APPENDIX 2

2007 PACIFIC MACKEREL STOCK ASSESSMENT, 2007 STOCK ASSESSMENT REVIEW PANEL REPORT, AND JUNE 2007 SCIENTIFIC AND STATISTICAL COMMITTEE REPORT

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June 2007

PACIFIC MACKEREL (*Scomber japonicus*) STOCK ASSESSMENT FOR U.S. MANAGEMENT IN THE 2007-08 FISHING SEASON

by

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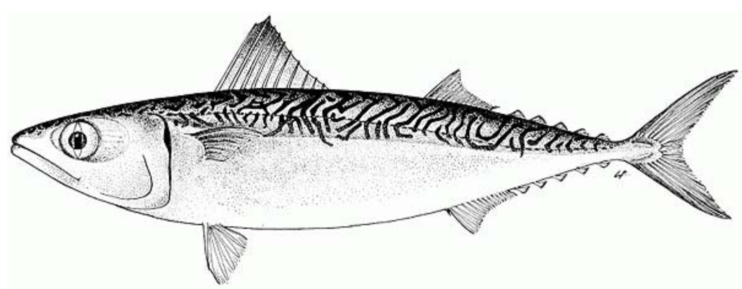

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LIST OF ACRONYMS AND ABBREVIATIONS

ADAPT	adaptive framework (age-structured, 'tunable' VPA)
ADEPT	ADAPT model modified for Pacific mackerel
ADMB	automatic differentiation model builder
ASAP	age structured assessment program
CA	California
CAA	catch-at-age
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CDFG	California Department of Fish and Game
CICIMAR-IPN	Centro Interdisciplinario de Ciencias Marinas – Instituto Politécnico Nacional (La Paz, Baja California, México)
CPFV	commercial passenger fishing vessel (or 'partyboat')
CPS	Coastal Pelagic Species
CPSMT	Coastal Pelagic Species Management Team
CPSAS	Coastal Pelagic Species Advisory Subpanel
CPUE	catch per unit of effort
CTD	Conductivity Temperature Depth instrument
CV	coefficient of variation
FMP	fishery management plan
GAM	generalized additive model
GLM	generalized linear model
GUI	graphical user interface
HG	harvest guideline
IMECOCAL	Investigaciones Mexicanas de la Corriente de California
CRIP-INP	Centro Regional de Investigación Pesquera – Instituto Nacional de la Pesca
MSY	maximum sustainable yield
MX	Mexico
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PFMC	Pacific Fishery Management Council
Ph	Larval production at hatching
RecFIN	Recreational Fishery Information Network
SAFE	Stock Assessment and Fishery Evaluation document
SCB	Southern California Bight
SS2	Stock Synthesis 2 (population assessment model)
SSB	spawning stock biomass
SSC	Scientific and Statistical Committee
STAR	Stock Assessment Review (Panel)
STD	Standard Deviation
SWFSC	Southwest Fisheries Science Center (NMFS)
VPA	virtual population analysis
WAA	weight-at-age

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 U.S. 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 (i.e., a 'fishing year' basis). 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 process was completed in May 2006—setting a 2006-07 'fishing year' (July1, 2006 – June 30, 2007) quota of 19,845 mt. In May 1-4, 2007, the PFMC, in conjunction with NOAA Fisheries (Southwest Fisheries Science Center), organized a Stock Assessment Review (STAR) in La Jolla, California, to provide external peer review of the methods used for assessment of Pacific mackerel. The following assessment report was initially prepared in draft form for the STAR Panel' consideration, and is updated here for the PFMC's current management cycle. The STAR Panel Report for Pacific mackerel (PFMC 2007) included recommendations for improving the input data, model configuration and selection. Many of these recommendations are incorporated into this updated 2007 assessment which, ultimately, is to be reviewed by the Science and Statistical Committee (SSC) of the PFMC in June 2007. Finally, in May 8-10, 2007, the assessment presented here was reviewed by the PFMC's CPS Management Team (CPSMT) and the CPS Advisory Subpanel (CPSAS). Electronic versions of model programs, input data, and displays (tables and figures) can be obtained from the authors directly.

EXECUTIVE SUMMARY

Stock

Pacific mackerel (*Scomber japonicus*) in the northeastern Pacific range from southeastern Alaska to Banderas Bay (Puerto Vallarta), Mexico, including the Gulf of California. They 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 U.S. and Mexico: one in the Gulf of California, one in the vicinity of Cabo San Lucas, and one extending along the Pacific coast north of Punta Abreojos, Baja California. The latter "northeastern Pacific" stock is harvested by fishers in the U.S. and Baja California, Mexico, and is considered in this assessment.

Catches

Catches in the assessment were a combination of U.S and Mexico commercial catches and U.S recreational catches. The Mexican commercial fishery for Pacific mackerel is primarily based in Ensenada and Magdalena Bay, Baja California. The Mexican purse seine fleet has slightly larger vessels, but is similar to southern California's with respect to gear (mesh size) and fishing practice. Demand for Pacific mackerel in Baja California increased in the late 1940's. Mexican 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 were then negligible until the early-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.

Table of catches (1996-2006).

Fishing Year	USA - Commercial Catch (mt)	Mexico- Commercial Catch (mt)	Recreational - CPFV Catch (mt)	Recreational - non-CPFV Catch (mt)	Total Catch (mt)
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	5,728	28	295	12,023
04	5,012	5,624	23	537	11,195
05	4,572	8,024	13	543	13,151
06	8,192	8,024	5	403	16,623

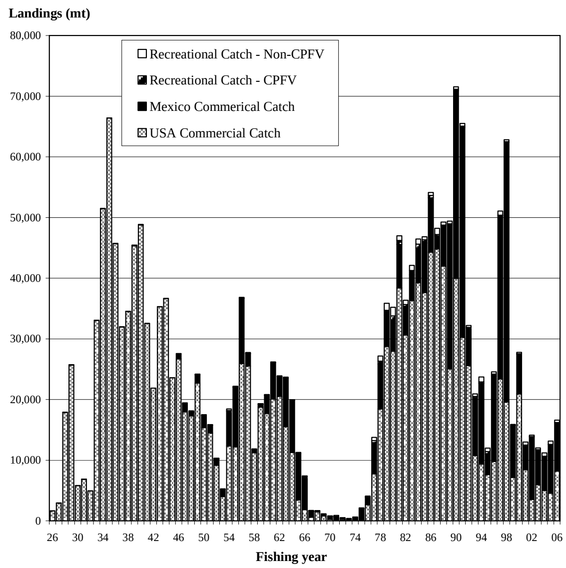

Figure of commercial and recreational landings (mt) of Pacific mackerel in California (CA) and Baja California (MX), from 1926-06.

Data and assessment:
The last assessment of Pacific mackerel was completed in 2006 for U.S. management in the 2006-07 fishing year. The current assessment includes catch data (1926-2006), Aerial spotter survey index data (1963-2001), CPFV recreational CPUE (1935-2006), and CalCOFI larval production at hatching (1951-2006). The final model, recommended by the 2007 STAR Panel, integrates these data into an Age-Structured-Assessment Program (ASAP, V.1.3.2). However, the assessment consists of several ASAP model scenarios (to ensure continuity with previous assessment and one Stock Synthesis (V.2.00c) model scenario that was not supported by the STAR Panel.

Unresolved Problems and Uncertainties:
The assessment suffers from a lack of biological and relative abundance data from Mexico. In particular, there is currently no true fishery-independent index of relative abundance for the whole stock. Further, despite close agreement of many of the outputs from the ASAP and SS2 model runs (i.e., additional model runs performed during the STAR Panel), diagnostics and outputs from the SS2 modeling runs revealed that SS2 model invariably ran up against the harvest rate limit in a number of years. This problem could not be resolved during the STAR, and the Panel and the stock assessment team (STAT) agreed that an updated version of the ASAP should form the basis of this assessment. Nevertheless, the Panel recommended that future stock assessments continue to examine the possibility of using SS2 as an alternative to the ASAP platform. Although analyses presented to the Panel suggested that SS2 and ASAP lead to similar outcomes when configured in a similar manner, SS2 deals better with indices that are not tied to a fishery, can include age-reading error, and allows weight-at-age in the catch to differ from weight-at-age in the population.

Spawning Stock Biomass
After a period of low abundance (1940-1977) spawning stock biomass (SSB) increased in the late 1970s reaching a peak of 662,372 mt in 1982. Since 1982 SSB has declined, reaching an estimate of 86,777 mt in 2007. A table of SSB estimated in the last 10 years is presented below.

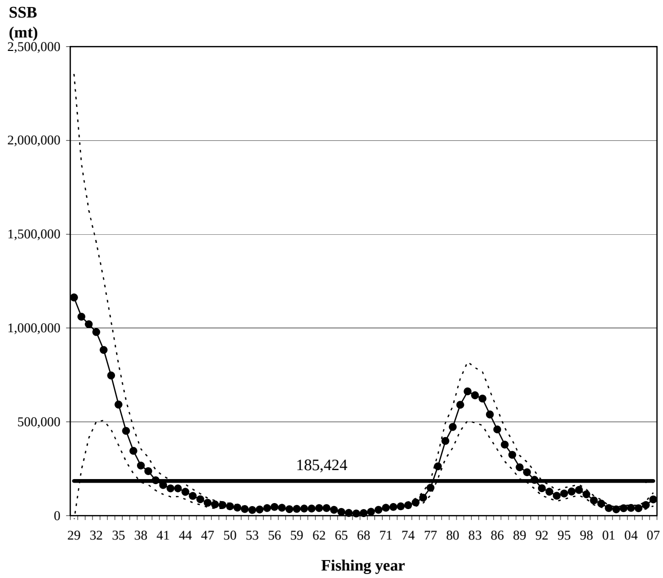

Figure of estimated spawning stock biomass (SSB, in mt) of Pacific mackerel generated from the ASAP-E1 model (1929-07). The confidence interval (± 2 STD) associated with this time series is also presented. Estimated 'virgin' SSB (185,424 mt) from stock-recruit relationship is presented as a bold horizontal line.

Recruitment
Recruitment was modeled following a standard Beverton & Holt stock-recruit relationship. Steepness was estimated to be 0.31 and Sigma-R (σ_R) was fixed to 0.7. Predicted recruits in the model showed large year classes in 1976, 1978, and 1980-1982, but low level of recruitment throughout the 1990s and the early 2000s. The number of recruits estimated by the model is presented in a table below.

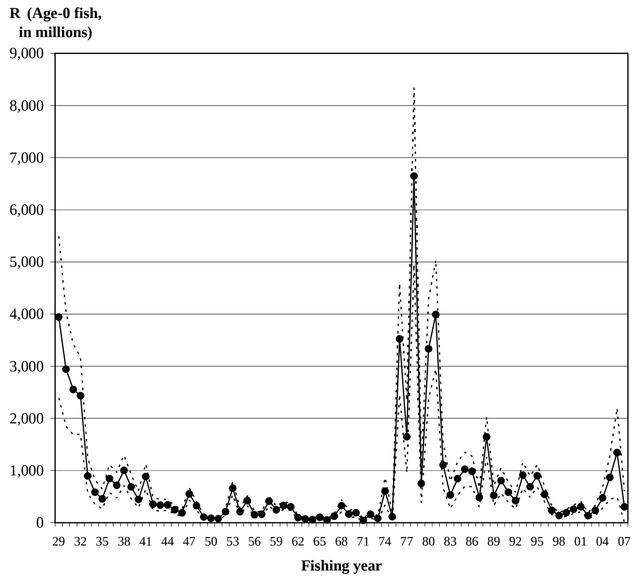

Figure of estimated recruitment (age-0 fish in millions, R) of Pacific mackerel generated from the ASAP-E1 model (1929-07). The confidence interval (± 2 STD) associated with this time series is also presented.

Management performance

Since 2000 Pacific mackerel has been managed based on a Federal Management Plan (FMP) harvest policy, stipulating that maximum sustainable yield (MSY) control rule for this species should be set to an Harvest Guideline (HG):

HARVEST = (BIOMASS-CUTOFF) x FRACTION x STOCK DISTRIBUTION,

where HARVEST is the HG, CUTOFF (18,200 mt) is the lowest level of estimated biomass at which harvest is allowed, FRACTION (30%) is the fraction of biomass above CUTOFF that can be taken by fisheries, and STOCK DISTRIBUTION (70%) is the average fraction of total BIOMASS (Ages 1+) assumed in U.S. waters (PFMC 1998). Harvest guidelines under the federal FMP are applied to a July-June fishing season.

Age 1+ Biomass was low from the late 1940s to the early 1970s, reaching a peak in 1982, and since then generally declined reaching 359,290 mt in 2007. However, landings of Pacific mackerel have been consistently below the HGs since 2001.

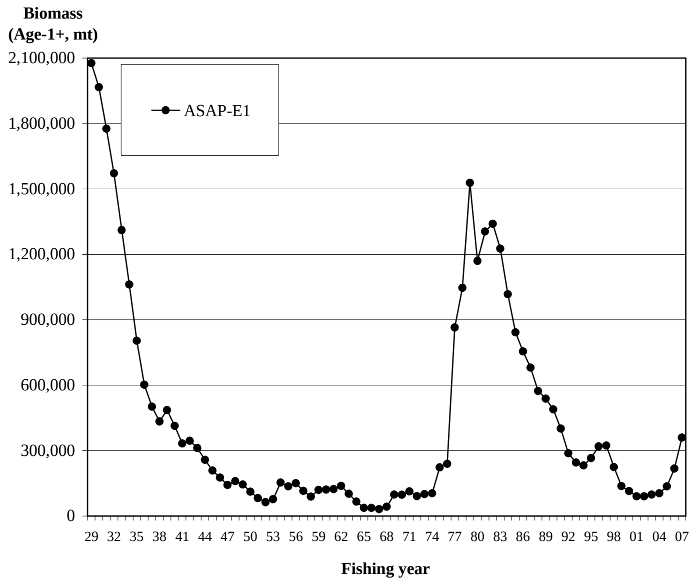

Figure of estimated biomass (Age-1+ fish, in mt) of Pacific mackerel generated from the ASAP-E1 model (1929-07).

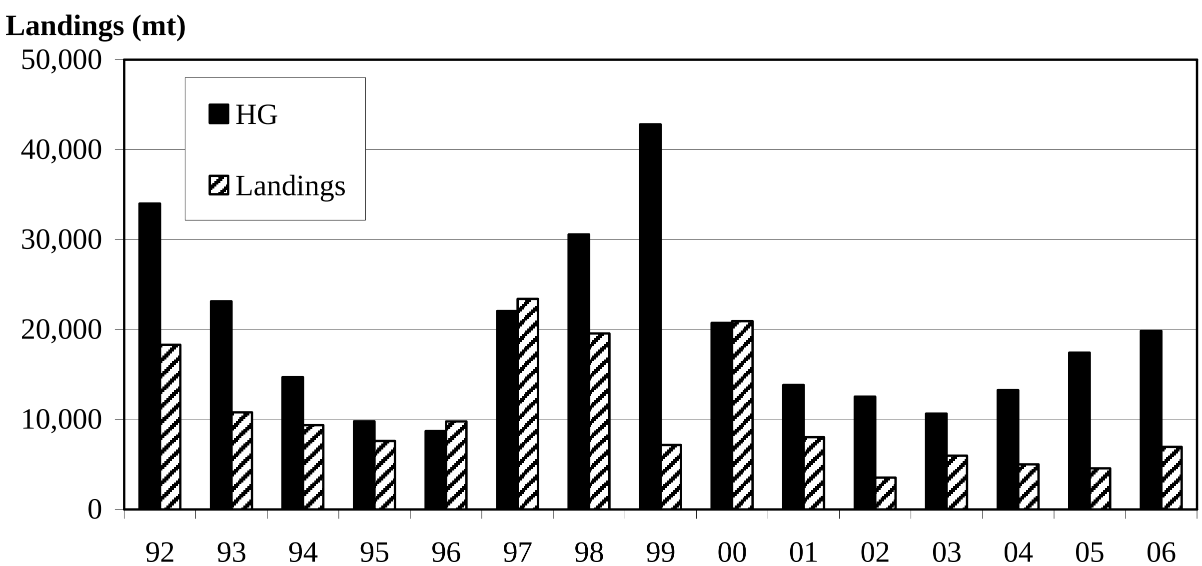

Figure of commercial landings (California directed fishery in mt) and quotas (HGs in mt) for Pacific mackerel (1992-06 Fishing seasons).

Table of estimated recruitment, Age 1+ biomass and spawning stock biomass (1996-2007)

Fishing Year	Recruits (Age-0)	Biomass (Age-1+)	SSB
96	541,059	319,197	128,394
97	235,404	323,042	137,003
98	135,354	224,066	113,751
99	190,579	137,303	81,273
00	255,315	113,862	64,071
01	305,743	90,098	40,164
02	133,326	90,134	33,739
03	233,929	98,091	39,714
04	472,241	104,183	41,169
05	866,391	135,903	39,433
06	1,343,580	217,724	56,496
07	302,694	359,290	86,777

Harvest Guideline for the 2007-08 Fishing Season

Biomass (Age-1+)	Cutoff (mt)	Fraction	Distribution	2007-08 Harvest Guideline (mt)
359,290	18,200	30%	70%	71,629

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 10.0 - 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): northerly movement in the summer is 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 CPS, particularly jack mackerel and Pacific sardine.

During the last two decades, the stock has more fully occupied the northernmost portions of its range in response to a warm oceanographic regime in the northeast Pacific Ocean, and Pacific mackerel have been found as far north as British Columbia, Canada (Ware and Hargreaves 1993; Hargreaves and Hungar 1995). During summer months, Pacific mackerel have become common incidental catch in commercial whiting and salmon fisheries off the Pacific northwest. In addition, they are taken by recreational anglers on CPFVs. Pacific mackerel sampled from Pacific northwest incidental fisheries are generally older and larger-at-age than those captured in the southern California fishery (Hill 1999).

Life History

Pacific mackerel found off the Pacific coast of the U.S. is the same species found elsewhere in the Pacific, Atlantic, and Indian oceans (Collette and Nauen 1983). Synopses of the biology of Pacific mackerel are available in Kramer (1969) and Schaefer (1980).

There are possibly three spawning stocks in the northeastern Pacific: one in the Gulf of California, one near Cabo San Lucas, and one along the Pacific coast north of Punta Abreojos, Baja California. Spawning occurs from Point Conception, California to Cabo San Lucas, from three 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 mackerel have been recently reported as far north as Oregon and Washington.

Like most coastal pelagic species, Pacific mackerel have indeterminate fecundity and seem to spawn whenever sufficient food is available and appropriate environmental 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 every day 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.

Dynamics of the Pacific mackerel population have been thoroughly described by Parrish and MacCall (1978). Pacific mackerel experience cyclical periods of abundance ('boom-bust') typical of other small pelagic species (e.g. sardine, anchovy) with short life spans and high intrinsic rates of increase. Analyses of mackerel scale-deposition data (Soutar and Issacs 1974) indicate 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). Pacific mackerel recruitment is variable over space and time, and loosely linked to spawning biomass. Reproductive success, measured as spawning biomass divided by number of recruits, is highly variable and somewhat cyclic, with periods of roughly three to seven years.

Stock Structure and Management Units

There are possibly three spawning stocks along the Pacific coasts of the U.S. and Mexico: one in the Gulf of California, one in the vicinity of Cabo San Lucas, and one extending along the Pacific coast north of Punta Abreojos, Baja California (Collette and Nauen 1983; Allen et al. 1990; MBC 1987). The latter "northeastern Pacific" stock is harvested by fishers in the U.S. and Baja California, Mexico, and is considered in this assessment.

The PFMC manages the northeastern Pacific stock as a single unit, with no area- or sector-specific allocations. The PFMC's harvest control rule does, however, prorate the seasonal HG by a 70% portion assumed to reside in U.S. waters (PFMC 1998).

Fishery Description

Pacific mackerel are currently harvested by three fisheries: the California commercial fishery, a sport fishery based primarily in southern California, and the Mexican commercial fishery 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. There is no directed fishery for mackerel in Oregon or Washington, however, small amounts (100-300 $mt \cdot yr^{-1}$) are taken by whiting trawlers and salmon trollers. Pacific northwest catch 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 again in the 1980s and 1990s. During the early 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 a decline in demand, and then rose to a peak of 66,400 mt in 1935-36. During this period, Pacific mackerel was second only to Pacific sardine in annual landings. Harvests subsequently underwent a long-term decline and, for many years, demand for canned mackerel was 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 the mackerel population recovery in the late 1970s, the moratorium was lifted and the fishery subsequently ranked third in volume of California finfish landings through the 1990s. 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 often taken by recreational anglers in considerable numbers, though seldom as a target species (Young 1969). During 1980 through 1989, California's recreational catch averaged 1,500 mt per year and Pacific mackerel was numerically the most important species taken in the California CPFV fleet during the period of 1978 through 1989. Pacific mackerel is also harvested in California's recreational fishery as bait for directed fishing on larger pelagic species. Pacific mackerel is also caught by anglers in central California but in very modest amounts. The statewide sport harvest constitutes a small fraction (two to four percent by weight) of the total landings.

The Mexican fishery for Pacific mackerel is primarily based in Ensenada and Magdalena Bay, Baja California. The Mexican purse seine fleet has slightly larger vessels, but is similar to southern California's with respect to gear (mesh size) and fishing practice. The fleet operates in the vicinity of port and also targets other small pelagic species. Demand for Pacific mackerel in Baja California increased after World War II. Mexican 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 were then negligible until the early-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 in 1970, with a small allowance for incidental catch in mixed loads. In 1972, legislation was enacted which imposed a landing quota based on the age one-plus biomass. A series of successful year classes in the late 1970s initiated a recovery, and the fishery was reopened under a quota system in 1977. During the recovery period from 1977 to 1985, various adjustments were made to quotas for directed take of Pacific mackerel and to incidental catch limits.

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 percent during moratoriums. The fishing season was set to extend from July 1 to June 30 of the following year. Seasonal quotas, equal to 30 percent 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 CPS, 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 MacCall et al.'s (1985) simulation analyses, with the addition of a proration to nominally account for stock assumed in U.S. waters. The current maximum sustainable yield (MSY) control rule for Pacific mackerel is:

HARVEST = (BIOMASS-CUTOFF) x FRACTION x STOCK DISTRIBUTION,

where HARVEST is the HG, CUTOFF (18,200 mt) is the lowest level of estimated biomass at which harvest is allowed, FRACTION (30%) is the fraction of biomass above CUTOFF that can be taken by fisheries, and STOCK DISTRIBUTION (70%) is the average fraction of total BIOMASS (Ages 1+) assumed in U.S. waters (PFMC 1998). Harvest guidelines under the federal FMP are applied to the same July-June fishing season initially established by California.

California's recreational catch of Pacific mackerel is included within the U.S. HG, but there are no other restrictions (e.g. size or bag limits) on this fishery. Total annual harvest of Pacific mackerel by the Mexican fishery is not regulated by quotas, but there is a minimum legal size limit of 255 mm. International management agreements between the U.S. and Mexico have not yet been developed.

Management Performance

From 1985 to 1991, the biomass exceeded 136,000 mt and no state quota restrictions were in effect. State quotas for 1992-93 through 1999-00 fishing seasons averaged roughly 24,000 tons. More recently, HGs have been lower, generally below 15,000 mt. The HG established for 2006-07 was 19,845 mt (Crone et al. 2006), from which only 6,956 mt were landed as of Feb. 2007. From a management context, the fishery has failed to fully utilize seasonal HGs since 2001-02. Average yield since 2001-02 has been 5,680 mt (Table 1).

ASSESSMENT

Biological Data

Weight-at-length

Pacific mackerel weight-at-length was modeled using port sample data collected by CDFG from 1962 to 2006 (see '**Fishery Data**' section). The following 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-at-length parameters estimated for the 1962-2006 period were: a = 3.12517E-06 and b = 3.40352 (n = 95,761; Corr. R^2 = 0.971). To account for changes in weight-at-length over time, parameters were estimated for specific time periods and applied as time-varying parameters (five time blocks) in SS2. See Table 2 for time-specific parameters.

Growth

The von Bertalanffy growth equation was used to model the relationship between fork length (cm) and fractional age (nominal age + 0.5) for Pacific mackerel collected by the CDFG from 1962 to 2006:

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

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 the fish would have been zero length. The best estimate of von Bertalanffy parameters for Pacific mackerel was: L_∞ = 39.3 mm, K = 0.342494, and t_o = -1.75187 (n = 95,761; Corr. R^2 = 0.732). To account for changes in growth over time, parameters were estimated for specific time periods and applied as time-varying parameters (five time blocks) in SS2. See Table 2 for time-specific parameters.

Maximum Age and Size

The largest recorded Pacific mackerel was 63.0 cm FL and weighed 2.9 kg (Hart 1973; Roedel 1938), 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 four years old.

Maturity Schedule (ASAP)

Normalized net fecundity-at-age (fraction mature x spawning frequency x batch fecundity; Table 3) was used to interpret CalCOFI ichthyoplankton data and calculate spawning stock biomass (SSB) in this assessment. Fraction mature was estimated by fitting as logistic regression model to age and fraction mature data in 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}, all ages and both sexes, for all ASAP and SS2 model runs. 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). They considered the regression of *Z* on *f* to be the most reliable method, and the estimate (*M* = 0.5) falls within the mid-range of other estimates.

As requested by the 2007 STAR Panel, a series of ASAP models were run to test sensitivity to a range of natural mortality rates. Results of these runs are discussed in the 'Uncertainty and Sensitivity Analyses' section. No changes to the *M*=0.5 assumption were indicated. So, for purposes of this assessment, the annual rate of natural mortality (*M*) was fixed 0.5 yr^{-1}, which means that 39% of the stock would die of natural causes each year in the absence of fishing (Parrish and MacCall 1978).

Fishery Data

Overview

Fishery data for assessing Pacific mackerel include landings (California commercial, California recreational, and Mexico commercial), and port sample (biological) data from California's commercial fishery. CDFG has collected biological data on Pacific mackerel landed in southern California fishery (primarily San Pedro) since 1929. Samples have also been collected from the Monterey fishery when available. For this assessment, raw sample data were available from 1939 through 2006. Biological samples include whole body weight, fork length, sex, maturity, and otoliths for age determination. CDFG currently collects 12 random port samples per month (25 fish per sample) to determine age composition and weights-at-age for the directed fishery. Mexican port sampling data have been collected by INP-Ensenada since 1989, but were not available to the authors, so California commercial data are 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 Mexican catches are low. However, in recent years Baja California and California catches have been roughly equal in volume, so lack of Mexican data may affect results. A listing of CDFG sample sizes relative to total landings from 1939-40 to present is provided in Table 4.

Pacific mackerel were aged by CDFG biologists using annuli in whole sagittae. Historically, a birth date of May 1 was used to assign year class (Fitch 1951). For reasons unknown, the protocol changed to a July 1 birthdate in 1976-77 (when the resource rebounded and fishery sampling resumed). This change coincided with a change in the management season from a May 1 opening to July 1 opening.

Fishery inputs were compiled by 'biological year' based on the birthdates used to assigned age. Therefore, data prior to 1976-77 were aggregated in the 'biological year' of May 1 ($year_x$) through April 30 ($year_{x+1}$), and data from 1976-77 forward were aggregated July 1 ($year_x$) through June 30 ($year_{x+1}$). The 'biological year' used in this assessment is also synonymous with the 'fishing year' referred to in this document and with 'fishing season' as reported in the historical literature. That is, the change in birthdate assignment from May 1 to July 1 coincided with a change in the management season in the mid-1970s, and historical sources of landings and biological data reflect this change.

Landings

The assessment uses commercial and recreational landings in California and commercial landings in Baja California from 1926-27 through 2006-07. Seasonal aggregate landings are presented in Table 5 and Figure 1.

California commercial landings of Pacific mackerel were obtained from a variety of sources based on dealer landing receipts (CDFG), in some cases augmented with port sampling for mixed load portions. Data from 1926-27 to 1961-62 were obtained from Parrish and MacCall (1978). Monthly landings for the period May 1962 to Sept. 1976 were obtained from CDFG fish bulletins recovered to an electronic database format (PFEL 2005). Raw landing receipt data for Pacific mackerel from 1976 to 1991 are 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. 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 present are as follows: Oct – Dec 1976 are from Klingbeil and Wolf (1986); Jan - Dec 1977 are from Wolf and Worcester (1987); Jan 1978 – Dec 1981 are from Jacobson et al. (1994a); Jan 1982-Feb 2007 are from CDFG Wetfish Tables. Landings for March-June 2007 were substituted with corresponding months from 2006. Pacific mackerel landings from 1976-1981 were only reported by quarterly increments so, for purposes of weighting catch-at-age estimates for this period (following section), we apportioned quarters to months using monthly 'unspecified mackerel' landings from the PFEL LAS database (PFEL 2005).

California recreational landings (mt) from 1980 to 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 & Schneider 1999). CPFV catch (number) was converted to metric tons using and assumed average weight of 0.453 kg (1 lb.) per individual, based on RecFIN samples and consistent with Parrish and MacCall (1978). CPFV tonnage was expanded to total recreational tonnage using wave-specific ratios from RecFIN. Nominal amounts of recreational removals were assumed for 1926-35 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-Apr) data are from Parrish and MacCall (1978); 1970-71 through 1975-76 (May-Apr) data are from Schaefer (1980); quarterly data from Jul 1976 through Dec 1986 are from Jacobson et al. (1994); monthly data from Jan 1987 through Nov 2003 were provided by INP-Ensenada (Garcia and Sánchez, 2003; Celia Eva-Cotero, INP-Ensenada, pers. comm.); monthly landings from Dec 2003 through Dec 2004 were not available, so were substituted with corresponding months from the previous year. Ensenada landings in 2005, available from Cota et al. (2006a), was apportioned into monthly catch using ratios from the previous few years. Ensenada landings for Jan-Jun 2006 were taken from Cota et al (2006b). Monthly landings data for the Cedros Island (Jan 1981 - Dec 1994) and Magdalena Bay (Jan 1981 – May 2003) fisheries were provided by Roberto Felix-Uraga (CICIMAR-IPN, La Paz, pers. comm.). 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 so, for purposes of weighting catch-at-age estimates (following section), aggregate catch data (season or quarter) were apportioned to months by inflating the corresponding California data.

Small volumes (100 to 300 $mt \cdot yr^{-1}$) of Pacific mackerel are taken incidentally in other fisheries (e.g. whiting, salmon troll, sardine) off Oregon and Washington. Biological samples collected from these fisheries (Hill 1999) indicate age and size structures that are much older and larger than the directed fishery off California, so this catch is not included in the assessment.

Catch-at-age (ASAP)

Various sources were used to reconstruct a catch-at-age time series for Pacific mackerel. Age data for 1929 to 1932 and 1935 to 38 were derived from CDFG length composition data using Tomlinson's unpublished NORMSEP program (Parrish and MacCall 1978). Ages for all other biological years in this assessment were based on otolith data available from the literature or contemporary fishery databases. See 'Fishery Data / Overview' section (above) for details regarding birthdate assumptions. Sample sizes for developing catch-at-age estimates (1939-40 to present) are provided in Table 4.

Age compositions for 1929-30 to 1938-39 (May-April) were taken from Parrish and MacCall (1978) and adjusted according to our total landing estimates for this period, using weight-at-age data from Prager and MacCall (1988) (see also 'Weight-at-age' section).

Age compositions for the period 1939-40 to 1961-62 (May-April) were based on year class, age, and length data recovered from the historical literature (Fitch 1951, Fitch 1953a, Fitch 1953b, Fitch 1955, Fitch 1956, Fitch 1958, Hyatt 1960, Parrish and Knaggs 1971, Parrish and Knaggs 1972) and now available in a database individual-level resolution by biological year. Lengths were converted to weights using the weight-length relationship published by Fitch (1951). Age compositions were estimated by using the proportions-at-age and average weights-at-age to calculate tonnage per age group. Tons per age was converted to numbers at age using average fish weights for each biological year.

Age compositions from 1962-63 to 2006-07 were developed using CDFG port sample databases, coupled with pooled monthly landings for the three respective fisheries (see 'Landings' section). While no directed sampling for Pacific mackerel took place during the fishing moratorium (1970-1976), Pacific mackerel samples were collected from the jack mackerel fishery during this period. From 1962-63 onward, estimates of catch-at-age were weighted to take into account variation in sample size relative to total landings. Sample percent-by-weight for each age class was calculated by dividing the total weight of fish-at-age by the total weight of fish sampled in each month. Landed weight of fish in each age class was estimated as the product of metric tons landed and the percent-by-weight in the fishery sample. Numbers-at-age in the monthly landings were then calculated by dividing the landed weight-at-age by the average individual weight-at-age for the month. For months with landings but no fishery sample taken, data were substituted by summing sample information (i.e., fish numbers, weights, and sample weights) from the two adjacent (previous and following) months. Finally, numbers-at-age were summed across months to provide the catch-at-age for each biological year (May-April prior to 1976-77; July-June for 1976-77 to present).

Catch-at-age data compiled for ASAP input are provided in Table 6, and proportions-at-age are displayed in Figure 2. For years where age sampling was carried out (i.e. 1929-30 to 2006-07), an effective sample size (λ) of 45 was used. Effective sample size was set to zero for cases with landings but no samples (2007-08).

<u>Weight-at-age (ASAP)</u>
A year-specific weight-at-age matrix based on fishery samples was developed for use in the ASAP model. This matrix was used to calculate SSB and age 1+ biomass from modeled population estimates. Weight-at-age data are presented in Table 7. While it is possible that the population weight-at-age of Pacific mackerel differs from that derived from fishery samples, fishery-independent data do not exist to explore this question.

Weights-at-age from 1929-30 to 1938-39 were obtained from Prager and MacCall (1988). Weights-at-age from 1939-40 to 1961-62 were calculated from the historical database based on various sources (see 'Catch-at-age' section above), again, noting that weights were converted from lengths in the original source using the length-weight relationship published by Fitch (1951). Weights-at-age from 1962-63 to 2006-07 were obtained directly from CDFG port sample databases.

<u>Length composition (SS2)</u>

The SS2 model uses length composition for the commercial (US-Mexico) and the recreational (US-Private, Party, Charter, and Rental boats) fisheries. Time series of length distribution for the commercial fishery were derived from CDFG port sampling data collected from 1939 to 2006. Pacific mackerel length composition for the recreational fishery was developed from the Marine Recreational Fisheries (RecFIN) database using angler examined catch data from 1992 to 2006.

Length composition for both fisheries were derived using 1-cm bin length (Fork length), with the smallest bin equal to 4 cm and the largest equal to 60 cm. The 60-cm bin includes fish whose sizes are equal or greater than 60 cm. Number of length samples observed at each bin were weighted by 25, which is the average number of samples collected by CDFG by boat and trip. For each fishery, annual size distributions were developed in proportion, including both males and females data.

Observed length distribution data compiled for the SS2 model are presented in Figure 3 and 4. For the commercial fishery effective sample size was estimated to be 72, whereas for the recreational fishery the effective sample size was estimated to be 102.

Indices of Relative Abundance

Overview

Fishery-independent survey data used in the ASAP and SS2 models include 1) aerial sightings by spotter pilots, 2) larval production at hatching (P_h) from the CalCOFI program, 3) CPUE indices from CPFV logbooks. Survey data for Pacific mackerel vary in quality with respect to over space and time, but no single index is proposed to be superior with respect to comprehensiveness or sampling design. Strengths and weaknesses of each survey will be briefly addressed in the following sections (see 2007 STAR Panel Report).

Aerial Spotter Survey

Pilots employed by the fishing fleet to locate Pacific mackerel (and other pelagic fish) schools report data for each flight on standardized logbooks and provide them under contract to NOAA Fisheries. In this assessment 'Spotter' data for Pacific mackerel were calculated for year effects estimated using a Delta-Generalized Linear Model (Delta-GLM) (see Lo 2007, Appendix I). The 2007 STAR Panel determined that an alternative Generalized-Addive Model proposed by Lo (2007, Appendix I) was inconsistent with the assumptions related to how indices of abundance are included in stock assessment models. For the preferred Delta-GLM model Spotter data were aggregated using July to June annual period, for example, the estimate for 1993 was based on data collected from July 1992 to June 1993. Estimates of relative abundance (*I*) and their coefficients of variations were computed as:

$$\hat{I} = \hat{D}A$$

$$CV(\hat{I}) = CV(\hat{D})$$

where *A* is the total number of blocks covered by spotter pilots within the "traditional area covered by spotter pilot" each year; and *D* is the density of Pacific mackerel for each year.

In this assessment, the spotter index covers the period 1962-63 through 2001-02 (Figure 5, Appendix I). After the year 2000, there was rapid decline in both the number of active pilots and total logbooks returned, as well as a southward shift in effort to offshore areas off of Baja California. Although data from 2004 through 2006 were available, the 2007 STAR Panel recommended that these data be dropped from the assessment (see 2007 STAR Panel Report). The 2004-06 data were derived from a new sampling design (see Appendix I) and during this period the pilots did not fully comply with the requirements of the design. The 2007 STAR Panel questioned the validity of combining these data with the 1962-01 period, and proposed to further investigate the new time series data before they can be used in future assessments (see 2007 STAR Panel Report).

In the ASAP model, the selectivity pattern applied for this index is such that all age groups (ages 0-8+) were fully selected (Figure 6). This is based on the assumption that spotter pilots will record all fish schools sighted (including age-0 fish), not only those schools reported to the wetfish fleet. In the SS2 model the selectivity of this index was set to mirror the commercial fishery selectivity (Figure 7).

Commercial Passenger Fishing Vessel Logbook CPUE

California Fish and Game Code has required CPFV skippers to provide records of catch and effort data to CDFG since 1936. In the past, Pacific mackerel has been among the top five species reported on CPFV logs both in southern California and statewide. We utilized an historical logbook database (Hill and Barnes 1998, Hill and Schneider 1999) which summarizes CPFV catch and effort by month and Fish and Game statistical blocks (10 nautical mile squares). In the 2005 assessment, a single statewide index of relative abundance was developed and standardized using a Generalized Linear Model (GLM; Hill and Crone 2005, Crone et al. 2006). For the current assessment we also develop a single state wide index of relative abundance, but we use a Delta-Generalized Linear Model (Delta-GLM, described below) approach to model the year effect. Also, the new index of abundance is developed based on fishing year, contrary to the old approach that used calendar year. Length data from the Recreational Fisheries Information Network (RecFIN) database were used outside the model to estimate a fixed selectivity pattern for use in ASAP models. In the SS2 model the selectivity of this index was set to mirror the recreational fishery selectivity.

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. Technical issues 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 2006-07 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, given the catch rate is non-zero, separately (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/1000 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 an *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).

(7) We used a Delta-GLM function written in R codes (pers. Comm. (E.J. Dick, NMFS SWFSC, Fisheries Ecology Division) to estimate catch rates for the CPFV data. The major feature of this function is that it estimates the coefficients of variation for the relative index of abundance using a Jacknife (Leave-one-out) method. However, because the CPFV data are very extensive (78,376 observations) we could not estimate the year effect for the survey simultaneously with the coefficients of variation. In the current assessment we first estimate the year effect using all available data; then we resample the data by fishing year, and estimate the coefficient of variation for each of the fishing years. Likewise, our estimates of coefficients of variation are based on 200 bootstrap samples (with replacement), taken in each fishing year from 1935-36 to 2006-07. Finally, Figure 8 compares year-effect estimated from the Delta-GLM to estimates from the GLM used in Hill and Crone (2005) for the CPFV time series data (see also Figure 5).

<u>CalCOFI Larval Survey</u>

CalCOFI ichthyoplankton data from 1951 to 2006 were compiled and an annual index of daily larval production at hatching (per 10 m^2) for the Southern California Bight was calculated (Figure 5, Appendix II). Past assessments of Pacific mackerel (Hill and Crone 2005, Crone et al. 2006) used a CalCOFI larval index based on “Proportion positive bongo net tows.” However, because of the implementation of the SS2 model (which does not allow 0 values), and also based on the recommendation of the 2006 SSC report (see SSC 2006), it was necessary to develop the new larval production index (Lo et al. 2007, Appendix II). Data from all available years were used, but data were filtered to include only cruises from April through July, peak spawning months for Pacific mackerel . The filtered data grid included standard CalCOFI lines (line 93-line 77)). A weighted-non linear regression was used to estimate larval production at hatching (i.e., P_h) in years with sufficient catch-length data:

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

However, in years where only one or two length classes had positive catches in the survey, P_h was estimated by inverting the mortality curve for Pacific mackerel larvae, following the equation below:

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

where P is the mean daily larval production at length L =2.5 mm, t_L is the age at 2.5 mm length, and $\alpha$is the overall mean mortality rate estimate. For further details on the development of this index and its variance we refer the reader to Appendix II (Lo et al. 2007). Coefficients of variations used as input in the models for this index were approximated as the square root of $\log(1+CV^2)$.

During the 2007 STAR Panel we compared coastwide larval densities to larval densities off Mexico and larval densities for the Southern California Bight (SCB, i.e., using data derived from CalCOFI surveys that covered Mexico and the SCB (1951-1984)). We found that the CalCOFI index (i.e. SCB index) could be a good proxy for coastwide-relative abundance of Pacific mackerel in periods of high abundance, otherwise the index could contribute little information on the coast-wide status of spawning stock biomass (Figures 9a and 9b). Nevertheless the 2007 STAR Panel recommended to use the new index in this stock assessment. For both modeling platforms the modeled selectivity pattern used the normalized net fecundity ogive described above in 'Maturity Schedule' and provided in Table 3 and in Figure 10.

History of Modeling Approaches

Parrish and MacCall (1978) were the first to provide population estimates for Pacific mackerel using a traditional VPA. The ADEPT model (the 'ADAPT' VPA modified for Pacific mackerel; Jacobson 1993 and Jacobson et al 1994b) was used to evaluate population 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' was reviewed and adopted for Pacific mackerel at the 2004 STAR Panel (Hill and Crone 2004b). ASAP was implemented for assessment and management advice in the 2005-06 and 2006-07 seasons (Hill and Crone 2005; Crone et al. 2006).

