068.985	0.1641
1986	163.6113	1.215	0.4568	0.079	74.7448	12.9438	372	27805.07	4815.101	0.1732
1987	103.1131	0.8812	0.4219	0.0789	43.5071	8.1407	401	17446.36	3264.440	0.1871
1988	72.0007	0.7326	0.3759	0.0778	27.0675	5.6059	372	10069.09	2085.409	0.2071
1989	49.0351	0.5382	0.3353	0.0743	16.4421	3.649	379	6231.567	1382.970	0.2219

1990	36.58	0.4025	0.31	0.0704	11.3401	2.5772	390	4422.646	1005.100	0.2273
1991	31.8418	0.3669	0.2719	0.0655	8.659	2.0887	355	3073.959	741.5032	0.2412
1992	29.4926	0.386	0.2175	0.059	6.4155	1.7429	365	2341.645	636.1745	0.2717
1993	30.1896	0.4177	0.1819	0.0537	5.4916	1.6235	439	2410.830	712.7012	0.2956
1994	35.3125	0.4781	0.1697	0.0524	5.9936	1.8525	406	2433.403	752.0986	0.3091
1995	45.4523	0.5974	0.1725	0.0546	7.839	2.4819	343	2688.784	851.3066	0.3166
1996	54.9084	0.7079	0.1844	0.0578	10.1266	3.1762	373	3777.207	1184.711	0.3136
1997	47.649	0.6301	0.1972	0.0603	9.3949	2.8733	516	4847.761	1482.637	0.3058
1998	35.2852	0.5236	0.2005	0.0611	7.073	2.1568	464	3281.873	1000.741	0.3049
1999	26.2324	0.4727	0.1872	0.0604	4.912	1.5854	450	2210.402	713.4182	0.3228
2000	20.2908	0.4709	0.1662	0.0613	3.3722	1.2453	423	1426.445	526.7597	0.3693
2001	16.0772	0.5273	0.1254	0.0577	2.016	0.9295	473	953.5639	439.6377	0.461
2002	12.8185	0.1654	0.0768	0.0444	0.9843	0.5689	227	223.4301	129.1322	0.578
2003	10.2487	0.1381	0.0364	0.0255	0.3729	0.261	38	14.1711	9.9175	0.6998
2004	8.217	0.7163	0.0123	0.0109	0.1009	0.0892	342	34.5127	30.5233	0.8844
2005	6.6032	0.7399	0.0028	0.0037	0.0183	0.0244	278	5.0749	6.7749	1.335

Table 2. Total number of flights by region (figure 1) and season prior to 2000 and after 2000:

Prior to 2000: 1963-1999

Season \ Region	1	2	3	4	5	6
1	133	1947	1499	-	2	-
2	191	2612	1184	36	134	-
3	329	4761	1938	263	1522	76
4	207	2315	2373	32	26	-

2000-2005

Season \ Region	1	2	3	4	5	6
1	19	29	11	-	-	-
2	41	97	14	-	12	17
3	12	295	4	11	198	33
4	13	16	3	-	-	-

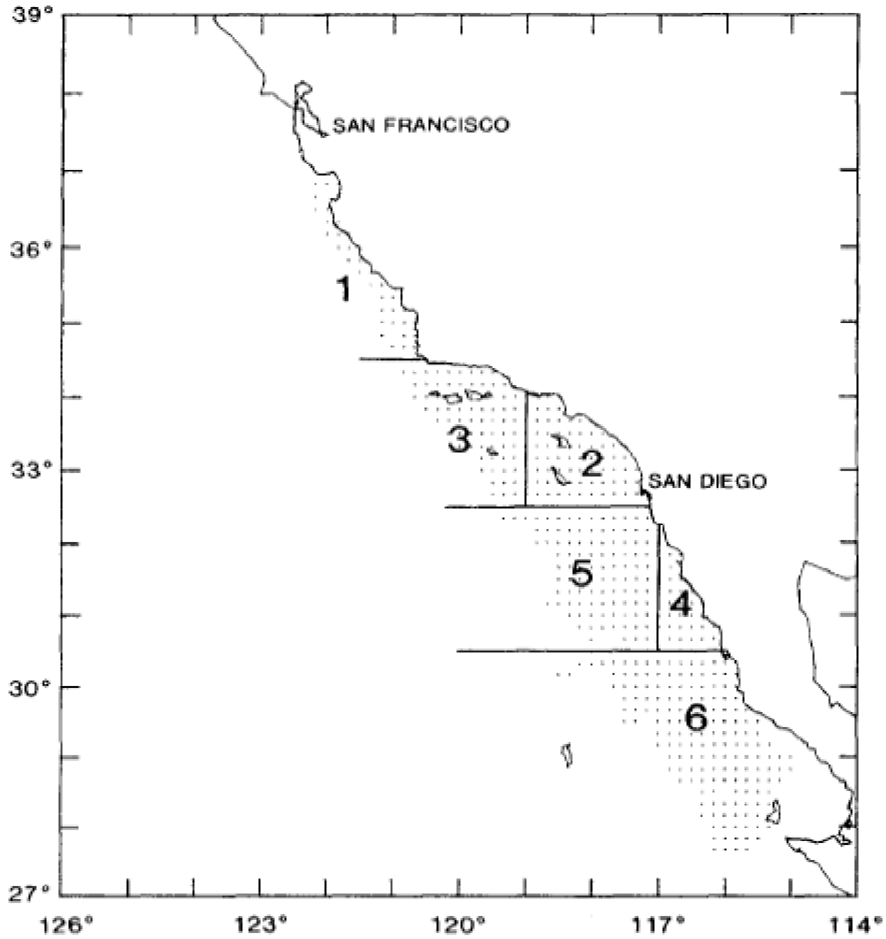


FIG. 2. Study area, regions, and blocks covered by fish spotters in 1989. Regions are outlined and denoted by numbers. Blocks are denoted by dots.

Figure 1 Study area, regions, and blocks covered by fish spotter in 1989. Regions are outlined and denoted by numbers. Blocks are denoted by dots (reproduced from Lo et al. 1992)

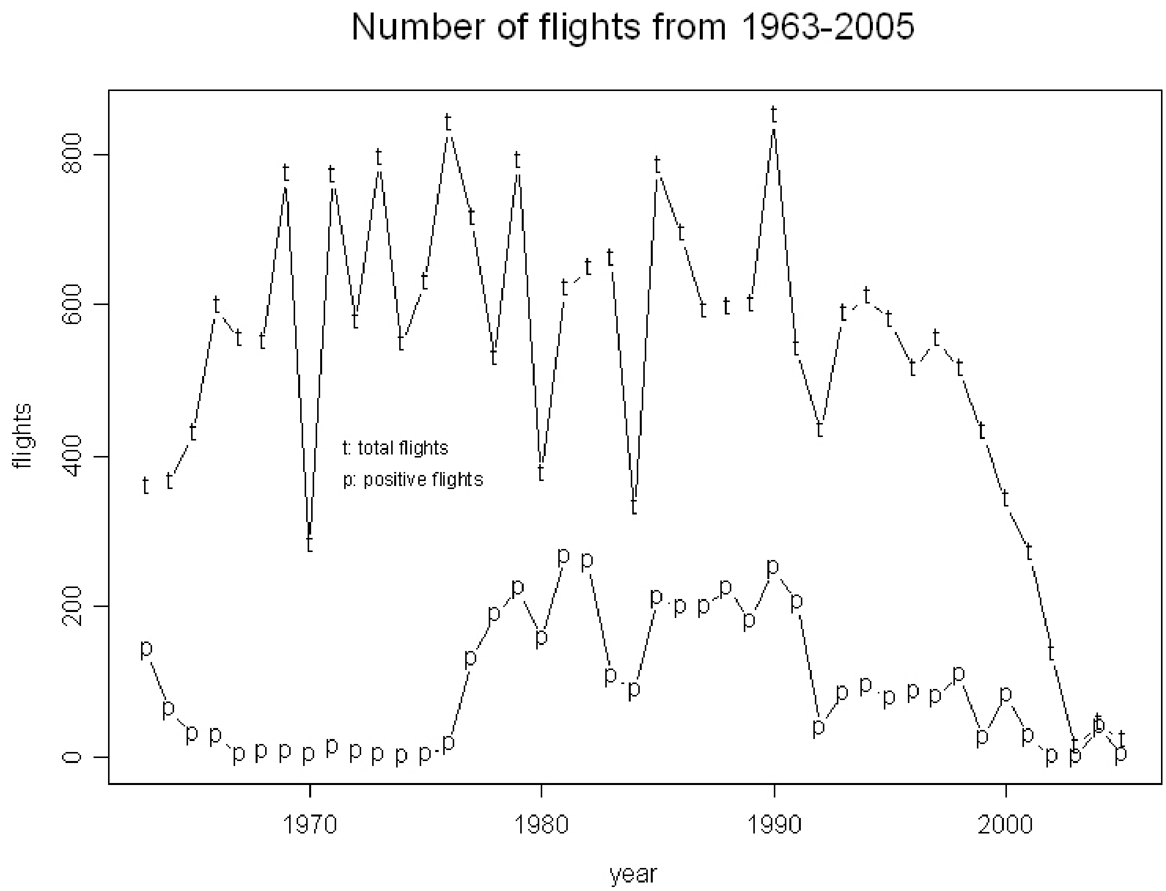


Figure 2. Total flights and number of flights with positive sightings of Pacific mackerel, 1963-2005

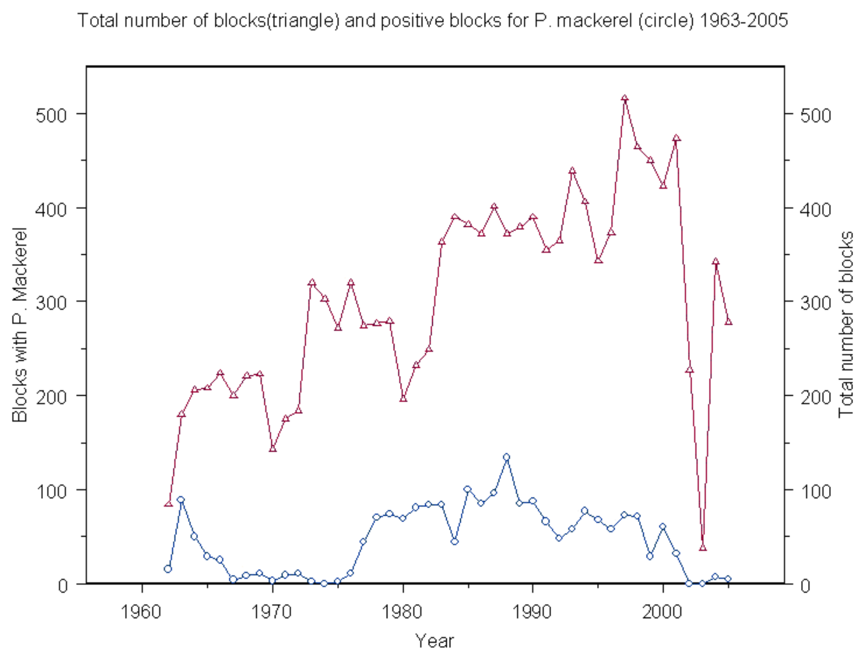


Figure 3. Total number of blocks covered (triangle)and blocks covered by flights with positive sighting (circle) of Pacific mackerel, 1963-2005

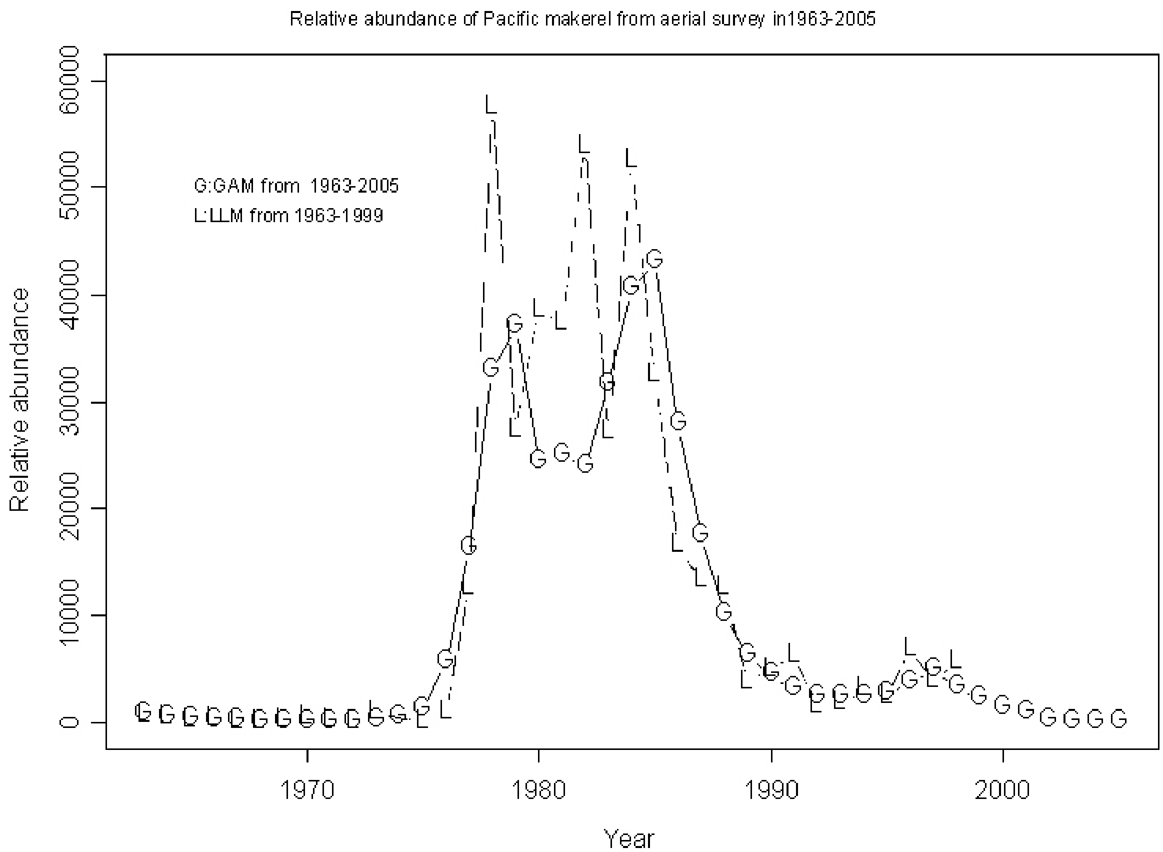


Figure 4: Time series of relative abundance (total tonnage) of Pacific mackerel from 1963-2005 using GAM and that of 1963-1999 using LLM

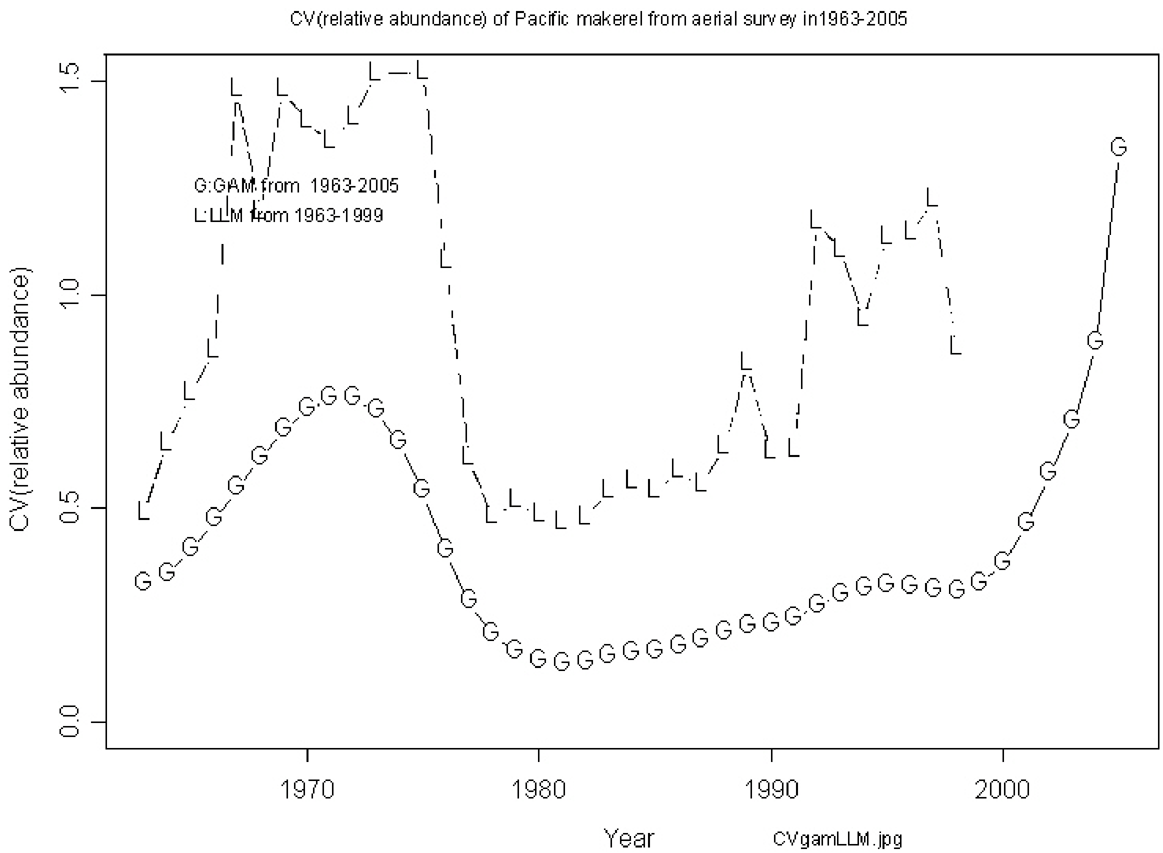


Figure 5: Time series of CV(relative abundance)(total tonnage) of Pacific mackerel from 1963-2005 using GAM and that using LLM from 1963-1999..

Appendix 3B

Daily Larval Production of Pacific Mackerel (*Scomber japonicus*) Off California From 1951-2006

Nancy C. H. Lo, Yuhong Huang, and Emmanis Doval

NOAA Fisheries
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla CA 92037
USA

ABSTRACT

Daily larval production at hatching /10m^2 of Pacific mackerel (*Scomber japonicus*) from 1951-2006 was estimated based on data collected from California Cooperative Oceanic Fisheries Investigations (CalCOFI) surveys off the coast from San Diego to Avila Beach, north of Point Conception, California in April-July, the peak spawning time of Pacific mackerel off California. This area has been covered by all CalCOFI surveys. The time series showed the peak daily larval production was in 1987 with 46.39/10m^2/d, with minor peaks were in 1981, and 1986. The density of daily larval production has been decreasing since 1997. The larval production was particularly low in 2003- 2006. This cost-effective fishery-independent time series should be beneficial to the assessment and better understanding of the dynamics of the Pacific mackerel population.

INTRODUCTION

The time series of Pacific mackerel larval abundance and distribution by month from 1951-56 was reported by Kremer (1960) and from 1951-84 by Moser et al (1993) for historical survey area from San Francisco to Baja California. Since 1985, the CalCOFI survey area has been reduced to cover the area in the Southern California Bight (CalCOFI line 93 – line 77, Fig.1 2 and 3), primarily most years in 1985-present.

The purpose of constructing the time series of daily larval production was to use this time series as an index for the spawning biomass in the stock assessment. Ideally, methods such as the daily egg production method (DEPM) for pelagic fishes (Lo et al. 1996) should be used to estimate spawning biomass of Pacific mackerel. This kind of method requires data on fish egg stages, duration and abundance plus the reproductive output of adult fishes (MacGregor 1966). Due to the high patchiness of Pacific mackerel eggs and larvae, and the fact that the eggs were consistently identified only in the last 10 years, it is not possible to carry out a DEPM analysis over the whole 1951-2006 time period at this moment. Fortunately, mackerel larval data from CalCOFI surveys are readily available from 1951 and comprehensive correction algorithms can be applied to reduce the possible biases of measurement, such as extrusion through the net mesh, avoidance from the net, etc. It seems reasonable to consider the larval production of Pacific mackerel as a possible index of spawning biomass (Ahlstrom 1959) as has been done for many other fish populations (Smith 1972, Lo 1986, Lo et al. 1989). In this paper,we analyzed Pacific mackerel larval data from 1951-2006 for the current CalCOFI survey area in April-July (Fig.1). Although this area is smaller than that of the historical CalCOFI survey (Fig. 2), it encompasses the primary spawning area of Pacific mackerel off California (Moser et al. 1993).

METERIAL AND METHODS

The CalCOFI survey was conducted annually from 1949- 1966, after which it was conducted every 3 years through 1984, covering the area from Baja California to the north of San Francisco (Fig. 2). Starting in 1985, the survey was conducted annually but covered only the southern area from San Diego to Avila Beach, just north of Point Conception. As Pacific mackerel larvae are most concentrated in mid-Baja California in the summer and second off Southern California in Spring, for consistency of available datasets, only Pacific mackerel larval data from the CalCOFI database from April-July were used in this study (Ahlstrom 1959, Moser et al. 2001). Larvae were collected by oblique tows with a 1-m ring net to 150 m from 1951-68, and the depth was increased to 210 m in 1969. Bongo net replaced 1-m ring net in 1978. A standard haul factor used to compute number of larvae / $10m^2$ ws intended to account for variability in the volume of water filtered per unit of depth (Smith and Richardson 1975).

Sampler biases caused by net selectivity for small larvae and gear avoidance for larger larvae were adjusted following the method of Lo (1985). Retention rates for extrusion can be expressed as function of larval length and mesh size (Lenarz 1972; Zweifel and Smith 1981; Lo 1983) and those for avoidance can be expressed as a function of larval length and the diurnal time of capture (Hewitt and Methot 1982). All larval abundance data were adjusted to conform to the following standard condition: no extrusion, no day-night difference in avoidance, and a constant water volume filtered per unit depth. The data were then converted to daily production/$10m^2$ (P_t) by dividing the corrected total number of larvae in each length group by the duration (the number of days larvae remain within each length group). A set of laboratory data on larval growth conducted by Hunter and Kimbrell (1980) was used to model temperature dependent larval growth curves which were used to convert length to age from hatching.

CORRECTION FACTORS

Extrusion

There are no existing data on the length-specific extrusion rate for Pacific mackerel. Therefore, the retention coefficient of jack mackerel larvae due to extrusion was used as a proxy for mackerel. Jack mackerel larvae and Pacific mackerel larvae are approximately the same length at hatching and are morphologically similar: jack mackerel hatch at about 2-2.5mm and Pacific mackerel at about 2-3mm; morphology of both is similar in yolk sac stage. On average, Pacific mackerel tend to be just slightly longer and more robust than jack mackerel (Watson pers. Comm.). Hewitt et al. (1985) reported that only the smallest class of jack mackerel larvae (3.0 mm) are extruded to a significant degree through the 0.505 mm CalCOFI nets, with 28% of the catch in that size class retained in the net. The extrusion correction factor is equal to 1/.28 or 3.571. Although 0.55mm mesh net was used prior to 1968, the difference in extrusion of mackerel larvae is likely to be insignificant as was the case for anchovy larvae (Lo 1983).