ASAP Model Description

<u>Overview</u>

The Age-Structured Assessment Program model ('ASAP'; Legault and Restrepo 1999, Appendix C) is based on the AD Model Builder (ADMB) software environment, a high-level programming language that utilizes C++ libraries for nonlinear optimization (Otter Research 2001). The general estimation approach used in the ASAP is that of a flexible forward-simulation that allows for the efficient and reliable estimation of a large number of parameters. The population dynamics and statistical principles of ASAP are well established and date back to Fournier and Archibald (1982) and Deriso et al. (1985).

The following is a brief description of estimation methods employed in the ASAP model. Readers interested in further details and model equations should refer to Legault and Restrepo (1999).

- Model estimation begins in the first year of available data with an estimate of the population abundance-at-age.

- The spawning stock for that year is calculated and the associated recruitment for the next year is determined via the stock-recruitment relationship (in this case, based on a Beverton-Holt model). Recruitment variability is accommodated by accounting for divergence from the estimated central tendency (expected value).

- Each cohort estimated in the initial population abundance at age is then reduced by the total mortality rate and subsequently, projected into the next year/age combination. This process of estimating recruitment and projecting the population forward continues until the final year of data is reached.

- Total mortality rates (Z) used to decrease cohort abundances over time represent the sum of natural mortality (M) and the fishing mortalities (F) from all fisheries.

- The Fs for each fishery are assumed to be separable into age (commonly referred to as selectivity) and year (commonly referred to as F-multipliers). The product of selectivity-at-age and the year specific F-multiplier equals the F for each fishery/year/age combination.

- The added structure of time-varying selectivity can be incorporated via the estimation of random walks.

- Predicted catch in weight- and catch-at-age are estimated using Baronov's catch equation and user-provided mean weights at age and natural mortality.

- The method of maximum likelihood serves as the foundation of the overall numerical estimation. Sources of data are compartmentalized into various likelihood components, depending on the level of structure of the overall, fully-integrated population model. Generally, the ASAP model can include up to nine likelihood components and a few penalties.

- The tuning indices are assumed to represent changes in the population over time for specific age ranges and can be measured in numbers or weight.

- Given the large number of parameters, it is possible to fit both the catch-at-age and the abundance indices relatively well, but often at the expense of producing somewhat unrealistic trends in other stock parameters of interest (e.g., recruitment, selectivity, and catchability). Constraints and penalty functions can be employed to the constrain estimation to more feasible regions of parameter space.

- Because the number of parameters can be large and highly nonlinear, it is often difficult to estimate all parameters simultaneously in one run of the model. In practice, the minimization usually proceeds in phases, where groups of parameters are estimated simultaneously, while the remaining parameters are maintained at their initially assigned (starting) values. Once the objective function is minimized for a particular phase, more parameters are evaluated in a step-wise fashion. Estimation within additional phases continues until all parameters are estimated. For this assessment, parameters were estimated in the following order: Phase (1): Selectivity in 1st Year, Fmult in 1st Year, Catchability in 1st Year, Stock-Recruitment Relationship, and Steepness; Phase (2): N in 1st year; Phase (3): Fmult Deviations, Recruitment Deviations; Phase (4): Selectivity Deviations.

Assessment Program with Last Revision Date

ASAP version 1.3.2 (compiled 14 Sept. 2004) was used for all runs presented in this paper. ASAP was implemented using NFT GUI version 2.7 (compiled 4 Mar. 2005).

Likelihood Components and Model Parameters

Likelihood components in the final ASAP base model ('Base-E1') are listed in Table 8, and included: (1) fit to catch; (2) fit to catch-at-age; (3) fits to three indices; (4) stock-recruit fit; (5) penalty for recruitment deviations; and (6) an F penalty.

Convergence Criteria

The iterative process for determining numerical solutions in the model was continued until the difference between successive likelihood estimates was < 0.0001. The number of function evaluations ranged from 800 to 10,000, depending on the model configuration and initial values. Fidelity of model convergence was explored by modifying selected initial values (stock size at the beginning of the time series, catchability coefficients associated with indices of abundance, etc.) and then comparing the likelihoods and estimates of key management parameters.

Critical Assumptions and Consequences of Assumption Failures

In the ASAP-E1 model, we assumed that the commercial fishery selectivity parameters vary through time, but that Sigma-R and natural mortality rate were constant. Increasing Sigma-R from 0.25 (value used in the 2004 model) to 0.7 led to a more productive stock and higher SSB and Age 1+ biomass, particularly during the peaks of abundance. Although to a lesser extent, blocking the commercial selectivity resulted in significant differences between the 2004 and 2007 biomass estimates. In retrospect, harvest guidelines for the 2005 and 2006 fishing season would have been higher, had these stock assessments used a higher Sigma-R value. The 2007 STAT and STAR Panel agreed that a Sigma of 0.7 better reflects the life history and dynamics of Pacific mackerel, and better meets the expectation of model runs in term of uncertainties in recruitment and stock abundance. Finally, natural mortality (M) was assumed to be 0.5 $yr^{-1}$for all ages and Figures 34 and 35 show the effects of varying M from 0.35 to 0.7 on estimates of Age 1+ biomass and recruitment from the ASAP-E1 model.

SS2 Model Description

Overview

The Stock Synthesis 2 (SS2, Methot 2005, 2007) is based on the AD Model Builder software environment, which is essentially a C++ library of automatic differentiation code for nonlinear statistical optimization (Otter Research 2001). The model framework allows the integration of both size and age structure, and with multiple stock sub-areas (Methot 2005). Hence, the model is closely similar to A-SCALA (Maunders and Watters, 2003); Multifan (Fournier et al. 1990);

Multifan-CL (Fournier, Hampton and Siebert, 1998). The latest version SS2.V2.00c was released in March 2007, and is maintained through the NOAA Fisheries Toolbox (NFT 2007). The general estimation approach used in the SS2 model derives goodness of fit to the model in term of quantities that retain the characteristics of the raw data. The model tends to incorporate all relevant sources of variability and estimates goodness of fit in term of the original data, potentially allowing that final estimates of model precision capture most relevant sources of uncertainties (see Methot 2005).

The SS2 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 type of data; 3) A statistical sub-model that quantifies the difference between observed data and their expected values and implement algorithms to search for the set of parameters that maximizes the goodness of fit. Another layer of the model is the estimation of management quantities, such as short term-forecast of the catch level given a specified fishing mortality policy. Finally, these sub-models and layer are fully integrated and the SS2 model use forward-algorithms, which begin estimation prior or in the first year of available data and continues forward up to the last year of data (see Methot 2005).

Assessment Program with Last Revision Date

SS2 Version 2.00c , compiled March 27, 2007, is used in this report. SS2.V2.00c is also implemented through NFT's GUI (NFT 2007). The reader is referred to Methot (2005, 2007) for a complete description of SS2's population dynamics model.

Likelihood Components and Model Parameters

In the SS2-C1 model we assumed that both growth and selectivity parameters vary through time. Further, because the main objective of this model is to show that SS2 can mimic ASAP estimates of the most important fisheries parameters, all growth parameters were fixed in each of the blocks, whereas some of the selectivity parameters were freely estimated and others were fixed. In addition, size selectivity for the commercial fishery and the spotter survey index was assumed to follow a double normal pattern (a new feature in SS2.V2.00c) with six parameters, and a two parameter logistic curve was assumed for the recreational fishery and CPFV index. We set the expected larval production survey index to be equal to spawning biomass (i.e., population fecundity). In that respect, Maturity-at-age was assumed to be a logistic function (Figure 10, see also, Methot 2007), following the equation :

$$mat = \frac{1}{(1+\exp(slope * age(\inf lexion)))}$$

and the number eggs produced is expressed as:

$$Eggs = 0.88 * BodyWeight - 0.025$$

For all fishery and surveys, age selectivity was conditioned on size selectivity. Further, the fraction of the season elapsed before catch rates are measured or surveys are conducted were set up to: 0.33 for the commercial fishery and the spotter survey index; 0.25 for the recreational fishery and the CPFV index, and 0.75 for the Larval production at hatching (P_h).

Convergence Criteria

The convergence criterion for maximum gradient was set to 0.000001 in SS2 model runs. Fidelity of model convergence was briefly 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 multi-dimensional numerical estimation method.

Model Selection and Evaluation

ASAP Model Scenarios

A primary goal of this assessment was to compare Pacific mackerel population analyses from the ASAP to SS2 model. For brevity, several ASAP model scenarios and results are presented in this report as basic summaries to examine the effect of different data treatments and ultimately for comparison to the an SS2 model described in following sections. To show continuity from previous assessments, we developed a series of ASAP models that range from an update of the assessment as described in Hill and Crone (2005) and Crone et al. (2006), to one that is more similar to the SS2 base model (that is, as far as such a comparison can be made). The changes included strict updates to fishery and index data, introduction of new index methods (described elsewhere in this report), application of inverse weighting to index observations (model CVs) to account for uncertainty in year-to-year estimates, and an increase in the age structured component from 6+ to 8+ years. Each ASAP model scenario was based on the modifications from the previous model, and is described here:

Run name	*Description*
ASAP-2006	final model from 2006 assessment (see Crone et al. 2006)
ASAP-A1	strict update of ASAP-2006 assessment, with updated fishery data and indices using old index methods; no changes to parameterization.
ASAP-B1	same as ASAP-A1, using new index methods; index CVs fixed at 0.3.
ASAP-B2	same as ASAP-B1, with index CVs based on index model CVs
ASAP-B3	same as ASAP-B2, but CVs based on the approximation: $\sigma^2 = \ln(1+CV^2)$.
ASAP-C1	same as ASAP-B3, but plus group increased from age 6+ to 8+.
ASAP-E1	same as ASAP-C1, but Sigma-R changed from 0.25 to 0.7.

SS2 Model (SS2-C1) Scenario

The SS2-C1 model is a two fisheries (commercial and recreational), one season and one gender (female) model. This model includes all three available indices (i.e., CPFV, aerial spotter survey, and Larval production at hatching(P_h)). The P_h index was cast as the spawning biomass survey, CPFV as a relative index of abundance (CPUE), and the aerial spotter survey as a relative index of total biomass. Catch data (in mt) for the recreational and commercial fisheries cover the 1926-2006 period. Length data for the commercial fishery span from 1939 to 2006, whereas the recreational length composition covers the 1992-2006 fishing seasons. Season is defined in the model as the fishing year, corresponding to May-April for the 1926 to 1975 and July-June for the 1976 to 2006 period.

Model Scenario Comparison

ASAP Model Results (Pre-2007 STAR Panel)
Summary results from the above ASAP models are provided in Table 9 and in Figures 11-13. With the exception of ASAP-B1, each of the models was able to converge. Each model provided estimates of Recruitment, SSB, and Total (1+) Biomass that lay well within the range of uncertainty of the other model runs. A comparison of some basic model outputs is provided in Table 9. Objective functions from ASAP models B2 through C1 (new indices and CV methods) were slightly lower than ASAP-2006 and ASAP-A1. Estimates of B-zero were similar among all scenarios, ranging from 201,736 mt to 219,733, but slightly lower for B2, B3, C1. Beverton-Holt steepness (*h*) was slightly higher in models B2, B3, and C1 in comparison to 2006 and A1. Peak SSB and Total Biomass is slightly higher during the peak period but lower in 2006 in comparison to the 2006 and A1 models (Table 9). This change is probably due to differences in the magnitude of change between the old and new index methods. A comparison of ASAP-C1 to SS2 results is made in the SS2 section of this report.

SS2-C1 Model Results (Pre-2007 STAR Panel)

Indices of Relative Abundance
The observed estimates for the suite of relative (‘tuning’) indices of abundance and model fits are presented in Figure 14-16. For all indices, coefficients of variations (CVs) were rescaled in the SS2-C1 model, by assuming a multiplicative effect for the year- to- year variability in the magnitude of relative abundance estimates (i.e., CVs for each index were multiplied by a factor to approximate the overall expectation in variance of the model). Observed values for the three surveys are compared in Figure 5.

Selectivity Estimates
Time-varying selectivity estimated for the commercial fishery and the aerial spotter index is presented in Figure 7. Selectivity parameters estimated from SS2-C1 are similar to ASAP model estimates (see “ASAP-E1 Selectivity Results Section” for a complete description of these time-varying patterns). The selectivity curve estimated for the recreational fishery and the CPFV index is presented in Figure 17.

Harvest Rate
The estimated harvest rate time series for the SS2-C1 model is presented in Figure 18. Maximum harvest rate estimated by this model was approximately equal to 0.51.

Biomass of Age 1+
The estimated time series of population biomass (‘B’, age 1+ fish) for the SS2-C1 model is compared to ASAP-C1 results in Figure 19. Note that estimate of Age-1+ biomass from both modeling platforms was closely similar.

Spawning Stock Biomass

The estimated time series of SSB for the SS2-C1 model is compared to ASAP-C1 results in Figure 20. Note that SSB estimated from SS2-C1 were higher then 1971-2001' ASAP-C1 estimates, however results from both models were closely similar from 2002 to 2006.

Recruitment

The estimated time series of recruitment ('R'; abundance of age-0 fish) for the SS2-C1 model is compared to ASAP-C1 results in Figure 21. In most years number of recruits estimated by SS2-C1 was higher than ASAP-C1 model estimates.

ASAP Final Base Model E1 Results

Overview

The final ASAP base model (E1) was generally similar to previous Pacific mackerel assessments but did incorporate some key changes, including those recommended by the 2007 STAR Panel. Changes from previous ASAP-based assessments (Hill and Crone 2005; Crone et al. 2006) include the following:

- Additional year of catch, catch-at-age, and weight-at-age data;
- Plus group for age data increased from 6+ to 8+ years;
- Effective sample size for age comps iteratively adjusted from 15 to 45;
- Fishery selectivity estimated for three time blocks: 1929-69; 1970-77; 1978-06;
- New index methods (final STAR versions) were included, with inverse-weighting of observations based on model CVs;
- Survey timings were adjusted to better match timing of data collection;
- Sigma-R for the spawner-recruit model was increased from 0.25 to 0.7 (2007 STAR Panel recommendation)

Catch

ASAP model fit to catch data is displayed in Figure 22. The observed and predicted time series essentially overlay each other, indicating precise fit to this data source.

Catch-at-age

Effective sample size for the California catch-at-age data was iteratively adjusted and ultimately set to λ=45 for all years (Figure 23). Pearson residuals for the catch-at-age fits are displayed in Figure 24. Residual patterns were random, with no obvious trends over age or time. Catch-at-age proportions contributed to 44% of the total model likelihood (Table 8).

Indices of Abundance

Model fits to the three indices of relative abundance are displayed in Figures 25-27.
Trends in the residual patterns were apparent for all three indices. This is an indication of tension in trend and overall magnitude of change among the three indices. All three time series have peaks and lows during the same approximate periods of time, however, the magnitude of change for the Aerial Spotter and CalCOFI indices is far greater than that shown for the CPFV index. Index fits contributed to 46% of the total model likelihood (Table 8).

Selectivity Estimates

Fishery selectivities (S_{age}) estimated for the three time blocks are displayed in Figure 28. Generally speaking, selectivities followed a dome-shaped pattern for the two periods of directed fishing (1929-1969 and 1978-2006), with the latter period having a wider shape (i.e. more fish of the youngest and oldest ages selected). This difference reflects changes in utilization among the two eras; fishing primarily for canneries in the early period and a broader range of markets (including pet food) in the latter. During the moratorium (1970-1977), CPS seiners captured Pacific mackerel incidental to other CPS target species (esp. jack mackerel) and tended to be smaller and younger (Figure 28).

Fishing Mortality Rate

The fishing mortality multiplier is displayed in Figure 29, and fishing mortality-at-age is displayed in Figure 30. Fmult increased steadily throughout the historic fishery, peaking at close to 0.7 by the mid-1960s. For the recent period, Fmult peaked at 0.54 in 1998 (an El Nino season) when the stock was relatively low but availability was high for the Ensenada fishery.

Biomass of Age 1+ stock for PFMC Management

Stock biomass (Ages 1+) time series for PFMC management is displayed in Table 11. Stock biomass peaked at 1.52 million mt in 1979, declined to a low of about 90,000 mt in 2001, increasing again in the recent most years. While the trend in stock biomass was generally similar to past assessments, the magnitude increased due to changes in Sigma-R and higher estimates of recruitment throughout the time series (see ‘Recruitment’ and 2007 STAR Panel Report). Age 1+ biomass is projected to be 359,290 mt as of July 1, 2007.

Spawning Stock Biomass

A time series of SSB is provided in Table 10 and Figure 31. SSB peaked at 662,372 mt in 1982, declining precipitously to the current level of 86,777 mt. B_0 is estimated to be 185, 424 mt.

Recruitment

Recruitment time series (age-0 abundance) are presented in Table 11 and displayed in Figure 32. The recruitment trend is similar in pattern to that of previous assessments, with large year-classes in 1976, 1978, 1980, 1981, and 1982. The primary difference from previous assessments (Hill and Crone 2005; Crone *et al.* 2006) is the overall magnitude of the recruitment estimates – a direct effect of increasing Sigma-R from 0.25 to 0.7.

Stock-Recruit Relationship

Fit to the stock-recruitment relationship is displayed in Figure 33. In general, estimated recruitment was loosely constrained to a stock-recruitment relationship in the baseline model (Beverton-Holt model; Sigma-R= 0.7). Compensatory productivity (‘steepness’ parameter) of the population at low adult stock sizes was estimated to be h=0.31 – a very low value for small pelagic species, but similar in range to past assessments for this stock.

Uncertainty and Sensitivity Analyses

We performed various sensitivity tests to investigate potential effects of assumptions on parameter estimation from model runs. In this section we present the results of sensitivity analyses for the ASAP-E1 model and for parameters whose uncertainties are most likely to affect management guidelines for Pacific Mackerel, i.e., Sigma-R($\sigma_{R)}$, natural mortality (M), and the indices of relative abundance used in the assessment.

<u>Sensitivity of ASAP-E1 Model Results to Sigma-R</u>
We varied σ_R from 0.25 to 1 and compared the root mean square error (RMSE) for recruitment residuals and the pre-specified $\sigma_{R.}$ We found that the peaks of abundance were highly sensitive to the value assumed for $\sigma_{R.}$ The STAR Panel and the STAT agreed that the best value of σ_R to use in the assessment was 0.7. A σ_R of 0.7 is considerably higher than the assumed value (0.25) in the 2004 -2006 assessment models, but reflects better the life history characteristics of Pacific mackerel and meets better the overall expectation of the model for recruitment deviations.

<u>Sensitivity of ASAP-E1 Model Results to M</u>
We varied M from 0.35 to 0.7 and the results of the sensitivity tests are presented in Figure 34 and 35. As expected Age-0 abundance and Age-1+ biomass increased with increasing M. However, the magnitude of difference was higher during peaks of abundance, and the model results were less stables for M between 0.55 and 0.6 (See also Table 11). Both the STAR Panel and the STAT agreed that an M= 0.5 was the most appropriate value to be used in the assessment.

<u>Sensitivity of ASAP-E1 Model Results to Indices</u>
This sensitivity was performed by dropping one of the three relative abundance indices. Recruit abundance and Age-1+ biomass estimated for these tests are presented in Table 11 and Figures 36 and 37. Again, dropping one of the indices has the most effects during peaks of abundance and on estimates for the most recent years (i.e., 2004-2007). For the 2004-07 period (i.e., a period with no aerial spotter data) the results show that the CalCOFI larval production at hatching tends to decrease Age-1+ biomass estimates, whereas the CPFV index tends to increase these levels of biomass.

<u>Comparison of base-run results to previous assessments</u>
Age 1+ biomass and SSB estimated from the 2006 ASAP model and 2004 ADEPT model are compared to ASAP-E1 estimates in Figures 38 and 39.

HARVEST CONTROL RULE FOR U.S. MANAGEMENT IN 2007-08

In Amendment 8 to the CPS FMP (PFMC 1998), the recommended maximum sustainable yield (MSY) control rule for Pacific mackerel was:

HARVEST = (BIOMASS-CUTOFF) x FRACTION x DISTRIBUTION,

where HARVEST is the U.S. HG, CUTOFF (18,200 mt) is the lowest level of estimated biomass at which harvest is allowed, FRACTION (30%) is the fraction of biomass above CUTOFF that should be taken by all fisheries, and DISTRIBUTION (70%) is the average fraction of total BIOMASS assumed in U.S. waters. CUTOFF and FRACTION values applied in the Council's harvest policy for mackerel are based on analyses published by MacCall et al. (1985). BIOMASS (359,290 mt) is the estimated biomass of fish age 1 and older for the whole stock projected for July 1, 2007. Based on this formula, the 2007-08 HG would be 71,629 mt (Table

12). Figure 40 presents commercial landings and quotas for Pacific mackerel from 1992 to 2006. The recommended HG for the 2007-08 fishing season is 361% higher than the 2006-07, HG, and higher than the maximum yield since 1992-03 (mt).

RESEARCH AND DATA NEEDS

CDFG has sampled California's Pacific mackerel fishery for age composition and size-at-age for many decades, and the current stock assessment model incorporates a complete time series of landings and age composition data beginning in 1929. Ensenada landings have rivaled California's for the past decade, but the stock assessment does not include real biological data from the Mexican fishery. Mexican landings are included in the assessment, but must be pooled with the southern California catch. INP-Ensenada has collected biological samples (size, sex, otoliths) since 1989, but the data have not been available for U.S. stock assessments. There is a need to establish a program of data exchange with Mexican scientists (INP) to fill this information gap. The MexUS-Pacifico (NMFS-INP) meetings are the most appropriate forum for such an exchange.

There is a lack of population-wide biological data for Pacific mackerel. Representative population sampling is required to reduce uncertainty regarding the maturity schedule, fecundity, and growth. The maturity schedule used in the current assessment was developed more than 20 years ago, during a period of high population abundance, and could be vastly different now. The fishery weights-at-age from southern California are assumed to represent weights-at-age for the whole population.

Fishery-independent survey data for measuring changes in mackerel spawning biomass are generally lacking. The current CalCOFI sampling pattern provides information on mackerel egg distributions in the Southern California Bight, the extreme northern end of the spawning area. Mexican research institutions have conducted a number of egg and larval surveys off of Baja California in recent years (IMECOCAL program). Access to this data would enable us to continue the historical CalCOFI time series, which begins in 1951. This information could be incorporated directly into the assessment model.

CPFV logbook data for Baja California blocks should be explored as a potential new index of CPUE. Due to difference in trips types and effort recorded for these trips, the data should be analyzed separately from the existing CPFV index.

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).

In addition to the above, the 2007 STAR Panel for Pacific mackerel made the following specific recommendations in their report (following bullets excerpted from the report; redundancies to the above points have been removed):

- Age-reading studies should be conducted to construct an age-reading error matrix for inclusion in future (SS2) assessments.

- The next assessment should continue to examine the possibility of using SS2 as the assessment platform. The analyses presented to the Panel suggested that ASAP and SS2 lead to similar outcomes when configured in a similar manner. However, SS2 deals better with indices that are not tied directly to a fishery, can include age-reading error, and allows weight-at-age in the catch to differ from weight-at-age in the population. In principle, it should be easier to represent uncertainty using the MCMC algorithm for assessments based on SS2.

- The SS2 assessment model runs performed during the 2007 STAR panel were based on fitting to age-composition data for the commercial fishery. Future SS2 assessments should consider fitting to the length composition and the conditional age-at-length information. This will require estimating time-varying growth curves and may require multiple time-steps within each year.

- The construction of the spotter plane index is based on the assumption that blocks are random within region (the data for each region is a "visit" by a spotter plane to a block in that region). The distribution of density-per-block should be plotted or a random effects model fitted in which block is nested within region to evaluate this assumption (e.g. examine whether certain blocks are consistently better or worse than the average).

- The CalCOFI data should be reviewed further to examine the extent to which CalCOFI indices for the SCB can be used to provide information on the abundance of the coastwide stock.

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Table 1. Commercial landings (California directed fishery) and quotas or HGs for Pacific mackerel. Units are metric tons. Incidental landings from Pacific northwest fisheries are not included, but typically range 100 to 300 mt per year.

Fishing Year	Quota or HG[/a]	Landings
92	34,010	18,307
93	23,147	10,793
94	14,706	9,372
95	9,798	7,615
96	8,709	9,788
97	22,045	23,413
98	30,572	19,578
99	42,819	7,170
00	20,740	20,936
01	13,837	8,039
02	12,535	3,541
03	10,652	5,961
04	13,268	5,012
05	17,419	4,572
06	19,845	6,956

[/a] California Quotas 1992-03 through 1998-99. PFMC HGs 1999-00 onward.
[/b] 2006-07 landings as of Feb, 2007 (CDFG wetfish tables).

Table 2. Pacific mackerel growth parameters estimated from CDFG port samples collected from 1962 to 2006.

Weight-at-length

Time Block	*a*	*b*	N	Corr. R^2
1926-61 (1962-06 estimate)	3.12517E-06	3.40352	95,761	0.971
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

Length-at-age (von Bertalanffy)

Time Block	*Linf*	*K*	*t0*	N	Corr. R^2
1926-61 (1962-06 estimate)	39.3	0.342494	-1.75187	95,761	0.732
1962-68	42.5	0.279912	-2.22289	5,598	0.906
1969-77	41.0	0.415795	-1.55281	7,104	0.668
1978-89	37.4	0.425483	-1.23346	45,957	0.699
1990-06	40.7	0.292865	-2.07671	37,102	0.848

Table 3. Normalized net fecundity [a] calculations for Pacific mackerel.

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. Normalized net fecundity is adjusted to a maximum value of 1.0. Batch fecundity assumed constant.

Table 4. Sample sizes for Pacific mackerel sampled from southern California's commercial fishery by the CDFG. Sample sizes relative to total tonnage (all sectors) are provided as fish per 1,000 mt.

Fishing Year	Landings (mt)	# Fish Sampled	Fish per 1,000 mt	Fishing Year	Landings (mt)	# Fish Sampled	Fish per 1,000 mt
39	45,454	1,524	34	73	401	239	596
40	48,868	2,258	46	74	634	179	282
41	32,597	2,445	75	75	2,149	1,326	617
42	21,922	1,287	59	76	4,092	2,202	538
43	35,341	2,250	64	77	13,751	1,943	141
44	36,694	1,520	41	78	27,173	3,810	140
45	23,638	2,088	88	79	35,612	3,491	98
46	27,616	2,637	95	80	34,252	6,711	196
47	19,437	1,397	72	81	46,778	5,067	108
48	18,125	631	35	82	36,124	4,764	132
49	24,189	1,835	76	83	41,422	2,694	65
50	17,493	1,019	58	84	45,819	2,394	52
51	15,857	911	57	85	46,567	2,607	56
52	10,326	397	38	86	54,024	3,000	56
53	5,266	447	85	87	47,632	4,150	87
54	18,465	811	44	88	49,080	4,479	91
55	22,201	572	26	89	49,309	3,583	73
56	36,835	1,011	27	90	71,551	2,121	30
57	27,753	931	34	91	65,505	1,689	26
58	11,875	903	76	92	32,168	2,015	63
59	19,332	755	39	93	20,807	2,740	132
60	20,823	488	23	94	23,128	4,357	188
61	26,199	422	16	95	11,371	2,718	239
62	23,901	205	9	96	24,316	2,222	91
63	23,703	205	9	97	50,477	2,722	54
64	19,988	268	13	98	62,568	2,261	36
65	11,279	111	10	99	15,863	1,674	106
66	7,405	1,944	263	00	27,647	1,919	69
67	1,713	720	420	01	12,561	2,114	168
68	1,695	2,145	1,265	02	13,948	2,150	154
69	1,168	498	426	03	11,756	1,599	136
70	835	150	180	04	10,796	2,547	236
71	911	344	378	05	13,151	2,300	175
72	532	223	419	06	16,623	2,424	146

Table 5. Landings of Pacific mackerel by fishery (1926-06).

Fishing Year	USA -Commercial Catch (mt)	Mexico-Commercial Catch (mt)	Recreational - CPFV Catch (mt)	Recreational - non-CPFV Catch (mt)	Total Catch (mt)
26	1,630	0	6	11	1,647
27	2,928	0	6	11	2,945
28	17,874	0	6	11	17,891
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	5,728	28	295	12,023
04	5,012	5,624	23	537	11,195
05	4,572	8,024	13	543	13,151
06	8,192	8,024	5	403	16,623

Table 6. Catch-at-age from ASAP models (1929-06).

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	26,590	14,955	5,148	1,891	663	652	331	96	65
04	46,350	7,066	2,288	1,658	706	141	94	37	94
05	71,583	9,839	5,043	730	285	174	90	23	0
06	71,664	23,704	4,708	1,871	548	200	166	48	0

Table 7. Weight-at-age from the ASAP models (1929-07).

Fishing Year	0	1	2	3	4	5	6	7	8+
29	0.074	0.167	0.297	0.402	0.523	0.615	0.704	0.800	0.830
30	0.060	0.139	0.301	0.422	0.511	0.603	0.698	0.800	0.830
31	0.077	0.114	0.276	0.399	0.527	0.606	0.701	0.800	0.830
32	0.058	0.081	0.277	0.379	0.508	0.604	0.711	0.800	0.830
33	0.059	0.083	0.200	0.299	0.493	0.585	0.700	0.800	0.830
34	0.065	0.142	0.198	0.233	0.431	0.538	0.683	0.800	0.830
35	0.079	0.186	0.217	0.251	0.379	0.472	0.629	0.790	0.830
36	0.086	0.193	0.284	0.338	0.393	0.453	0.574	0.750	0.820
37	0.119	0.176	0.318	0.429	0.461	0.502	0.575	0.740	0.800
38	0.124	0.174	0.310	0.448	0.532	0.582	0.633	0.726	0.790
39	0.191	0.246	0.363	0.460	0.583	0.680	0.775	0.795	0.878
40	0.180	0.260	0.339	0.442	0.527	0.640	0.729	0.834	0.820
41	0.115	0.259	0.343	0.439	0.559	0.650	0.806	0.807	0.850
42	0.180	0.236	0.373	0.471	0.546	0.626	0.684	0.909	0.830
43	0.165	0.292	0.339	0.474	0.574	0.650	0.629	0.881	1.000
44	0.144	0.271	0.379	0.472	0.587	0.660	0.754	0.735	0.948
45	0.121	0.234	0.383	0.494	0.611	0.704	0.745	0.819	0.842
46	0.125	0.261	0.384	0.487	0.617	0.679	0.736	0.778	0.812
47	0.119	0.291	0.400	0.499	0.622	0.709	0.753	0.788	0.818
48	0.107	0.227	0.354	0.506	0.616	0.706	0.764	0.895	0.871
49	0.109	0.192	0.319	0.456	0.607	0.725	0.799	0.917	0.917
50	0.084	0.249	0.323	0.455	0.564	0.664	0.784	0.799	0.871
51	0.162	0.255	0.346	0.429	0.569	0.694	0.827	0.835	0.853
52	0.173	0.297	0.386	0.471	0.568	0.719	0.832	0.988	0.850
53	0.162	0.296	0.411	0.512	0.603	0.763	0.834	0.850	1.100
54	0.084	0.257	0.387	0.505	0.585	0.744	0.701	0.879	0.870
55	0.140	0.253	0.357	0.484	0.583	0.744	0.762	0.778	0.878
56	0.111	0.248	0.373	0.485	0.598	0.752	0.722	0.910	0.870
57	0.179	0.310	0.374	0.509	0.602	0.649	0.650	0.700	1.000
58	0.176	0.292	0.396	0.488	0.617	0.685	0.775	0.750	0.750
59	0.132	0.251	0.398	0.510	0.602	0.702	0.754	0.840	0.850
60	0.102	0.276	0.391	0.507	0.611	0.699	0.768	0.820	0.870
61	0.144	0.252	0.389	0.495	0.584	0.647	0.817	0.830	0.850
62	0.276	0.320	0.420	0.540	0.622	0.712	0.782	0.890	0.860
63	0.197	0.298	0.434	0.538	0.627	0.730	0.743	0.840	0.930
64	0.181	0.300	0.400	0.503	0.612	0.748	0.812	0.820	0.870
65	0.109	0.195	0.384	0.501	0.596	0.723	0.735	0.880	0.850
66	0.149	0.273	0.419	0.525	0.658	0.790	0.833	0.850	0.930
67	0.166	0.235	0.488	0.510	0.599	0.723	0.869	0.917	0.849
68	0.138	0.266	0.391	0.562	0.593	0.709	0.902	0.952	1.070
69	0.103	0.322	0.428	0.505	0.662	0.746	0.907	1.000	1.100
70	0.099	0.232	0.402	0.584	0.730	0.837	0.850	1.000	1.200
71	0.266	0.282	0.457	0.481	0.740	0.955	0.880	0.900	1.200
72	0.147	0.266	0.449	0.508	0.552	0.746	1.000	0.900	1.100
73	0.119	0.329	0.433	0.609	0.606	0.686	0.758	0.803	0.838
74	0.107	0.303	0.604	0.740	0.837	0.800	0.800	0.800	1.000
75	0.127	0.361	0.517	0.973	1.053	1.029	1.350	0.900	0.900
76	0.170	0.297	0.672	0.864	1.291	1.223	1.531	1.200	1.000
77	0.122	0.322	0.600	0.847	1.063	1.100	1.300	1.500	1.300
78	0.062	0.334	0.473	0.705	0.908	1.100	1.200	1.400	1.600
79	0.082	0.189	0.440	0.598	0.810	0.969	1.200	1.300	1.500
80	0.072	0.176	0.270	0.437	0.598	0.874	1.066	1.300	1.400
81	0.083	0.190	0.239	0.391	0.597	0.715	0.953	0.929	1.400
82	0.032	0.151	0.237	0.345	0.516	0.773	0.916	1.000	1.200
83	0.049	0.191	0.302	0.390	0.458	0.511	0.688	0.900	1.100
84	0.120	0.235	0.351	0.396	0.505	0.614	0.638	0.871	0.910
85	0.157	0.285	0.418	0.461	0.484	0.560	0.612	0.697	0.850
86	0.148	0.290	0.408	0.508	0.561	0.595	0.630	0.719	0.784
87	0.133	0.272	0.414	0.523	0.600	0.691	0.717	0.766	0.826
88	0.101	0.301	0.415	0.576	0.666	0.734	0.806	0.815	0.899
89	0.104	0.193	0.381	0.542	0.647	0.749	0.757	0.739	0.827
90	0.094	0.267	0.377	0.554	0.649	0.680	0.749	0.775	0.803
91	0.071	0.217	0.397	0.514	0.591	0.664	0.724	0.766	0.799
92	0.087	0.175	0.330	0.459	0.544	0.661	0.691	0.725	0.805
93	0.073	0.228	0.294	0.408	0.583	0.607	0.720	0.756	0.832
94	0.100	0.156	0.248	0.361	0.493	0.597	0.644	0.733	0.785
95	0.081	0.179	0.275	0.431	0.586	0.689	0.740	0.758	0.920
96	0.105	0.182	0.318	0.471	0.589	0.649	0.674	0.705	0.751
97	0.149	0.239	0.333	0.446	0.572	0.637	0.719	0.718	0.749
98	0.139	0.267	0.325	0.419	0.530	0.615	0.631	0.667	0.689
99	0.148	0.228	0.399	0.509	0.575	0.633	0.688	0.754	0.768
00	0.114	0.266	0.370	0.550	0.590	0.608	0.646	0.712	0.731
01	0.103	0.253	0.347	0.534	0.567	0.619	0.617	0.635	0.627
02	0.133	0.218	0.303	0.412	0.552	0.687	0.656	0.728	0.650
03	0.125	0.284	0.414	0.603	0.679	0.745	0.809	0.794	0.838
04	0.159	0.280	0.407	0.596	0.685	0.821	0.926	0.820	0.902
05	0.106	0.267	0.380	0.463	0.556	0.665	0.737	0.797	0.840
06	0.115	0.232	0.361	0.509	0.715	0.794	0.847	0.918	0.935
07	0.115	0.232	0.361	0.509	0.715	0.794	0.847	0.918	0.935

Table 8. Likelihood function components for the ASAP-E1 and sensitivity test model runs.

Component	RSS	nobs	Lambda	Likelihood	%Total Likelihood
Catch_Fleet_1	0.0201	79	100	2.00987	
Catch_Fleet_Total	0.0201	79	100	2.00987	**0.2%**
Discard_Fleet_1	0	79	0	0	
Discard_Fleet_Total	0	79	0	0	
CAA_proportions	N/A	711	see_below	524.626	**44.2%**
Discard_proportions	N/A	711	see_below	0	
Index_Fit_1 (SPOTTER)	165.434	39	1	119.525	**10.1%**
Index_Fit_2 (CPFV)	15.5464	67	1	107.834	**9.1%**
Index_Fit_3 (CalCOFI)	78.0771	37	1	318.819	**26.9%**
Index_Fit_Total	259.057	143	3	546.179	46.0%
Selectivity_devs_fleet_1	36.3896	2	0	0	
Selectivity_devs_Total	36.3896	2	0	0	**0.0%**
Catchability_devs_index_1	0	39	1	0	
Catchability_devs_index_2	0	67	1	0	
Catchability_devs_index_3	0	37	1	0	
Catchability_devs_Total	0	143	3	0	**0.0%**
Fmult_fleet_1	31.231	78	0	0	
Fmult_fleet_Total	31.231	78	0	0	**0.0%**
N_year_1	2.45627	8	0	0	
Stock-Recruit_Fit	58.803	79	1	55.5721	**4.7%**
Recruit_devs	58.803	79	1	58.803	**5.0%**
SRR_steepness	1.14554	1	0	0	
SRR_virgin_stock	4.53861	1	0	0	
Curvature_over_age	52.2818	14	0	0	
Curvature_over_time	72.7793	693	0	0	
F_penalty	1.9564	711	0.001	0.0019564	**0.0%**
Mean_Sel_year1_pen	0	9	1000	0	
Max_Sel_penalty	0.29413	1	100	0	
Fmult_Max_penalty	0	?	100	0	
Objective Function				1187.19	**100.0%**

Table 9. Comparison of results across models and scenarios.

	ASAP-2006	**ASAP-A1**	**ASAP-B2**	**ASAP-B3**	**ASAP-C1**	**SS2-C1**	**ASAP-E1**
Parameters (N)	181	183	183	183	189	96	198
Objective Function	1169.81	1207.74	932.34	1113.26	1119.50	1627.57	1187.19
B-zero	212,783	219,733	208,066	201,736	208,833	109,395	185,424
S-R Steepness	0.3585	0.3509	0.3759	0.3935	0.4061	0.4140	0.3086
Peak Recruits (1E+06)	3441.31	3207.87	3217.7	3412.22	3355.79	5338.31	6,646
Peak SSB	270,299	270,144	289,671	300,466	297,524	459,259	662,372
Peak 1+ Biomass	677,918	674,537	733,509	754,570	745,075	1,671,570	1,527,518
2006 Age 1+ Biomass	112,700	71,061	60,032	43,054	42,728	42,596	217,724

Table 10. Recruitment (Age-0 fish, in 1,000s), Biomass (Age 1+, mt), and Spawning Stock Biomass (mt) estimates from ASAP-E1 model (1929-07).

Fishing Year	Recruits (Age-0)	Biomass (Age-1+)	SSB
29	3,942,010	2,076,641	1,162,770
30	2,943,430	1,966,275	1,060,530
31	2,554,250	1,775,905	1,020,420
32	2,434,210	1,571,531	978,710
33	894,967	1,311,376	883,367
34	583,607	1,062,044	747,106
35	455,935	803,457	592,114
36	844,859	602,379	451,514
37	716,790	501,610	344,994
38	1,003,570	433,648	267,252
39	683,986	485,735	237,022
40	444,659	413,195	188,787
41	883,869	332,040	162,671
42	354,547	345,024	145,339
43	335,498	311,508	145,301
44	339,405	257,440	126,880
45	247,012	208,074	104,667
46	188,381	175,920	87,675
47	550,999	141,803	68,557
48	323,971	159,990	59,430
49	107,598	144,428	56,178
50	83,756	111,370	49,533
51	77,090	81,387	43,206
52	210,352	62,892	35,015
53	662,508	76,886	29,896
54	207,874	153,855	32,920
55	421,322	136,024	40,177
56	151,306	150,758	46,515
57	159,643	114,888	41,766
58	413,086	88,903	34,538
59	246,057	119,331	35,840
60	327,459	121,338	37,546
61	301,526	123,183	37,781
62	95,409	138,021	40,440
63	68,649	102,133	40,079
64	55,427	65,515	30,919
65	101,160	37,012	19,681
66	50,034	37,284	14,235
67	124,302	31,536	11,612
68	324,593	42,704	13,447
69	163,732	97,686	20,533
70	188,980	97,473	31,397
71	42,172	112,970	41,784
72	156,853	90,955	46,056
73	82,249	100,095	49,677
74	601,704	104,265	55,446
75	113,283	223,006	70,294
76	3,522,840	239,210	95,840
77	1,648,420	864,507	148,673
78	6,645,990	1,046,654	263,041
79	749,739	1,527,518	397,917
80	3,333,160	1,169,718	472,604
81	3,991,480	1,305,203	590,565
82	1,103,210	1,340,657	662,372
83	529,493	1,226,013	641,691
84	841,667	1,017,542	623,557
85	1,025,320	841,907	539,151
86	983,582	754,676	459,036
87	481,162	680,052	378,397
88	1,642,980	573,022	324,384
89	521,270	538,188	258,032
90	806,597	488,840	231,281
91	583,382	401,334	190,701
92	421,100	287,372	145,855
93	908,875	245,610	127,578
94	687,579	232,125	105,836
95	897,366	265,455	117,870
96	541,059	319,197	128,394
97	235,404	323,042	137,003
98	135,354	224,066	113,751
99	190,579	137,303	81,273
00	255,315	113,862	64,071
01	305,743	90,098	40,164
02	133,326	90,134	33,739
03	233,929	98,091	39,714
04	472,241	104,183	41,169
05	866,391	135,903	39,433
06	1,343,580	217,724	56,496
07	302,694	359,290	86,777

Table 11. Comparison of likelihood components and parameter estimates for sensitivity tests based on the ASAP-E1 model.