Avoidance /evasion

The correction factor for avoidance/evasion was estimated using the algorithm developed for anchovy and Pacific hake (Lo et al. 1989, Lo in submission). Because larvae are able to avoid or evade the net to the same degree under sufficient light to see, and larger larvae are better able to avoid the sampler, we used the model by Lo et al. (1989) for the retention (or capture) coefficient of mackerel larvae for a specific larval length (*L*) and hour of the day (*h*):

$$R_{L,h} = \left(\frac{1+D_L}{2}\right) + \left(\frac{1-D_L}{2}\right) * \cos\left(\frac{2\pi * h}{24}\right) \qquad (1)$$

where D_L is the noon/night catch ratio for length *L*. Data from 1951 to 1978 in the historical large area were used to model the catch ratio:

$$D_L = \frac{\bar{y}_{L,noon}}{\bar{y}_{L,night}}$$

The numerator is the mean catch at noon (11:00 am – 1:00 pm) of larvae size *L*. The denominator is the mean catch in the night (9:00 pm - 3:00 am) of larval length *L*. We then used an exponential curve to model the relationship between D_L and larval length *L*.

Shrinkage

The shrinkage factor was based on the work on Pacific hake (Bailey 1982) which reported on the percentage of shrinkage in the standard length of first-feeding larvae due to preservatives and time of handling for Pacific hake. Shrinkage was 8.9% for formalin-preserved larvae (*L*). Because in regular CalCOFI surveys, formalin is the standard preservative used, a correction factor is needed to convert formalin-preserved length (*L*) to life length (L_L) in order to apply the larval Pacific mackerel growth curves derived from laboratory data by Hunter and Kimbrell (1980). The multiplier applied to larvae from 2.5 -11.5 mm from CalCOFI surveys is 1/(1-0.089)=1.098 to convert formalin preserved-length to live length, i.e., $L_L = L * 1.098$.

GROWTH OF MACKEREL LARVAE

Growth curves

Hunter and Kimbrell (1980) reported growth data for seven groups of Pacific mackerel reared at different temperatures from 16.8 – 22.1^{o}C. A temperature-dependent logistic growth curve was derived where the coefficient of the age was a polynomial function of temperature (Bartsch 2005):

$$L_L = \frac{28.2616}{1+\exp(-\beta_{temp} t + 2.3476)} \quad \text{for } t<25 \text{ d} \qquad (2)$$

where L_L is the life length, $\beta_{temp} = 0.2828 - 0.0229 temp + 0.0007 temp^2$, t (days) is age (d) from hatch, and *temp* is temperature in ^oC.

To convert length to age from hatching, we inverted the equation (2) and obtained:

$$t = \frac{2.3476 - \ln(28.2616/(L*1.098)-1)}{\beta_{temp}} \text{ for } 2.23\text{mm} <= L < 20\text{mm} \qquad (3)$$

where t is age after hatching and L is formalin-preserved length. Note the logistic growth curve gave minimum live length being 2.45 mm for newly hatched larvae at t=0.

The larvae collected in each tow were grouped as 2.5 mm (2.0 mm - 3.0 mm), 3.75 (3.5 and 4.0 mm), and 4.75 (4.5 and 5.0mm). To obtain the final age of a larva, the actual length of a larva in each length group from each tow was generated by a random selection from a uniform distribution within each length category. For the larvae in the length category of 2.5 mm, age 0 was assigned for formalin-preserved length <2.23 mm

Size class duration and daily larval production

The duration was estimated by the difference of the mid-ages where the mid-ages are the ages corresponding to the mid-lengths: the midpoint between two size groups. The daily larval production in each age group was the larval density in each age group divided by its duration, the time the larvae stayed in each size group.

DAILY LARVAL PRODUCTION AT HATCHING (P_h)

The daily larval production at hatching (P_h) was estimated for each year from a larval mortality curve in the form of exponential function, unlike that of northern anchovy (Lo 1985, 1986) and Pacific hake (Hollowed 1992) whose daily mortality rates decreased with age as the larvae matured. Larvae with length >11.75mm length group were excluded because few larvae of those sizes observed due to their evasion from the net is uncertain. A weighted nonlinear regression was used to obtain estimates of the coefficients for years with sufficient catch-length data:

$$P_t = P_h \exp(\alpha t) \qquad (4)$$

where P_t is the daily mackerel larval production at age t days from hatching, and α is the daily instantaneous mortality rate.

For most years, we fitted equation (4) to the data using a weighted nonlinear regression to estimate the P_h and α, where the weight was 1/SD for each 4-day interval: 0-4, 5-8, …, 17-20 d. As larvae older than 20 days occurred in few tows each year, the mortality curve was constructed based on larvae of age <=20 days at most, to avoid bias. However due to the patchiness of larvae and their ability to avoid the net, the unweighted nonlinear regression was used for some years because the large variances in the young age categories down-weighted the corresponding larval productions too much to produce reasonable estimates of P_h and mortality rate. There were also some years where only one or two length groups had positive catches, mostly small larvae say larvae <4 mm, P_h was estimated by inverting the mortality curve (equation 4)

$$\hat{P}_h = \overline{P}_L \exp(-\hat{\alpha} t_L) \qquad (5)$$

and the variance of $\hat{P}_h$ was estimated as:

$$\mathrm{var}(\hat{P}_h) = \mathrm{var}(\overline{P}_L)(\exp(-\hat{\alpha} t_L))^2 + (\overline{P}_L \exp(-\hat{\alpha} t_L)(-t_L))^2 \,\mathrm{var}(\hat{\alpha}) - \mathrm{var}(\overline{P}_L)(\exp(-\hat{\alpha} t_L)(-t_L))^2 \,\mathrm{var}(\hat{\alpha})$$

where $\overline{P}_L$ is the mean daily larval production at length L=2.5mm and t_L is the associated age of 2.5mm and the over all mean mortality rate was used for $\hat{\alpha}$ (Goodman 1960).

RESULTS

Avoidance

The relationship between the mean noon/night catch ratio (D_L) and larval length (L) based on data of 1951-1978 is

$$D_L = 2.7 \exp(-0.39L) \qquad (6)$$

where the standard errors of two coefficients are 0.47 and 0.05. (Fig.4). The estimated capture rates of larvae by length and time of day (equation 1) are shown in Fig. 5.

Mortality curves and the daily larval production at hatching (P_h)

Mortality curves were constructed for years when the data are sufficient (Table 1). The mortality curve and larval production at age for 1981 are given for illustration (Fig. 6). For those years, the estimates of the daily larval production/10m^2 were the intercepts of the mortality curves (equation 4) (Table 1). An unweighed nonlinear regression was used for years 1985, 1986, 1988, and 1992. For other years when the data were not sufficient, an overall mortality rate was used in equation (5) for1953, 1962, 1969, 1972, 1993, 1994, 2003, and 2006.

The time series of daily larval production (P_h/10m^2) from 1951-2006 off the California coast from San Diego to north of Point Conception fluctuated with the highest peak of 46.38 larvae/day/10m^2 in 1987 and minor peaks at 1981 and 1986 (Table 1 and Fig. 7). The larval production has been declining with moderate fluctuations since 1997 in this survey area.

For comparative purposes, we computed the mean counts of larvae per $10m^2$ with corrected for biases. The time series of P_h and mean counts of larvae had similar trend but the time series of simple means was more variable than that of P_h (Fig. 7 and 8). Nevertheless, the fluctuations in the time series of Pacific mackerel larvae are partially due to the fact that Pacific mackerel larvae are one of the most 'patchy distributed' pelagic species in the CalCOFI time series and that patches can be very large and dense.

Analyses in this study were based on larval abundance corrected for all possible biases. The extrusion factor was based on Jack mackerel larval data, therefore future surveys on Pacific mackerel larvae are recommended to obtain direct measurements and to verify if the extrusion factor based on Jack mackerel larvae is reasonable to use for Pacific mackerel larvae. The avoidance correction factor was based on 1951-1978 data because including other year's data did not contribute to the modeling of the day/night ratio with the length.

The long time series of daily Pacific mackerel larval production, a cost-effective fishery-independent population index obtained yearly, is beneficial to the assessment of the Pacific mackerel population and better understanding of the dynamics of the Pacific mackerel population (Deriso and Quinn, NRC 1998).

LITERATURE CITED

Ahlstrom, E. 1959. Vertical distribution of pelagic fish eggs and larvae off California and Baja California. U.S. Fish Wild. Serv. Fish. Bull 161 Vol.60. 146 p.

Bailey, K.M. 1982 The early life history of the Pacific hake, *Merluccius productus*. Fish. Bull.80: 589-598. Bartsch, J. 2005. The influence of spatio-temporal egg production variability on the modeled survival of the early life history stages of mackerel(*Scomber scombrus*) in the eastern North Atlantic. ICES Journal of Marine Science,62:1049-1960.

Deriso, R and T. Quinn, NRC-Committee on fish stock assessment methods. 1998. Improving fish stock assessments. National Academy Press.177 p.

Goodman, L.A. 1960. On the exact variance of products, Journal of American Statistical Association, 55(292):708-713.

Hewitt, R.P., and R. D. Methot, Jr. 1982. Distribution and mortality of northern anchovy larvae in 1978 and 1979. CalCOFI Rep. 23:226-245.

Hewitt, R.P., G. H. Theilacker, and N.C.H. Lo. 1985. Causes of mortality in young jack mackerel. Mar. Ecol. Prog. Ser. 26: 1-10.

Hollowed, A.B. 1992. Spatial and temporal distributions of Pacific mackerel, *Scomber japonicus*, larvae and estimates of survival during early life stages, *CalCOFI*

Report 33:100-123 Hunter, J.R. and C. A. Kimbrell 1980. Early life history of Pacific mackerel, *Scomber japonicus*. Fish. Bull., U.S. 78(1):89-101.

Kramer, D. Development of eggs and larvae of Pacific mackerel and distrubtion and abundance of larvae, 1952-1956. Fish and Wildlife Service Vol. 60, Fishery Bulletin 174:393-438.

Lenarz, 1972. W.H. Mesh retention of *Sardinops caerulea* and *Engraulis mordax* by plankton nets. Fish. Bull. U.S. 70:839-848.

Lo, N.C.H. 1983. Re-examination of three parameters associated with anchovy egg and larval abundance: temperature dependent incubation time, yolk-sac growth rate and egg and larval retention in mesh nets. NOAA Tech. Memo. NMFS-SWFC-31. 32 p.

Lo ,N.C.H. 1985. Egg production of the central stock of northern anchovy, *Engraulis morax*, 1951-82. Fish. Bull., U.S. 83(2):137-150.

Lo, N.C.H. 1986. Modeling life-stage-specific instantaneous mortality rates, an application to northern anchovy, *Engraulis modax,* eggs and larvae. Fish. Bull., U.S. 84(2):395-407.

Lo, N.C.H., John R. Hunter, and Roger P. Hewitt. 1989. Precision and bias of estimates of larval mortality. Fish. Bull., U.S. 87:399-416.

Lo, N.C.H., Y.A. Green Ruiz, M.J. Cervantes, H.G. Moser, and R.J. Lynn. 1996. Egg production and spawning biomass of Pacific sardine (Sardinops sagax) in 1994, determined by the daily egg production method. Calif. Coop. Oceanic Fish. Invest. Rep. 37:160-174.

Lo, N.C.H. in submission. Daily larval production of Pacific hake (*Merluccius productus*) off California in 1951-2006.

MacGregor, J. S. 1966. Synopsis on the biology of jack mackerel *(Trachurus symmetricus).* U.S. Fish Wildl. Serv. Spec. Sci. Rpt. Fish. 526. 16 p.

Moser, H.G., R. L. Charter, P.E. Smith, D.A. Ambrose, S.R. Charter, C.A. Meyer, E. M. Sandknop, and W. Watson 1993. Distributional Atlas of fish larvae and eggs in the California current region: Taxa with 1000 or more total larvae, 1951 through 1984. CalCOFI ATLAS no. 31. 233 p.

Moser, H.G., R. L. Charter, P.E. Smith, D.A. Ambrose, W. Watson, S.R. Charter, and E. M. Sandknop. 2001. Distributional Altas of fish larvae and eggs in the Southern California Bight region:1951-1984. CalCOFI ATLAS no 34. 166 p.

Smith P.E. 1972. The increase in spawning biomass of northern anchovy, *Engraulis mordax.* Fish. Bull. 70(3):849-874.

Smith P.E. and S. L. Richardson. 1975. Standard techniques for pelagic fish egg and larva surveys. FAO Fisheries Technical Paper No. 175. FIR/T175. Food and Agriculture Organization of the United Nations, Rome. 100 p.

Zweifel, J.R., and P.E. Smith. 1981. Estimates of the abundance and mortality of larval anchovies (1951-1975): application of a new method. Rapp. P.-v Reun. Cons. Int. Explor. Mer. 178:248-259.

Table 1. mackerel larval production at hatch (P_h), the mortality coefficient (β) and their standard errors (SE), total number of tows (n) , positive tows (n_p) larvae/10m^2(density),mean temperatures(temp) and weighted temperature(wt-temp).

year	P_h	se(Ph)	β	se(β)	n	n_p	density <=11.75mm	se(density)	Temp	wt-tmep	Idex
1951	0.015	0.019	-0.051	0.148	128	6	0.152	0.102	14.99	16.04	1
1952	0.023	0.023	-0.013	0.123	200	7	0.256	0.115	14.51	15.76	1
1953	0.187	0.096	**-0.327**	**0.023**	244	2	0.423	0.407	13.82	15.52	4
1954	1.148	0.312	-0.629	0.069	200	17	2.183	0.890	14.58	17.03	1
1955	0.287	0.143	-0.392	0.072	194	7	2.152	1.394	14.88	15.27	1
1956	0.113	0.058	-0.342	0.097	220	5	0.257	0.208	14.43	15.10	1
1957	0.044	0.029	-0.139	0.074	223	2	0.272	0.230	17.45	18.26	1
1958	0.629	0.157	-0.287	0.039	257	26	2.934	0.779	16.40	17.00	1
1959	0.184	0.062	-0.292	0.060	271	16	0.785	0.256	15.65	17.14	1
1960	0.585	0.309	-0.338	0.087	213	6	2.327	1.582	15.37	16.76	1
1961	0.067	0.035	-0.131	0.062	110	3	0.225	0.142	15.16	17.82	1
1962	0.125	0.148	**-0.327**	**0.023**	78	2	0.279	0.196	15.14	13.51	4
1963	0.517	0.331	-0.370	0.122	125	6	3.146	1.974	15.84	16.08	2
1965	0.057	0.056	-0.233	0.171	132	4	0.320	0.193	14.54	15.49	2
1966	0.381	0.288	-0.336	0.152	213	7	1.382	0.728	16.10	16.57	2
1969	0.167	0.086	**-0.327**	**0.023**	170	2	0.366	0.312	14.71	18.04	4
1972	0.246	0.126	**-0.327**	**0.023**	73	1	0.577	0.577	15.48	15.70	4
1978	5.436	1.652	-0.280	0.037	198	34	35.729	12.459	16.00	16.00	1
1981	21.845	7.563	-0.329	0.045	209	51	84.943	26.113	15.58	17.32	1
1984	2.222	1.560	-0.494	0.112	175	10	9.515	5.751	15.79	16.67	1
1985	0.579	0.192	-0.222	0.113	53	5	2.340	1.188	14.18	14.31	3
1986	10.974	2.634	-0.519	0.271	56	15	30.586	14.484	14.72	16.07	3
1987	46.389	23.731	-0.889	0.121	66	13	83.368	53.892	15.43	14.94	2
1988	2.876	0.963	-0.157	0.097	55	13	9.832	6.776	14.42	16.07	3
1989	1.187	0.551	-0.370	0.100	123	14	4.100	1.887	16.10	17.10	1

1991	0.848	1.075	-0.009	0.209	36	4	6.372	5.911	16.66	16.10	2
1992	0.315	0.390	-0.092	0.127	132	12	1.941	1.653	16.64	16.29	3
1993	0.643	0.236	**-0.327**	**0.023**	57	2	1.623	1.162	14.78	14.66	4
1994	0.094	0.449	**-0.327**	**0.023**	91	1	0.053	0.053	15.24	15.90	4
1995	0.758	0.244	-0.221	0.042	121	11	3.209	1.312	15.61	15.80	1
1996	7.922	2.884	-0.560	0.075	60	9	13.742	8.541	15.12	15.87	1
1997	8.767	4.288	-0.821	0.103	128	13	14.960	10.659	15.98	16.98	1
1998	0.370	0.286	-0.326	0.249	161	7	1.330	0.613	16.27	14.57	2
2001	0.394	0.195	-0.148	0.399	132	3	1.697	1.160	15.22	14.76	1
2003	0.333	0.280	**-0.327**	**0.023**	128	1	0.756	0.756	15.60	14.80	4
2005	0.068	0.052	-0.039	0.076	190	10	2.162	0.842	15.12	15.19	1
2006	0.103	0.305	**-0.327**	**0.023**	147	1	0.245	0.245	13.36	15.10	4
Whole	**1.618**	**0.301**	**-0.327**	**0.023**							

Index
1. Weighted nls for age<=20 d
2. Weighted nls for age<=10 d
3. Unweighted nls for age <=20 d
4. Equation (5) using larval production at length 2.5mm

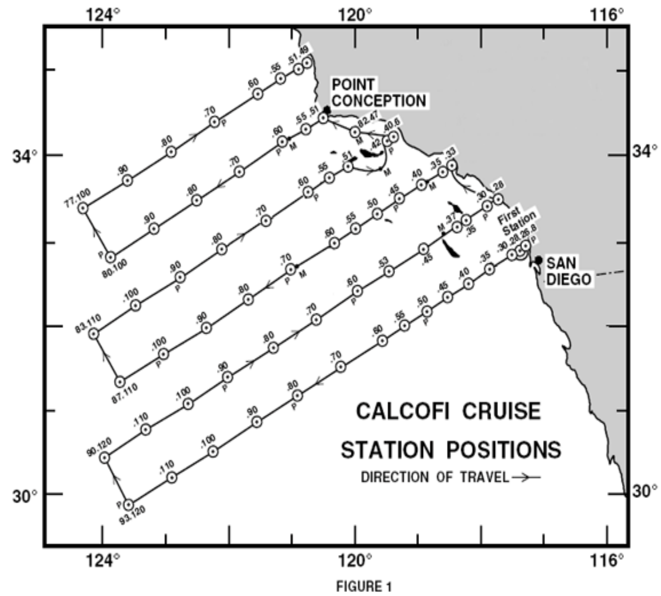


Figure 1. CalCOFI survey area from 1985-present from CalCOFI lines 93.3-76.7

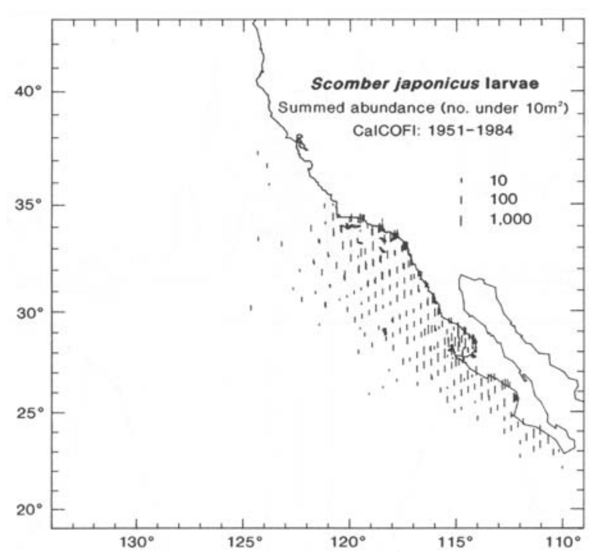


Figure 2.Total Pacific mackerel larval abundance/10m^2 from CalCOFI surveys from 1951-1984 (Moser et al. 1993).

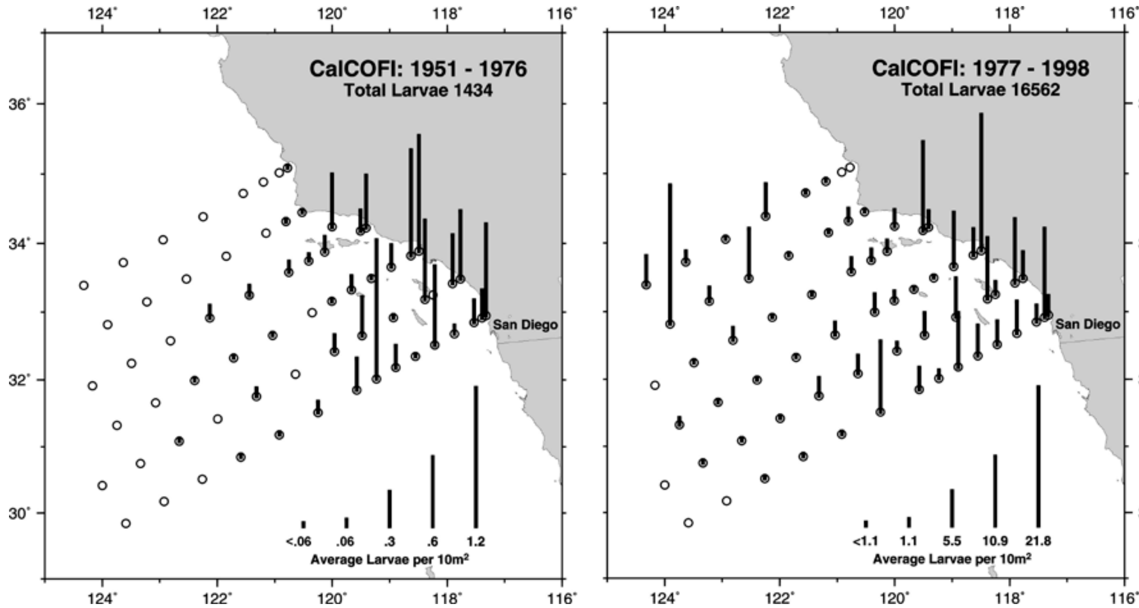


Figure 3. The average Pacific mackerel larvae/10m^2 in the current CalCOFI survey area from 1951-1976 and from 1977-1998 over all cruises (Moser et al. 2001)