	BASE MODEL	SURVEY SENSITIVITY TEST			NATURAL MORTALITY SENSITIVITY TEST						
Likelihood Component	**E1-Base (M=0.5; 3 indices)**	**no SPOT**	**no CPFV**	**no CalCOFI**	**M=0.35**	**M=0.40**	**M=0.45**	**M=0.55**	**M=0.60**	**M=0.65**	**M=0.70**
Catch_Fleet_1	2.00987	2.1221	1.92671	0.847732	2.23729	2.21827	2.11548	1.85278	3.97118	1.49316	1.30135
Catch_Fleet_Total	2.00987	2.1221	1.92671	0.847732	2.23729	2.21827	2.11548	1.85278	3.97118	1.49316	1.30135
Discard_Fleet_1	0	0	0	0	0	0	0	0	0	0	0
Discard_Fleet_Total	0	0	0	0	0	0	0	0	0	0	0
CAA_proportions	524.626	527.134	475.263	509.928	502.662	510.241	517.593	531.309	572.286	543.583	549.111
Discard_proportions	0	0	0	0	0	0	0	0	0	0	0
Index_Fit_1 (SPOTTER)	119.525	0	90.8859	129.575	119.046	118.627	118.912	120.249	123.055	121.612	122.181
Index_Fit_2 (CPFV)	107.834	85.5177	0	95.4181	115.378	113.137	110.526	105.29	104.531	100.974	99.2433
Index_Fit_3 (CalCOFI)	318.819	330.757	303.26	0	319.077	318.902	318.906	318.554	313.566	317.164	316.033
Index_Fit_Total	546.179	416.275	394.146	224.993	553.501	550.667	548.344	544.093	541.152	539.749	537.457
Selectivity_devs_fleet_1	0	0	0	0	0	0	0	0	0	0	0
Selectivity_devs_Total	0	0	0	0	0	0	0	0	0	0	0
Catchability_devs_index_1	0	0	0	0	0	0	0	0	0	0	0
Catchability_devs_index_2	0	0	0	0	0	0	0	0	0	0	0
Catchability_devs_index_3	0	0	0	0	0	0	0	0	0	0	0
Catchability_devs_Total	0	0	0	0	0	0	0	0	0	0	0
Fmult_fleet_1	0	0	0	0	0	0	0	0	0	0	0
Fmult_fleet_Total	0	0	0	0	0	0	0	0	0	0	0
N_year_1	0	0	0	0	0	0	0	0	0	0	0
Stock-Recruit_Fit	55.5721	50.4925	64.4788	58.6725	54.6041	54.8511	55.174	56.0845	50.8916	57.521	58.4993
Recruit_devs	58.803	54.7517	65.9066	61.2757	58.031	58.228	58.4855	59.2117	55.0701	60.3574	61.1376
SRR_steepness	0	0	0	0	0	0	0	0	0	0	0
SRR_virgin_stock	0	0	0	0	0	0	0	0	0	0	0
Curvature_over_age	0	0	0	0	0	0	0	0	0	0	0
Curvature_over_time	0	0	0	0	0	0	0	0	0	0	0
F_penalty	0.0019564	0.00180446	0.000652647	0.00248601	0.000901324	0.00126393	0.00161947	0.0022736	0.000213006	0.00284291	0.00311001
Mean_Sel_year1_pen	0	0	0	0	0	0	0	0	0	0	0
Max_Sel_penalty	0	0	0	0	0	0	0	0	0	0	0
Fmult_Max_penalty	0	0	0	0	0	0	0	0	0	0	0
Total	1187.19	1050.78	1001.72	855.72	1171.04	1176.21	1181.71	1192.55	1223.37	1202.71	1207.51

Table 12. Proposed HG for Pacific mackerel for the 2007-08 management year opening July 1, 2007. See 'Harvest Guideline' section for methods used to derive the HG.

Biomass (Age-1+)	Cutoff (mt)	Fraction	Distribution	2007-08 Harvest Guideline (mt)
359,290	18,200	30%	70%	71,629

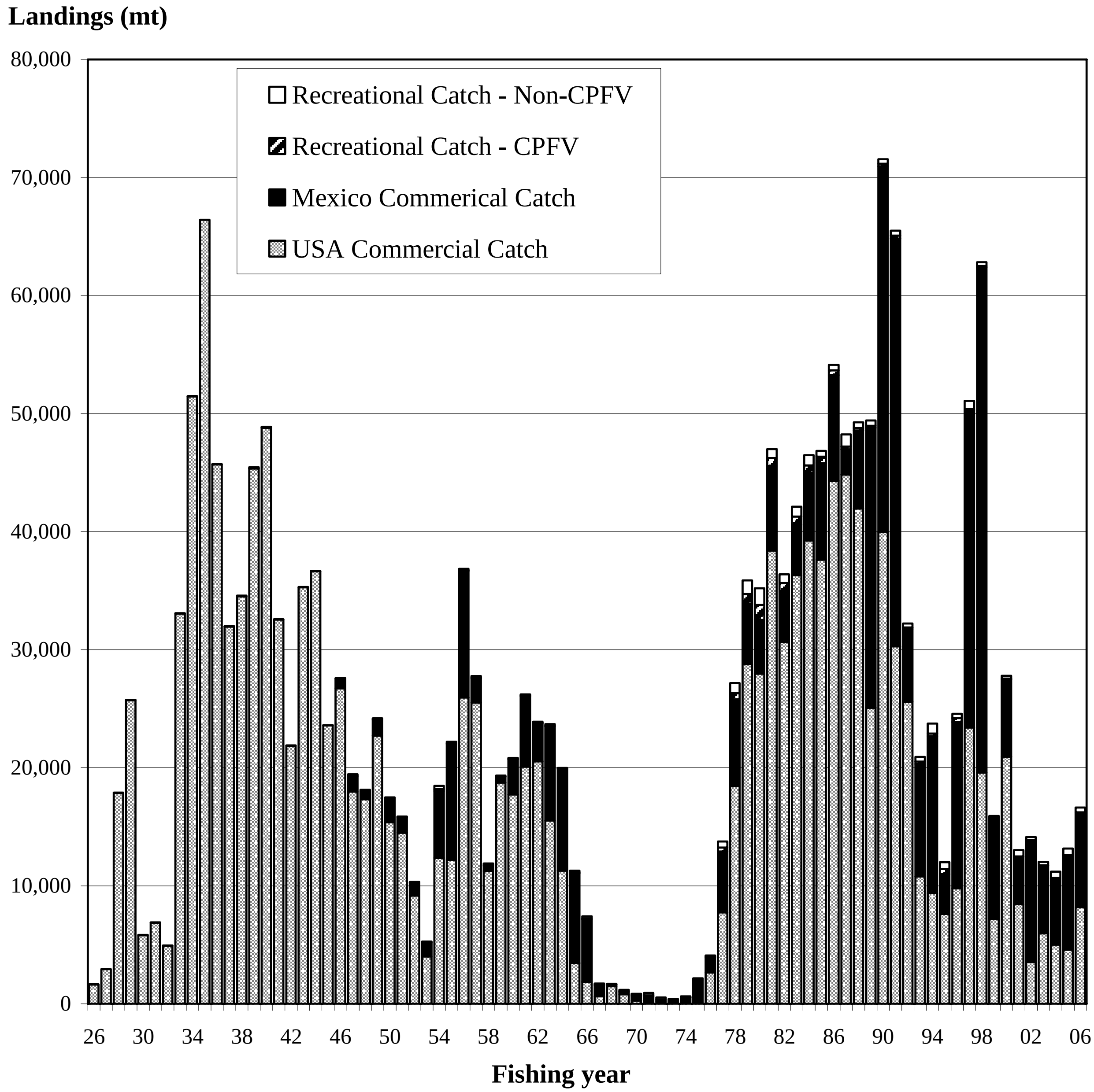

Figure 1. Commercial and recreational landings (mt) of Pacific mackerel in California (CA) and Baja California (MX) used in the ASAP and SS2-C1 models (1926-06). See Fishery Data section for description of fishing year.

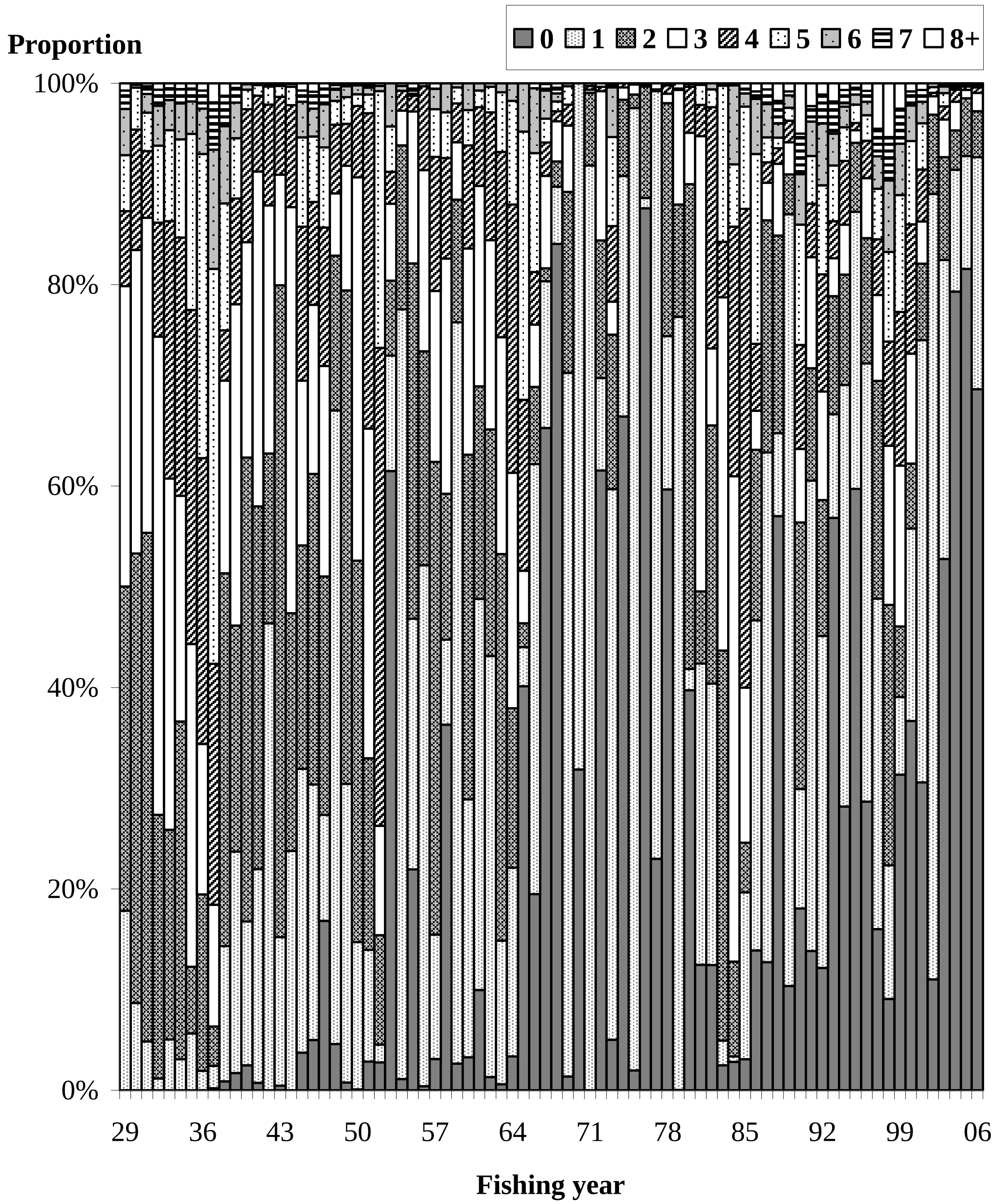

Figure 2. Pacific mackerel catch-at-age (in proportion) estimates used in the ASAP-E1 model (1926-06).

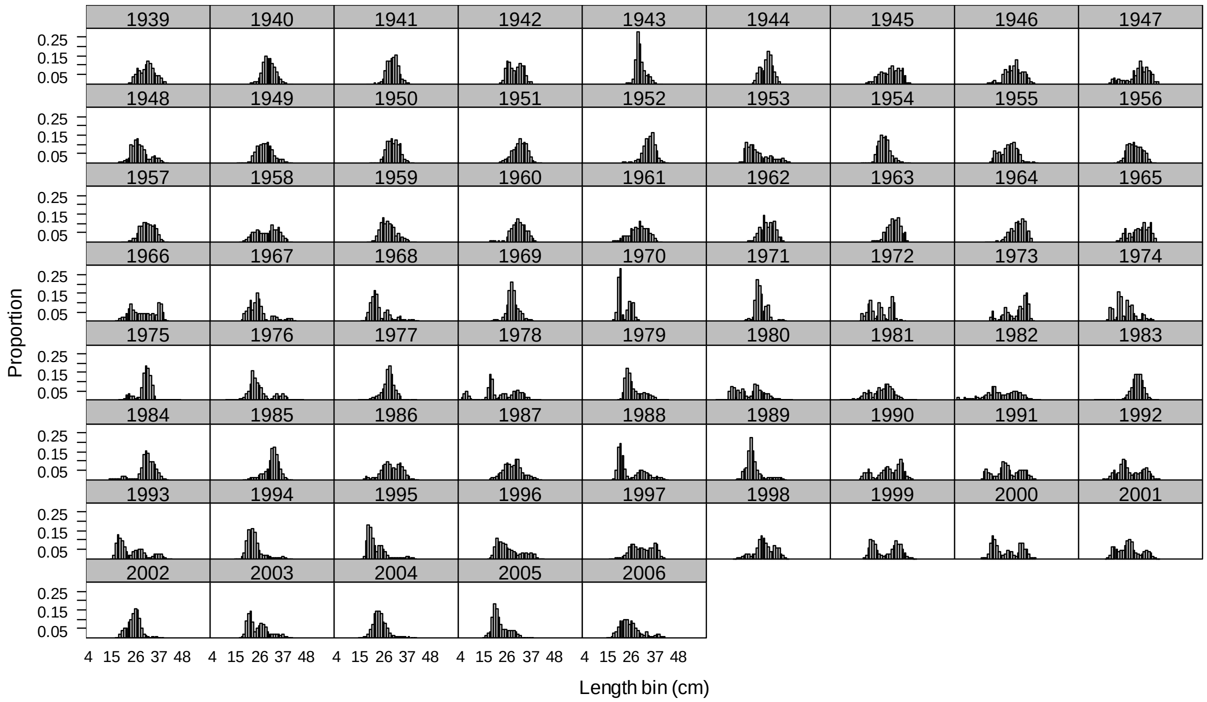

Figure 3. Whole catch lengths for the Pacific mackerel commercial fishery (1939-06). See Fishery Data section for description of fishing year.

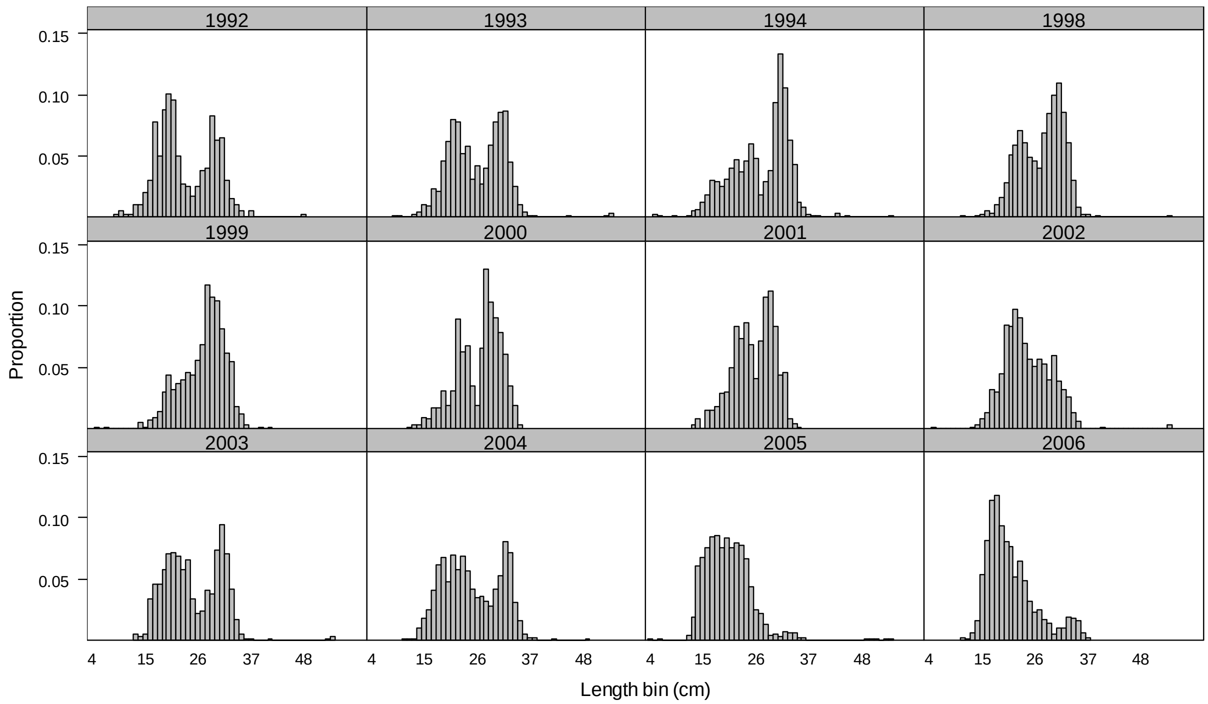

Figure 4. Whole catch lengths for the Pacific mackerel recreational fishery (1992-06). See Fishery Data section for description of fishing year.

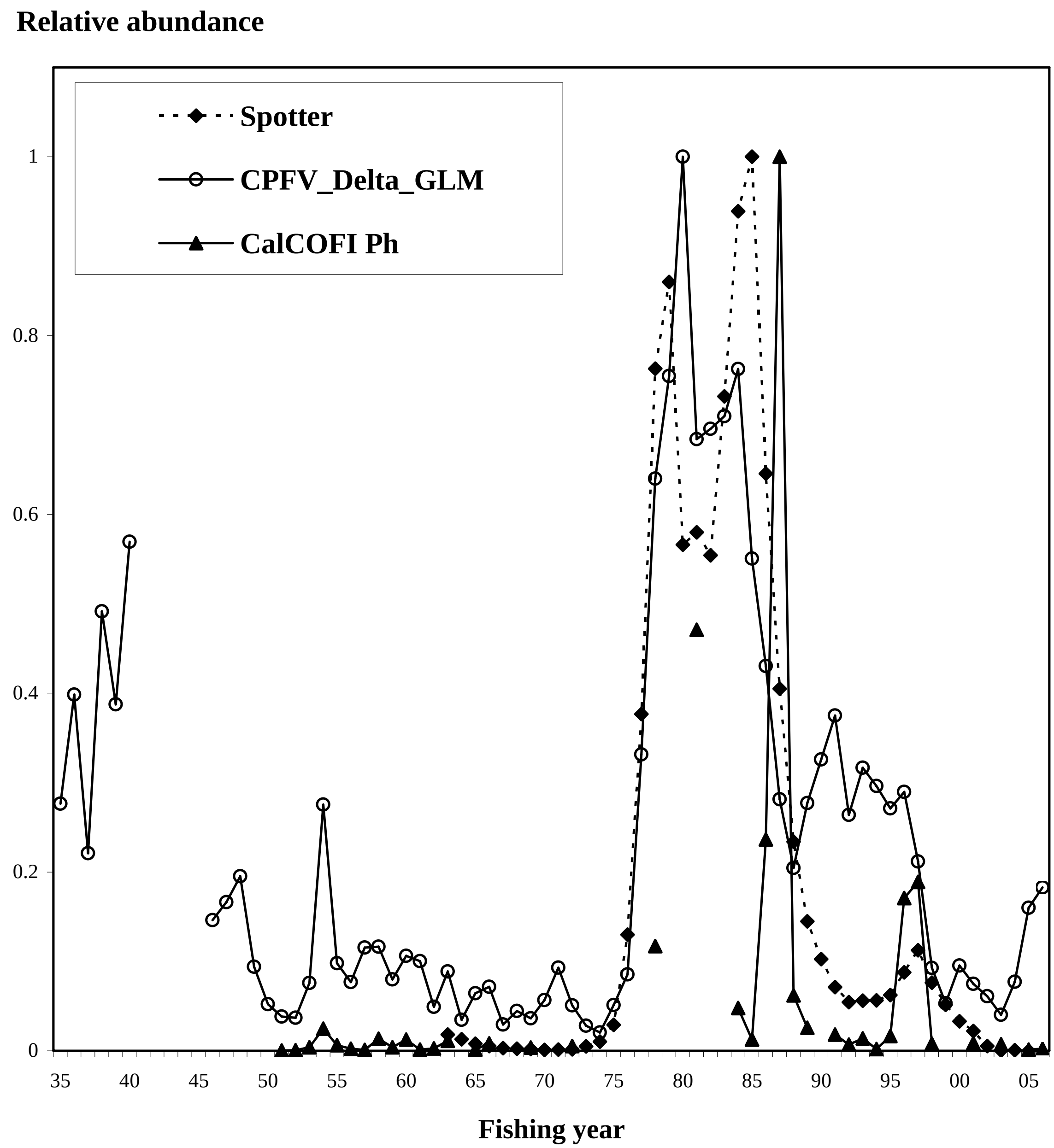

Figure 5. Indices of abundance time series for Pacific mackerel used in the ASAP-E1 (1926-07). Indices are rescaled (normalized) to a maximum of 1.

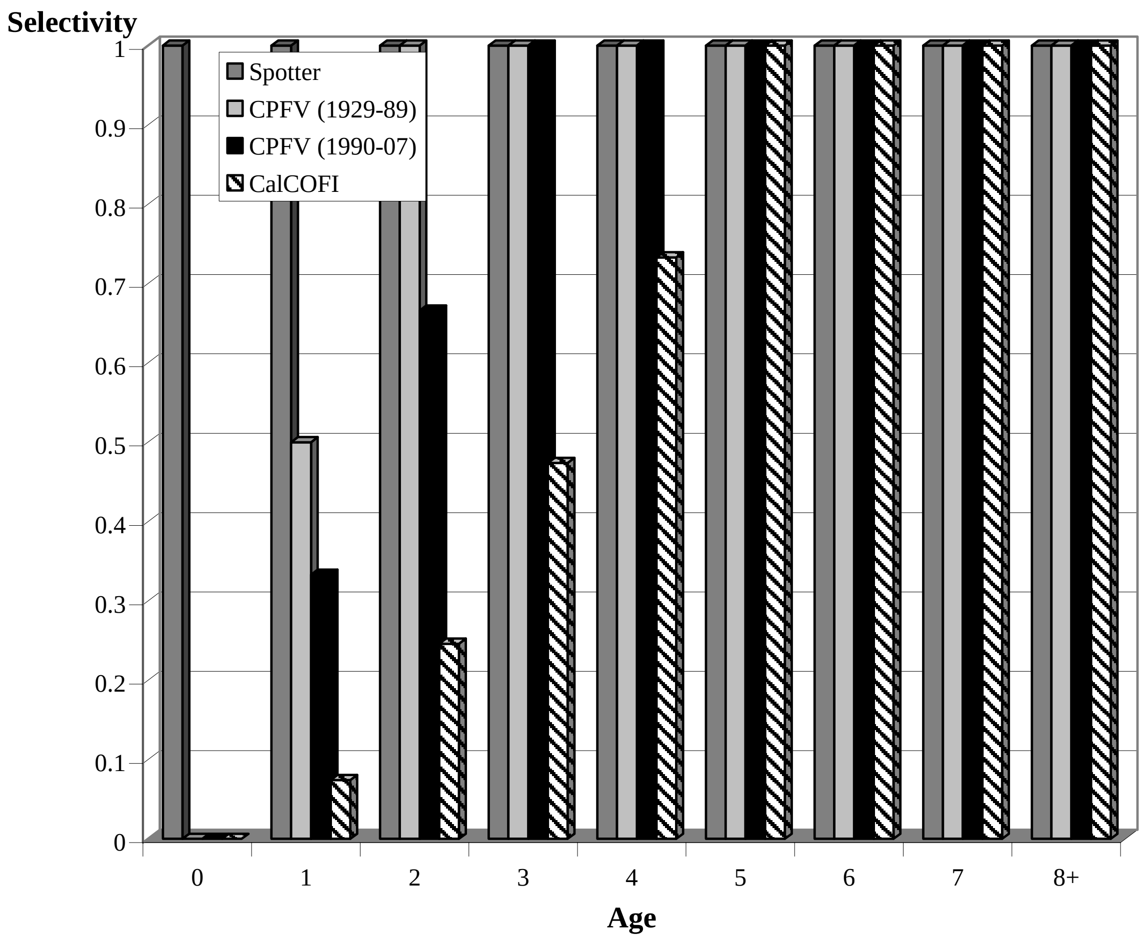

Figure 6. Assumed selectivity ogives for survey-related indices of abundance (Spotter, CPFV, and CalCOFI) from the ASAP-E1 model (1926-07). Note that CPFV ogive represents 1990-07, with ogive for 1929-89 parameterized with slightly different probabilities for ages 1 and 2.

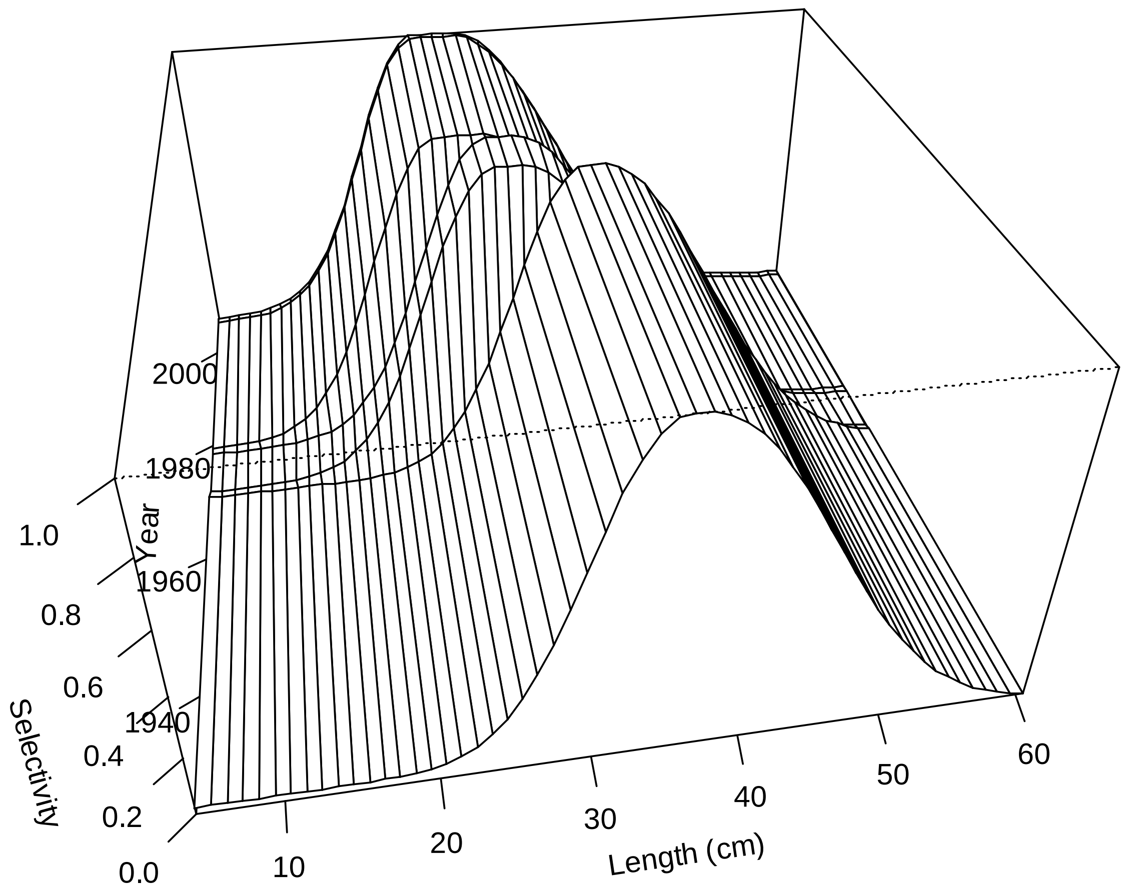

Figure 7. Time varying selectivity curves, for the Pacific mackerel commercial fishery (1926-06). See Data section for description of block designs for selectivity parameters.

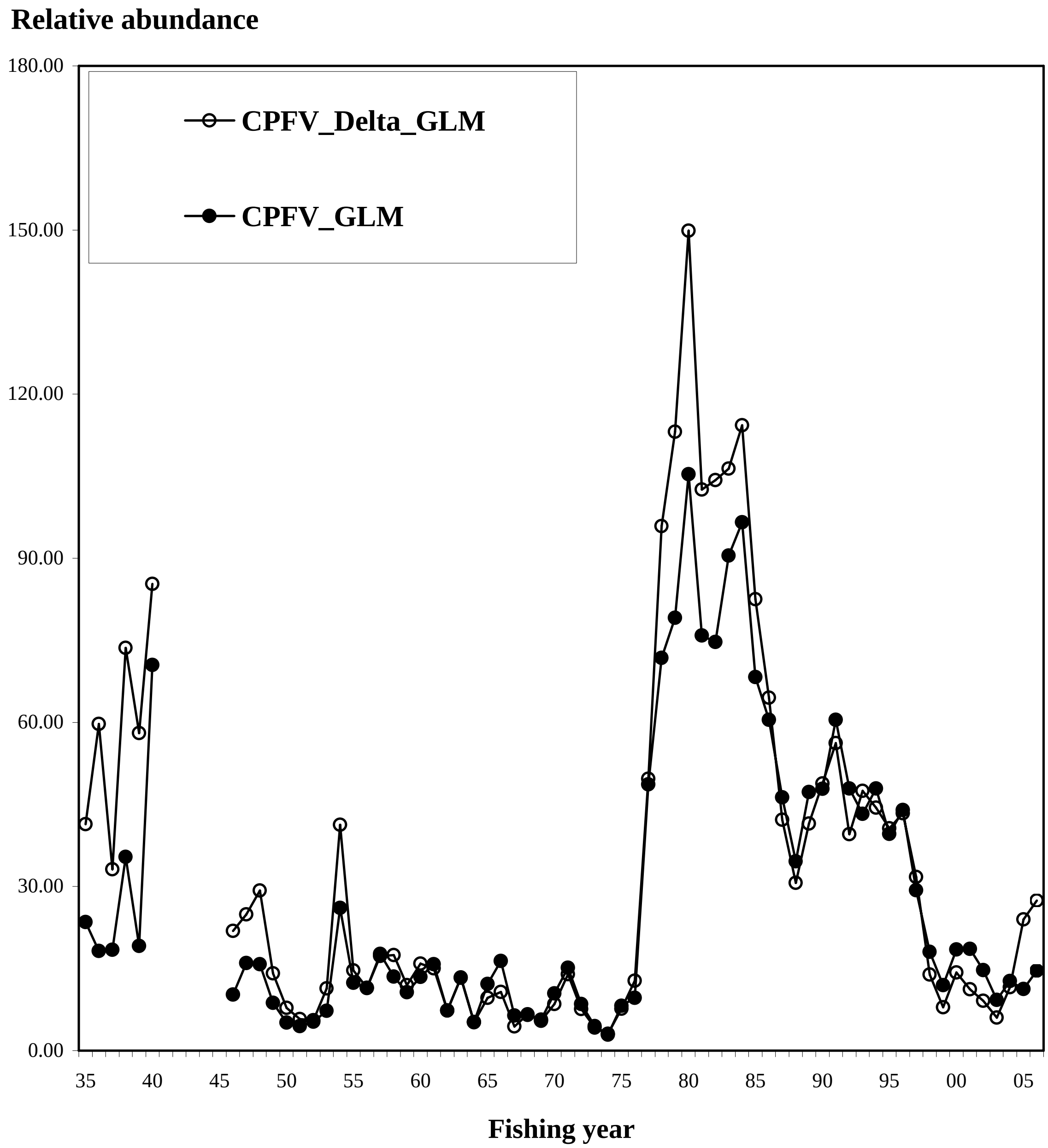

Figure 8. Indices of abundance time series for Pacific mackerel used in the ASAP-E1 model (1926-06) comparing GLM to Delta_GLM.

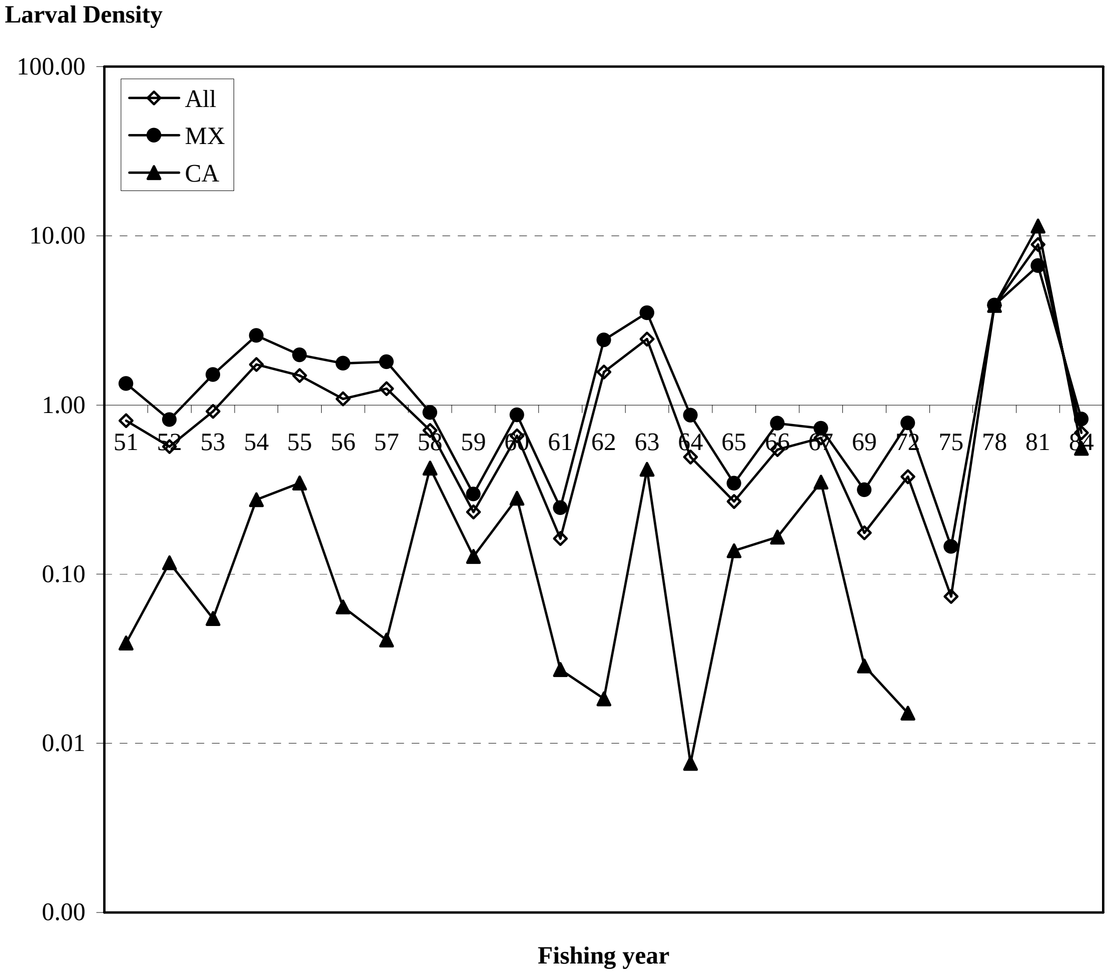

Figure 9a. Coastwide larval densities (diamonds), larval densities off Mexico (squares), and larval densities for the SCB (results based on CalCOFI surveys that covered Mexico and the SCB (1951-1984)).

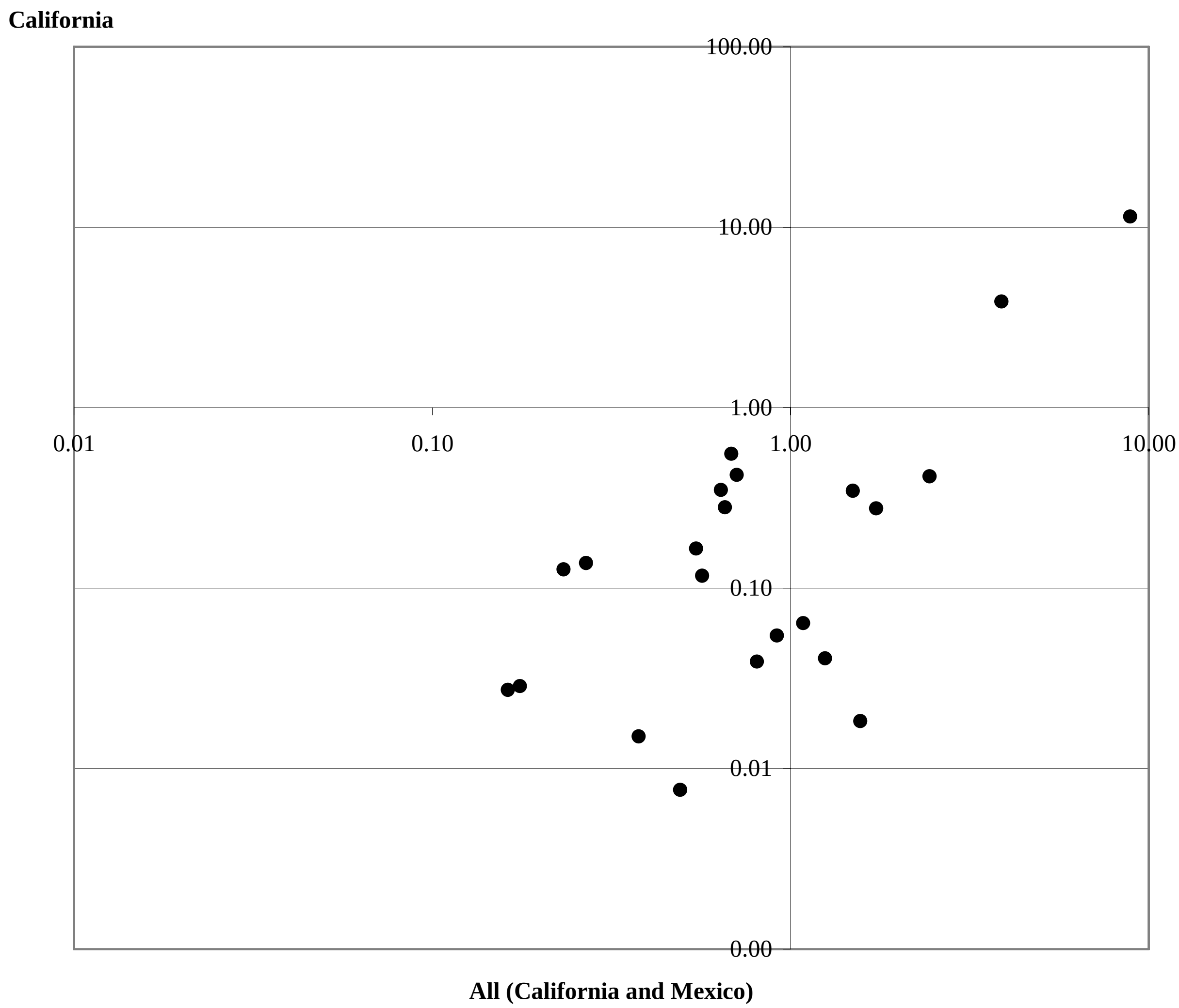

Figure 9b. Average larval densities (Mexico and the SCB) versus larval densities for the SCB based on CalCOFI surveys that covered Mexico and the SCB (1951-1984).

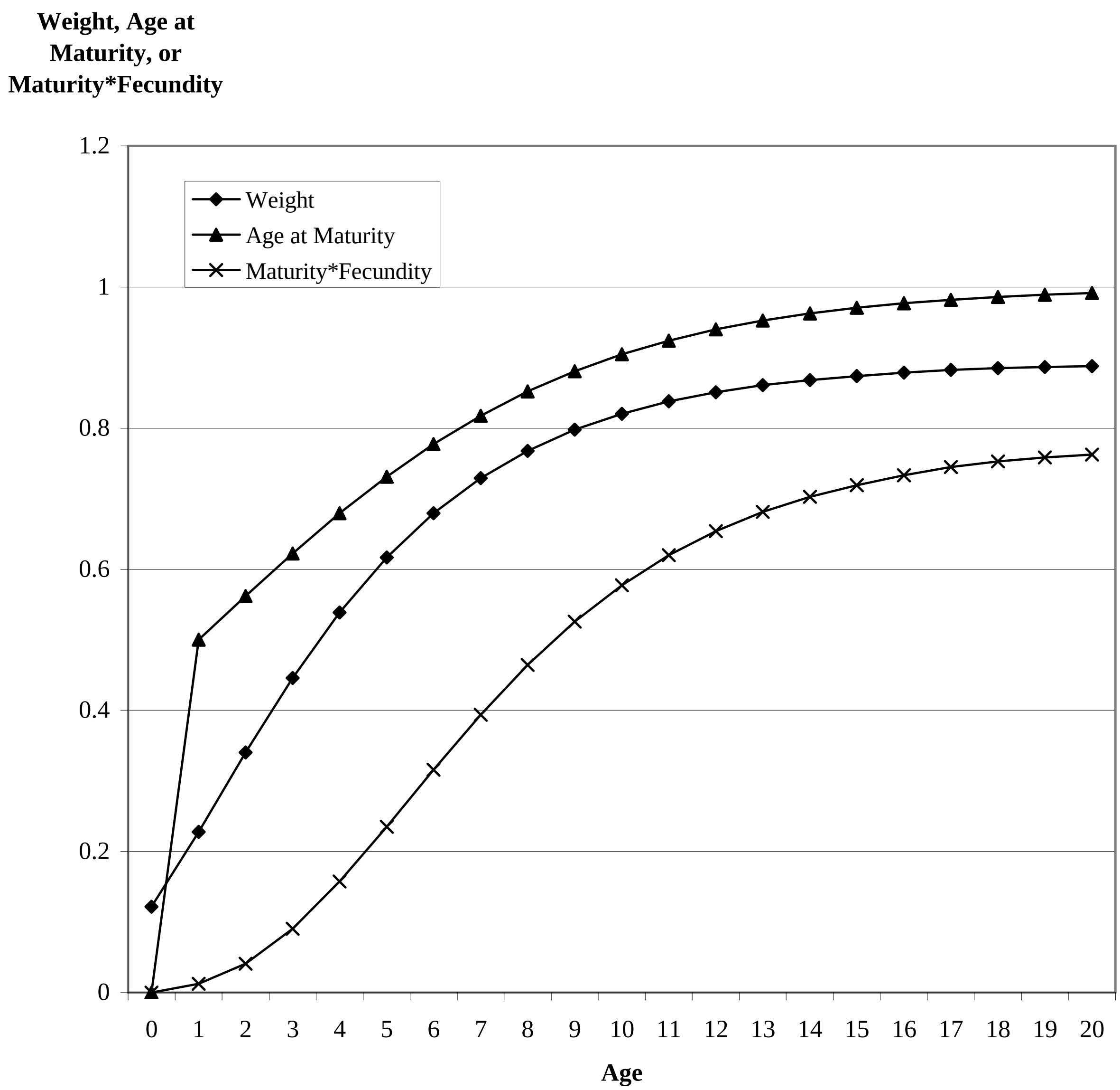

Figure 10. Maturity, fecundity, and weight-at-age curves derived from the SS2-C1 model. Fecundity was estimated as a linear function of body-weight (See Section: SS2 Model Description).