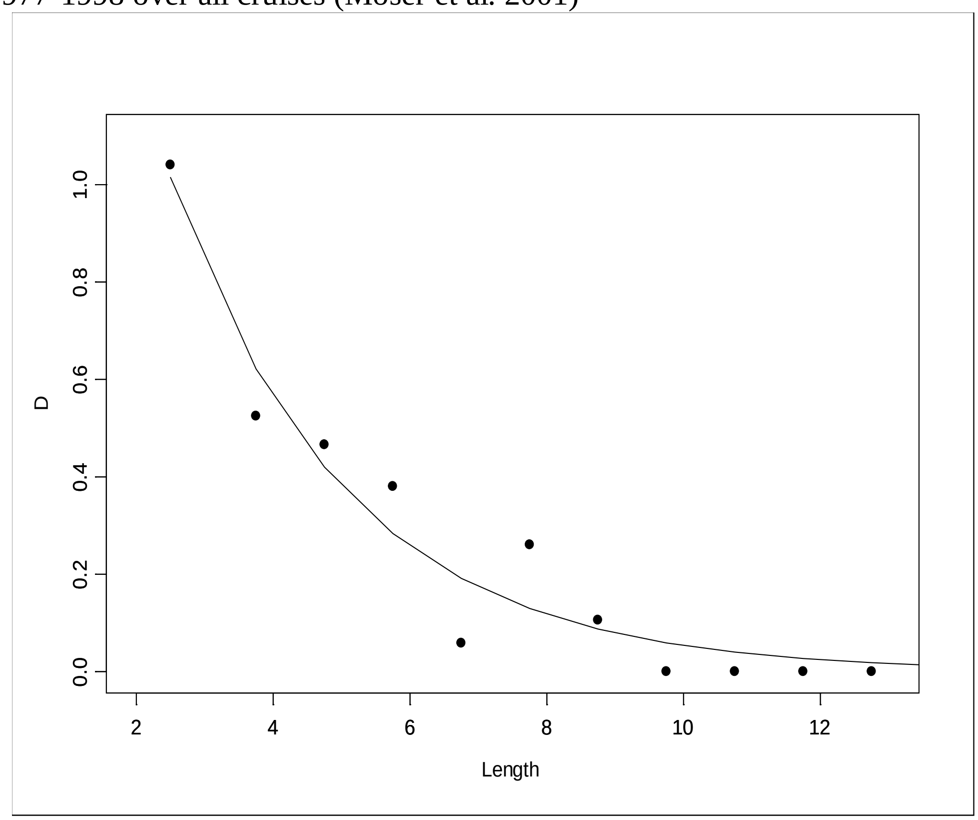


Figure 4: Noon/night catch rates of Pacific mackerel larvae (D) and larval length (mm) based on data of 1951-1978.

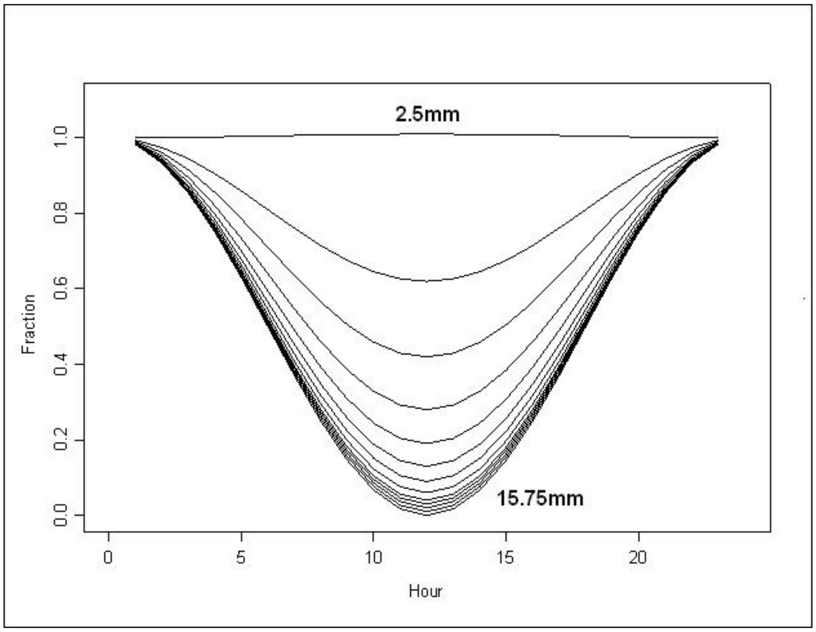


Figure 5. Fraction of Pacific mackerel larvae captured as a function of time of day for 2.5mm-15.75mm.

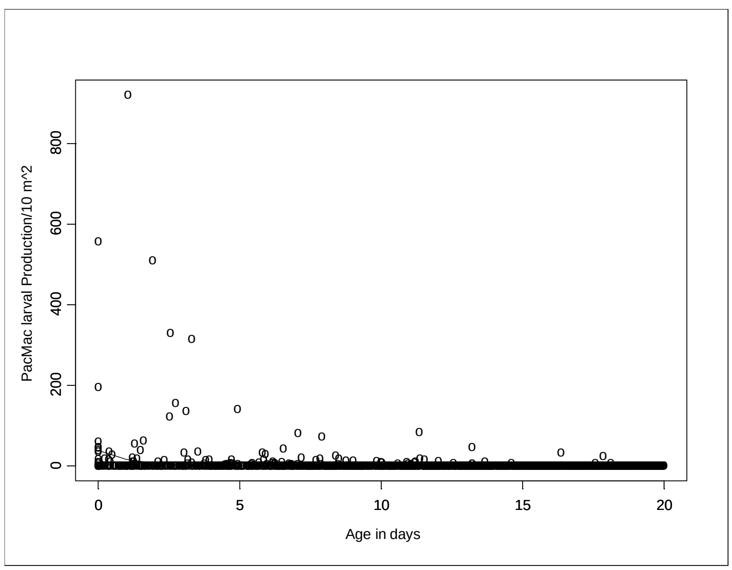


Figure 6: Daily larval production/10m^2 and age with Mortality curve
(p_t=21.84 exp (-.33t)) in 1981.

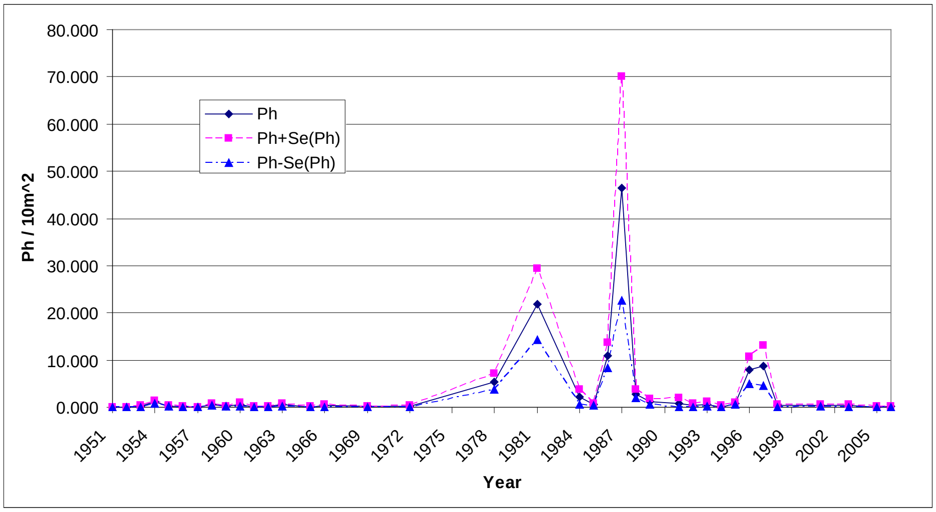


Figure 7: Mackerel larval production /10m^2 at hatching (p_h) off area from San Diego to San Francisco, in April-July from 1951 – 2006.

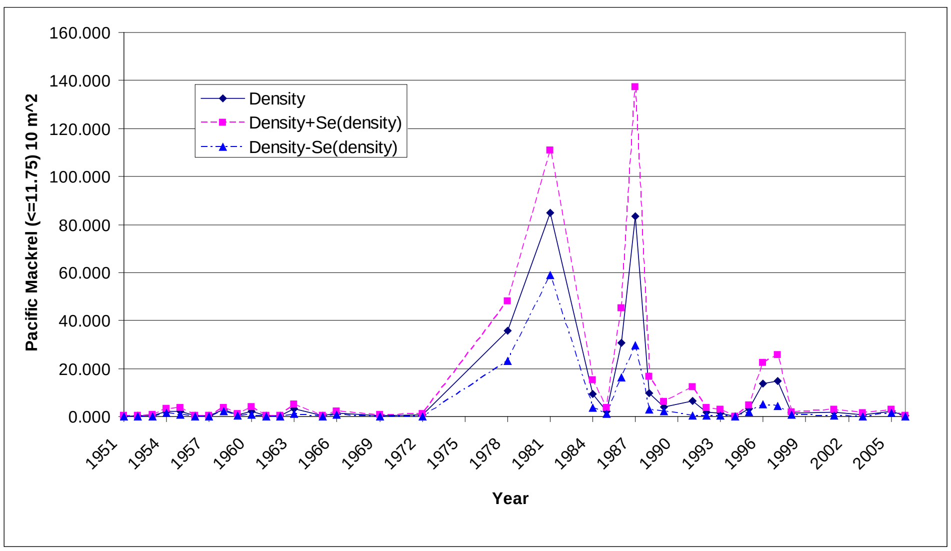


Figure 8: The time series of larval density (number/10m^2) off area from San Diego to San Francisco in 1951-2006.

Appendix 3C

Time series of relative abundance of Pacific mackerel from ichthyoplankton surveys and aerial surveys in 1951-2008

Nancy C. H. Lo and Jane Zhengyu Fan
NOAA Fisheries
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla CA 92037
USA

Introduction

Two time series of relative abundance indices of Pacific mackerel used for the 2007 and 2008 stock assessment (Appendix I and II Dorval et al. 2007 and Crone et al. 2009) were a fishery-independent time series of daily Pacific mackerel larval production at hatching (P_h), and Delta GLM relative abundance based on logbooks of aerial spotter pilots.

The P_h time series was based on data collected during April-July, the peak time of larval densities, from 1951-2006 in the current CalCOFI survey area from San Diego to the north of Point Conception (Figure 1-3; Appendix II). The other abundance index was the time series of Delta GLM relative abundance based on data collected by the spotter pilots hired by fishing vessels off California from fishing years (July-June) 1962-2001(calendar years 1963-2002)(Figure 4, appendix I). The estimation procedures for both time series were described in Dorval et al. (2007) and Crone et al.(2009).The spotter pilot time series has not been updated since 2007, and the original time series from 1962-2001 fishing year was used in the current stock assessment. As to the larval production time series off California, no larvae were observed in 2007 and 2008, therefore the current time series of larval production is basically the original time series plus two zeros for 2007 and 2008

One of concerns of the 2007 STAR panel was about the time series of P_h in that this time series was based larval data collected from the current CalCOFI survey area and it may not be representative of the spawning biomass of the entire Pacific mackerel population, because Pacific mackerel are distributed from Baja California to north of California (Figure 1c). One of the reasons why P_h was constructed only for the current CalCOFI area was the lack of the larval data from Mexico after 1984. We also believe that the P_h in the CalCOFI survey area is likely to be representative of the whole population. To examine possible bias of the time series of P_h from the CalCOFI area and to extend the time series of larval densities of both CalCOFI and Mexican regions to the current time period, we constructed a time series in this report based on available larval data from California and Mexico from 1951-1984 and 1998-2000, with data from Mexico in the later period made available to us in 2008. We also updated the relative abundance from the spotter pilot data from 1962-2001 to 1962-2006 fishing year even though only the time series of 1962-2001 fishing year was used in the stock assessment.

Time series of Larval densities/10m^2 in 1951-1984 and 1998-2000 off California and Mexico

The historical CalCOFI survey covered waters of California and Mexico (Figure 1) from 1951-1984 and annual indexes of larval abundance were examined by MacCall and Prager (1988). Beginning in 1985 the CalCOFI surveys covered only the southern California from San Diego to just north of Point Conception

(Figure 1a and 1d). No systematic ichthyoplankton surveys were conducted off Mexico in 1985-1996 till the establishment of the Investigaciones Mexicanas de la Corriente de California (IMECOCAL) in September 1997 (Baumgartner et al. 2008). IMECOCAL surveys are conducted four times a year, similar to the current CalCOFI survey schedule, to collect ichthyoplankton samples from CalCOFI lines 100-137 and to offshore CalCOFI station 80 (193,000km^2) (Figure 1a). Data of Pacific mackerel larvae from October 1997-January 2001 were provided by Instituto Politécnico Nacional (IPN) Mexico.

Based on historical data, the peak month of larval densities is May off California and August off Mexico. To extend the months to increase sample size for this analysis, we chose months prior and after the peak month: April-July off California and June-September off Mexico (Figure 2). Thus larval data from IMECOCAL in June –September and the current CalCOFI region in April-July, were used to construct a new time series for a large survey area. Because the data from Mexico included only total larvae caught without number of larvae by length group, it was impossible to compute the daily larval production (P_h) as the P_h requires larval counts by length (Appendix II). Therefore we computed a simple weighted mean larval density for each year during the peak larval months. The final mean larvae densities were weighted mean larval densities from these two regions with weights being the survey area size:198,000km^2 and 193,000km^2 for CalCOFI and IMOCOCAL, respectively, for 1951-1984 and 1998-2000 when both areas were covered (Figure 5)

We constructed another time series of the simple mean larval density/10 m^2 in the current CalCOFI area for April- June, 1951-2008 to provide a 'continuity' across the time series of the weighted mean from CalCOFI and IMECOCAL, in the gaps from 1985-1997 and 2001-2008.

Updated GLM relative abundance of Pacific mackerel from 1962-2006

GLM relative abundance from the spotter data (Appendix I) was updated to fishing years 1962-2006 from 1962-2001 to include data from fishery-independent aerial surveys conducted by spotter pilots contracted by the SWFSC in 2004, 2005 and 2007 (Figure 4 and 6).

Results

The time series of weighted mean of larval densities for 1951-1984 and 1998-2001, time series of simple mean larval densities in the IMMECOCAL survey area in the same period and the time series of simple mean for the CalCOFI area from 1951-2008 showed the peak points during 1980s off California and smaller increases in the first half of 1960s (1962 and 1963) and in 1998-2000 off Mexico(Figure 5 and Table 1). During the peak times, 1981 and 1987, larvae were densest in California waters (MacCall and Prager 1988). Lacking data from Mexico in 1987, we know at least larval production was high off California. In the late 1990s, larvae were densest in Mexican waters. Therefore, the spawning area of Pacific mackerel moved between California and Mexico with higher density during peak time off California. Because the larval densities were relative low after 1990s and so were landings off Mexico, data from Mexico may not have much effect on the general trend of the spawning biomass of Pacific mackerel.

To determine whether the time series of the larval production (P_h) in the CalCOFI area was representative for the whole area of California and Mexico, we computed a simple correlation coefficient between P_h off California and the weighted mean off California and Mexico for 1951-1984 (Table 1). The correlation was 0.94 for all years excluding years when no larvae were caught. The correlation (0.23) was low for years with low densities, say P_h <5. Thus, the P_h time series off California captured the high peak years while for years with low larval densities, the two time series did not match well, mainly for years prior to 1965 (Figure 7). Although years of high larval densities may vary between California and Mexico, the magnitude of larval density in California waters was much higher than those in Mexican waters. As it is unlikely to construct a time series for both regions from 1951-present in a timely fashion, the time series of P_h from the current CalCOFI region can serve as a conservative index of spawning biomass for recent years when the population is low, and it does catch the high peak years. The P_h time series is a better index for the spawning biomass than the simple larval density estimates because it estimates the daily larval production at hatching (Appendix II). Note the time series of larval densities for the current CalCOFI survey area corrected for bias due to extrusion and avoidance of the net for 1951-2006 was also included in Appendix II (Figure 8).

For the time series of spotter pilot data (Figure 4,Table 1)), even though only the 1962-2001 time series is used for the stock assessment, we included the data from surveys conducted in 2004,2005 and 2007 in the GLM model adjusted for many factors: day/night (night) , season (April-June), region (region 2, Southern California bight) , pilot (number 17, arbitrary) and survey type (surveys prior to 2002) (Appendix I).This time series from 1962-2006 fishing year indicated that the relative population is still low in recent years. This time series could, theoretically, be included in the future to increase the length of the time series of the relative abundance for the stock assessment.

References.

Baumgartner, T., R. Durazo, B. Larvniegos, G. Gaxiola, J. Gomez and J. Garcia. 2008. Ten years of observations from IMECOCAL observations in the southern region of the California Current Ecosystem. Globec International Newsletter, October, 2008.

Dorval, E., K. Hill, N. Lo, J. McDaniel. 2007. Pacific mackerel (*Scomber japonicus*) stock assessment for U.S. management in the 2007-08 fishing season, submitted to Pacific Fishery Management Council.

Crone, P., K. Hill, N. Lo, J. McDaniel.2009. Pacific mackerel (*scomber japonicus*) stock assessment for usa management in the 2009-10 fishing year.

Lo, N.C.H. 2007. Spotter data analysis for the Pacific mackerel in 1963-2002 using Delta GLM. In Dorval et al. 2007 and Crone et al. 2009. Appendix I

Lo,N. C. H., Y. Huang and E. Dorval. 2007. Daily Larval Production of Pacific mackerel (*Scomber japonicus*) off California in 1951-2006. In Dorval et al 2007 and Crone et al. 2009.Appendix II.

MacCall A. D. and M. H. Prager 1988 Historical changes in abundance of six fish species off southern California based on CalCOFI egg and larva sample. CalCOFI Rep. vol. 29. p91-101

Moser, H.G., R.L. Charter, P.E. smith, D.A. Ambrose, S. R. Charter, C.A. Meyer, E.M. Sandknop and W.

Watson. 1993. Distributional Atlas of fish larvae and eggs in the California Current region: taxa with 1000 or more total larvae,1951through1984. CalCOFI ATLAS no 31. 233p.

.

Table 1. Pacific mackerel daily larval production/10m^2(P_h), weighted mean, simple mean, number of tows (n), relative abundance (REL_ABN) from spotter pilot log book and survey data, and egg densities.

	1. Ph in CalCOFI area				2 Wt mean in CalCOFI and IMECOCAL area			3.Mean in CalCOFI area	
Year	P_h	cv	n	n.pos	wt mean	cv	n	Larvae/10m^2	cv
1951	0.015	1.271	128	6	1.33	0.83	324	0.12	0.45
1952	0.023	0.978	200	7	0.59	0.16	550	0.32	0.48
1953	0.187	0.790	244	2	1.07	0.45	499	0.11	0.96
1954	1.148	0.272	200	17	1.84	0.52	424	0.71	0.37
1955	0.287	0.496	194	7	1.67	0.86	459	0.70	0.62
1956	0.113	0.511	220	5	1.98	1.12	489	0.16	0.52
1957	0.044	0.664	223	2	2.24	0.60	533	0.09	0.86
1958	0.629	0.250	257	26	0.99	0.28	545	1.22	0.27
1959	0.184	0.336	271	16	0.51	0.12	711	0.34	0.29
1960	0.585	0.528	213	6	1.22	0.82	528	0.85	0.63
1961	0.067	0.533	110	3	0.17	0.09	252	0.08	0.59
1962	0.125	0.688	78	2	4.80	2.83	205	0.07	0.70
1963	0.517	0.640	125	6	6.60	3.31	271	0.96	0.57
1964	0	0	204	-	0.46	0.21	340	0.02	1.00
1965	0.057	0.982	132	4	0.46	0.12	405	0.15	0.54
1966	0.381	0.754	213	7	0.77	0.22	562	0.45	0.52
1967	0.000	0.000	60	0	0.70	0.29	170	0.36	0.88
1968	0.000	0.000	56	0	0.00	0.00	110	0.00	0.00
1969	0.167	0.751	170	2	0.27	0.10	467	0.10	0.85
1972	0.246	0.958	73	1	0.33	0.23	176	0.14	1.00
1975	0.000	0.000	202	0	0.04	0.04	383	0.00	0.00
1978	5.436	0.304	198	34	9.85	2.70	468	11.51	0.30
1979	0	0	51	-	0.00	0.00	51	0.00	0.00
1980	0	0	90	-	0.00	0.00	90	0.00	0.00
1981	21.845	0.346	209	51	17.13	4.81	316	30.83	0.30
1982	0.000	0.000	11	0	0.00	0.00	11	0.00	0.00
1984	2.222	0.702	175	10	1.85	0.86	270	2.95	0.55
1985	0.579	0.331	53	5				3.32	0.74
1986	10.974	0.240	56	15				11.12	0.38
1987	46.389	0.512	66	13				32.69	0.53
1988	2.876	0.335	55	13				16.04	0.59
1989	1.187	0.465	123	14				2.19	0.34
1990	0.000	0.000	80	0				0.00	0.00
1991	0.848	1.268	36	4				4.59	0.88
1992	0.315	1.239	132	12				2.31	0.65
1993	0.643	0.699	57	2				0.45	0.72
1994	0.094	2.975	91	1				0.05	1.00
1995	0.758	0.322	121	11				1.46	0.35
1996	7.922	0.364	60	9	2.13	1.31	121	4.24	0.61
1997	8.767	0.489	128	13				4.73	0.67
1998	0.370	0.773	161	7	**4.23**	**2.48**	**301**	0.39	0.44
1999	0.000	0.000	61	0	**2.30**	**1.00**	**204**	0.00	0.00
2000	0.000	0.000	132	0	**3.87**	**1.56**	**280**	0.00	0.00

2001	0.394	0.494	132	3		0.34	0.82
2002	0.000	0.000	114	0		0.00	0.00
2003	0.333	0.915	128	1		0.21	1.00
2004	0.000	0.000	120	0		0.00	0.00
2005	0.068	0.758	190	10		1.23	0.46
2006	0.103	0.932	147	1		0.07	1.00
2007	0.000	0.000	125	0		0.00	0.00
2008	0.000	0.000	30	0		0.00	0.00