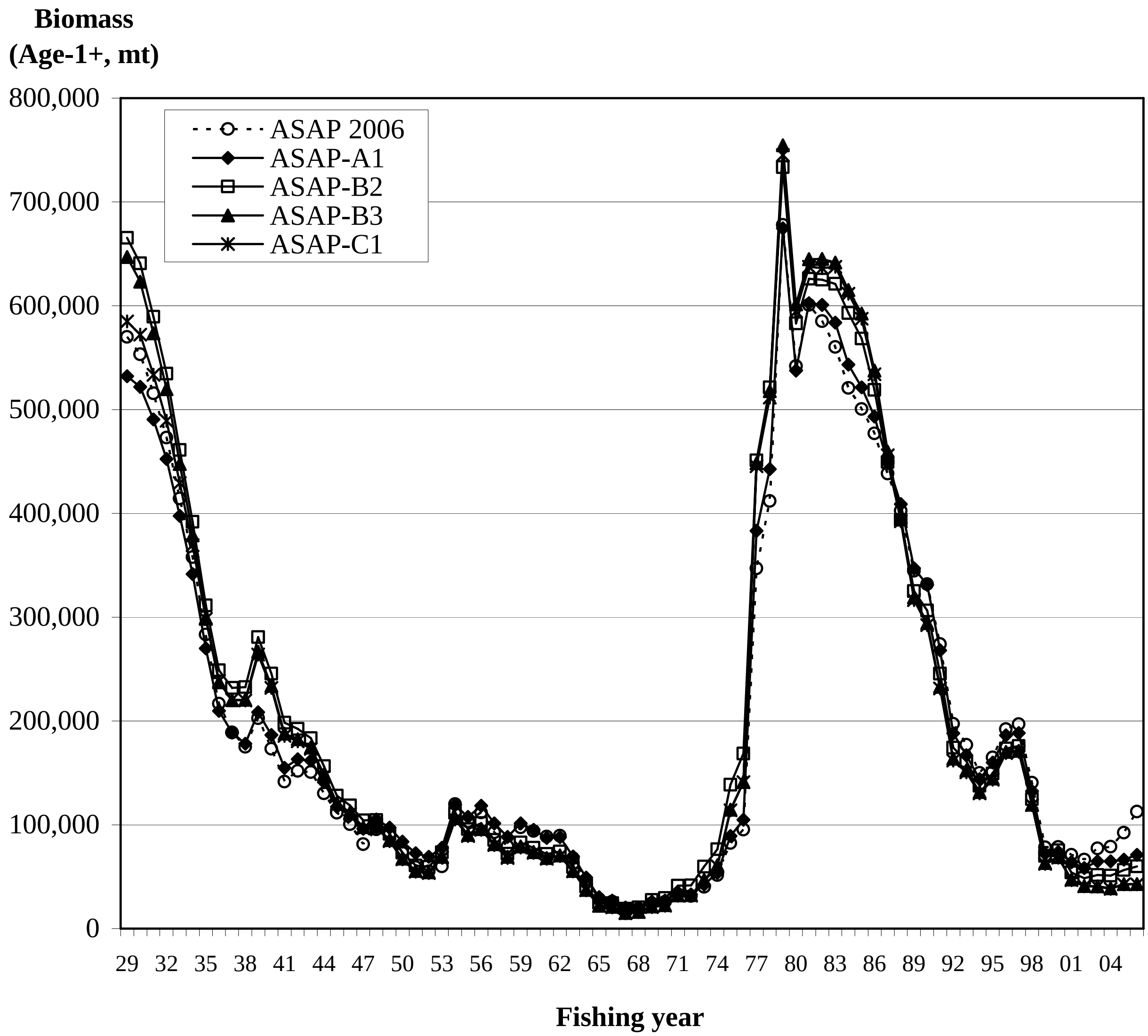

Figure 11. Estimated biomass (Age 1+ fish, in mt) of Pacific mackerel generated from the ASAP 2006, A1, B2, B3 and C1 models.

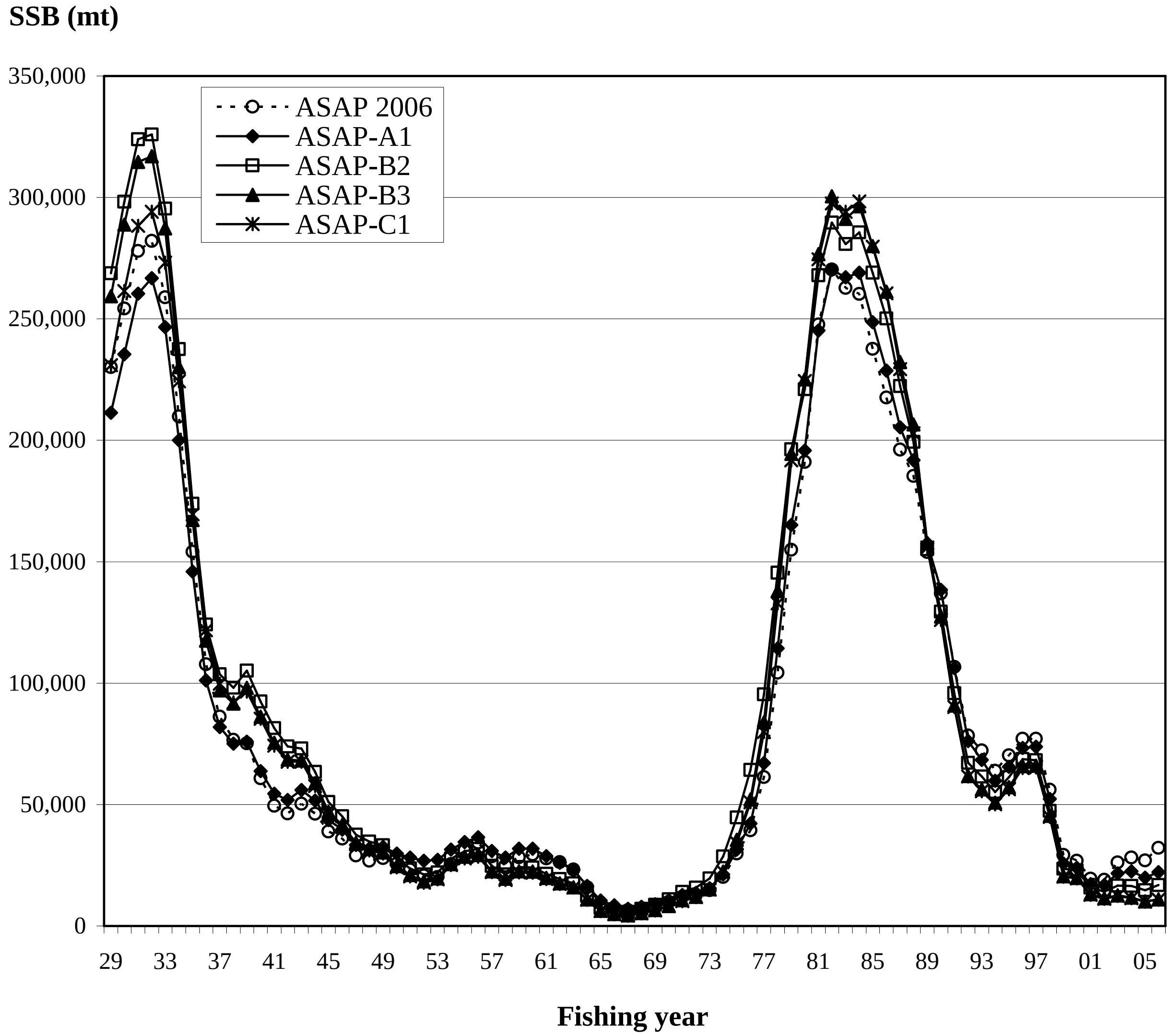

Figure 12. Estimated spawning stock biomass (SSB, in mt) of Pacific mackerel generated from the ASAP 2006, A1, B2, B3, and C1 models.

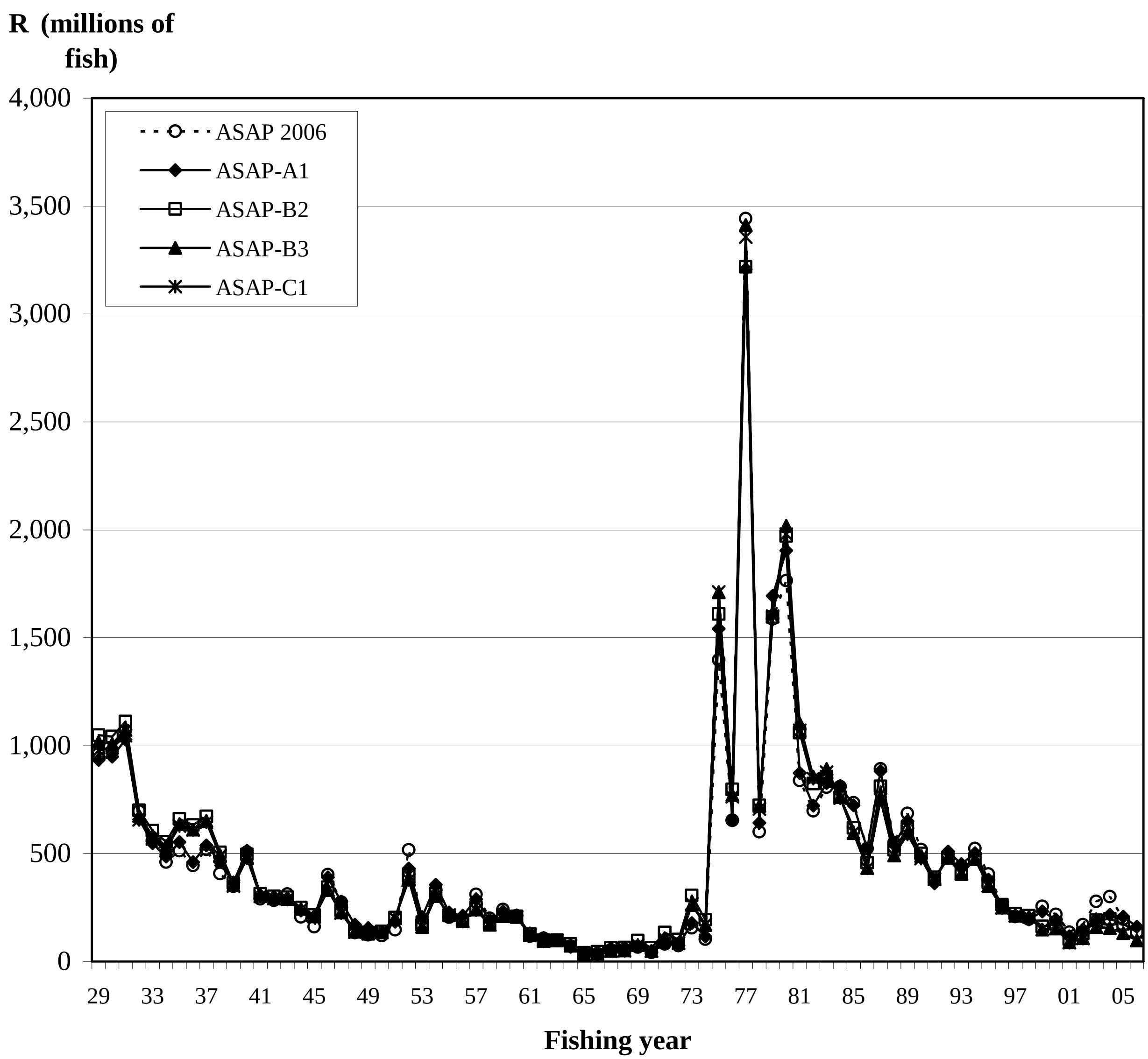

Figure 13. Estimated recruitment (Age-0 fish in millions, R) of Pacific mackerel generated from the ASAP 2006, A1, B2, B3, and C1 models.

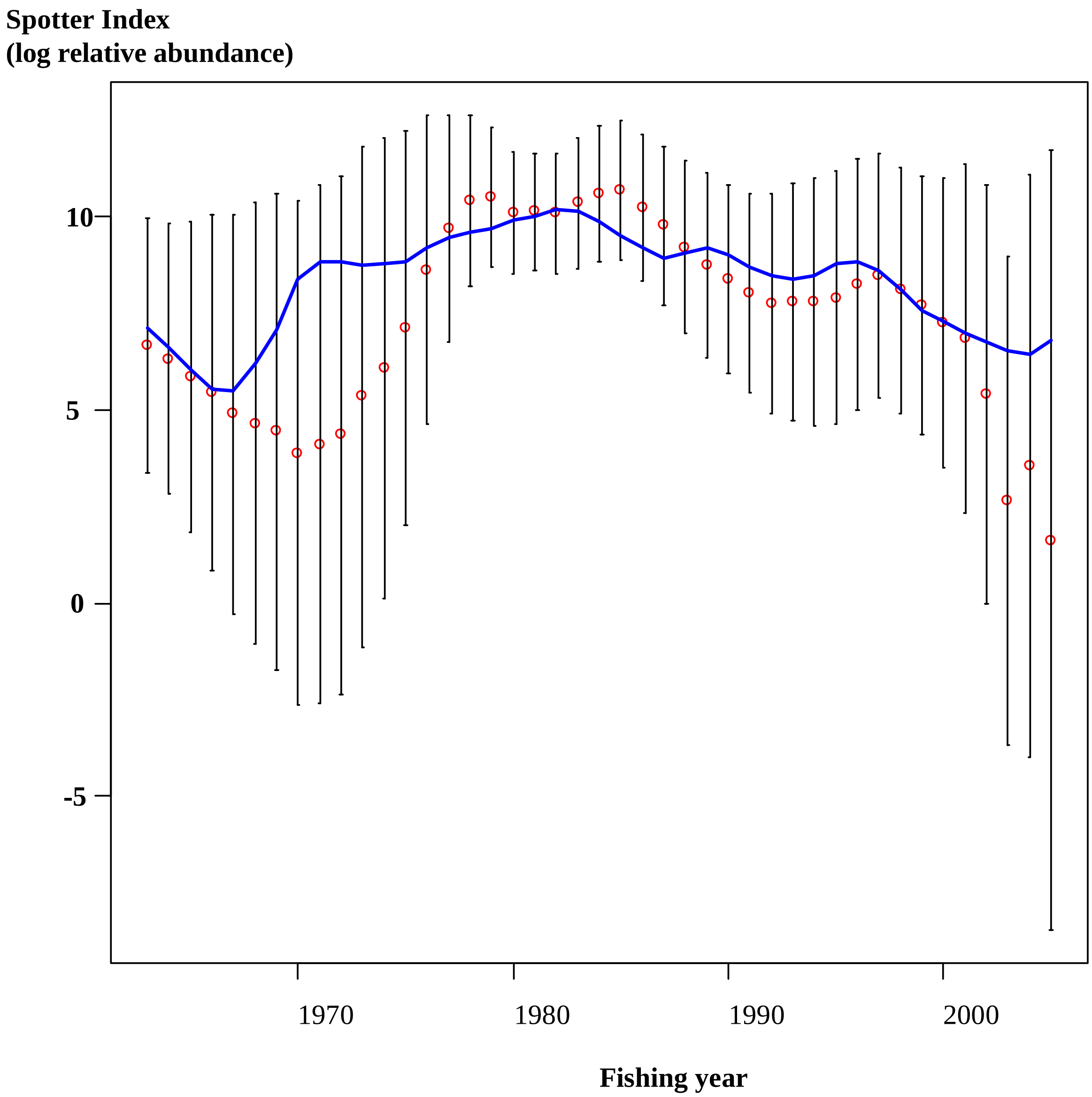

Figure 14. Relative abundance (in log scale) fits for the aerial spotter survey derived from the SS2-C1 model (1935-06). Line indicates predicted values from the SS2-C1 model. Bars are standard errors of observed values. See Data Section for a description of Fishing year.

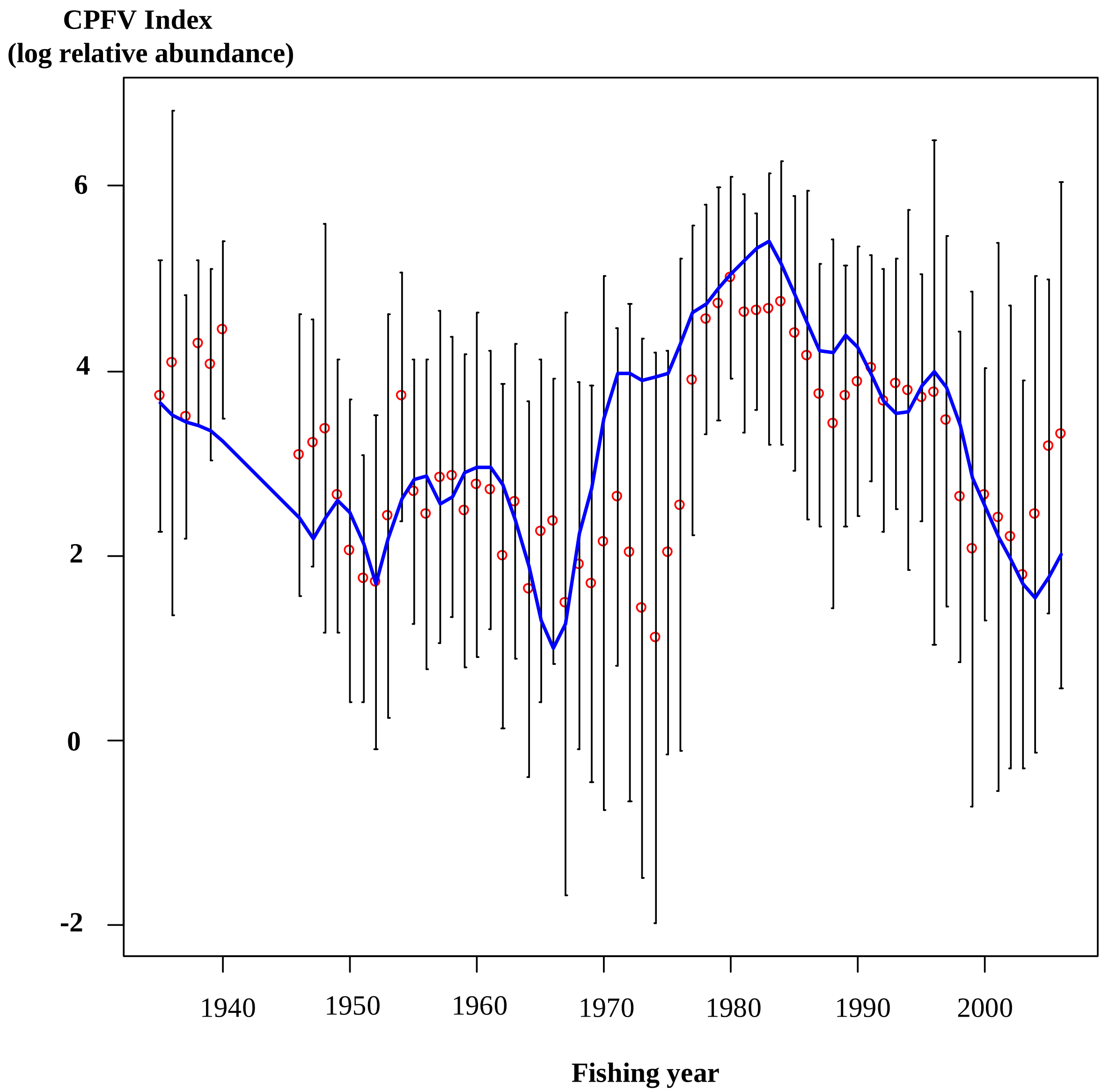

Figure 15. Catch rate (in log scale) fits of the CPFV index time series by the SS2-C1 model (1935-06). Line indicates predicted values from the SS2-C1 model. Bars are standard errors of observed values. See Data Section for a description of Fishing year.

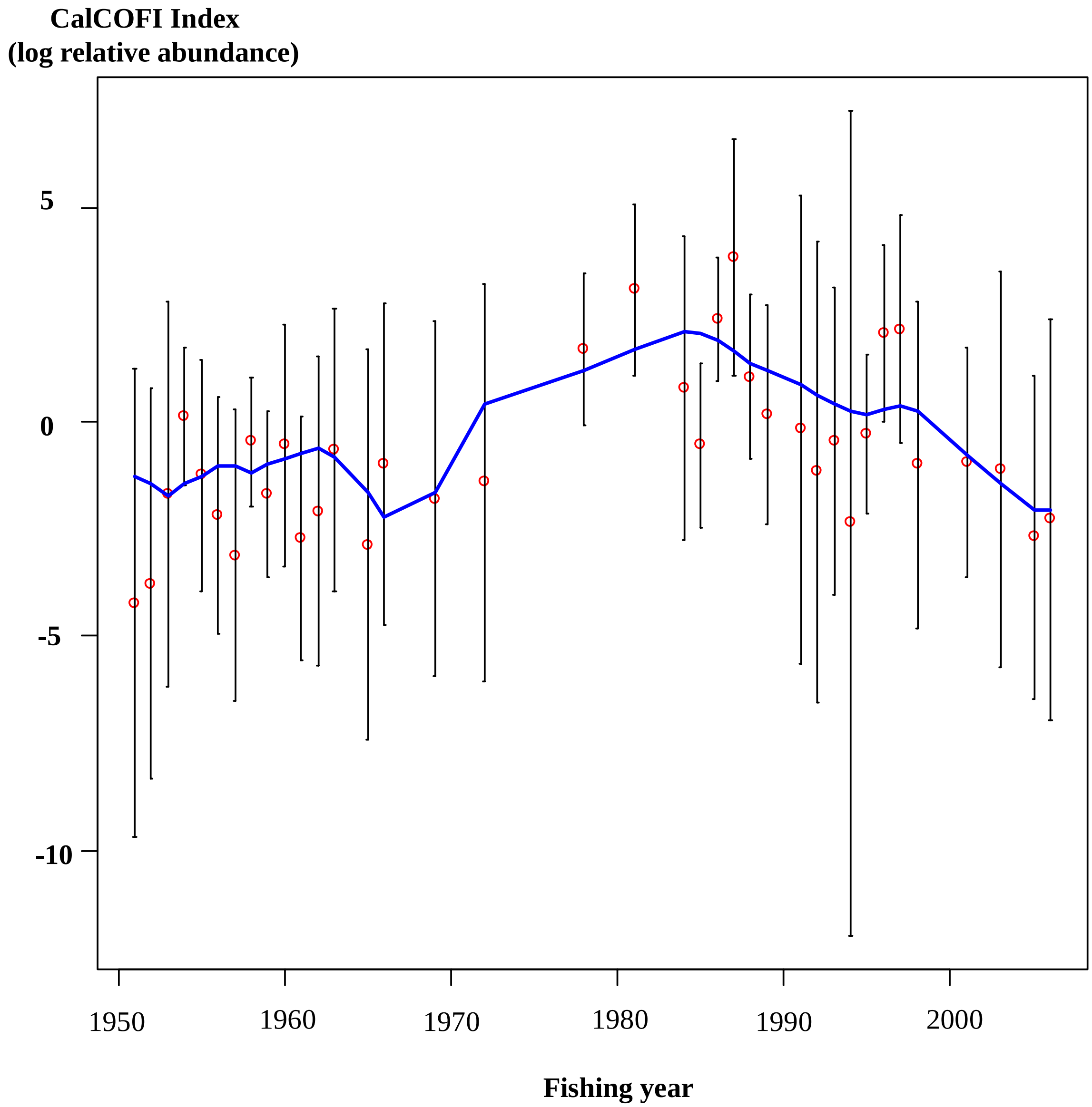

Figure 16. Daily larval production/10 m^2 (in log scale) fits derived from the SS2-C1 model (1951-06). Line indicates predicted values from the SS2-C1 model. Bars are standard errors of observed values. See Data Section for a description of Fishing year.

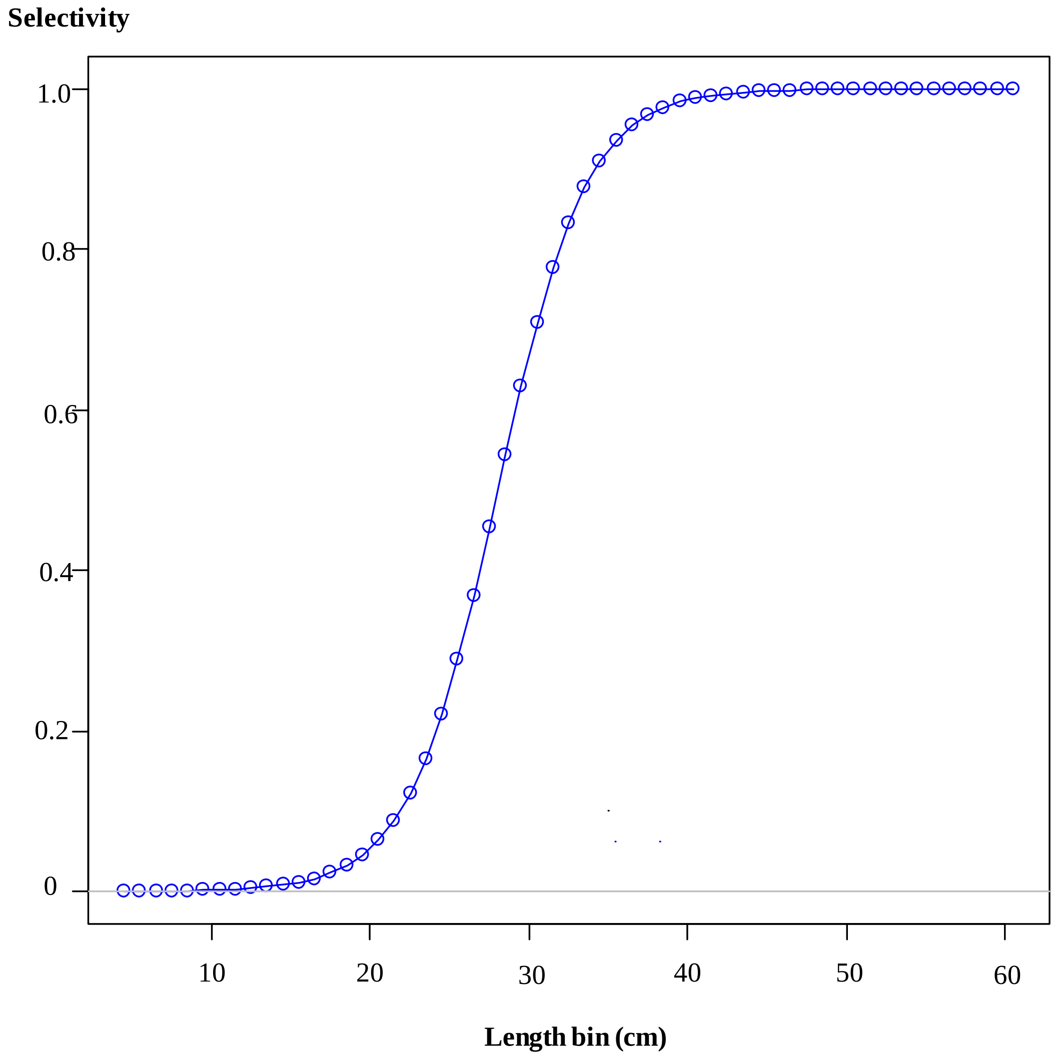

Figure 17. Size selectivity curve, for the Pacific mackerel recreational fishery and the CPFV index, derived from the SS2-C1 model (1939-06). See Data section for description of block designs for selectivity parameters.

Harvest rate/Fishing year

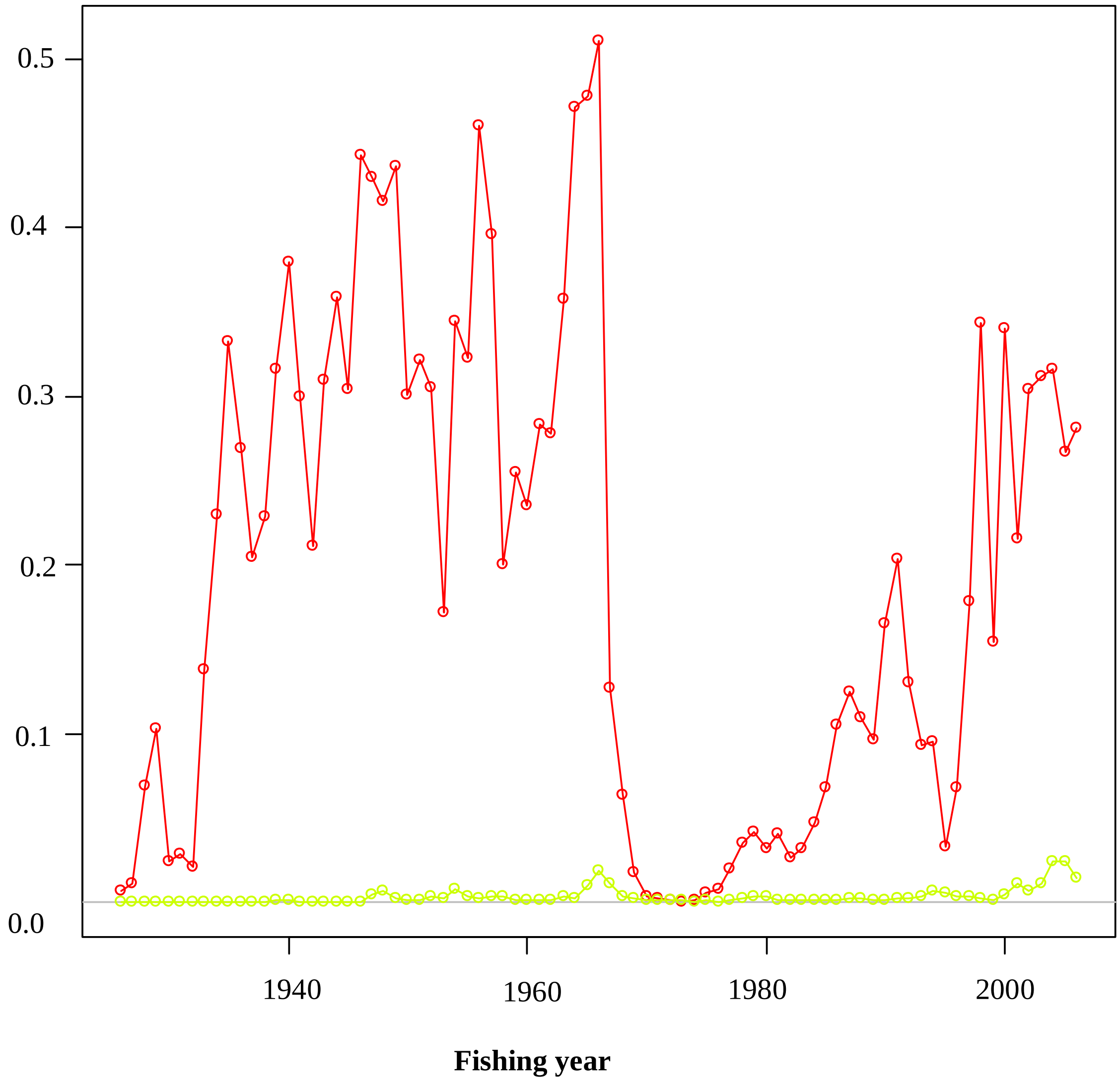

Figure 18. Harvest rate of Pacific mackerel estimated by the SS2-C1 model for the commercial (dark gray) and recreational (light gray line) fisheries (1926-06). See Data section for a description of Fishing year.

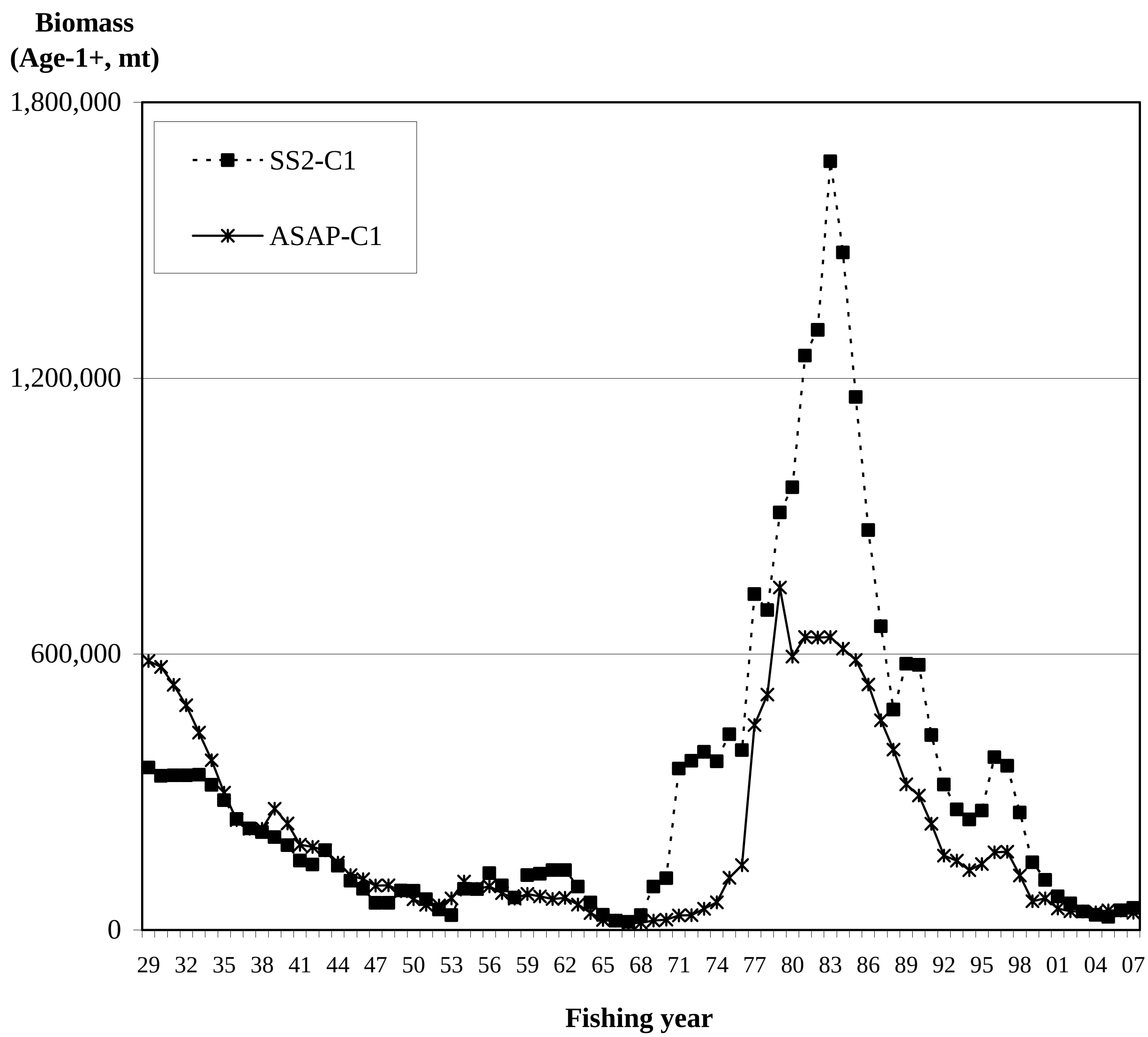

Figure 19. Estimated biomass (Age 1+ fish, B in mt) of Pacific mackerel generated from the ASAP-C1 and SS2-C1 models (1929-07).

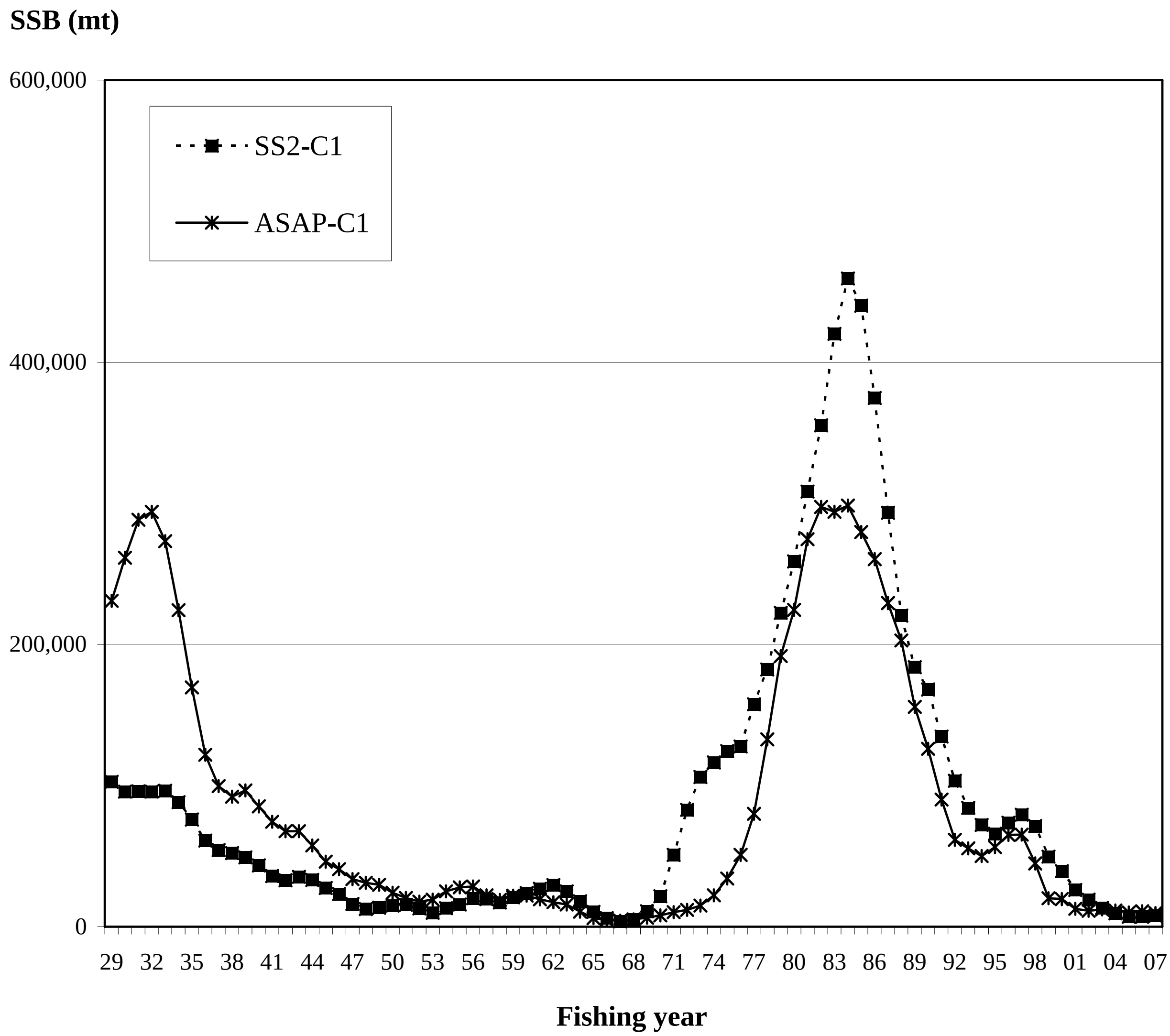

Figure 20. Estimated spawning stock biomass (SSB, in mt) of Pacific mackerel generated from the ASAP-C1 and SS2-C1 models (1929-07).

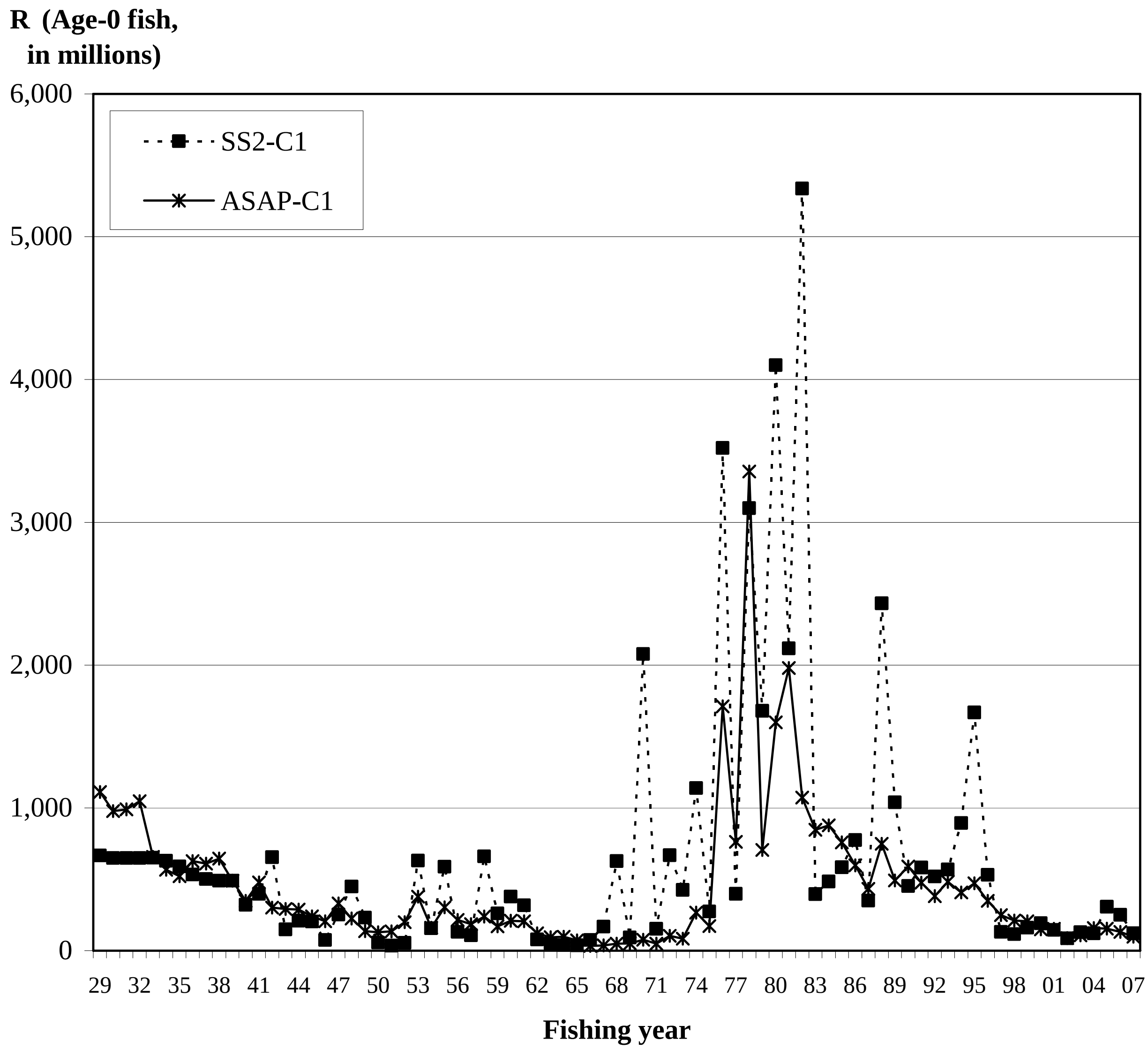

Figure 21. Estimated recruitment (Age-0 fish in millions, R) of Pacific mackerel generated from the ASAP-C1 and SS2-C1 models (1929-07).