4. Biase-correct larval density in CalCOFI area			5. Spotter data from fishing year 1962-2001				6. Spotter data from fishing year 1962-2006		7. Egg density in CalCOFI area from March - Sept 1990-2008			
year	density<= 11.75mm	cv	Fishing YEAR	REL_ABN	CV_RA	BLOCKS	REL_ABN	CV_RA	Year	**eggs/10m^2**	**cv**	**n**
1951	0.15	0.67	1962	461.35	0.52	151	488.16	0.50				
1952	0.26	0.45	1963	1541.53	0.32	186	1591.38	0.31				
1953	0.42	0.96	1964	549.34	0.46	198	579.43	0.44				
1954	2.18	0.41	1965	707.89	0.51	206	740.52	0.50				
1955	2.15	0.65	1966	272.08	0.67	220	286.63	0.66				
1956	0.26	0.81	1967	19.88	0.98	210	20.58	0.97				
1957	0.27	0.85	1968	178.55	1.42	215	184.72	1.42				
1958	2.93	0.27	1969	782.89	1.39	217	817.66	1.38				
1959	0.78	0.33	1970	22.03	2.44	148	23.36	2.43				
1960	2.33	0.68	1971	76.70	0.89	176	79.81	0.88				
1961	0.22	0.63	1972	5.46	2.05	217	5.75	2.05				
1962	0.28	0.70	1973	28.95	2.87	226	30.55	2.87				
1963	3.15	0.63	1975	4.31	3.01	214	4.55	3.01				
1964	0.00	0	1976	15492.54	0.55	242	16225.21	0.54				
1965	0.32	0.60	1977	31112.79	0.28	206	31970.60	0.27				
1966	1.38	0.53	1978	40320.84	0.22	229	41144.15	0.21				
1967	0.00	0.00	1979	44380.55	0.18	214	45256.61	0.17				
1968	0.00	0.00	1980	22164.44	0.15	199	22486.83	0.15				
1969	0.37	0.85	1981	25829.50	0.14	210	26060.76	0.13				
1972	0.58	1.00	1982	36237.16	0.13	251	36694.46	0.12				
1975	0.00	0.00	1983	30524.24	0.27	271	31642.33	0.26				
1978	35.73	0.35	1984	45635.38	0.16	305	46928.21	0.15				
1979	0.00	0	1985	38944.25	0.21	315	40481.34	0.19				
1980	0.00	0	1986	18979.22	0.17	268	19354.60	0.16				
1981	84.94	1.00	1987	12087.23	0.25	295	12351.81	0.25				
1982	0.00	0.00	1988	16673.37	0.30	300	17292.42	0.29				
1984	9.51	0.60	1989	2700.95	0.34	252	2845.31	0.33				
1985	2.34	0.51	1990	5445.68	0.26	276	5657.61	0.25				
1986	30.59	0.47	1991	2391.01	0.27	250	2457.52	0.26				
1987	83.37	0.65	1992	1207.58	0.48	293	1255.72	0.47				
1988	9.83	0.69	1993	1764.32	0.34	328	1937.48	0.32				
1989	4.10	0.46	1994	2097.70	0.56	283	2187.12	0.55				
1990	0.00	0.00	1995	6317.02	0.37	246	6557.24	0.36	1990	3.75	0.60	172
1991	6.37	0.93	1996	1907.85	0.55	255	1991.96	0.53	1991	9.88	0.59	121
1992	1.94	0.85	1997	5050.92	0.35	390	5166.42	0.34	1992	9.23	0.38	154
1993	1.62	0.72	1998	2248.20	0.42	324	2336.47	0.41	1993	14.12	0.41	131
1994	0.05	1.00	1999	1187.88	0.46	332	1239.30	0.45	1994	1.51	0.60	199
1995	3.21	0.41	2000	3230.88	0.42	283	3341.78	0.40	1995	9.13	0.65	121

1996	13.74	0.62	2001	548.80	1.34	306	389.37	1.33	1996	13.97	0.57	131
1997	14.96	0.71	2002			408	0.00	0.00	1997	25.48	0.45	173
1998	1.33	0.46	2003			340	274.97	0.89	1998	18.72	0.34	256
1990	0.00	0.00	2004			297	1353.12	1.05	1999	1.26	0.89	125
2000	0.00	0.68	2005			0		2.59	2000	11.14	0.77	132
2001	1.70	0.00	2006			258	637.22		2001	5.29	0.70	131
2002	0.00	1.00							2002	0.07	1.00	131
2003	0.76	0.93							2003	0.49	0.68	128
2004	0.00	0.00							2004	3.44	0.69	135
2005	2.16	0.39							2005	2.27	1.00	150
2006	0.25	1.00							2006	4.92	0.72	153
2007	0.00	0.00							2007	1.94	0.74	134
2008	0.00	0.00							2008	0.00	0.00	103

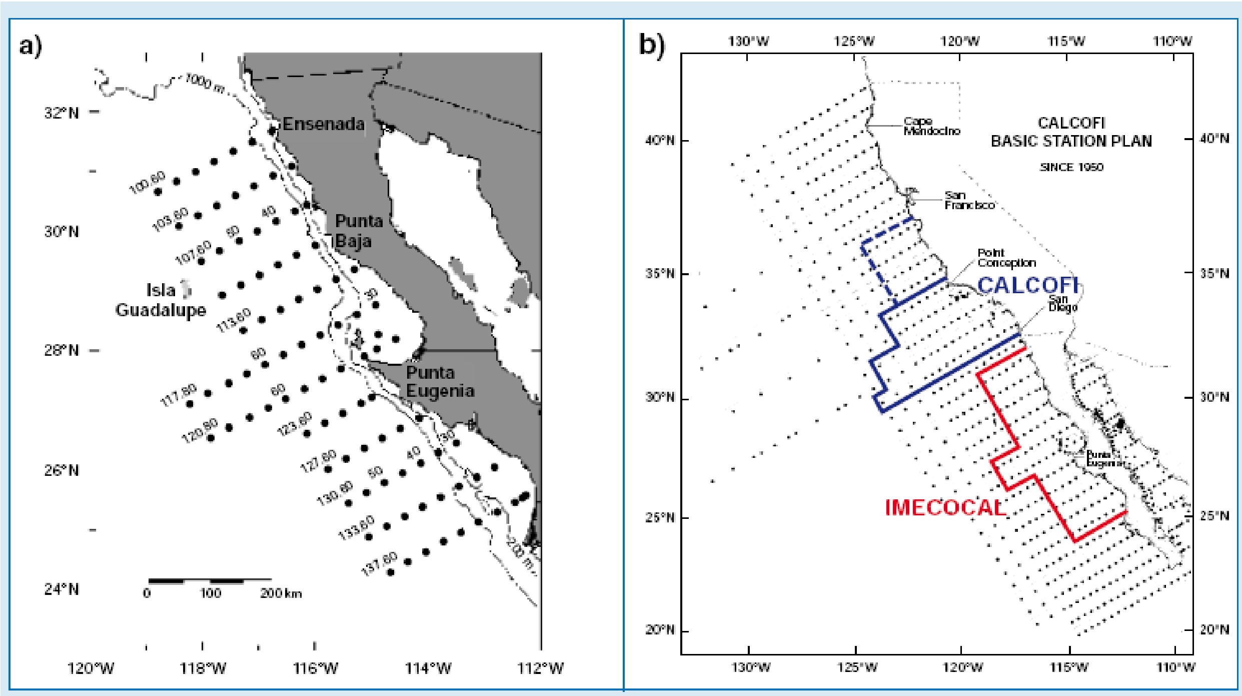


Figure 1 a. IMECOCAL survey with line and station numbers. b. Historical CalCOFI survey area, the current CalCOFI area from San Diego to north of Point Conception, IMECOCAL survey area. The area above the CalCOFI area is the additional survey area for daily egg production method for Pacific sardine (Baumgartner et al. 2008)

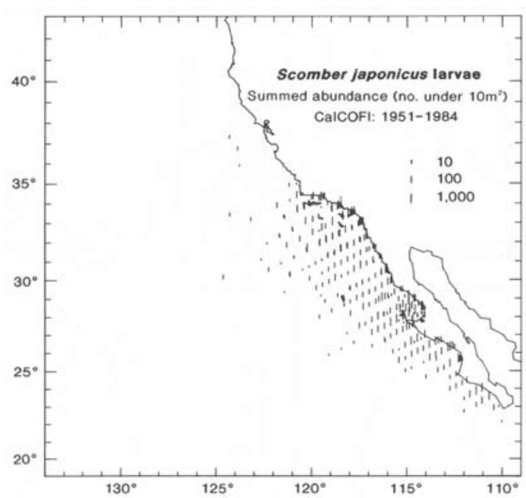


Figure 1c.Total Pacific mackerel larval abundance/$10m^2$ from CalCOFI surveys from 1951-1984 (Moser et al. 1993)

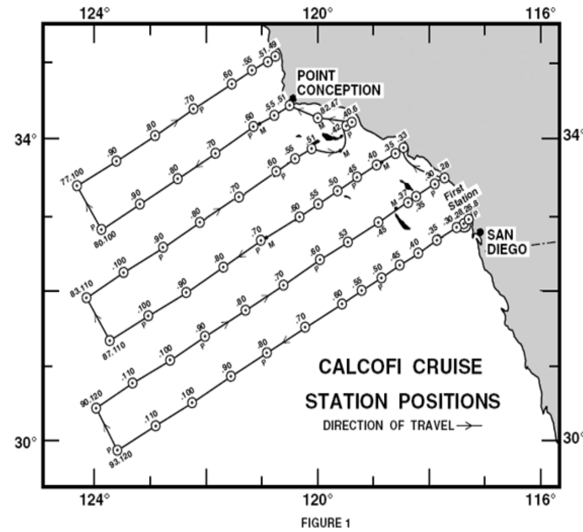


Figure 1d. CalCOFI survey area from 1985-present from CalCOFI lines 93.3-76.7.

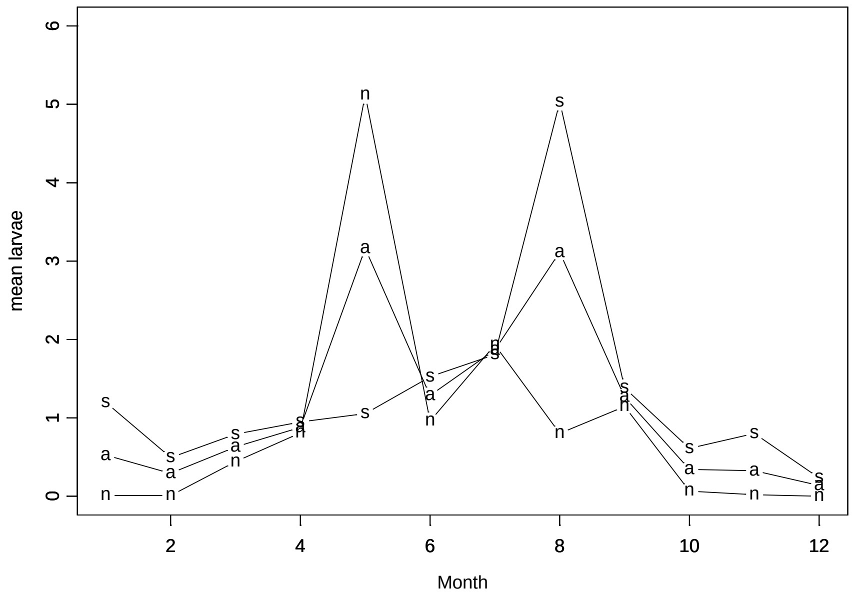


Figure 2. Mean larvae /10m^{2}by month for the north of the US-Mexico boarder (n), south (s), and the historical total CalCOFI survey area (a), from 1951-1984

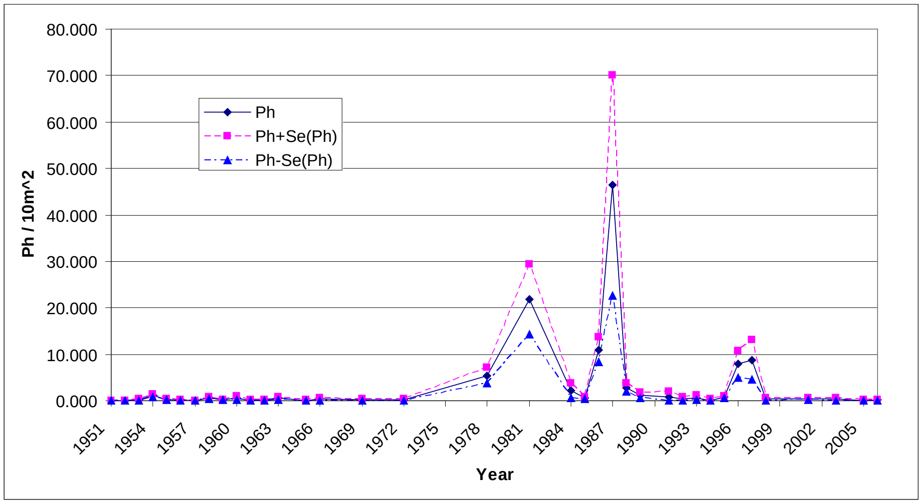


Figure 3: Pacific mackerel larval production /10m^2 at hatching (p_h) off area from San Diego to San Francisco, in April-July from 1951 –2006 (see Appendix II)

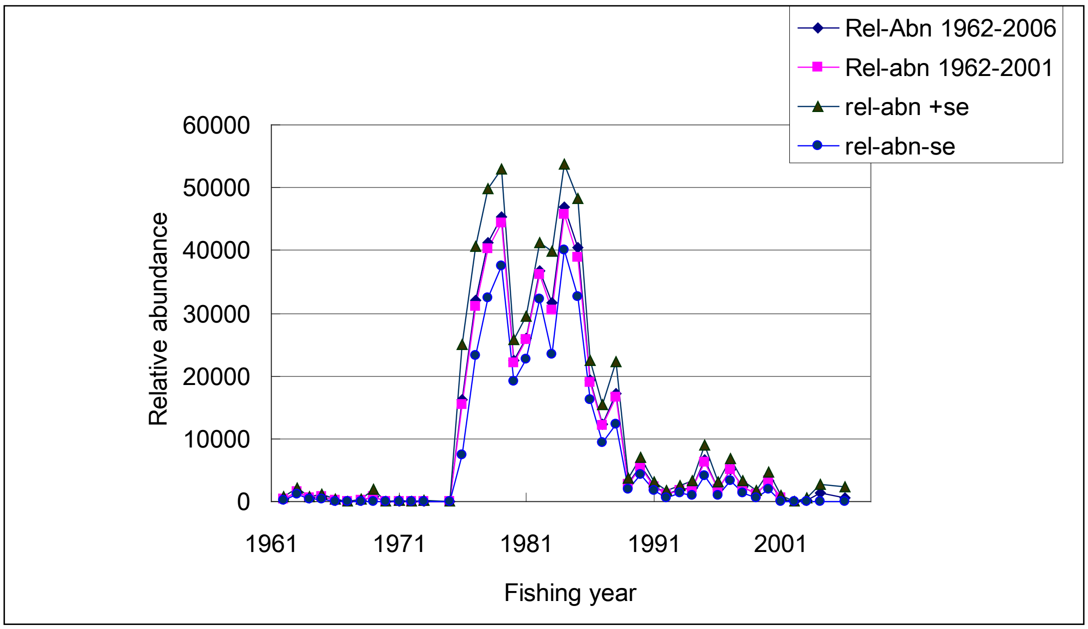


Figure 4: Time series of relative abundance (total tonnage) of Pacific mackerel using GLM from 1962-2001 and from 1962-2006.

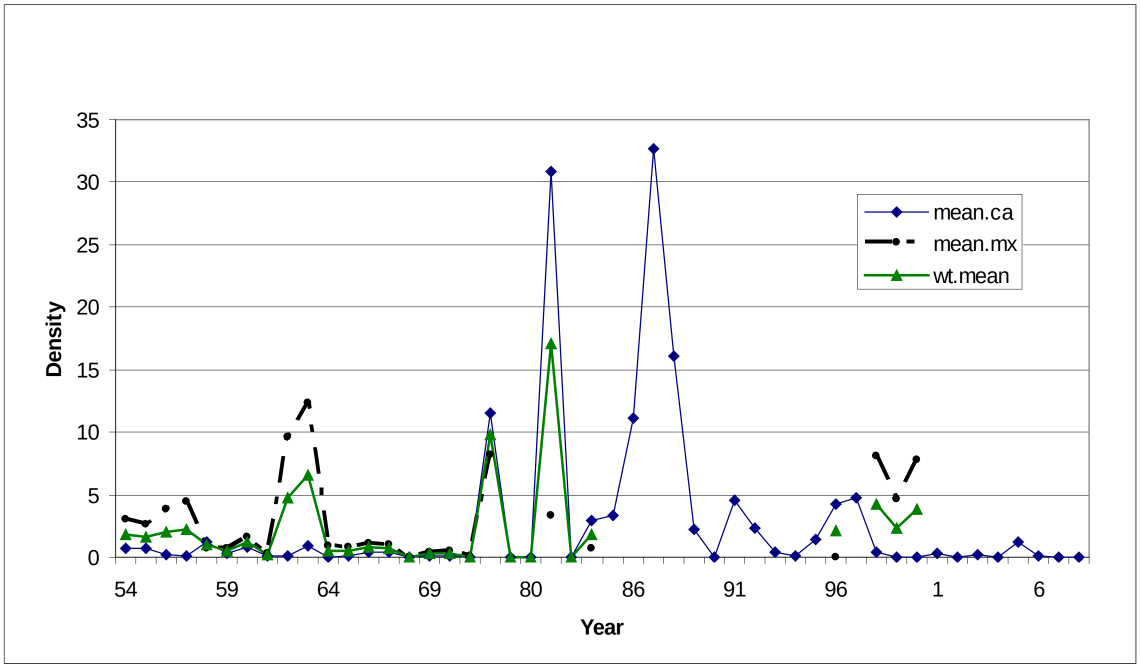


Figure 5. Simple mean larval densities (number of larvae/10 m^2) for current CalCOFI area in April-July (diamond), for IMECOCAL in July-September (circle) and weighted mean larval densities (triangle)

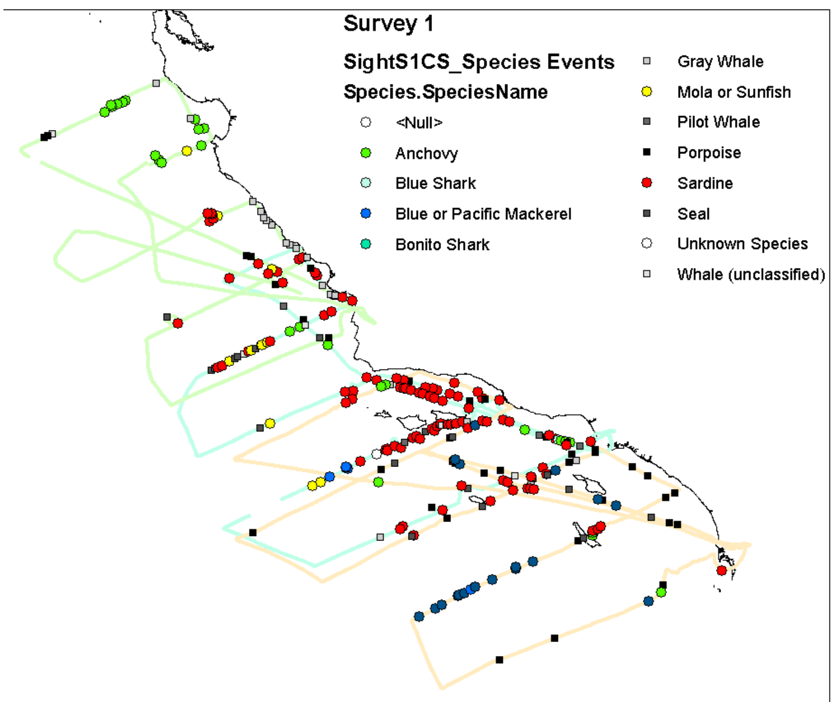


Figure 6. The first fishery-independent aerial survey conducted by three pilots in early March 2004 with sightings of difference fish/mammal

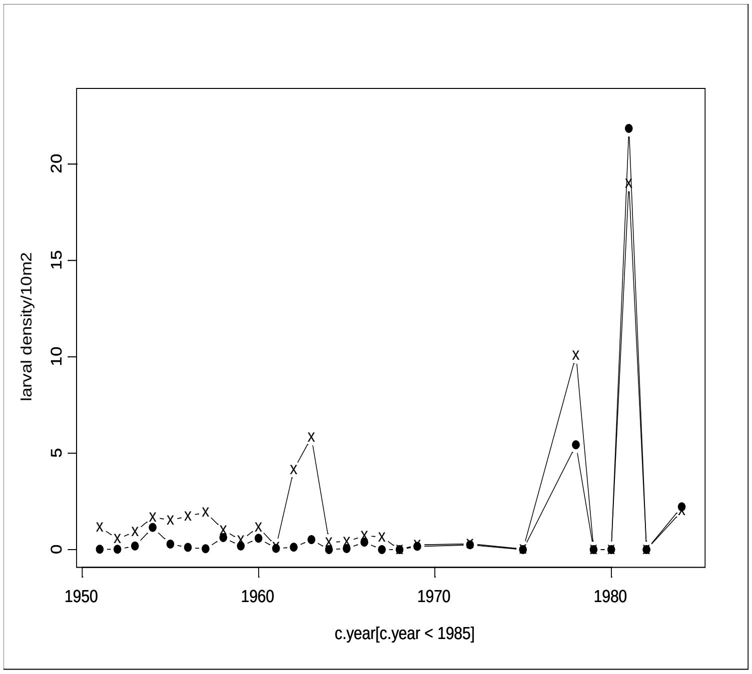


Figure 7. Time series of Pacific mackerel larval production (P_h) off California region (dots) and weighted mean (x) from CalCOFI and IMECOCAL in 1951-1984.

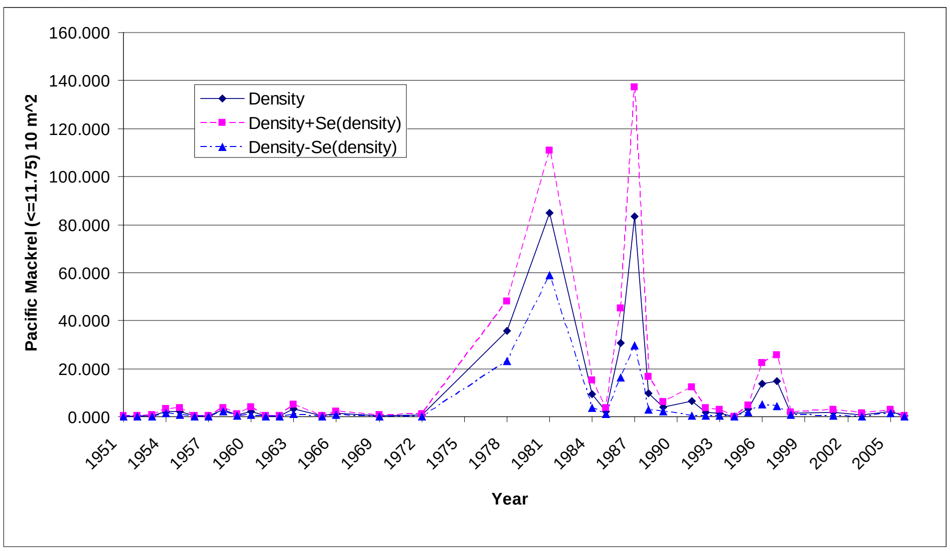


Figure 8: The time series of larval density (number/10m^2) corrected from bias off area from San Diego to San Francisco in 1951-2006 (see Appendix II).