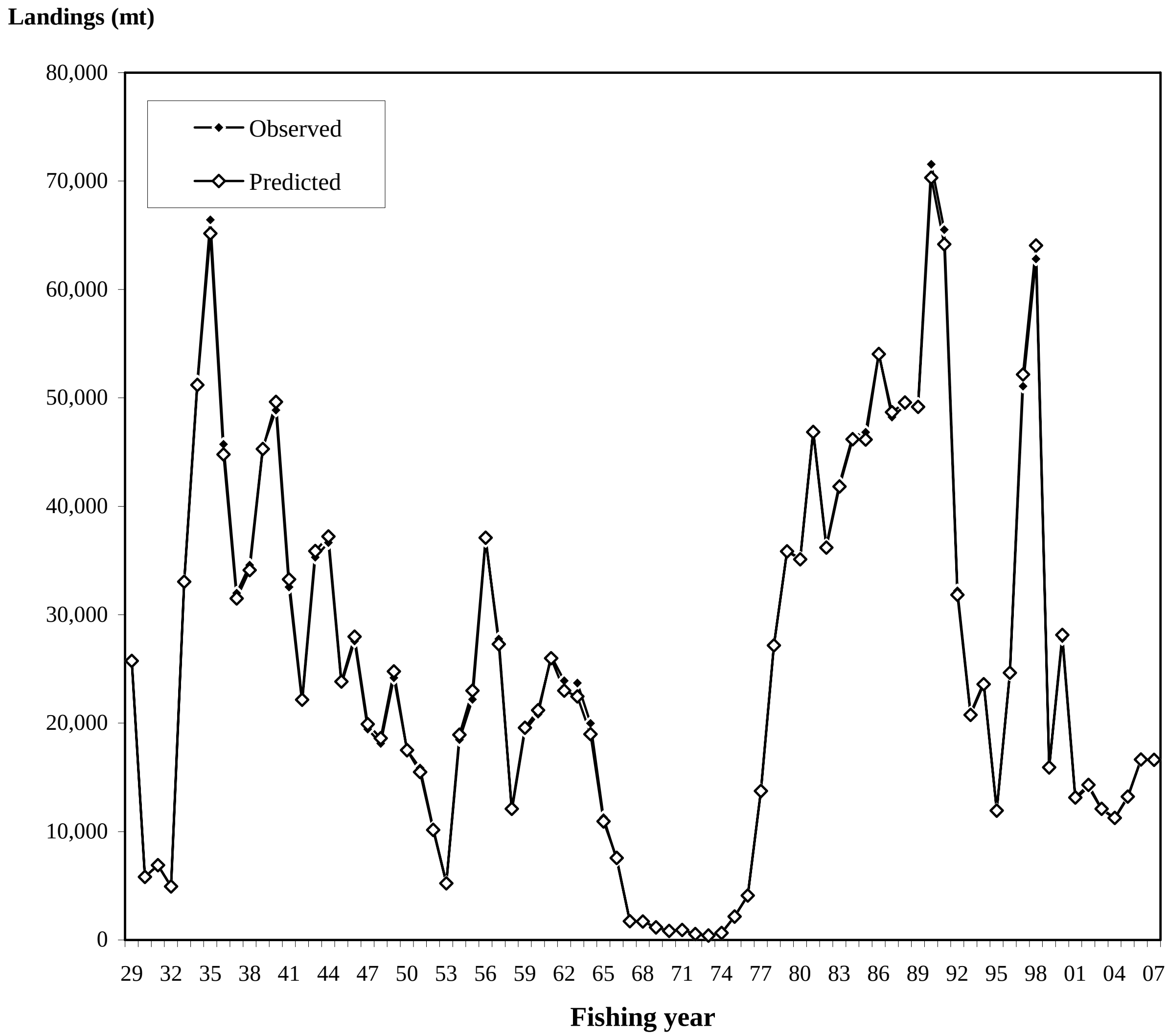

Figure 22. Observed and predicted estimates of total landings (mt) for Pacific mackerel generated from the ASAP-E1 model (1929-07).

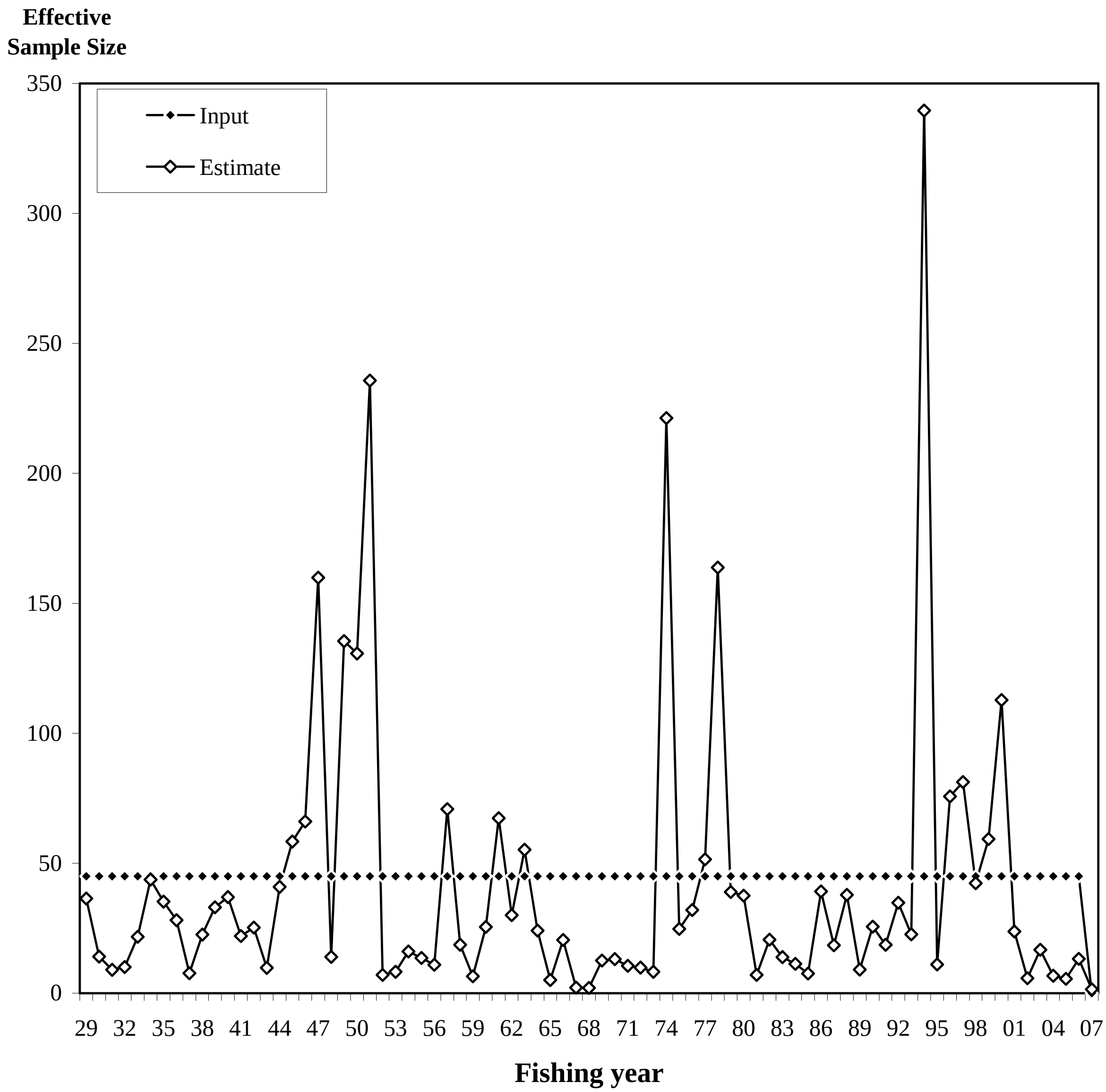

Figure 23. Effective sample sizes estimated for catch-at-age data generated from the ASAP-E1 model (1929-07). Catch-at-age data were given a lambda weighting of '45' for all years.

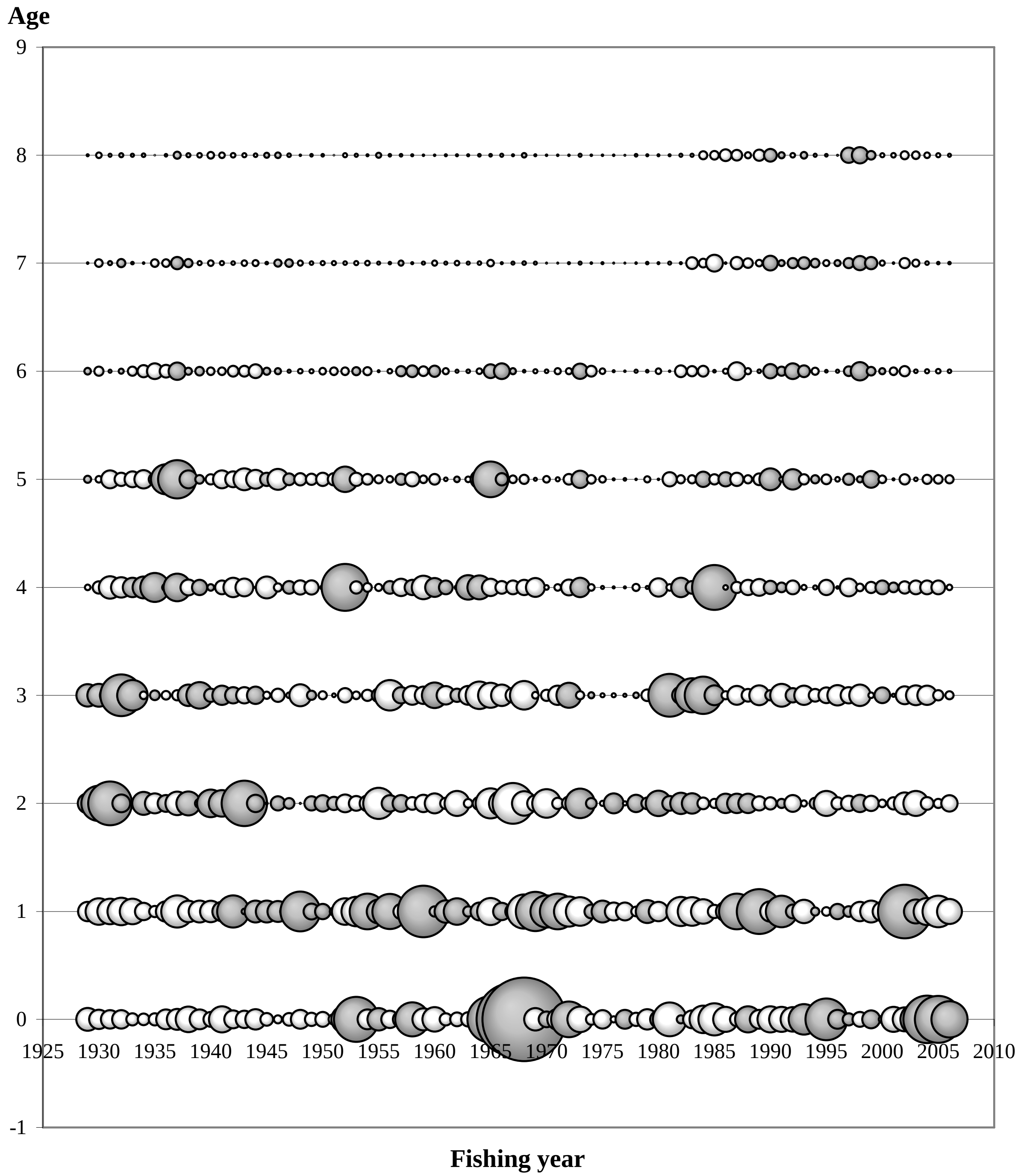

Figure 24. Pearson residual plot for Pacific mackerel catch-at-age fitted to the ASAP-E1 model (1929-07).

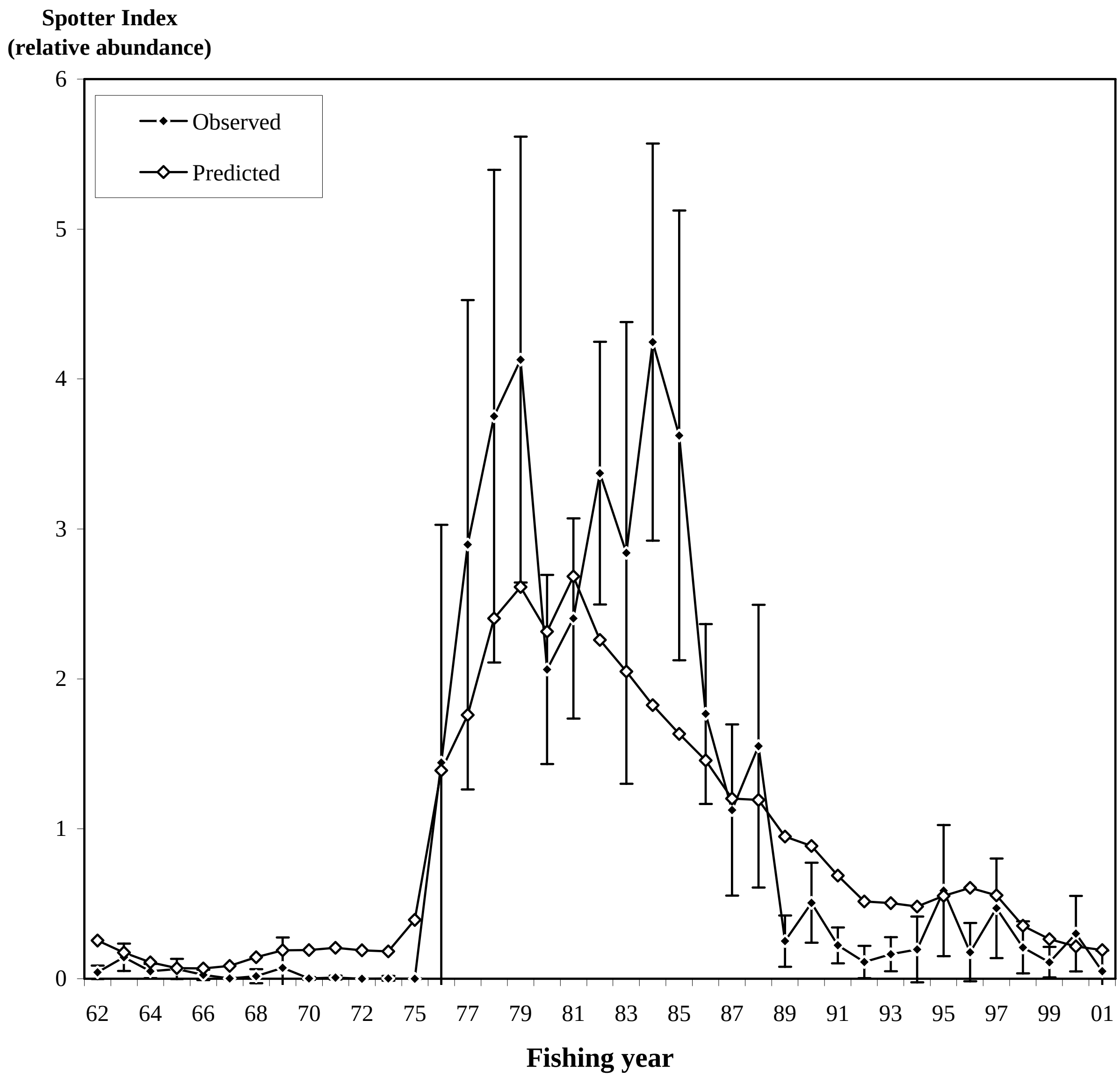

Figure 25. Observed and predicted estimates of the Spotter index of relative abundance (see Appendix 1) for Pacific mackerel generated from the ASAP-E1 model (1962-01). Bars represent ± 2 STD. *Note: Observed values were internally re-scaled by ASAP.

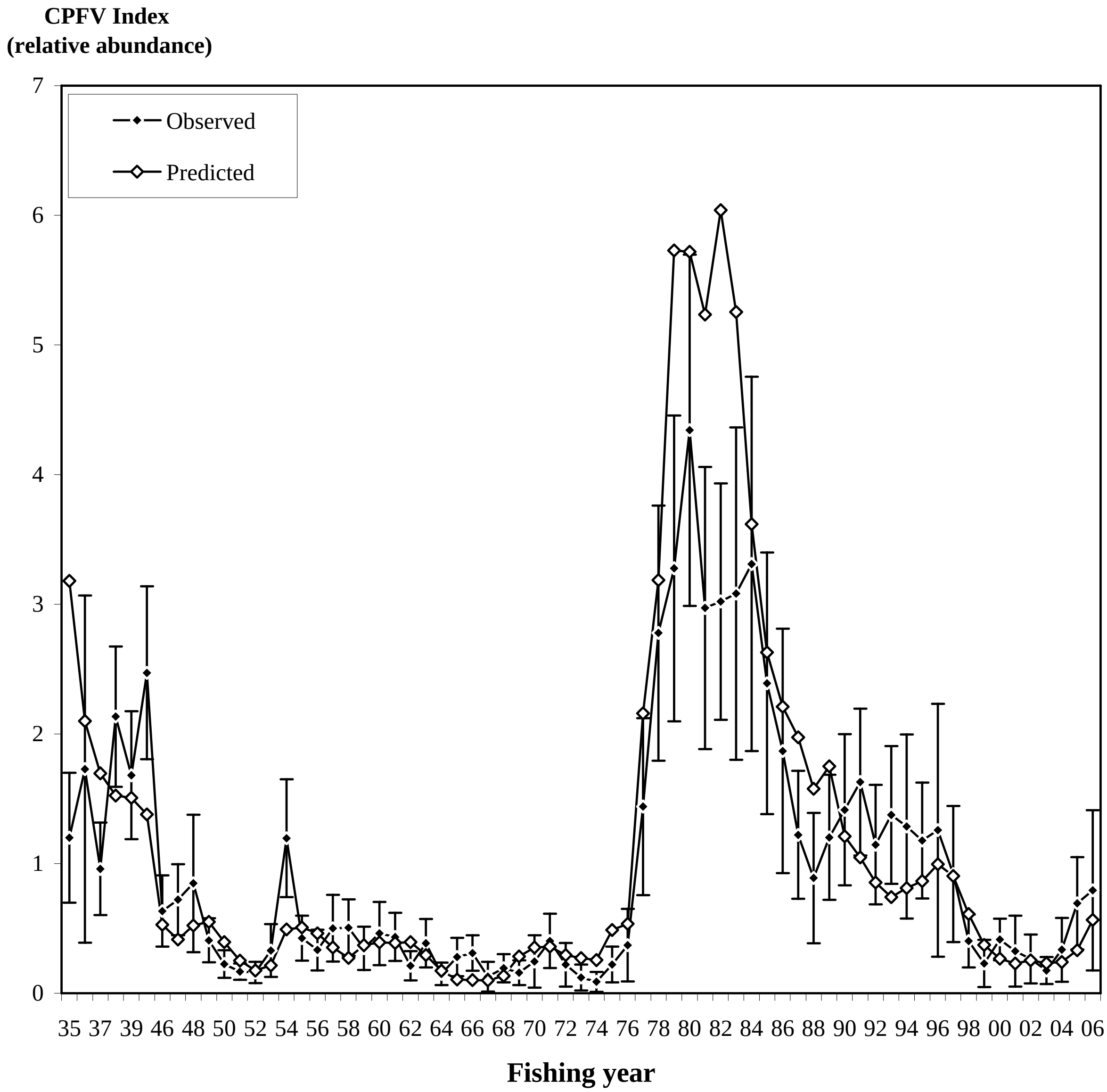

Figure 26. Observed and predicted estimates of the CPFV index of relative abundance for Pacific mackerel generated from the ASAP-E1 model (1935-06). Bars represent ± 2 STD. *Note: Observed values were internally re-scaled by ASAP.

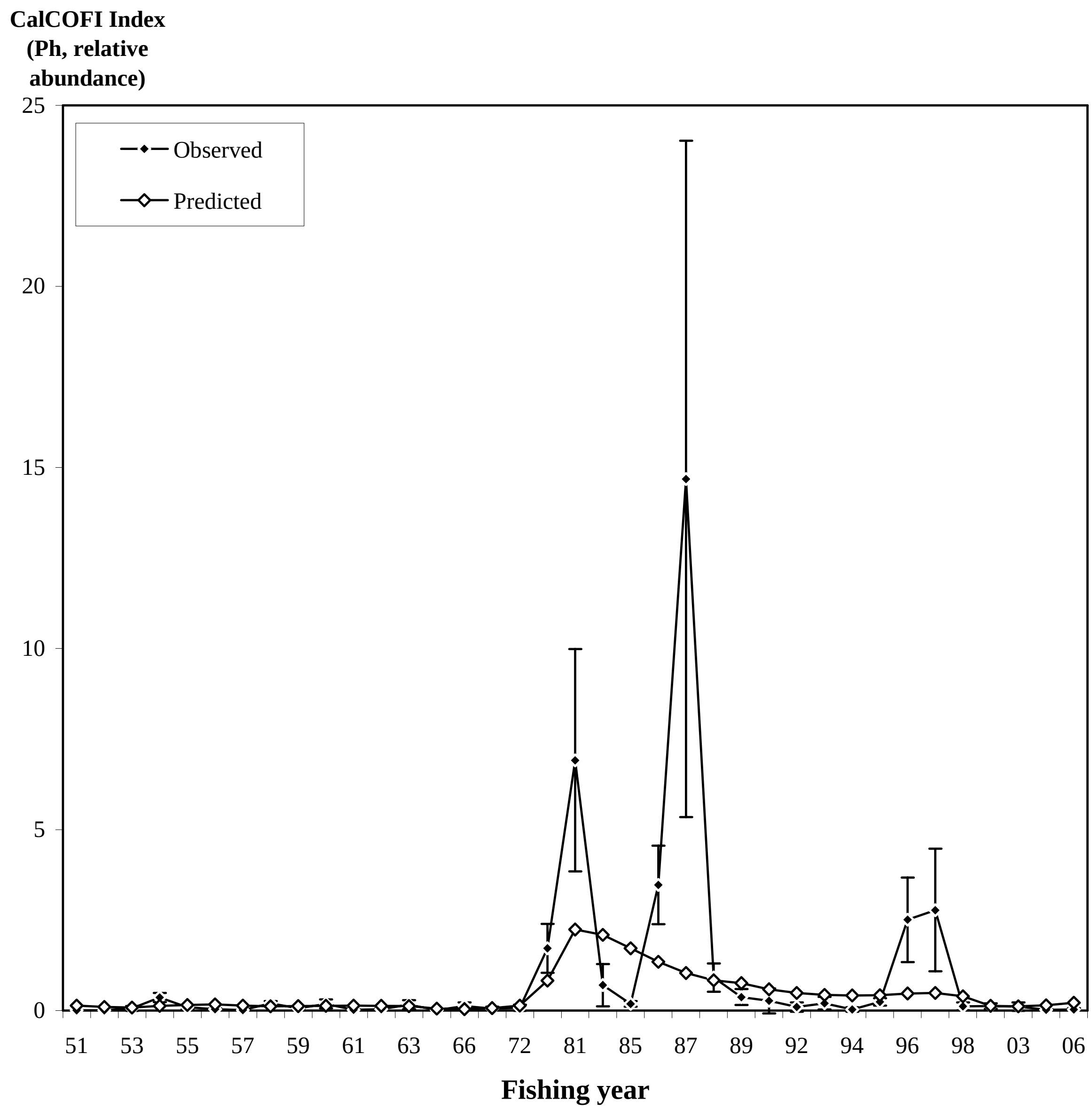

Figure 27. Observed and predicted estimates of the CalCOFI index of relative abundance (see Appendix 2) for Pacific mackerel generated from the ASAP-E1 model (1951-06). Bars represent ± 2 STD. *Note: Observed values were internally re-scaled by ASAP.

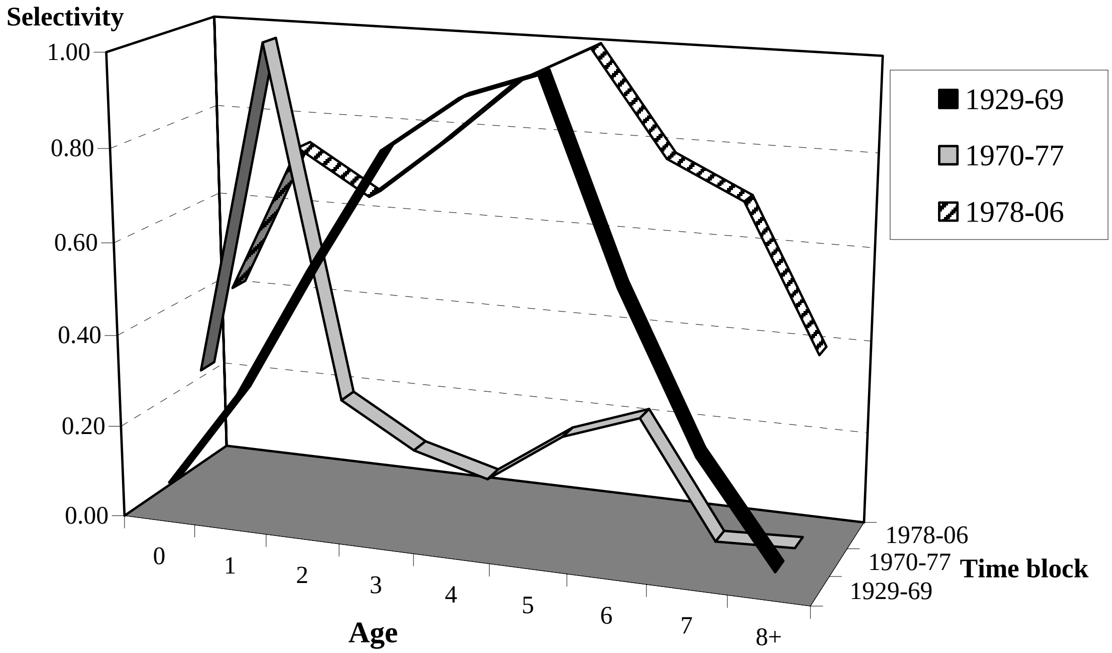

Figure 28. Estimated selectivity schedule for commercial fishery (catch-at-age) data from the ASAP-E1 model (1926-07) based on three time blocks (1929-69, 1970-77, and 1978-06).

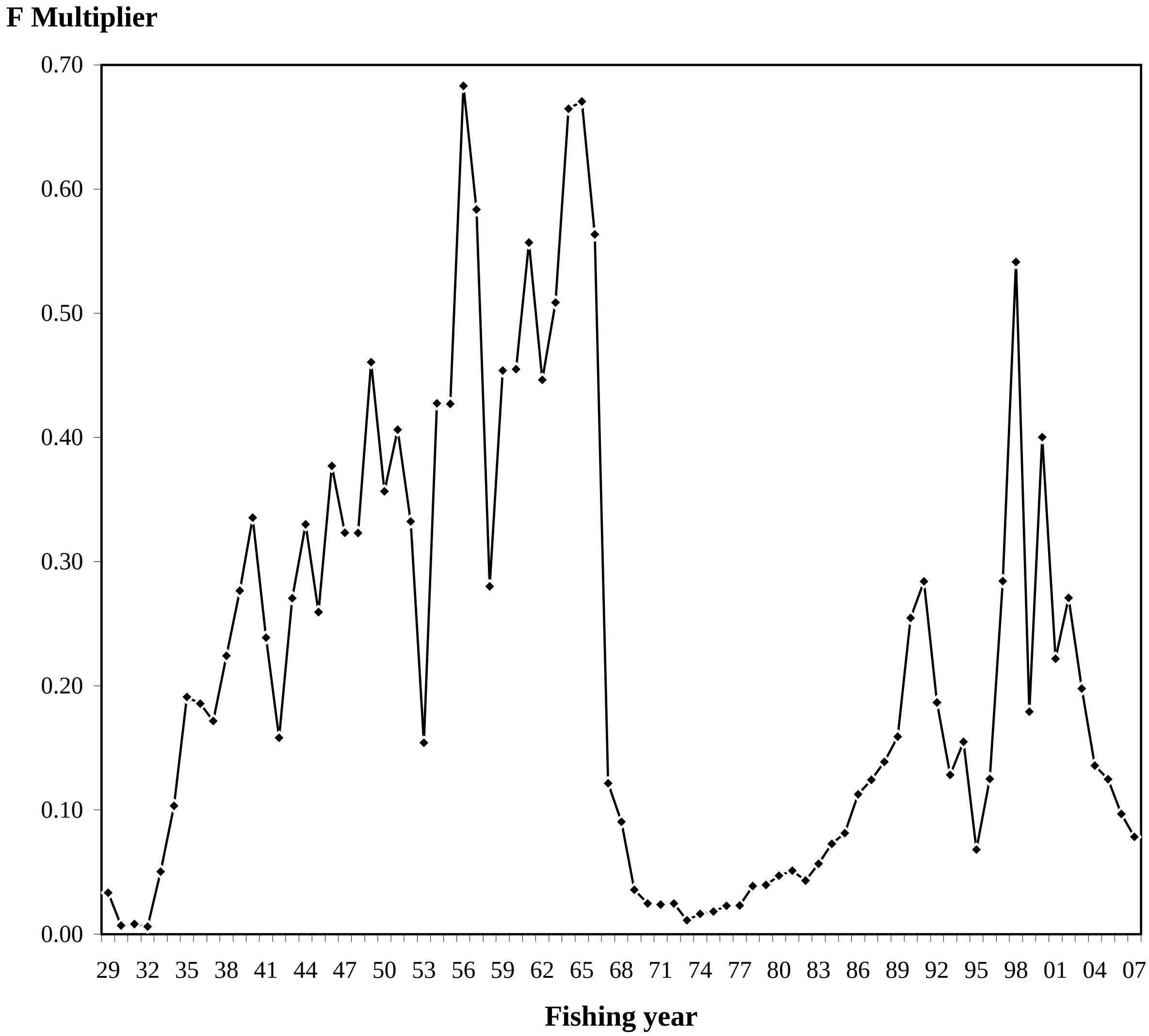

Figure 29. F multiplier for Pacific mackerel generated from the ASAP-E1 model (1929-07).

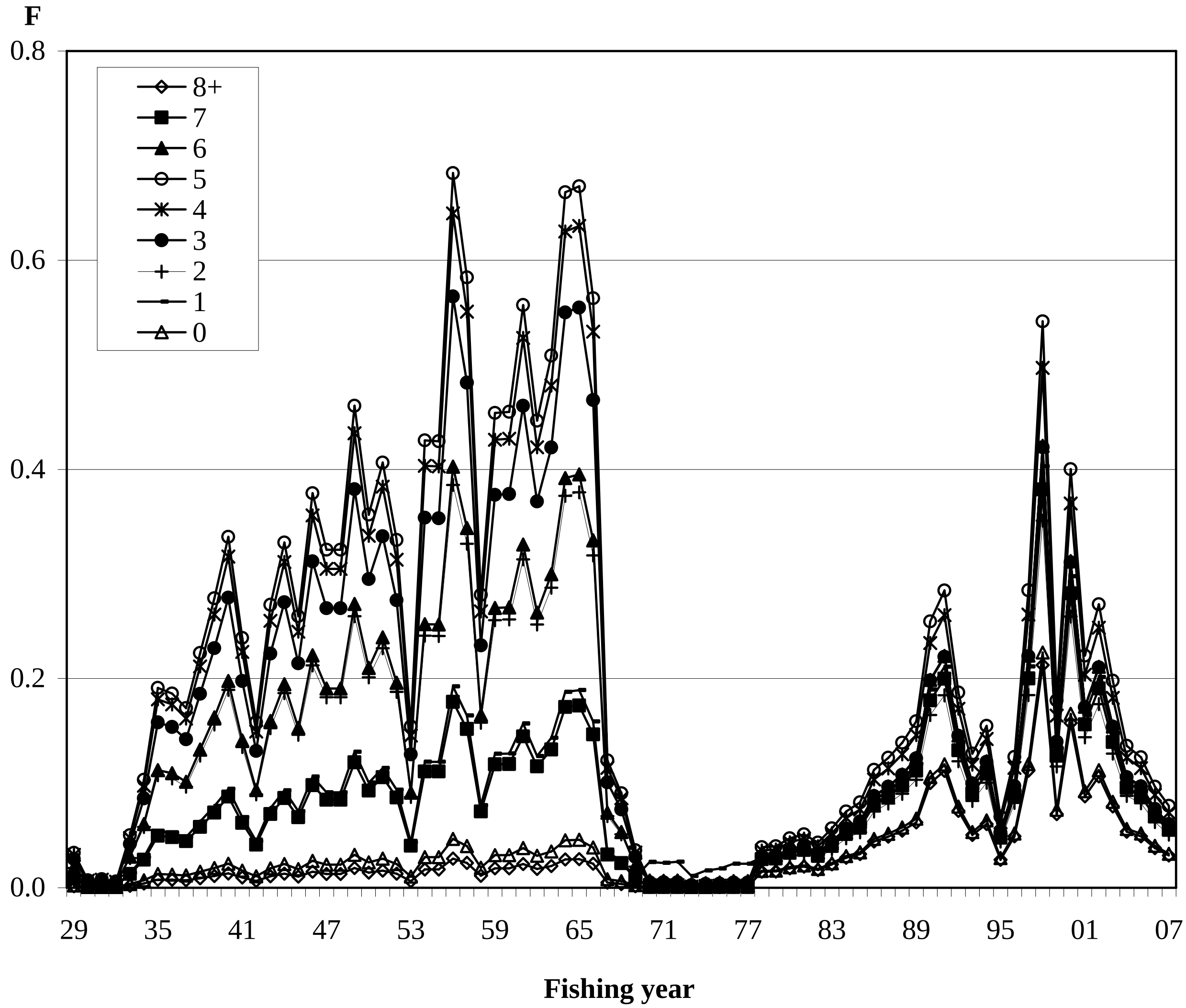

Figure 30. Estimated instantaneous fishing mortality (total) F-at-age for Pacific mackerel generated from the ASAP-E1 model (1929-07).

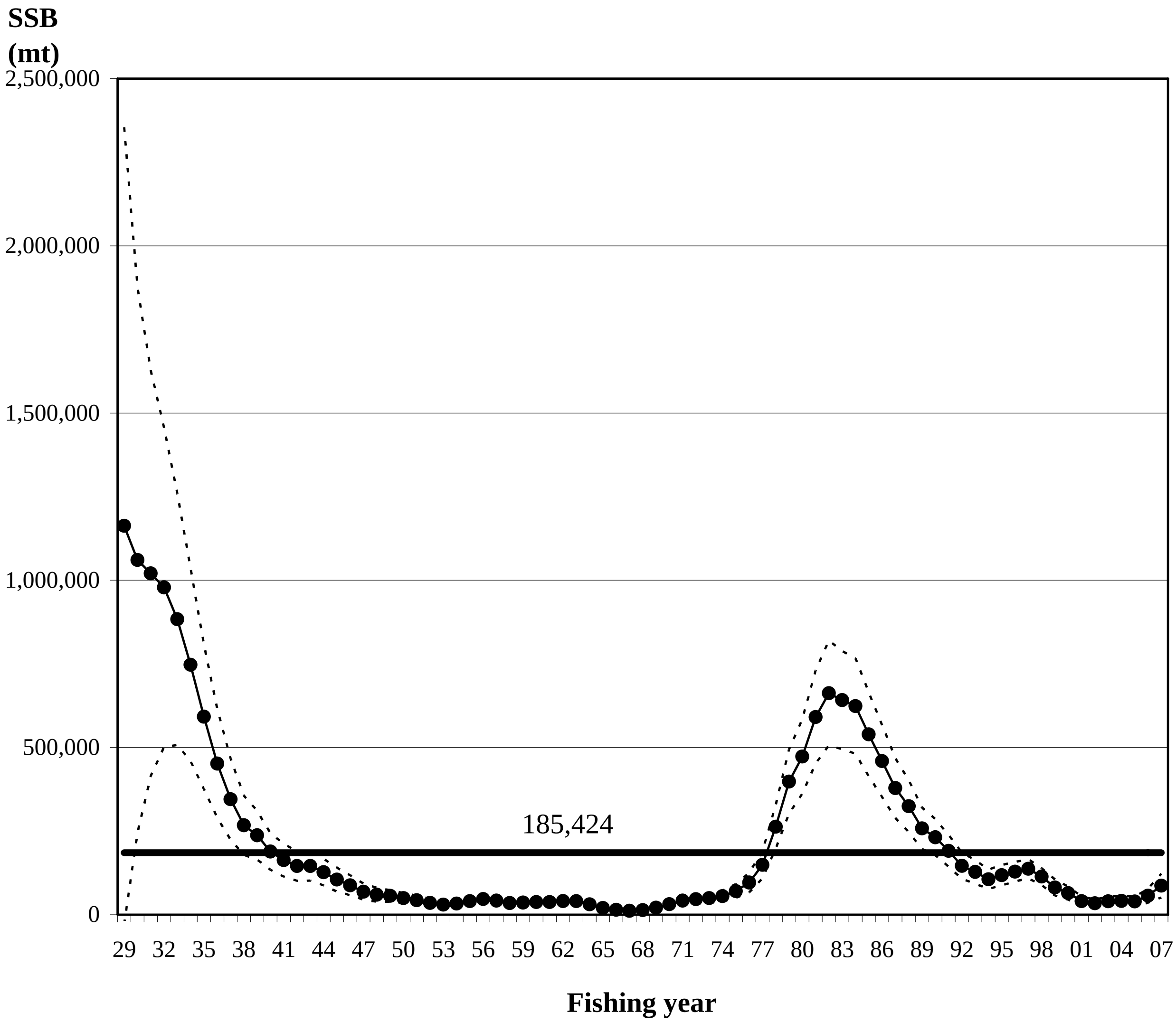

Figure 31. Estimated spawning stock biomass (SSB, in mt) of Pacific mackerel generated from the ASAP-E1 model (1929-07). The confidence interval (± 2 STD) associated with this time series is also presented. Estimated 'virgin' SSB from stock-recruitment relationship is presented as a bold horizontal line.

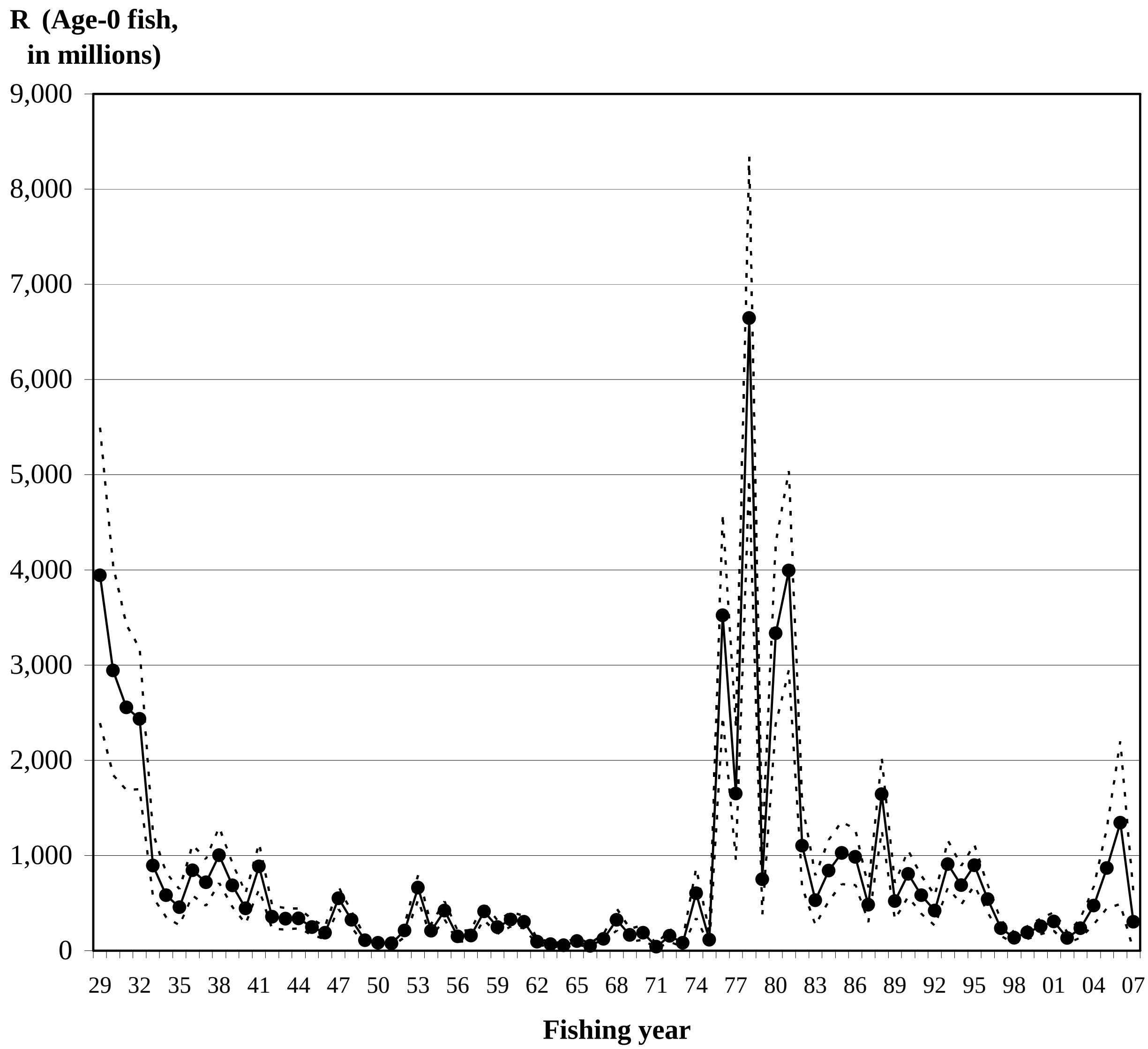

Figure 32. Estimated recruitment (age-0 fish in millions, R) of Pacific mackerel generated from the ASAP-E1 model (1929-07). The confidence interval (± 2 STD) associated with this time series is also presented.

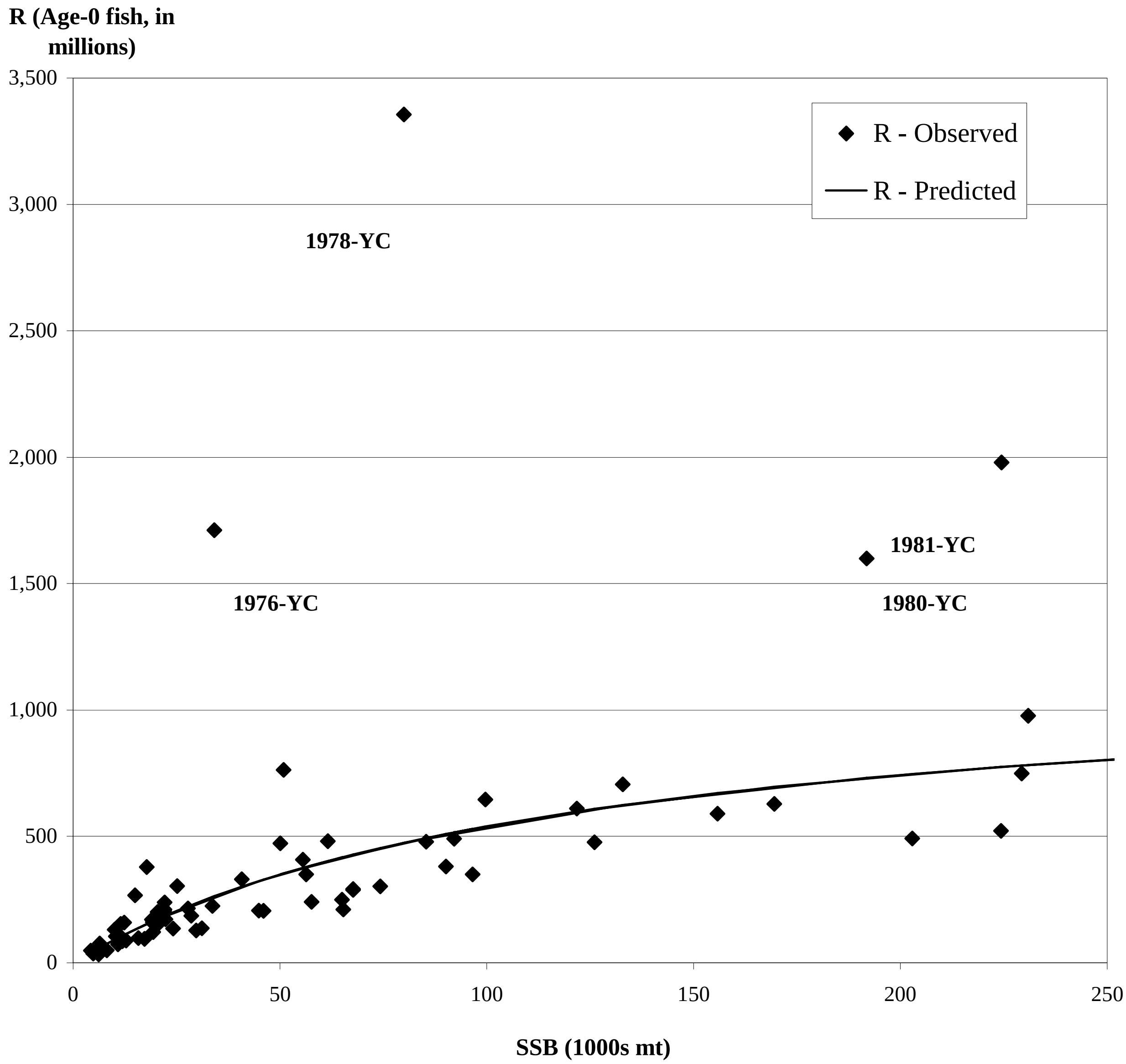

Figure 33. Beverton-Holt stock (SSB, in 1000s mt)-recruitment (Age-0 fish (R), in millions) relationship for Pacific mackerel estimated in the ASAP-E1 model (1929-07). Recruitment estimates are presented as (year+1) values. Strong year classes are highlighted. Steepness=0.31.

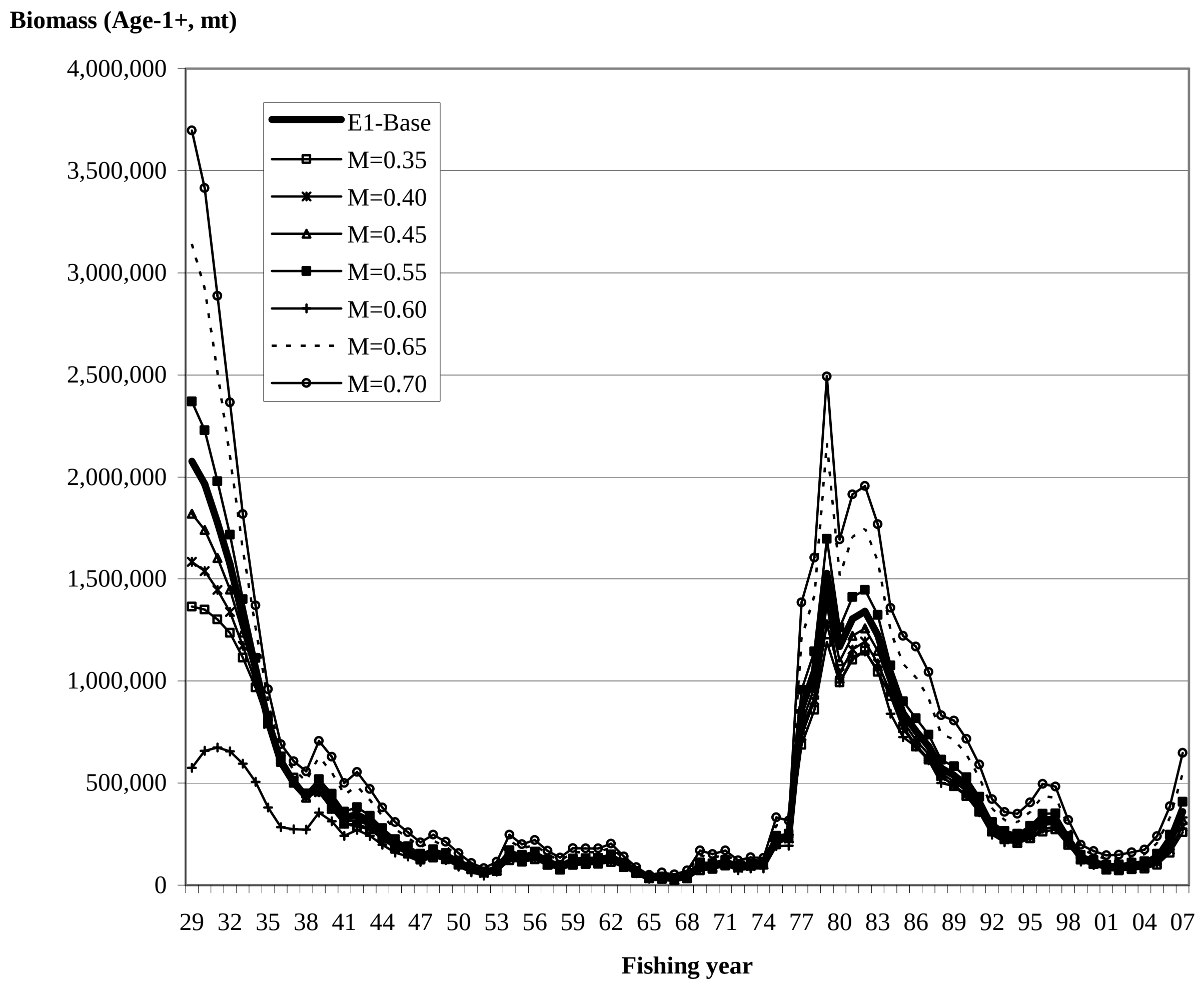

Figure 34. Biomass (Age-1+ fish) from sensitivity analysis to natural mortality generated from the ASAP-E1 model.

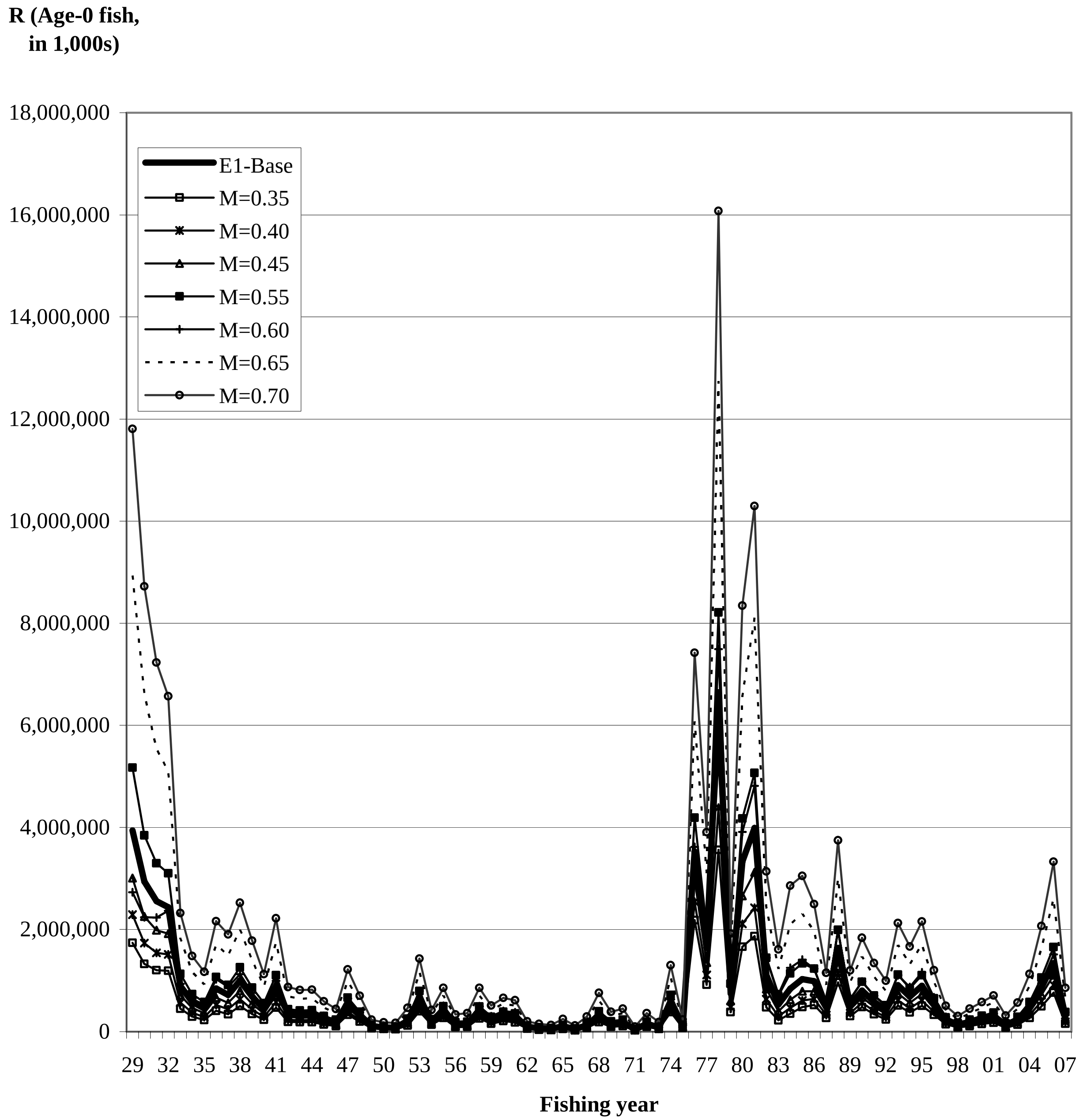

Figure 35. Recruitment (Age-0 abundance) from sensitivity analysis to natural mortality generated from the ASAP-E1 model.

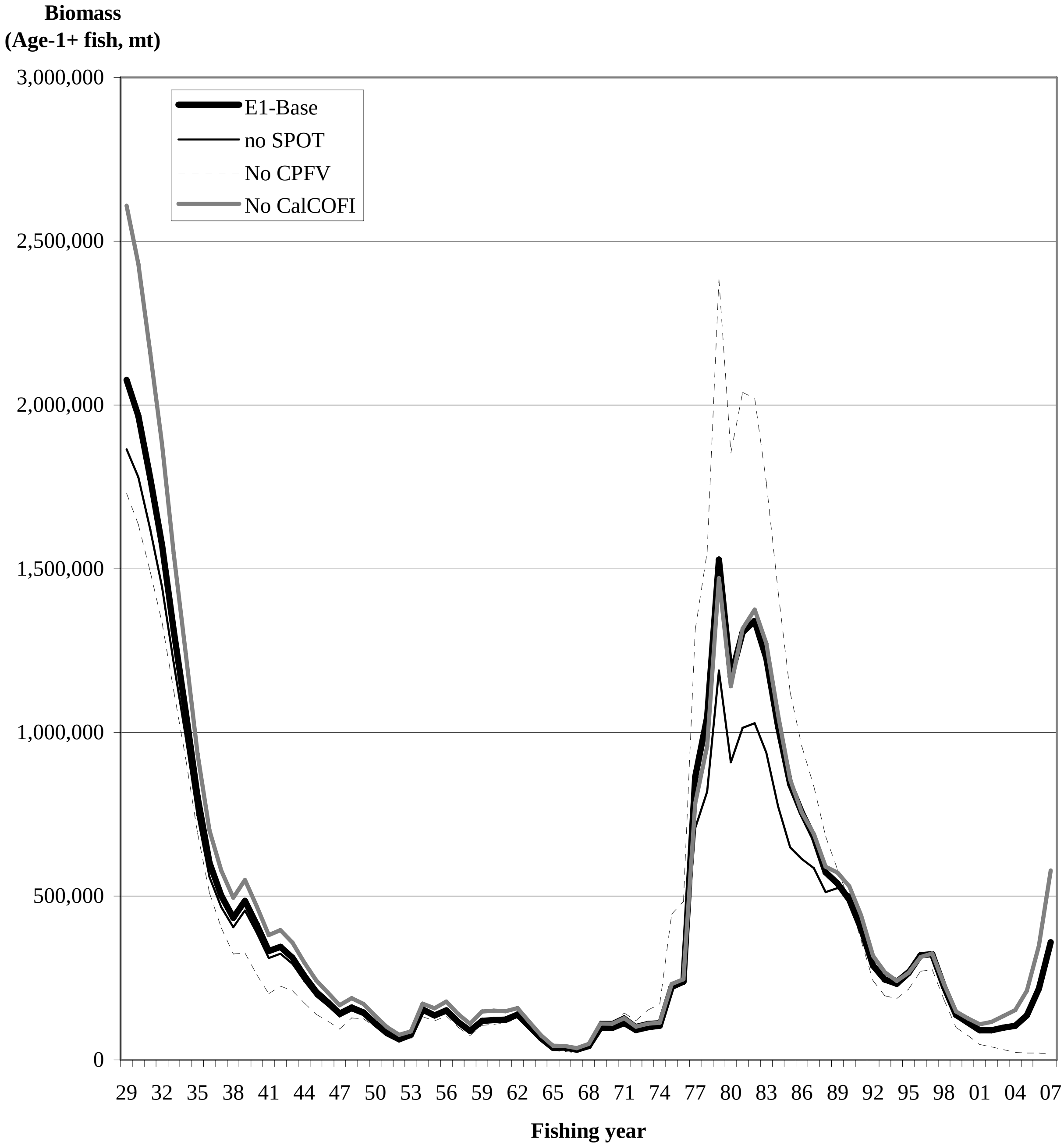

Figure 36. Biomass (Age-1+ fish) estimated from sensitivity analysis to relative abundance indices. Thin black line represents results without the spotter survey data, dashed line represents results without the CPFV survey data and gray line represents results without the CalCOFI survey data.

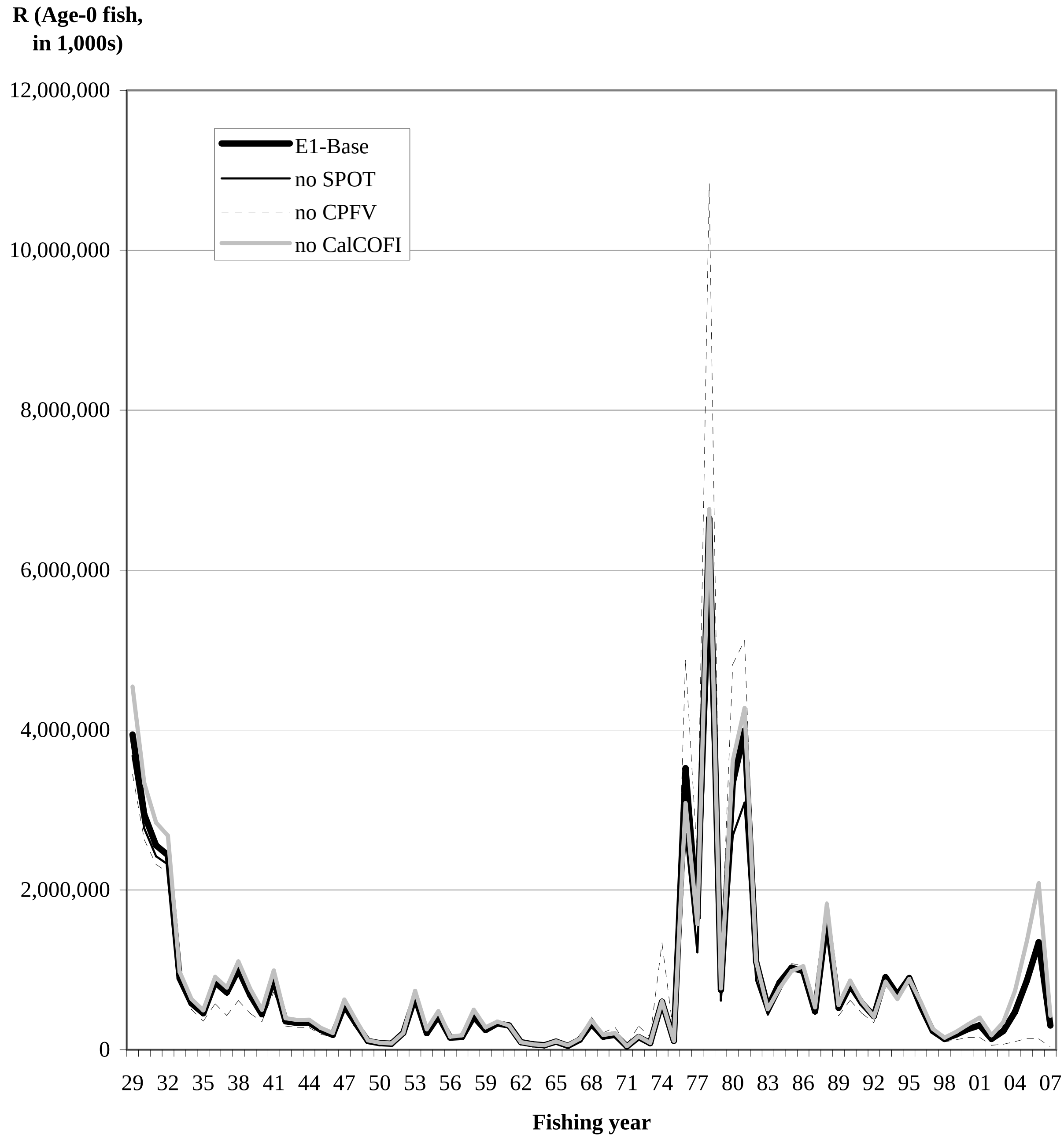

Figure 37. Recruitment (Age-0 fish) estimated from sensitivity analysis to relative abundance indices. Thin black line represents results without the spotter survey data, dashed line represents results without the CPFV survey data and gray line represents results without the CalCOFI survey data.

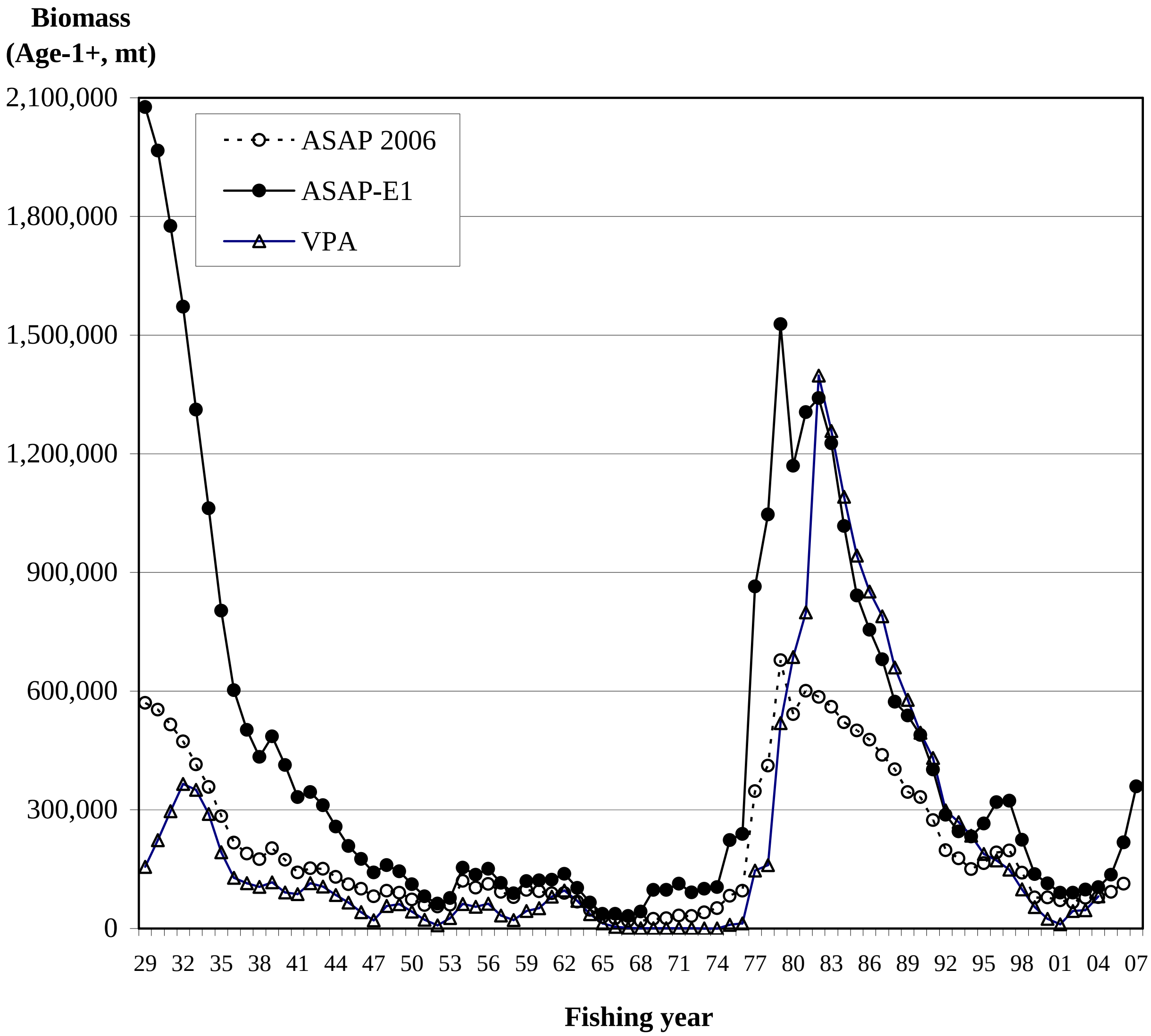

Figure 38. Estimated biomass (Age-1+ fish, in mt) of Pacific mackerel generated from the ASAP-E1, ASAP 2006, and VPA models (1929-07).

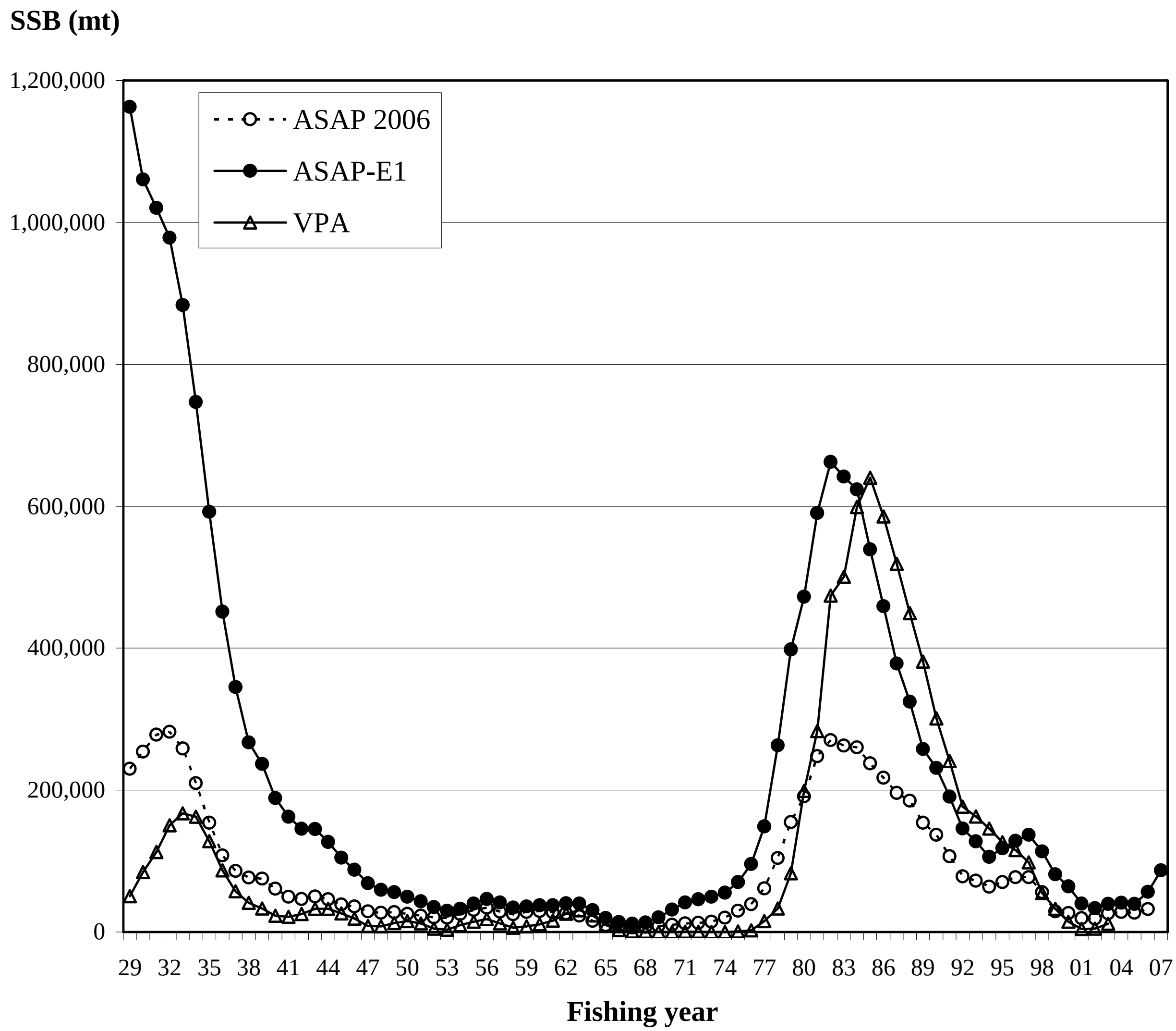

Figure 39. Estimated spawning stock biomass (SSB, in mt) of Pacific mackerel generated from the ASAP-E1, ASAP 2006, and VPA models (1929-07).

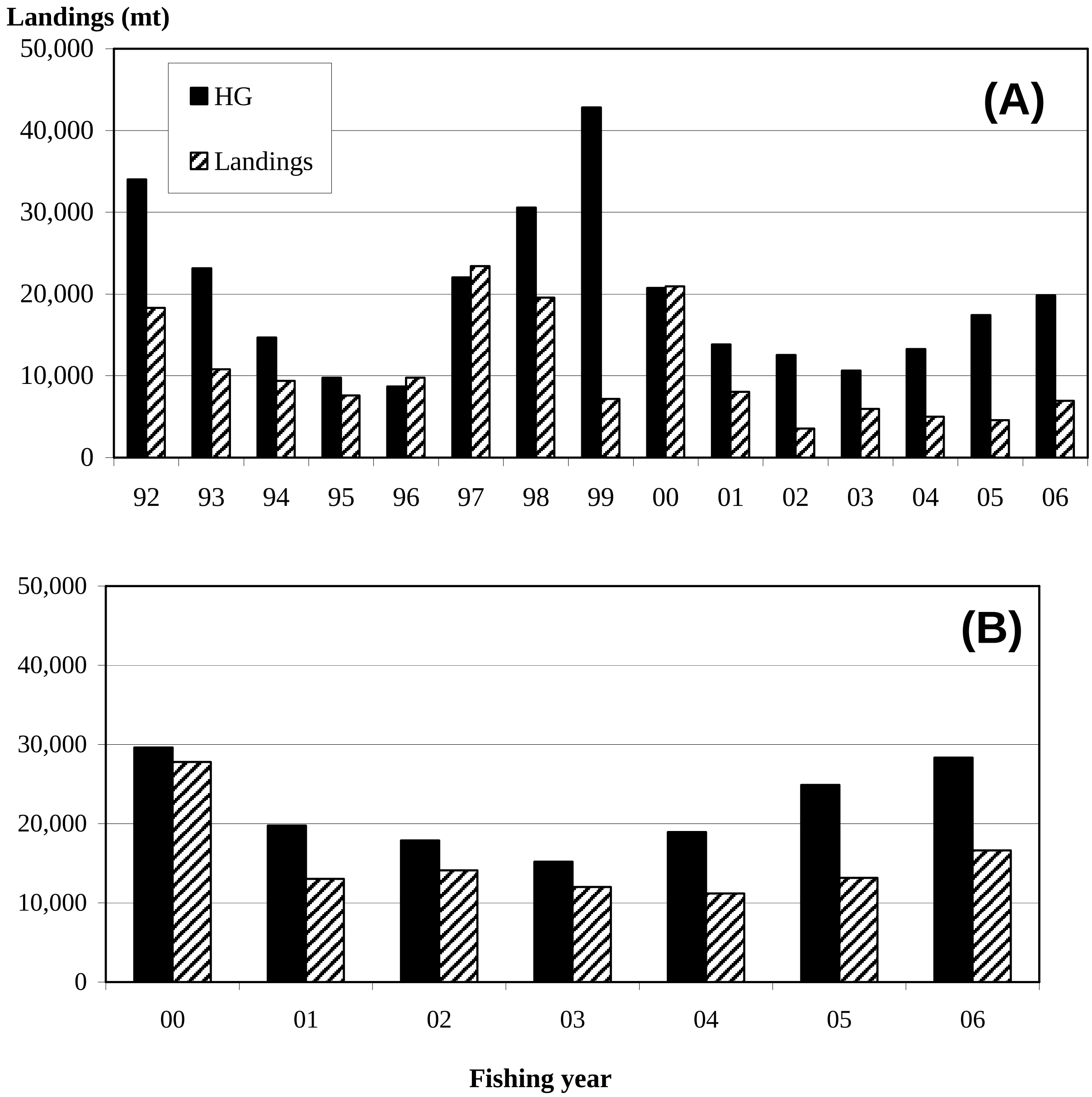

Figure 40. Commercial landings (California directed fishery in mt) and quotas (HGs in mt) for Pacific mackerel based on the harvest control rule, display (A, 1992-06 Fishing seasons). Total landings (mt) and hypothetical quotas for Pacific mackerel based on no 'U.S. Distribution' parameter in the harvest control rule (B, 2000-06 Fishing seasons). Note that incidental landings from Pacific Northwest fisheries are not included, but typically range 100 to 300 mt per year.

APPENDIX I

Spotter data analysis for the Pacific mackerel in 1963-2002 using Delta GLM

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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 fishing year 1962 to 2001 for Pacific mackerel (*Scomber japonicus*) using GLM. Note a fishing year is from July of current year to June of the following year. Because of the lower number of flights with positive sightings of Pacific mackerel in the spotter survey, for comparison purposes, we also used a Generalized Additive Model (GAM) to obtain estimates of total tonnage as a relative index for the Pacific mackerel for the entire time series from fishing year 1962-2004.

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 a 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 nighttime 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:

$$\textbf{(1)}\ \boldsymbol{I} = \boldsymbol{DA}$$

where ***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***

$$\textbf{(2)}\ \boldsymbol{D} = \boldsymbol{dP}$$

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 GLM 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 Delta-GLM using S+, to allow us to incorporate other possible distribution of tonnages/block (y) of Pacific mackerel 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.

For the Delta-GLM, we chose family of Poisson and used log as the link function for the tons/block of positive flights (d), e.g. log (the expected tonnage/block) = x'B and family of Binomial and the link function of the logistic, for the proportion of positive flight (P), e.g. log(P/(1-P)) = x'B. All independent variables: year effect, day/night, season, region and survey type were treated as categorical data for the entire time series from 1962-2004(1963-2005 calendar year). For data analysis for fishing year years 1962-2002 when only data from the log books of commercial spotted pilots were used, survey index was excluded. The estimate of density of Pacific mackerel is $\hat{D} = \hat{d}\hat{P}$ with variance:

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

where the estimated variance of estimates of d and P came directly from S+. 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.

$$\hat{I} = \hat{D}A$$

$$CV(\hat{I}) = CV(\hat{D}).$$

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

Two sets of time series were obtained: one for fishing years 1962-2001 and the other one from fishing years 1962-2004

Delta GAM model

For comparison purposes, 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 (Goodman 1960) stated above as for GLM. Two time series of relative abundance from GAM were computed: one for the shorter period from 1962-2001 and the other for the entire time series from 1962-2004

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 and Figure 2). The estimates of density (d) and proportion of positives (p) for fishing year 1962-2001 were adjusted for night time, season 2 (April-June), region 2, and pilot number 17. For the entire time series, the estimates were also adjusted for survey 1 (traditional aerial survey prior to calendar year 2004) The adjusted relative tonnages serve as the relative abundance of Pacific mackerel from spotter data set were presented using the delta-GLM (Table 1, Figure 2). For the entire period from 1962-2004, both time series of Delta-GLM and GAM were constructed for comparison purposes (Figure 3). We also presented the time series of total number of flights with sightings of Pacific mackerel and number of blocks with Pacific mackerel (Figures 4 and 5).

Discussion

The relative abundance of Pacific mackerel peaked at the mid-1980 and has been decreased since 1985 (Figure 2 and 3). Although the flight numbers were lower after 2002, the relative abundance from GLM for 1962-2004 was much smoother than that of the shorter period, in particular for the period of 1980-90 (Figure 2 and 3). The time series from GAM is much smoother than that from GLM as expected. The total number of flights decreased continuous since late 1990's (Figure 4 and 5). However total number of blocks covered has been similar except 2003 (Figure 5). 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 dramatically since 2001 off California, we compared the overall time (season) and space (region) between these two periods by the total number of flights (Table 2). The overall distributions between these two periods are similar. Most of the efforts were in regions 1-3 for all seasons and much of the efforts were shifted to regions 4-6 in the 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 (Figure 6). We compared the time series of the CVs of relative abundance for Pacific mackerel based on the LLM and GAM. The patterns of CVs estimated from the two time series have a 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 6) 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). The variance of estimates from GLM may be also underestimated as those of GAM.

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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), fishing years1962-2001

F. YEAR	T/B+,d	SE_T/B+	%BLK,p	SE_%BLK	T/B	SE_T/B	BLOCKS	REL_ABN	SE_RA	CV_RA
1962	8.46	0.40	0.36	0.19	3.06	1.58	151	461.35	238.89	0.52
1963	15.91	0.40	0.52	0.17	8.29	2.65	186	1541.53	493.15	0.32
1964	9.11	0.42	0.30	0.14	2.77	1.27	198	549.34	251.73	0.46
1965	11.77	0.83	0.29	0.15	3.44	1.75	206	707.89	359.87	0.51
1966	7.08	0.69	0.17	0.12	1.24	0.83	220	272.08	182.19	0.67
1967	0.95	0.44	0.10	0.10	0.09	0.09	210	19.88	19.45	0.98
1968	17.50	4.08	0.05	0.07	0.83	1.18	215	178.55	253.51	1.42
1969	96.31	6.31	0.04	0.05	3.61	5.00	217	782.89	1084.40	1.39
1970	6.13	1.65	0.02	0.06	0.15	0.36	148	22.03	53.73	2.44
1971	4.37	0.51	0.10	0.09	0.44	0.39	176	76.70	68.28	0.89
1972	2.02	1.05	0.01	0.03	0.03	0.05	217	5.46	11.19	2.05
1973	16.10	2.17	0.01	0.02	0.13	0.37	226	28.95	83.17	2.87
1975	2.70	1.23	0.01	0.03	0.02	0.06	214	4.31	12.98	3.01
1976	270.43	3.59	0.24	0.13	64.02	35.19	242	15492.54	8516.02	0.55
1977	297.08	3.30	0.51	0.14	151.03	42.51	206	31112.79	8757.76	0.28
1978	301.07	3.17	0.58	0.13	176.07	38.56	229	40320.84	8830.43	0.22
1979	298.39	3.37	0.70	0.13	207.39	37.38	214	44380.55	8000.07	0.18
1980	156.74	1.51	0.71	0.11	111.38	17.09	199	22164.44	3400.97	0.15
1981	175.64	1.88	0.70	0.10	123.00	17.03	210	25829.50	3576.51	0.14
1982	194.90	2.00	0.74	0.10	144.37	18.70	251	36237.16	4693.99	0.13
1983	232.71	2.53	0.48	0.13	112.64	30.48	271	30524.24	8260.05	0.27
1984	227.55	2.06	0.66	0.10	149.62	23.31	305	45635.38	7108.24	0.16
1985	230.52	2.12	0.54	0.11	123.63	25.60	315	38944.25	8062.92	0.21

1986	116.19	1.12	0.61	0.10	70.82	12.01	268	18979.22	3218.51	0.17
1987	83.35	1.81	0.49	0.12	40.97	10.42	295	12087.23	3074.82	0.25
1988	121.13	1.72	0.46	0.14	55.58	16.91	300	16673.37	5072.79	0.30
1989	36.22	0.74	0.30	0.10	10.72	3.65	252	2700.95	919.88	0.34
1990	50.12	0.80	0.39	0.10	19.73	5.19	276	5445.68	1432.73	0.26
1991	25.56	0.52	0.37	0.10	9.56	2.58	250	2391.01	644.33	0.27
1992	26.35	0.95	0.16	0.08	4.12	1.98	293	1207.58	580.14	0.48
1993	21.50	0.56	0.25	0.09	5.38	1.85	328	1764.32	608.26	0.34
1994	61.99	1.84	0.12	0.07	7.41	4.16	283	2097.70	1175.93	0.56
1995	93.01	1.91	0.28	0.10	25.68	9.54	246	6317.02	2346.62	0.37
1996	45.29	1.37	0.17	0.09	7.48	4.09	255	1907.85	1041.72	0.55
1997	40.64	0.98	0.32	0.11	12.95	4.57	390	5050.92	1781.99	0.35
1998	34.66	0.94	0.20	0.08	6.94	2.89	324	2248.20	937.73	0.42
1999	20.08	0.93	0.18	0.08	3.58	1.64	332	1187.88	545.21	0.46
2000	26.54	1.03	0.43	0.18	11.42	4.80	283	3230.88	1357.19	0.42
2001	21.30	1.72	0.08	0.11	1.79	2.40	306	548.80	734.92	1.34

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	1,947	1,499	-	2	-
2	191	2,612	1,184	36	134	-
3	329	4,761	1,938	263	1,522	76
4	207	2,315	2,373	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	-	-	-

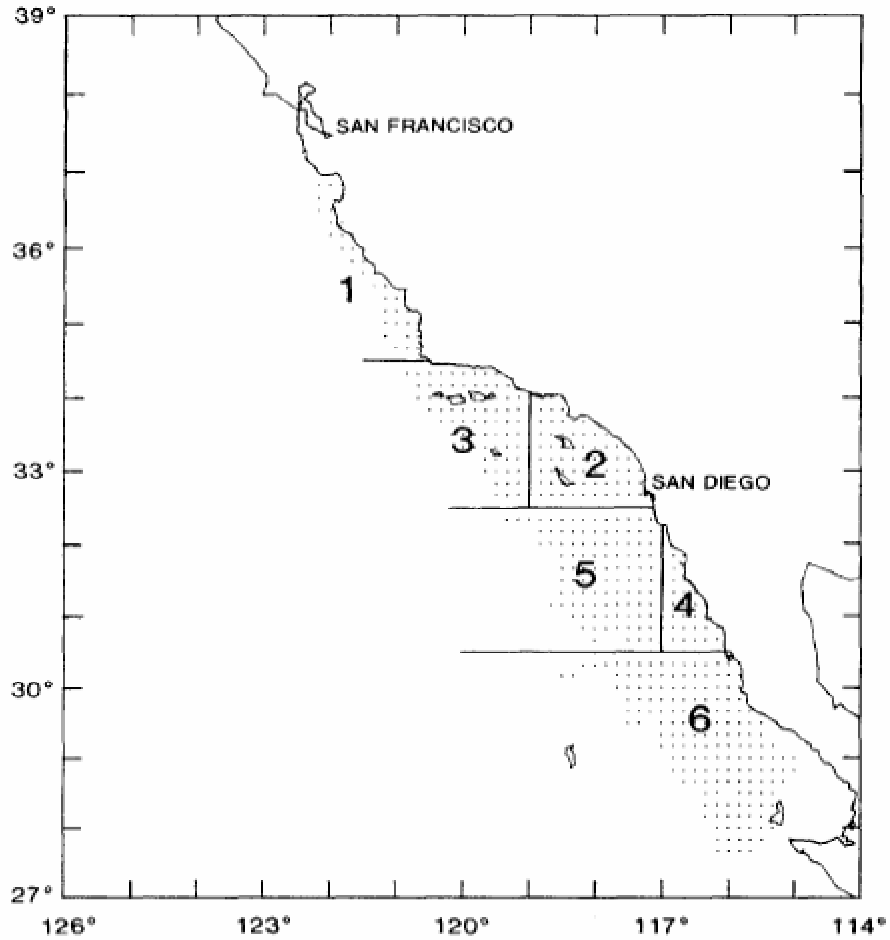

FIG. 2. Study area, regions, and blocks covered by fish spotters in 1989. Regions are outlined and denoted by numbers. Blocks are denoted by dots.

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)

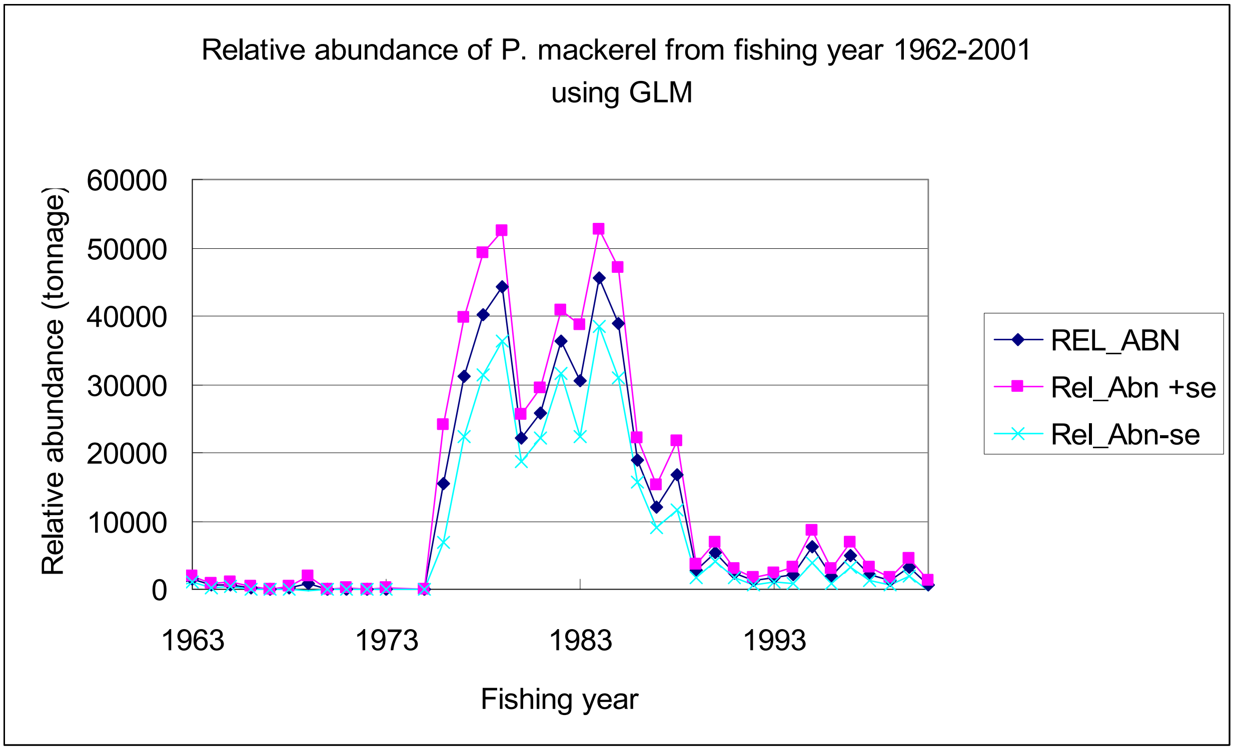

Figure 2: Time series of relative abundance (total tonnage) of Pacific mackerel from 1962-2001.

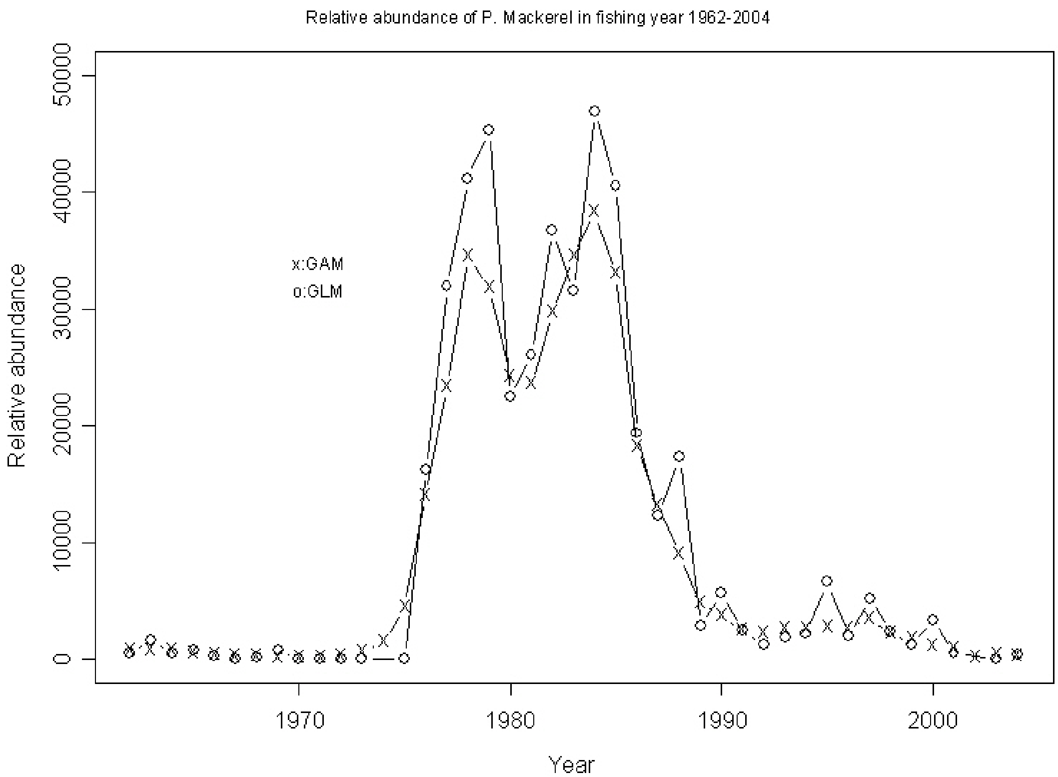

Figure 3: Time series of relative abundance (total tonnage) of Pacific mackerel using GLM (circle) and using GAM(cross) for fishing years 1962-2004

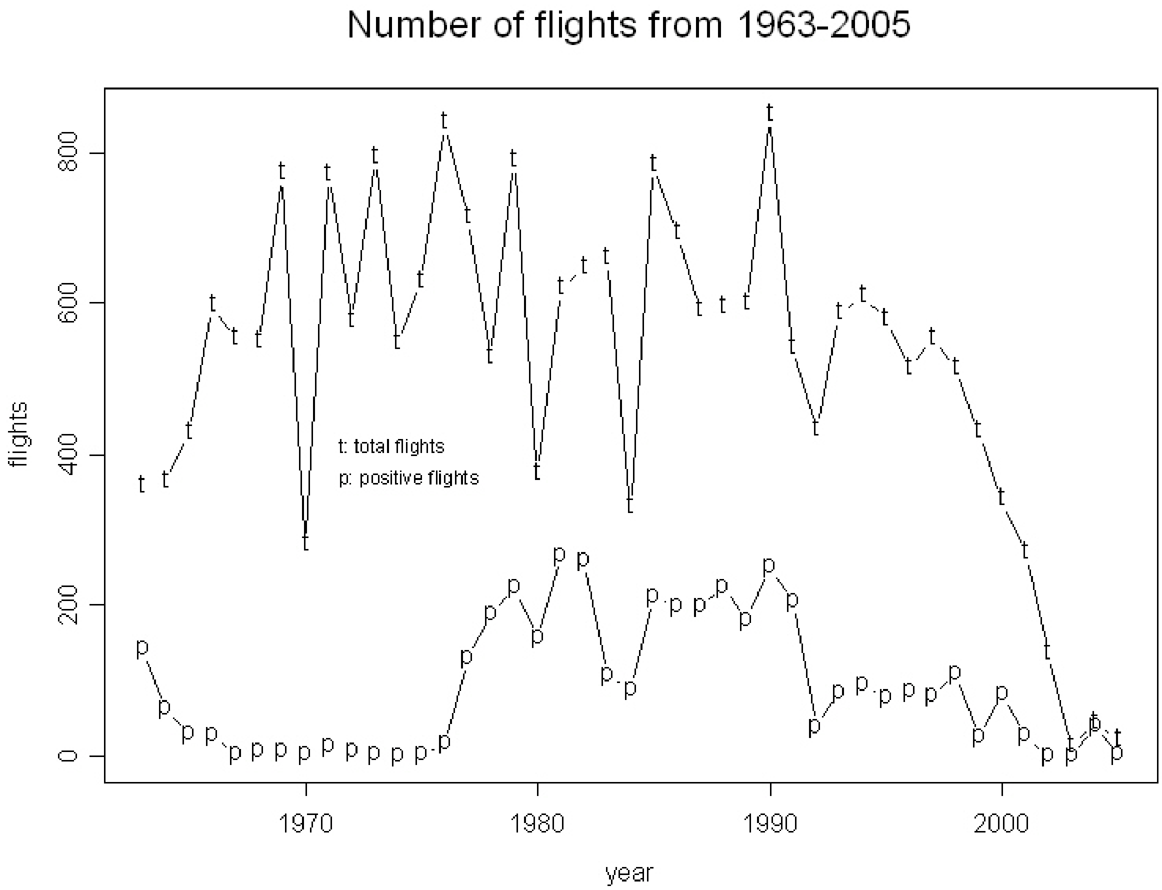

Figure 4. Total flights and number of flights with positive sightings of Pacific mackerel, 1963-2005.

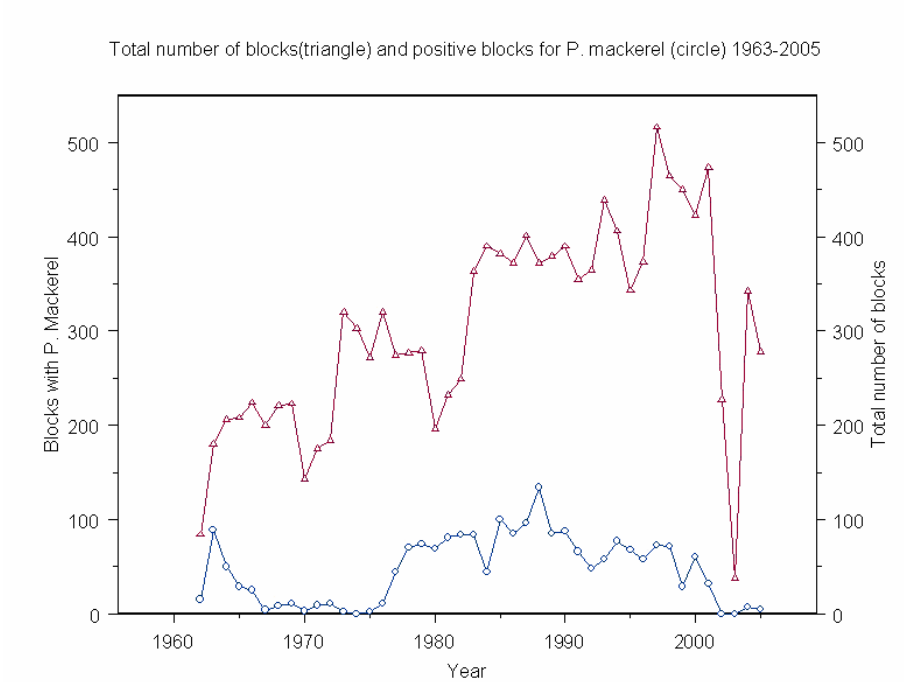

Figure 5. Total number of blocks covered (triangle)and blocks covered by flights with positive sighting (circle) of Pacific mackerel, 1963-2005

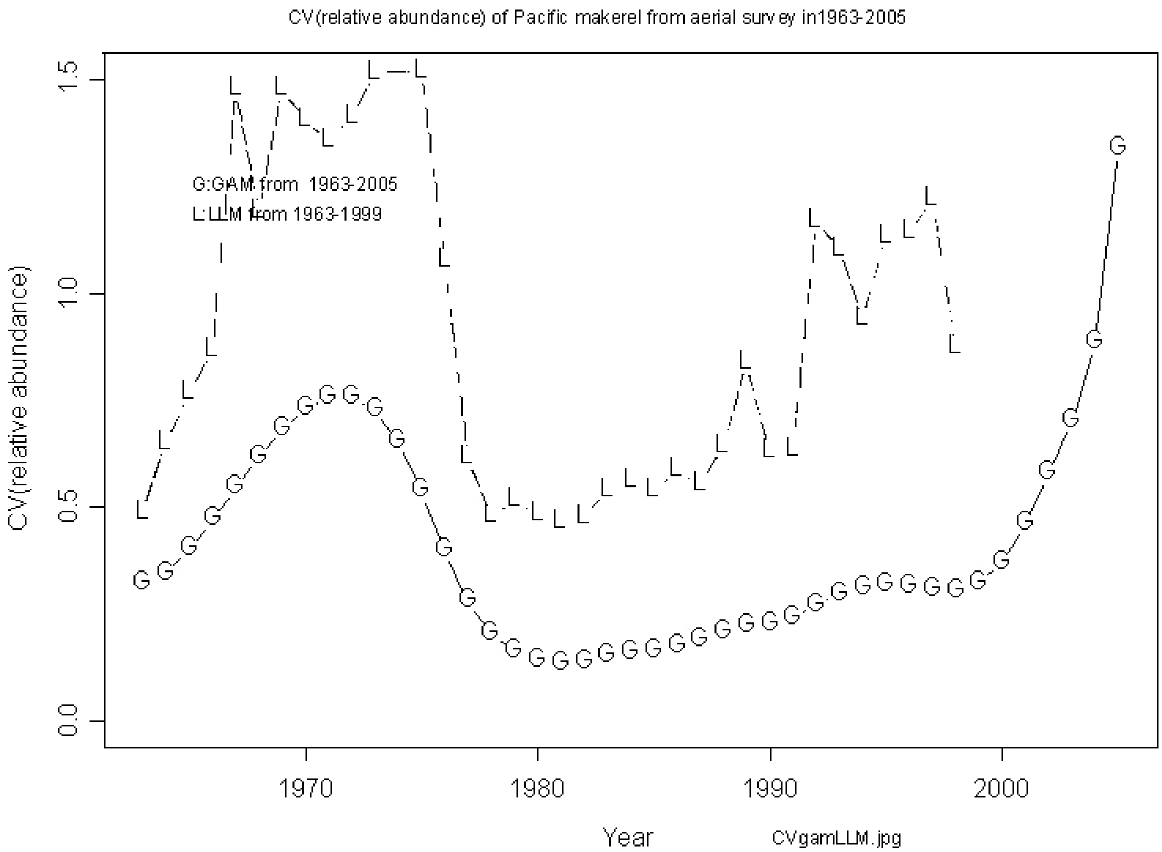

Figure 6: Time series of CV(relative abundance)(total tonnage) of Pacific mackerel from 1963-2005 using GAM and that using LLM from 1963-1999..

APPENDIX II

DAILY LARVAL PRODUCTION OF PACIFIC MACKEREL (*SCOMBER JAPONICUS*) OFF CALIFORNIA IN 1951-2006

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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 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 primarily cover the area in the Southern California Bight (CalCOFI line 93 – line 77, Fig.1, 2, and 3).

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).

MATERIALS AND METHODS

The CalCOFI survey was conducted annually from 1949-1966, after which it was conducted every three 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 / $10m^2$ was 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 preparation). Because larvae are able to avoid or evade the net to the same degree under sufficient light, 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): $R_{L,h}$:

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

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 -11.5mm 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):

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

where $\beta_{temp} = 0.2828 - 0.0229 temp + 0.0007 temp^2$

where t (days) is age (d) from hatch and L_L is the life length and *temp* is temperature in ^oC.

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

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

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

The larvae collected in each tow were grouped as 2.5mm (2.0mm - 3.0mm), 3.75(3.5 and 4.0mm), 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 2.5mm, age 0 was assigned for formalin-preserved length <2.45mm

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:

$$P_t = P_h \exp(\alpha t) \text{ ....(4)}$$

where P_t is the daily mackerel larval production at age t days from hatching, and $\alpha$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/standard deviation 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 downweighted 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 <4mm, 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 by

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

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 the two coefficients are 0.47 and 0.05 respectively (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 correction 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 pelagic species in the CalCOFI time series and 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).

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Table 1. Mackerel larval production at hatching (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**	**Index**
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

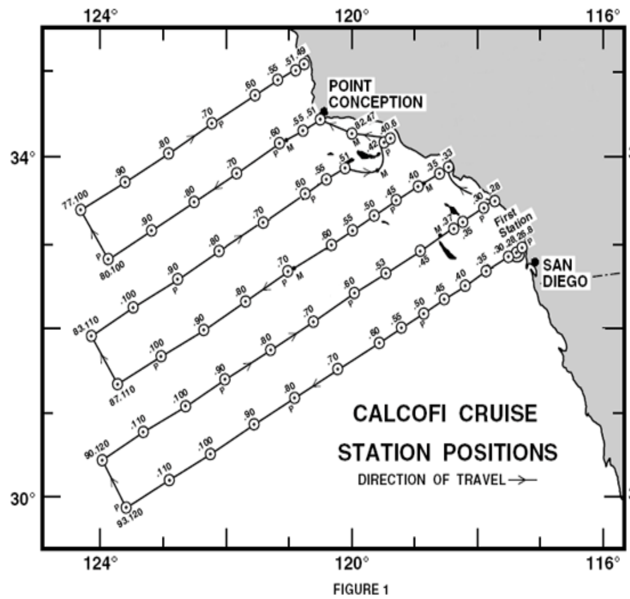

Figure 1. CalCOFI survey area from 1985-present from CalCOFI lines 93.3-76.7

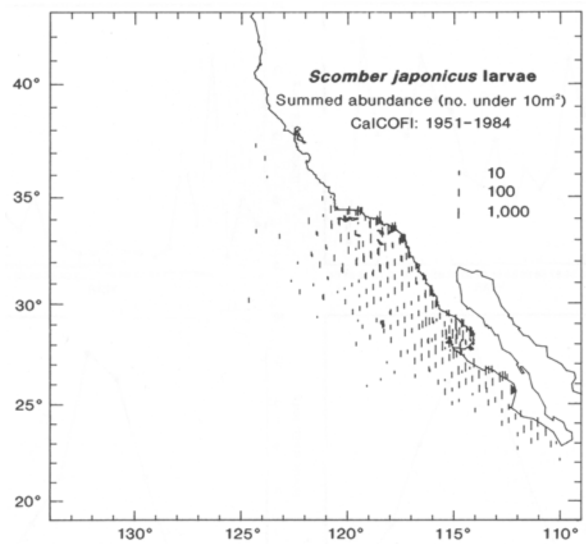

Figure 2. Total Pacific mackerel larval abundance/10m^2 from CalCOFI surveys from 1951-1984 (Moser et al. 1993).

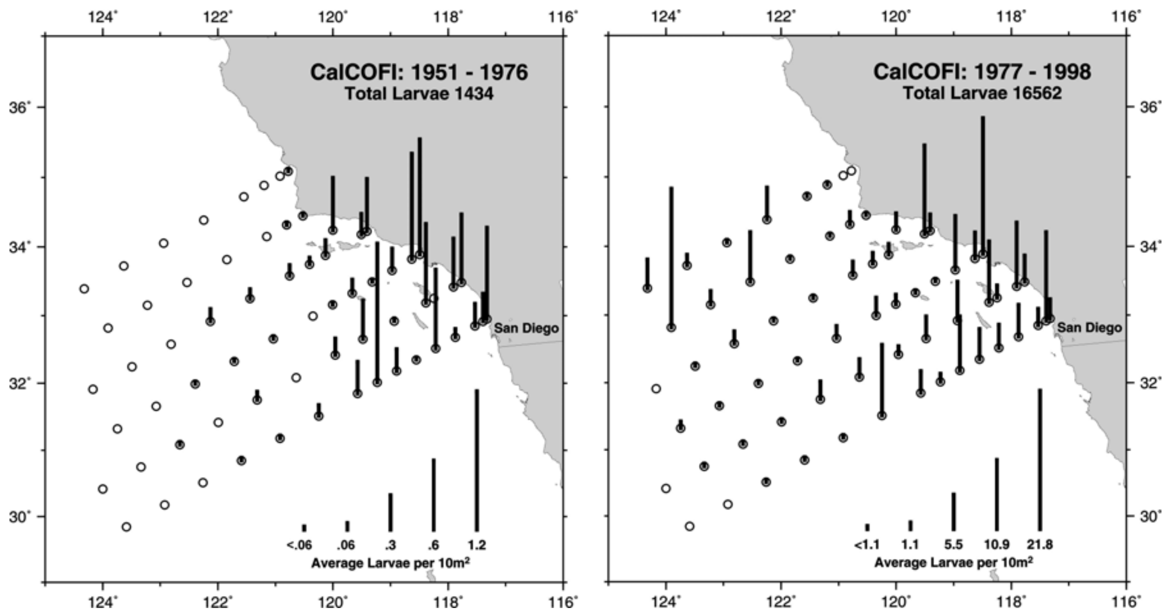

Figure 3. The average Pacific mackerel larvae/10m^2 in the current CalCOFI survey area from 1951-1976 and from 1977-1998 over all cruises (Moser et al. 2001)

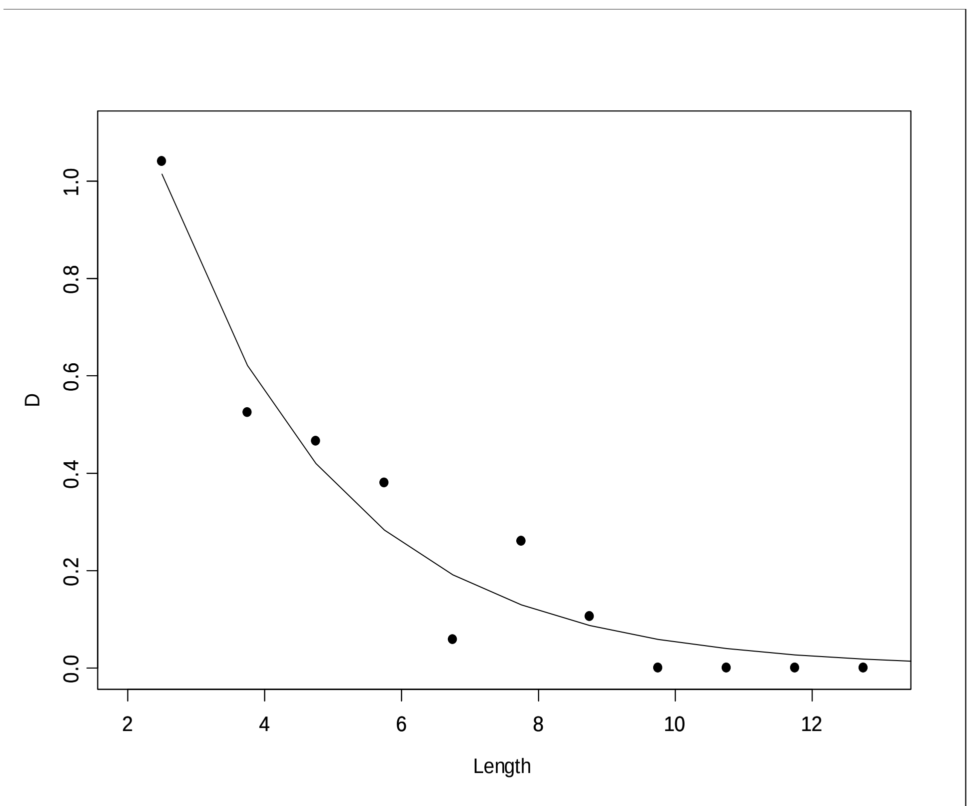

Figure 4: Noon/night catch rates of Pacific mackerel larvae (D) and larval length (mm) based on data of 1951-1978.

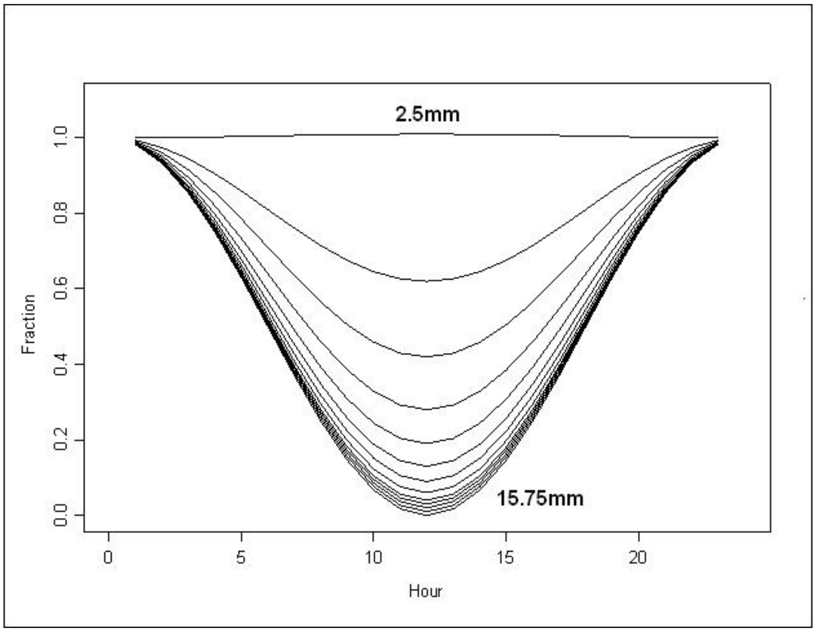

Figure 5. Fraction of Pacific mackerel larvae captured as a function of time of day for 2.5mm-15.75mm.

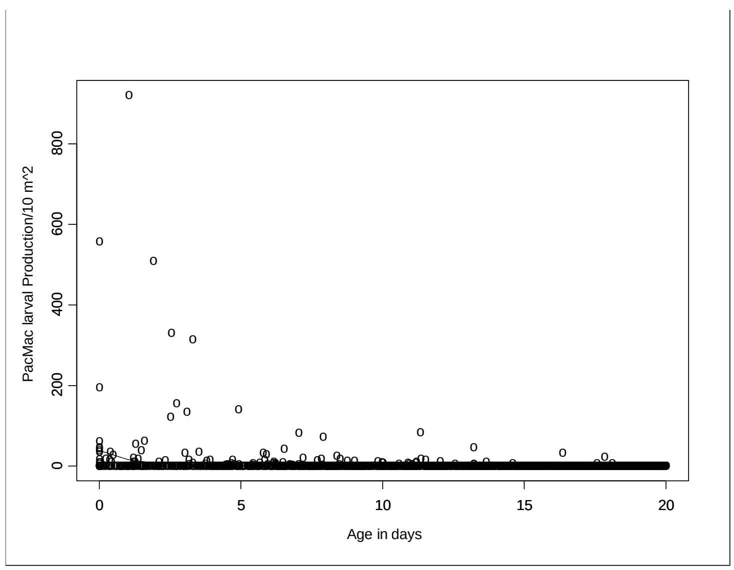

Figure 6: Daily larval production/$10m^2$ and age with Mortality curve (p_t=21.84 exp (-.33t)) in 1981.

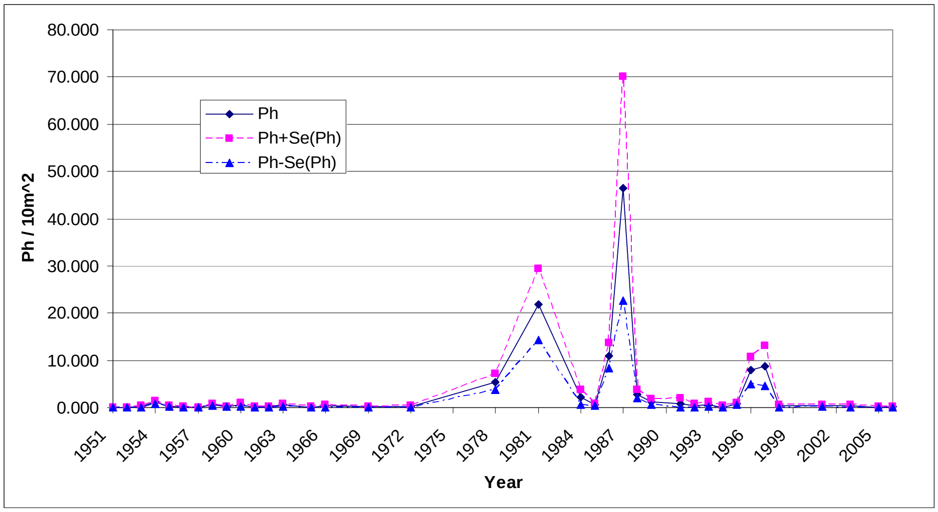

Figure 7: Mackerel larval production /10m^2 at hatching (p_h) off area from San Diego to San Francisco, in April-July from 1951 – 2006.

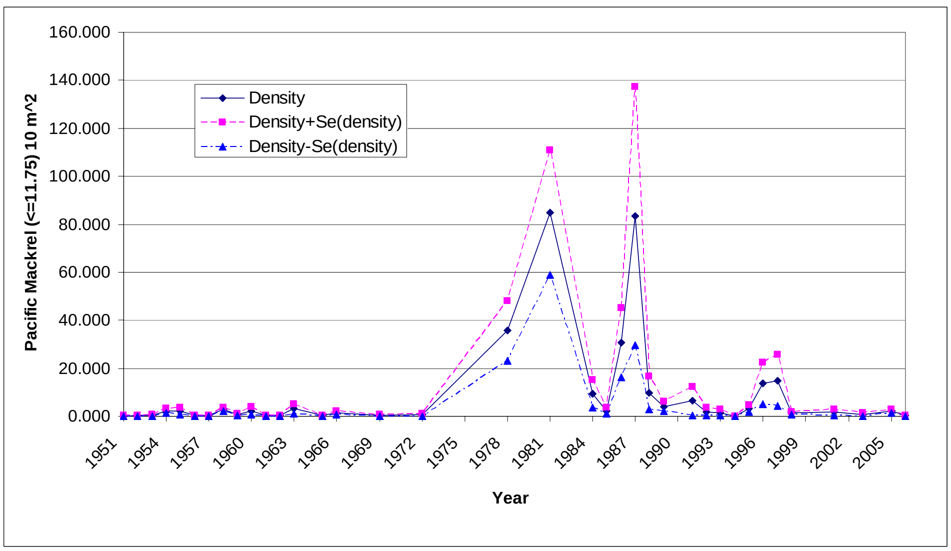

Figure 8: The time series of larval density (number/10m^2) off area from San Diego to San Francisco in 1951-2006.

APPENDIX A

DAT FILE FOR ASAP BASE MODEL E1:

```
# E1: SigmaR=0.7; M=0.5
# Number of Years
   79
# First Year
   1929
# Number of Ages
   9
# Natural Mortality Rate by Age
   0.5   0.5   0.5   0.5   0.5   0.5   0.5   0.5   0.5
# Fecundity Option
   0
# Maturity Vector
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
```

```
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
   0.00   0.07   0.25   0.47   0.73   1.00   1.00   1.00   1.00
# Weight at Age Vector
   0.074   0.167   0.297   0.402   0.523   0.615   0.704   0.800   0.830
   0.060   0.139   0.301   0.422   0.511   0.603   0.698   0.800   0.830
   0.077   0.114   0.276   0.399   0.527   0.606   0.701   0.800   0.830
   0.058   0.081   0.277   0.379   0.508   0.604   0.711   0.800   0.830
   0.059   0.083   0.200   0.299   0.493   0.585   0.700   0.800   0.830
   0.065   0.142   0.198   0.233   0.431   0.538   0.683   0.800   0.830
   0.079   0.186   0.217   0.251   0.379   0.472   0.629   0.790   0.830
   0.086   0.193   0.284   0.338   0.393   0.453   0.574   0.750   0.820
   0.119   0.176   0.318   0.429   0.461   0.502   0.575   0.740   0.800
   0.124   0.174   0.310   0.448   0.532   0.582   0.633   0.726   0.790
   0.191   0.246   0.363   0.460   0.583   0.680   0.775   0.795   0.878
   0.180   0.260   0.339   0.442   0.527   0.640   0.729   0.834   0.820
   0.115   0.259   0.343   0.439   0.559   0.650   0.806   0.807   0.850
   0.180   0.236   0.373   0.471   0.546   0.626   0.684   0.909   0.830
   0.165   0.292   0.339   0.474   0.574   0.650   0.629   0.881   1.000
   0.144   0.271   0.379   0.472   0.587   0.660   0.754   0.735   0.948
   0.121   0.234   0.383   0.494   0.611   0.704   0.745   0.819   0.842
   0.125   0.261   0.384   0.487   0.617   0.679   0.736   0.778   0.812
   0.119   0.291   0.400   0.499   0.622   0.709   0.753   0.788   0.818
   0.107   0.227   0.354   0.506   0.616   0.706   0.764   0.895   0.871
   0.109   0.192   0.319   0.456   0.607   0.725   0.799   0.917   0.917
   0.084   0.249   0.323   0.455   0.564   0.664   0.784   0.799   0.871
   0.162   0.255   0.346   0.429   0.569   0.694   0.827   0.835   0.853
   0.173   0.297   0.386   0.471   0.568   0.719   0.832   0.988   0.850
   0.162   0.296   0.411   0.512   0.603   0.763   0.834   0.850   1.100
   0.084   0.257   0.387   0.505   0.585   0.744   0.701   0.879   0.870
   0.140   0.253   0.357   0.484   0.583   0.744   0.762   0.778   0.878
   0.111   0.248   0.373   0.485   0.598   0.752   0.722   0.910   0.870
   0.179   0.310   0.374   0.509   0.602   0.649   0.650   0.700   1.000
   0.176   0.292   0.396   0.488   0.617   0.685   0.775   0.750   0.750
   0.132   0.251   0.398   0.510   0.602   0.702   0.754   0.840   0.850
   0.102   0.276   0.391   0.507   0.611   0.699   0.768   0.820   0.870
   0.144   0.252   0.389   0.495   0.584   0.647   0.817   0.830   0.850
   0.276   0.320   0.420   0.540   0.622   0.712   0.782   0.890   0.860
   0.197   0.298   0.434   0.538   0.627   0.730   0.743   0.840   0.930
   0.181   0.300   0.400   0.503   0.612   0.748   0.812   0.820   0.870
   0.109   0.195   0.384   0.501   0.596   0.723   0.735   0.880   0.850
   0.149   0.273   0.419   0.525   0.658   0.790   0.833   0.850   0.930
   0.166   0.235   0.488   0.510   0.599   0.723   0.869   0.917   0.849
   0.138   0.266   0.391   0.562   0.593   0.709   0.902   0.952   1.070
   0.103   0.322   0.428   0.505   0.662   0.746   0.907   1.000   1.100
   0.099   0.232   0.402   0.584   0.730   0.837   0.850   1.000   1.200
   0.266   0.282   0.457   0.481   0.740   0.955   0.880   0.900   1.200
   0.147   0.266   0.449   0.508   0.552   0.746   1.000   0.900   1.100
   0.119   0.329   0.433   0.609   0.606   0.686   0.758   0.803   0.838
   0.107   0.303   0.604   0.740   0.837   0.800   0.800   0.800   1.000
   0.127   0.361   0.517   0.973   1.053   1.029   1.350   0.900   0.900
   0.170   0.297   0.672   0.864   1.291   1.223   1.531   1.200   1.000
   0.122   0.322   0.600   0.847   1.063   1.100   1.300   1.500   1.300
   0.062   0.334   0.473   0.705   0.908   1.100   1.200   1.400   1.600
   0.082   0.189   0.440   0.598   0.810   0.969   1.200   1.300   1.500
   0.072   0.176   0.270   0.437   0.598   0.874   1.066   1.300   1.400
   0.083   0.190   0.239   0.391   0.597   0.715   0.953   0.929   1.400
   0.032   0.151   0.237   0.345   0.516   0.773   0.916   1.000   1.200
   0.049   0.191   0.302   0.390   0.458   0.511   0.688   0.900   1.100
   0.120   0.235   0.351   0.396   0.505   0.614   0.638   0.871   0.910
   0.157   0.285   0.418   0.461   0.484   0.560   0.612   0.697   0.850
   0.148   0.290   0.408   0.508   0.561   0.595   0.630   0.719   0.784
   0.133   0.272   0.414   0.523   0.600   0.691   0.717   0.766   0.826
   0.101   0.301   0.415   0.576   0.666   0.734   0.806   0.815   0.899
   0.104   0.193   0.381   0.542   0.647   0.749   0.757   0.739   0.827
   0.094   0.267   0.377   0.554   0.649   0.680   0.749   0.775   0.803
   0.071   0.217   0.397   0.514   0.591   0.664   0.724   0.766   0.799
   0.087   0.175   0.330   0.459   0.544   0.661   0.691   0.725   0.805
   0.073   0.228   0.294   0.408   0.583   0.607   0.720   0.756   0.832
   0.100   0.156   0.248   0.361   0.493   0.597   0.644   0.733   0.785
   0.081   0.179   0.275   0.431   0.586   0.689   0.740   0.758   0.920
   0.105   0.182   0.318   0.471   0.589   0.649   0.674   0.705   0.751
   0.149   0.239   0.333   0.446   0.572   0.637   0.719   0.718   0.749
   0.139   0.267   0.325   0.419   0.530   0.615   0.631   0.667   0.689
   0.148   0.228   0.399   0.509   0.575   0.633   0.688   0.754   0.768
   0.114   0.266   0.370   0.550   0.590   0.608   0.646   0.712   0.731
   0.103   0.253   0.347   0.534   0.567   0.619   0.617   0.635   0.627
   0.133   0.218   0.303   0.412   0.552   0.687   0.656   0.728   0.650
   0.125   0.284   0.414   0.603   0.679   0.745   0.809   0.794   0.838
   0.159   0.280   0.407   0.596   0.685   0.821   0.926   0.820   0.902
   0.106   0.267   0.380   0.463   0.556   0.665   0.737   0.797   0.840
   0.115   0.232   0.361   0.509   0.715   0.794   0.847   0.918   0.935
   0.115   0.232   0.361   0.509   0.715   0.794   0.847   0.918   0.935
# Number of Fleets
   1
#$FLEET-1
# Selectivity Start Age
   1
# Selectivity End Age
   9
# Selectivity Est. Start Age
   1
# Selectivity Est. End Age
   9
# Release Mortality
```

```
  0.0
# Number of Selectivity Changes by Fleet
  2
# Selectivity Change Years
 1970   1978
# Fleet 1 Catch at Age - Last Column is Total Weight
      9.28  12433.52  22466.85  20819.02   5208.01   3874.57   3198.38   1273.12    506.68  25733.54
         0    1392.8   7164.29    4838.4   1916.24    670.23     43.87     17.46      6.95   5825.88
         0     957.2   9990.74   6190.18   1307.12    752.89    371.31     147.8     58.82   6890.14
         0    144.48      3222   5844.95   1393.72    940.26    489.13     194.7     77.49   4938.95
         0   4620.12  19017.01     31887  23363.33      8277   2730.62   1086.93    432.58  33072.19
         0   4894.32  53353.79  35598.25  40807.82  15508.13   5669.25   2256.66    898.11  51483.81
         0  10871.51   12737.4  61704.13  63819.66  33633.06   6205.69   2470.19    983.09  66417.45
         0   2247.75  20403.77   17399.3  33062.36  35158.51   5252.24   2090.67    832.05  45714.21
    128.53    1475.8   2592.22   8035.18  15910.37  26039.26   7865.44   3130.86   1246.02  31987.62
    771.57  11577.22  31967.43  16527.64   4309.46   10883.8   6608.45   2630.51   1046.89  34561.76
   1802.77  23227.99  23713.35  33697.92  11093.97   6309.69   3744.21   1525.42    485.36  45453.99
   3199.27  18452.94  59415.03  27593.71  17024.69   2513.71    685.56    114.26         0  48868.18
    638.04  18396.72  31228.34  28817.98   6522.15    921.61     70.89     70.89         0  32560.77
         0   28454.8  10342.87  15109.17   6148.52   1096.25    142.99     47.66         0   21885.7
    426.03  14144.24  62072.75  10522.97   7412.94   1022.47    170.41     85.21         0   35304.7
         0  20800.04   20684.8  35319.73   8873.15    1613.3    230.47         0     57.62   36657.1
   2034.46  15336.68  12076.33   8920.31   8320.41   4825.32   1930.13     599.9    391.24  23601.43
   3289.73  16672.93  20261.72  11040.52   6704.06   4286.61   1819.32   1096.58    548.29  27582.46
    7426.5   4645.52  10460.31   9227.83   6067.61   3507.84   1896.13    695.25    221.22  19436.99
   2722.71  37272.92   9106.99   3661.57   4037.12    1408.3    657.21    281.66     93.89  18124.69
    565.75  21983.49  36329.33   9173.26   3071.22   1980.13    808.22    121.23     80.82  24188.91
     44.21   6587.64  17065.97   17154.4   3183.29    530.55    397.91     44.21     44.21  17493.02
   1030.94   4004.81   6859.73  11816.18  11300.71    674.08    237.91      79.3      79.3  15857.11
    509.56    324.26   1991.91   1991.91    8708.8   4678.66     92.65     46.32         0  10325.76
  11077.04   2069.34   1338.98   1379.56    568.05     811.5    770.93         0         0   5265.94
    693.87  47799.78  10176.73    2158.7   1233.54         0    308.39    154.19         0  18464.67
  15607.86  17730.53  25097.44  10738.21   1123.77    124.86    249.73    124.86    374.59  22200.87
    419.64  54867.37  22555.42  19093.43   8812.35    314.73         0         0         0  36834.99
   1996.08   7915.49  30078.85  10875.19   8534.96   3028.53   1307.78    344.15         0  27753.42
  11505.37   2665.88   4595.13   7401.32   3156.96   1438.17    912.01         0         0  11874.77
   1689.97   46896.6   7773.85   3633.43   2450.45   1013.98     253.5         0         0  19332.47
   1628.96  12726.27   17002.3  10181.02   5090.51   1730.77   1323.53         0         0  20822.52
   7344.83  28679.83  15564.05  14689.67   5770.94   1224.14    524.63         0         0   26199.2
    738.58  23298.65   12553.8  10472.06   7072.09    1421.2    186.57         0         0  23900.98
    284.46   6843.29  18432.22  10338.63   8843.01    2841.7    424.59         0         0  23702.99
   1389.15   7716.49   6521.08   9629.28  10969.27   4240.06    715.11         0         0  19987.93
  13074.05   1264.81    766.75   1700.61   5524.52   8676.71   1562.99         0         0  11279.44
   3689.34   8093.13   1457.55   1168.16    991.64   2240.26   1219.85     91.12         0   7405.18
   4530.49   1003.32     88.34    631.74    228.46    163.44     191.8     45.48       3.9   1713.31
   7417.78    499.49    221.14    353.17     89.26     85.63     68.09     51.89     37.44   1695.04
     46.32   2354.04    605.77    221.27      70.7     61.36      9.47         0         0   1168.22
   1405.04   3004.08         0         0         0         0         0         0         0    835.49
         0   2852.62    223.99       9.9     11.85       7.9         0         0         0    911.26
   1319.46    197.08    293.14       318      9.27      7.18         0         0         0       532
     50.08    546.98    153.25     32.92     74.92     88.38     49.33      2.06      2.06    400.94
   2154.23    768.64    244.31     39.29      13.1         0         0         0         0    633.81
    129.69   6334.53     89.64     65.67      1.89      3.59       1.8         0         0    2149.3
  13973.68    164.16   1763.31      0.75     22.98         0     26.91         0         0   4091.65
  11070.92  36733.93     77.95    286.78         0         0         0         0         0  13751.25
  73773.14   18836.9  28597.94   1165.54   1006.01    257.27         0         0         0  27172.62
      27.3  102761.6  14944.14  15203.87    222.15    674.58         0         0         0  35858.08
  63977.75    3375.6  77514.48   8220.94   7378.74    407.32    125.57         0         0  35203.07
  19073.13  45821.52  10973.96  69210.11   4792.33   3066.54     75.52    123.26         0  46984.54
  16128.82   36225.3  33231.45   9921.13  31045.14   2318.39    768.07         0         0  36371.39
   2841.49   2812.44  44335.77  40174.47   6319.26  17770.08    251.37         0         0  42117.51
   2874.61    532.91   9588.75  48965.24  25203.82   6271.07   7986.46    197.57         0  46468.33
   3250.53  17477.96   5188.93  16256.13  50114.46  10704.47    1388.6   1046.78         0   46827.8
  18857.41  44528.39  23015.91   5275.98   9001.56  25599.29   7434.51   1023.53   1085.34   54122.6
  18059.02  71919.59  32697.92   5325.97   2861.93   3517.06   4718.34   2063.79     848.6  48222.76
  104976.8   15168.1  36143.18  13133.26   2848.62   1942.85   2573.76   4155.11   3178.37  49264.61
   21820.5  161290.9   8376.37   6715.48   4513.48    2717.9   2542.54    866.91   1677.31  49405.81
  29559.33  19434.09  43284.43  11973.57  16877.91  19587.74   8229.01   6546.39    8186.6  71550.65
  27181.03  91781.73  21911.68  21684.28  10412.43   9327.48   6708.83   3023.18   4448.24  65504.89
   11121.1  30146.79  12343.23   9853.43  10636.66    8100.2   5593.94   2629.49   1025.04  32217.46
  51844.57   9383.17  10677.45   3439.66   3365.54   5042.96   2884.56   2893.11   1650.65   20919.9
  25603.69   38016.3   9946.38   4529.72   5751.48   3022.07   1869.19   1484.89    606.29  23737.04
  46200.33  21302.37   5280.72    982.52    552.27   1417.41    759.08    529.29    336.18  11995.83
  28943.78  43914.05  12553.55   6006.08    3740.6   2567.45   1367.78   1073.12    755.59  24562.68
  24318.16   49846.2  32821.51  12958.96   8403.64   7621.77   4900.96   4165.63   6853.01  51076.32
  13603.22  19878.34  38777.42  23702.43  15523.39  13343.25   10667.9   6471.86   7980.32  62822.66
   11997.3   2949.13   2680.44   6120.22   5834.41    4446.9   1946.44   1330.19    966.05  15909.85
  29466.53  15354.87   5178.47   8768.71  10300.19   6637.51   2844.88   1140.63    630.41   27791.9
  14207.16  20422.43   3517.09   1951.32   2407.56   2133.99    984.14    555.21    298.61  13010.41
   7247.46   51288.5   5175.57   1192.36    228.27     364.9    252.66         0         0  14122.78
  26589.82  14955.19   5147.96   1891.02    662.89    651.84    330.95      95.6     65.05  12022.88
  46349.62   7066.43   2287.65   1657.83    706.03    141.48     94.32     36.78     94.32  11195.41
  71582.68   9838.92   5043.35    729.78     285.3    174.03     89.59     22.52         0  13151.46
  71663.69  23704.07   4708.05    1870.8    548.46    200.24    166.33      48.2         0  16623.48
         0         0         0         0         0         0         0         0         0  16623.48
# Fleet 1 Discards at Age - Last Column is Total Weight
         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0
```

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Fleet 1 Proportion Released at Age

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

```
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0
# Number of Indices
   3
#$SPOTTER
#$CPFV
#$CALCOFI
# Index Weight Flag
   2
# Index Units
   1   2   2
# Index Month
   4   5   1
# Index Start Age
   1   2   2
# Index End Age
   9   9   9
# Index Fix Age
   -1   -1   -1
# Index Selectivity Choice
   -1   -1   -1
# Index Data - Year, Index, CV, Selectivity
# INDEX - 1
    1929      -999         1         1         1         1         1         1         1         1         1         1
    1930      -999         1         1         1         1         1         1         1         1         1         1
    1931      -999         1         1         1         1         1         1         1         1         1         1
    1932      -999         1         1         1         1         1         1         1         1         1         1
    1933      -999         1         1         1         1         1         1         1         1         1         1
    1934      -999         1         1         1         1         1         1         1         1         1         1
    1935      -999         1         1         1         1         1         1         1         1         1         1
    1936      -999         1         1         1         1         1         1         1         1         1         1
    1937      -999         1         1         1         1         1         1         1         1         1         1
    1938      -999         1         1         1         1         1         1         1         1         1         1
    1939      -999         1         1         1         1         1         1         1         1         1         1
    1940      -999         1         1         1         1         1         1         1         1         1         1
    1941      -999         1         1         1         1         1         1         1         1         1         1
    1942      -999         1         1         1         1         1         1         1         1         1         1
    1943      -999         1         1         1         1         1         1         1         1         1         1
    1944      -999         1         1         1         1         1         1         1         1         1         1
    1945      -999         1         1         1         1         1         1         1         1         1         1
    1946      -999         1         1         1         1         1         1         1         1         1         1
    1947      -999         1         1         1         1         1         1         1         1         1         1
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1948	-999	1	1	1	1	1	1	1	1	1	1
1949	-999	1	1	1	1	1	1	1	1	1	1
1950	-999	1	1	1	1	1	1	1	1	1	1
1951	-999	1	1	1	1	1	1	1	1	1	1
1952	-999	1	1	1	1	1	1	1	1	1	1
1953	-999	1	1	1	1	1	1	1	1	1	1
1954	-999	1	1	1	1	1	1	1	1	1	1
1955	-999	1	1	1	1	1	1	1	1	1	1
1956	-999	1	1	1	1	1	1	1	1	1	1
1957	-999	1	1	1	1	1	1	1	1	1	1
1958	-999	1	1	1	1	1	1	1	1	1	1
1959	-999	1	1	1	1	1	1	1	1	1	1
1960	-999	1	1	1	1	1	1	1	1	1	1
1961	-999	1	1	1	1	1	1	1	1	1	1
1962	461.35	0.518	1	1	1	1	1	1	1	1	1
1963	1541.53	0.32	1	1	1	1	1	1	1	1	1
1964	549.34	0.458	1	1	1	1	1	1	1	1	1
1965	707.89	0.508	1	1	1	1	1	1	1	1	1
1966	272.08	0.67	1	1	1	1	1	1	1	1	1
1967	19.88	0.979	1	1	1	1	1	1	1	1	1
1968	178.55	1.42	1	1	1	1	1	1	1	1	1
1969	782.89	1.385	1	1	1	1	1	1	1	1	1
1970	22.03	2.439	1	1	1	1	1	1	1	1	1
1971	76.7	0.89	1	1	1	1	1	1	1	1	1
1972	5.46	2.05	1	1	1	1	1	1	1	1	1
1973	28.95	2.873	1	1	1	1	1	1	1	1	1
1974	-999	1	1	1	1	1	1	1	1	1	1
1975	4.31	3.011	1	1	1	1	1	1	1	1	1
1976	15492.54	0.55	1	1	1	1	1	1	1	1	1
1977	31112.79	0.282	1	1	1	1	1	1	1	1	1
1978	40320.84	0.219	1	1	1	1	1	1	1	1	1
1979	44380.55	0.18	1	1	1	1	1	1	1	1	1
1980	22164.44	0.153	1	1	1	1	1	1	1	1	1
1981	25829.5	0.139	1	1	1	1	1	1	1	1	1
1982	36237.16	0.13	1	1	1	1	1	1	1	1	1
1983	30524.24	0.271	1	1	1	1	1	1	1	1	1
1984	45635.38	0.156	1	1	1	1	1	1	1	1	1
1985	38944.25	0.207	1	1	1	1	1	1	1	1	1
1986	18979.22	0.17	1	1	1	1	1	1	1	1	1
1987	12087.23	0.254	1	1	1	1	1	1	1	1	1
1988	16673.37	0.304	1	1	1	1	1	1	1	1	1
1989	2700.95	0.341	1	1	1	1	1	1	1	1	1
1990	5445.68	0.263	1	1	1	1	1	1	1	1	1
1991	2391.01	0.27	1	1	1	1	1	1	1	1	1
1992	1207.58	0.48	1	1	1	1	1	1	1	1	1
1993	1764.32	0.345	1	1	1	1	1	1	1	1	1
1994	2097.7	0.561	1	1	1	1	1	1	1	1	1
1995	6317.02	0.372	1	1	1	1	1	1	1	1	1
1996	1907.85	0.546	1	1	1	1	1	1	1	1	1
1997	5050.92	0.353	1	1	1	1	1	1	1	1	1
1998	2248.2	0.417	1	1	1	1	1	1	1	1	1
1999	1187.88	0.459	1	1	1	1	1	1	1	1	1
2000	3230.88	0.42	1	1	1	1	1	1	1	1	1
2001	548.8	1.339	1	1	1	1	1	1	1	1	1
2002	-999	1	1	1	1	1	1	1	1	1	1
2003	-999	1	1	1	1	1	1	1	1	1	1
2004	-999	1	1	1	1	1	1	1	1	1	1
2005	-999	1	1	1	1	1	1	1	1	1	1
2006	-999	1	1	1	1	1	1	1	1	1	1
2007	-999	1	1	1	1	1	1	1	1	1	1

INDEX - 2

1929	-999	1	0	0.5	1	1	1	1	1	1	1
1930	-999	1	0	0.5	1	1	1	1	1	1	1
1931	-999	1	0	0.5	1	1	1	1	1	1	1
1932	-999	1	0	0.5	1	1	1	1	1	1	1
1933	-999	1	0	0.5	1	1	1	1	1	1	1
1934	-999	1	0	0.5	1	1	1	1	1	1	1
1935	41.412	0.209	0	0.5	1	1	1	1	1	1	1
1936	59.696	0.387	0	0.5	1	1	1	1	1	1	1
1937	33.128	0.186	0	0.5	1	1	1	1	1	1	1
1938	73.639	0.127	0	0.5	1	1	1	1	1	1	1
1939	58.063	0.147	0	0.5	1	1	1	1	1	1	1
1940	85.304	0.135	0	0.5	1	1	1	1	1	1	1
1941	-999	1	0	0.5	1	1	1	1	1	1	1
1942	-999	1	0	0.5	1	1	1	1	1	1	1
1943	-999	1	0	0.5	1	1	1	1	1	1	1
1944	-999	1	0	0.5	1	1	1	1	1	1	1
1945	-999	1	0	0.5	1	1	1	1	1	1	1
1946	21.888	0.216	0	0.5	1	1	1	1	1	1	1
1947	24.906	0.19	0	0.5	1	1	1	1	1	1	1
1948	29.25	0.313	0	0.5	1	1	1	1	1	1	1
1949	14.111	0.209	0	0.5	1	1	1	1	1	1	1
1950	7.793	0.234	0	0.5	1	1	1	1	1	1	1
1951	5.758	0.189	0	0.5	1	1	1	1	1	1	1
1952	5.549	0.256	0	0.5	1	1	1	1	1	1	1
1953	11.365	0.31	0	0.5	1	1	1	1	1	1	1
1954	41.29	0.19	0	0.5	1	1	1	1	1	1	1
1955	14.683	0.203	0	0.5	1	1	1	1	1	1	1
1956	11.501	0.237	0	0.5	1	1	1	1	1	1	1
1957	17.313	0.256	0	0.5	1	1	1	1	1	1	1
1958	17.465	0.215	0	0.5	1	1	1	1	1	1	1
1959	11.982	0.24	0	0.5	1	1	1	1	1	1	1
1960	15.922	0.265	0	0.5	1	1	1	1	1	1	1
1961	15.009	0.214	0	0.5	1	1	1	1	1	1	1
1962	7.345	0.265	0	0.5	1	1	1	1	1	1	1

1963	13.3	0.242	0	0.5	1	1	1	1	1	1	1
1964	5.174	0.289	0	0.5	1	1	1	1	1	1	1
1965	9.66	0.263	0	0.5	1	1	1	1	1	1	1
1966	10.71	0.22	0	0.5	1	1	1	1	1	1	1
1967	4.406	0.448	0	0.5	1	1	1	1	1	1	1
1968	6.652	0.281	0	0.5	1	1	1	1	1	1	1
1969	5.455	0.304	0	0.5	1	1	1	1	1	1	1
1970	8.493	0.41	0	0.5	1	1	1	1	1	1	1
1971	13.934	0.259	0	0.5	1	1	1	1	1	1	1
1972	7.615	0.382	0	0.5	1	1	1	1	1	1	1
1973	4.178	0.413	0	0.5	1	1	1	1	1	1	1
1974	3.046	0.438	0	0.5	1	1	1	1	1	1	1
1975	7.665	0.309	0	0.5	1	1	1	1	1	1	1
1976	12.797	0.378	0	0.5	1	1	1	1	1	1	1
1977	49.681	0.237	0	0.5	1	1	1	1	1	1	1
1978	95.89	0.177	0	0.5	1	1	1	1	1	1	1
1979	113.094	0.18	0	0.5	1	1	1	1	1	1	1
1980	149.874	0.156	0	0.5	1	1	1	1	1	1	1
1981	102.548	0.183	0	0.5	1	1	1	1	1	1	1
1982	104.27	0.151	0	0.5	1	1	1	1	1	1	1
1983	106.374	0.208	0	0.5	1	1	1	1	1	1	1
1984	114.281	0.218	0	0.5	1	1	1	1	1	1	1
1985	82.501	0.211	0	0.5	1	1	1	1	1	1	1
1986	64.498	0.252	0	0.5	1	1	1	1	1	1	1
1987	42.182	0.202	0	0.5	1	1	1	1	1	1	1
1988	30.661	0.283	0	0.5	1	1	1	1	1	1	1
1989	41.511	0.201	0	0.5	1	1	1	1	1	1	1
1990	48.839	0.206	0	0.333	0.666	1	1	1	1	1	1
1991	56.214	0.174	0	0.333	0.666	1	1	1	1	1	1
1992	39.565	0.201	0	0.333	0.666	1	1	1	1	1	1
1993	47.48	0.193	0	0.333	0.666	1	1	1	1	1	1
1994	44.387	0.276	0	0.333	0.666	1	1	1	1	1	1
1995	40.647	0.19	0	0.333	0.666	1	1	1	1	1	1
1996	43.401	0.388	0	0.333	0.666	1	1	1	1	1	1
1997	31.747	0.285	0	0.333	0.666	1	1	1	1	1	1
1998	13.907	0.253	0	0.333	0.666	1	1	1	1	1	1
1999	7.936	0.396	0	0.333	0.666	1	1	1	1	1	1
2000	14.281	0.194	0	0.333	0.666	1	1	1	1	1	1
2001	11.216	0.421	0	0.333	0.666	1	1	1	1	1	1
2002	9.13	0.355	0	0.333	0.666	1	1	1	1	1	1
2003	6.041	0.298	0	0.333	0.666	1	1	1	1	1	1
2004	11.578	0.366	0	0.333	0.666	1	1	1	1	1	1
2005	23.96	0.256	0	0.333	0.666	1	1	1	1	1	1
2006	27.411	0.389	0	0.333	0.666	1	1	1	1	1	1
2007	-999	1	0	0.333	0.666	1	1	1	1	1	1

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1929	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1930	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1931	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1932	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1933	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1934	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1935	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1936	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1937	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1938	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1939	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1940	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1941	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1942	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1943	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1944	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1945	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1946	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1947	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1948	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1949	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1950	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1951	0.015	0.646	0	0.074	0.246	0.474	0.733	1	1	1	1
1952	0.023	0.54	0	0.074	0.246	0.474	0.733	1	1	1	1
1953	0.187	0.533	0	0.074	0.246	0.474	0.733	1	1	1	1
1954	1.148	0.176	0	0.074	0.246	0.474	0.733	1	1	1	1
1955	0.287	0.309	0	0.074	0.246	0.474	0.733	1	1	1	1
1956	0.113	0.317	0	0.074	0.246	0.474	0.733	1	1	1	1
1957	0.044	0.398	0	0.074	0.246	0.474	0.733	1	1	1	1
1958	0.629	0.162	0	0.074	0.246	0.474	0.733	1	1	1	1
1959	0.184	0.216	0	0.074	0.246	0.474	0.733	1	1	1	1
1960	0.585	0.327	0	0.074	0.246	0.474	0.733	1	1	1	1
1961	0.067	0.329	0	0.074	0.246	0.474	0.733	1	1	1	1
1962	0.125	0.426	0	0.074	0.246	0.474	0.733	1	1	1	1
1963	0.517	0.386	0	0.074	0.246	0.474	0.733	1	1	1	1
1964	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1965	0.057	0.542	0	0.074	0.246	0.474	0.733	1	1	1	1
1966	0.381	0.442	0	0.074	0.246	0.474	0.733	1	1	1	1
1967	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1968	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1969	0.167	0.493	0	0.074	0.246	0.474	0.733	1	1	1	1
1970	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1971	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1972	0.246	0.55	0	0.074	0.246	0.474	0.733	1	1	1	1
1973	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1974	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1975	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1976	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1
1977	-999	1	0	0.074	0.246	0.474	0.733	1	1	1	1

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    1978     5.436     0.196         0     0.074     0.246     0.474     0.733          1          1          1          1
    1979      -999         1         0     0.074     0.246     0.474     0.733          1          1          1          1
    1980      -999         1         0     0.074     0.246     0.474     0.733          1          1          1          1
    1981    21.845     0.222         0     0.074     0.246     0.474     0.733          1          1          1          1
    1982      -999         1         0     0.074     0.246     0.474     0.733          1          1          1          1
    1983      -999         1         0     0.074     0.246     0.474     0.733          1          1          1          1
    1984     2.222     0.417         0     0.074     0.246     0.474     0.733          1          1          1          1
    1985     0.579     0.213         0     0.074     0.246     0.474     0.733          1          1          1          1
    1986    10.974     0.156         0     0.074     0.246     0.474     0.733          1          1          1          1
    1987    46.389     0.318         0     0.074     0.246     0.474     0.733          1          1          1          1
    1988     2.876     0.215         0     0.074     0.246     0.474     0.733          1          1          1          1
    1989     1.187     0.291         0     0.074     0.246     0.474     0.733          1          1          1          1
    1990      -999         1         0     0.074     0.246     0.474     0.733          1          1          1          1
    1991     0.848     0.645         0     0.074     0.246     0.474     0.733          1          1          1          1
    1992     0.315     0.636         0     0.074     0.246     0.474     0.733          1          1          1          1
    1993     0.643     0.424         0     0.074     0.246     0.474     0.733          1          1          1          1
    1994     0.094     1.029         0     0.074     0.246     0.474     0.733          1          1          1          1
    1995     0.758     0.207         0     0.074     0.246     0.474     0.733          1          1          1          1
    1996     7.922     0.232         0     0.074     0.246     0.474     0.733          1          1          1          1
    1997     8.767     0.305         0     0.074     0.246     0.474     0.733          1          1          1          1
    1998      0.37     0.451         0     0.074     0.246     0.474     0.733          1          1          1          1
    1999      -999         1         0     0.074     0.246     0.474     0.733          1          1          1          1
    2000      -999         1         0     0.074     0.246     0.474     0.733          1          1          1          1
    2001     0.394     0.308         0     0.074     0.246     0.474     0.733          1          1          1          1
    2002      -999         1         0     0.074     0.246     0.474     0.733          1          1          1          1
    2003     0.333     0.549         0     0.074     0.246     0.474     0.733          1          1          1          1
    2004      -999         1         0     0.074     0.246     0.474     0.733          1          1          1          1
    2005     0.068     0.444         0     0.074     0.246     0.474     0.733          1          1          1          1
    2006     0.103     0.554         0     0.074     0.246     0.474     0.733          1          1          1          1
    2007      -999         1         0     0.074     0.246     0.474     0.733          1          1          1          1
# Phase Control Data
# Phase for Selectivity in 1st Year
   1
# Phase for Selectivity Deviations
   4
# Phase for F mult in 1st Year
   1
# Phase for F mult Deviations
   3
# Phase for Recruitment Deviations
   3
# Phase for N in 1st Year
   2
# Phase for Catchability in 1st Year
   1
# Phase for Catchability Deviations
   -5
# Phase for Stock Recruitment Relationship
   1
# Phase for Steepness
   1
# Recruitment CV by Year
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#Lambda for Each Index (cv=0.4)
   1   1   1
# Lambda for Total Catch in Weight
   100
# Lambda for Total Discards at Age
   0
# Lambda for Catch at Age by Year & Fleet
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        0
# Lambda for Discards at Age by Year & Fleet
        0
        0
        0
        0
        0
        0
        0
        0
        0
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        0
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        0
        0
        0
        0
        0
        0
        0
        0
        0
        0
        0
        0
# Lambda for F mult Deviations by Fleet
   0
# Lambda for N in 1st Year Deviations
   0
# Lambda for Recruitment Deviations
   1
# Lambda for Catchability Deviations by Index
   1   1   1
# Lambda for Selectivity Deviations by Fleet
   0
# Lambda for Selectivity Curvature at Age
   0
# Lambda for Selectivity Curvature Over Time
   0
# Lambda for Deviations from Initial Steepness
   0
# Lambda for Deviation from Initial log of Virgin Stock Size
   0
# NAA for Year 1
  100000  70000  50000  30000  20000  10000  5000  2500  1250
# Log of F mult in 1st year by Fleet
   -3
# log of Catchability in 1st year by index
   -7   -7   -7
# Initial log of Virgin Stock Size
   10
# Initial Steepness
   0.9
# Selectivity at Age in 1st Year by Fleet
     0.009
     0.092
     0.293
     0.703
         1
         1
         1
         1
         1
# Where to do Extras
   2
# Ignore Guesses
   0
# Projection Control Data
# Year for SSB ratio Calculation
   1929
# Fleet Directed Flag
   1
# Final Year of Projections
   2009
# Year Projected Recruits, What Projected, Target, non- directed F mult
      2008         2       0.3         1        -1
      2009         2       0.3         1        -1
# Test Value
   -23456
#####
# ---- FINIS ----
```

APPENDIX B

REPORT FILE FOR ASAP BASE MODEL E1:

```
obj_fun        = 1187.19
Component          RSS      nobs  Lambda  Likelihood
  Catch_Fleet_1        0.0200987   79   100   2.00987
Catch_Fleet_Total     0.0200987   79   100   2.00987
  Discard_Fleet_1        0   79   0   0
Discard_Fleet_Total     0   79   0   0
CAA_proportions      N/A            711    see_below      524.626
Discard_proportions      N/A            711    see_below      0
  Index_Fit_1         165.434   39   1   119.525
  Index_Fit_2         15.5464   67   1   107.834
  Index_Fit_3         78.0771   37   1   318.819
Index_Fit_Total     259.057   143   3   546.179
  Selectivity_devs_fleet_1   36.3896  2   0  0
Selectivity_devs_Total   36.3896  2   0  0
  Catchability_devs_index_1  0  39  1  0
  Catchability_devs_index_2  0  67  1  0
  Catchability_devs_index_3  0  37  1  0
Catchability_devs_Total  0  143  3  0
  Fmult_fleet_1     31.231   78   0  0
Fmult_fleet_Total   31.231   78   0  0
N_year_1           2.45627   8   0   0
Stock-Recruit_Fit   58.803  79   1   55.5721
Recruit_devs        58.803   79   1   58.803
SRR_steepness       1.14554       1 0   0
SRR_virgin_stock    4.53861      1 0  0
Curvature_over_age  52.2818   14   0   0
Curvature_over_time 72.7793   693   0   0
F_penalty           1.9564    711     0.001     0.0019564
Mean_Sel_year1_pen  0   9      1000  0
Max_Sel_penalty     0.294126        1       100 0
Fmult_Max_penalty   0        ?       100 0

 Input and Estimated effective sample sizes for fleet 1
1929  45  36.4235
1930  45  14.1065
1931  45  9.03445
1932  45  10.0344
1933  45  21.7392
1934  45  43.7267
1935  45  35.2486
1936  45  28.1357
1937  45  7.74268
1938  45  22.5496
1939  45  33.0862
1940  45  36.957
1941  45  22.0074
1942  45  25.3069
1943  45  9.81315
1944  45  40.8508
1945  45  58.3233
1946  45  66.061
1947  45  159.89
1948  45  13.9461
1949  45  135.444
1950  45  130.705
1951  45  235.666
1952  45  7.08767
1953  45  8.22747
1954  45  16.0746
1955  45  13.5809
1956  45  10.9595
1957  45  70.7721
1958  45  18.6598
1959  45  6.46058
1960  45  25.47
1961  45  67.3378
1962  45  30.0209
1963  45  55.2383
1964  45  24.0891
1965  45  5.12945
1966  45  20.5259
1967  45  2.181
1968  45  2.04551
1969  45  12.5601
1970  45  13.0982
1971  45  10.4686
1972  45  9.9036
1973  45  8.2392
1974  45  221.213
1975  45  24.7464
1976  45  32.0273
1977  45  51.5543
1978  45  163.816
1979  45  38.932
1980  45  37.5424
1981  45  7.01531
1982  45  20.6435
1983  45  13.8843
```

1984	45	11.2611
1985	45	7.60081
1986	45	39.1527
1987	45	18.4868
1988	45	37.8298
1989	45	9.11544
1990	45	25.5694
1991	45	18.6141
1992	45	34.816
1993	45	22.6914
1994	45	339.537
1995	45	11.0095
1996	45	75.7147
1997	45	81.2794
1998	45	42.3431
1999	45	59.3407
2000	45	112.848
2001	45	23.7145
2002	45	5.74643
2003	45	16.6502
2004	45	6.69053
2005	45	5.53676
2006	45	13.1955
2007	0	1.5126
Total	3510	3266.56

Input and Estimated effective Discard sample sizes for fleet 1

1929	0	1e+15
1930	0	1e+15
1931	0	1e+15
1932	0	1e+15
1933	0	1e+15
1934	0	1e+15
1935	0	1e+15
1936	0	1e+15
1937	0	1e+15
1938	0	1e+15
1939	0	1e+15
1940	0	1e+15
1941	0	1e+15
1942	0	1e+15
1943	0	1e+15
1944	0	1e+15
1945	0	1e+15
1946	0	1e+15
1947	0	1e+15
1948	0	1e+15
1949	0	1e+15
1950	0	1e+15
1951	0	1e+15
1952	0	1e+15
1953	0	1e+15
1954	0	1e+15
1955	0	1e+15
1956	0	1e+15
1957	0	1e+15
1958	0	1e+15
1959	0	1e+15
1960	0	1e+15
1961	0	1e+15
1962	0	1e+15
1963	0	1e+15
1964	0	1e+15
1965	0	1e+15
1966	0	1e+15
1967	0	1e+15
1968	0	1e+15
1969	0	1e+15
1970	0	1e+15
1971	0	1e+15
1972	0	1e+15
1973	0	1e+15
1974	0	1e+15
1975	0	1e+15
1976	0	1e+15
1977	0	1e+15
1978	0	1e+15
1979	0	1e+15
1980	0	1e+15
1981	0	1e+15
1982	0	1e+15
1983	0	1e+15
1984	0	1e+15
1985	0	1e+15
1986	0	1e+15
1987	0	1e+15
1988	0	1e+15
1989	0	1e+15
1990	0	1e+15
1991	0	1e+15
1992	0	1e+15
1993	0	1e+15
1994	0	1e+15
1995	0	1e+15
1996	0	1e+15

```
1997  0  1e+15
1998  0  1e+15
1999  0  1e+15
2000  0  1e+15
2001  0  1e+15
2002  0  1e+15
2003  0  1e+15
2004  0  1e+15
2005  0  1e+15
2006  0  1e+15
2007  0  1e+15
 Total  0  7.9e+16

Observed and predicted total fleet catch by year
 fleet 1 total catches
1929  25733.5  25741.2
1930  5825.88  5826.51
1931  6890.14  6890.51
1932  4938.95  4938.67
1933  33072.2  33026.3
1934  51483.8  51200.6
1935  66417.4  65162.1
1936  45714.2  44767
1937  31987.6  31515.6
1938  34561.8  34123.7
1939  45454  45303.2
1940  48868.2  49621.5
1941  32560.8  33260.4
1942  21885.7  22160.1
1943  35304.7  35866.8
1944  36657.1  37206.1
1945  23601.4  23820.3
1946  27582.5  27988.5
1947  19437  19896.3
1948  18124.7  18609.4
1949  24188.9  24773.1
1950  17493  17511.1
1951  15857.1  15488
1952  10325.8  10159.6
1953  5265.94  5235.93
1954  18464.7  18917.6
1955  22200.9  22998.1
1956  36835  37103.1
1957  27753.4  27264.1
1958  11874.8  12092.8
1959  19332.5  19567.7
1960  20822.5  21190.6
1961  26199.2  25973.2
1962  23901  22995.9
1963  23703  22452.1
1964  19987.9  18985.3
1965  11279.4  10930.6
1966  7405.18  7568.88
1967  1713.31  1731.05
1968  1695.04  1706.68
1969  1168.22  1171.2
1970  835.49  835.4
1971  911.26  911.775
1972  532  531.995
1973  400.94  401.037
1974  633.81  633.709
1975  2149.3  2148.25
1976  4091.65  4089.77
1977  13751.2  13732.6
1978  27172.6  27157.9
1979  35858.1  35844.3
1980  35203.1  35112.8
1981  46984.5  46839.6
1982  36371.4  36191
1983  42117.5  41808.5
1984  46468.3  46182.7
1985  46827.8  46141.2
1986  54122.6  54054.6
1987  48222.8  48690.2
1988  49264.6  49572.8
1989  49405.8  49161.9
1990  71550.6  70309.9
1991  65504.9  64165.5
1992  32217.5  31832.4
1993  20919.9  20750.8
1994  23737  23575.7
1995  11995.8  11926.2
1996  24562.7  24627.6
1997  51076.3  52164.2
1998  62822.7  64070
1999  15909.9  15923.5
2000  27791.9  28128.3
2001  13010.4  13135.2
2002  14122.8  14290.6
2003  12022.9  12100
2004  11195.4  11250.9
2005  13151.5  13208.4
2006  16623.5  16630.8
2007  16623.5  16623.5
Observed and predicted total fleet Discards by year
```

```
 fleet 1 total Discards
1929  0  0
1930  0  0
1931  0  0
1932  0  0
1933  0  0
1934  0  0
1935  0  0
1936  0  0
1937  0  0
1938  0  0
1939  0  0
1940  0  0
1941  0  0
1942  0  0
1943  0  0
1944  0  0
1945  0  0
1946  0  0
1947  0  0
1948  0  0
1949  0  0
1950  0  0
1951  0  0
1952  0  0
1953  0  0
1954  0  0
1955  0  0
1956  0  0
1957  0  0
1958  0  0
1959  0  0
1960  0  0
1961  0  0
1962  0  0
1963  0  0
1964  0  0
1965  0  0
1966  0  0
1967  0  0
1968  0  0
1969  0  0
1970  0  0
1971  0  0
1972  0  0
1973  0  0
1974  0  0
1975  0  0
1976  0  0
1977  0  0
1978  0  0
1979  0  0
1980  0  0
1981  0  0
1982  0  0
1983  0  0
1984  0  0
1985  0  0
1986  0  0
1987  0  0
1988  0  0
1989  0  0
1990  0  0
1991  0  0
1992  0  0
1993  0  0
1994  0  0
1995  0  0
1996  0  0
1997  0  0
1998  0  0
1999  0  0
2000  0  0
2001  0  0
2002  0  0
2003  0  0
2004  0  0
2005  0  0
2006  0  0
2007  0  0

Index data
index number 1
units = 1
month = 4
starting and ending ages for selectivity = 1  9
selectivity choice = -1
 year, sigma2, obs index, pred index
1962  0.237696  0.0429284  0.255483
1963  0.0974896  0.143439  0.174636
1964  0.190425  0.0511159  0.110152
1965  0.229574  0.0658689  0.0709493
1966  0.370805  0.0253169  0.0684113
1967  0.672149  0.00184983  0.085403
1968  1.10406  0.016614  0.144102
```

```
1969  1.07098  0.0728476  0.189422
1970  1.93856  0.00204988  0.192371
1971  0.583388  0.00713691  0.205613
1972  1.64914  0.000508051  0.188982
1973  2.22507  0.00269379  0.182216
1975  2.30918  0.000401044  0.392756
1976  0.264285  1.44157  1.38907
1977  0.0765202  2.89503  1.76011
1978  0.0468464  3.75184  2.40344
1979  0.0318862  4.12959  2.61365
1980  0.0231392  2.06239  2.31637
1981  0.0191367  2.40342  2.68464
1982  0.0167588  3.37185  2.25954
1983  0.0708694  2.84027  2.04952
1984  0.0240446  4.24635  1.82471
1985  0.0419564  3.62375  1.63257
1986  0.0284903  1.76601  1.45619
1987  0.0625202  1.12471  1.20059
1988  0.0883918  1.55145  1.19145
1989  0.110003  0.251322  0.948105
1990  0.0668817  0.506718  0.885703
1991  0.0703653  0.222483  0.687404
1992  0.207339  0.112365  0.514811
1993  0.112458  0.164169  0.50311
1994  0.273624  0.19519  0.482592
1995  0.12961  0.587796  0.553093
1996  0.260914  0.177525  0.606706
1997  0.117435  0.469986  0.555801
1998  0.160322  0.209194  0.352764
1999  0.191183  0.110532  0.263228
2000  0.162459  0.300632  0.215881
2001  1.02709  0.0510656  0.192274
index number 2
units = 2
month = 5
starting and ending ages for selectivity = 2  9
selectivity choice = -1
 year, sigma2, obs index, pred index
1935  0.0427539  1.1998  3.17901
1936  0.139561  1.72952  2.1
1937  0.034011  0.959791  1.69712
1938  0.0160003  2.13348  1.5258
1939  0.0213788  1.68221  1.50695
1940  0.0180609  2.47144  1.37943
1946  0.0456003  0.634143  0.530111
1947  0.0354637  0.721582  0.413427
1948  0.0934621  0.847437  0.523237
1949  0.0427539  0.408827  0.551986
1950  0.0533095  0.22578  0.394911
1951  0.0350978  0.166822  0.252111
1952  0.063478  0.160767  0.175973
1953  0.0917584  0.329269  0.215667
1954  0.0354637  1.19626  0.491537
1955  0.0403825  0.425399  0.507331
1956  0.0546482  0.333209  0.461195
1957  0.063478  0.501596  0.353534
1958  0.0451884  0.505999  0.27384
1959  0.0560022  0.347145  0.369956
1960  0.0678689  0.461295  0.392593
1961  0.0447783  0.434844  0.387378
1962  0.0678689  0.212801  0.393847
1963  0.0569133  0.38533  0.295456
1964  0.0802159  0.149902  0.173591
1965  0.0668817  0.279871  0.106
1966  0.0472652  0.310292  0.101739
1967  0.182908  0.127651  0.100705
1968  0.0759985  0.192723  0.134848
1969  0.0883918  0.158043  0.283136
1970  0.155378  0.246061  0.354081
1971  0.0649269  0.403699  0.359743
1972  0.136211  0.220623  0.295756
1973  0.15749  0.121046  0.272005
1974  0.175502  0.0882493  0.255037
1975  0.0911935  0.222072  0.488022
1976  0.133555  0.370757  0.536028
1977  0.0546482  1.43937  2.15826
1978  0.0308483  2.77814  3.18644
1979  0.0318862  3.27658  5.72933
1980  0.0240446  4.34218  5.71881
1981  0.0329405  2.97104  5.23524
1982  0.0225449  3.02093  6.03841
1983  0.0423543  3.08189  5.253
1984  0.0464293  3.31097  3.61779
1985  0.0435584  2.39024  2.62847
1986  0.0615691  1.86865  2.21007
1987  0.0399935  1.22211  1.97404
1988  0.0770434  0.888317  1.57687
1989  0.0396062  1.20266  1.75095
1990  0.0415603  1.41497  1.20968
1991  0.0298267  1.62864  1.0474
1992  0.0396062  1.14628  0.854867
1993  0.036572  1.3756  0.742572
1994  0.073414  1.28599  0.810226
1995  0.0354637  1.17763  0.865639
1996  0.140235  1.25742  0.994616
```

```
1997  0.0780947  0.91978  0.904276
1998  0.0620438  0.402916  0.612273
1999  0.145671  0.229923  0.37277
2000  0.036945  0.413752  0.267003
2001  0.163174  0.324952  0.229699
2002  0.118694  0.264516  0.254145
2003  0.0850798  0.175021  0.23193
2004  0.125712  0.33544  0.240627
2005  0.063478  0.694174  0.331494
2006  0.14091  0.794157  0.566115
index number 3
units = 2
month = 1
starting and ending ages for selectivity = 2  9
selectivity choice = -1
 year, sigma2, obs index, pred index
1951  0.348765  0.00474773  0.137553
1952  0.255882  0.00727985  0.0993217
1953  0.25005  0.0591884  0.0843542
1954  0.0305059  0.36336  0.128223
1955  0.0911935  0.0908399  0.158773
1956  0.0957546  0.0357662  0.170302
1957  0.147043  0.0139267  0.141463
1958  0.0259055  0.199088  0.114757
1959  0.0456003  0.0582388  0.125101
1960  0.10159  0.185161  0.132004
1961  0.102774  0.0212065  0.136343
1962  0.166765  0.0395644  0.135138
1963  0.138889  0.163638  0.124209
1965  0.257556  0.0180414  0.0576835
1966  0.178451  0.120592  0.0409857
1969  0.217567  0.052858  0.0730744
1972  0.264285  0.0778628  0.141912
1978  0.0376965  1.72058  0.827137
1981  0.048108  6.91428  2.24081
1984  0.160322  0.703297  2.09426
1985  0.0443699  0.183262  1.716
1986  0.0240446  3.47344  1.35008
1987  0.0963315  14.6828  1.04183
1988  0.0451884  0.910298  0.833193
1989  0.0812859  0.375704  0.758548
1991  0.347854  0.268405  0.588969
1992  0.339679  0.0997023  0.489079
1993  0.165325  0.203519  0.430678
1994  0.722143  0.0297524  0.415829
1995  0.0419564  0.239919  0.425871
1996  0.0524255  2.50743  0.475267
1997  0.0889491  2.77489  0.484423
1998  0.185152  0.117111  0.394175
2001  0.0906302  0.124707  0.13343
2003  0.263441  0.1054  0.117829
2005  0.179932  0.021523  0.144407
2006  0.26767  0.0326011  0.215319

Selectivity by age and year for each fleet rescaled so max=1.0
 fleet 1 selectivity at age
 0.0683332 0.281801 0.563647 0.827121 0.943572 1 0.589237 0.259853 0.0405972
 0.0683332 0.281801 0.563647 0.827121 0.943572 1 0.589237 0.259853 0.0405972
 0.0683332 0.281801 0.563647 0.827121 0.943572 1 0.589237 0.259853 0.0405972
 0.0683332 0.281801 0.563647 0.827121 0.943572 1 0.589237 0.259853 0.0405972
 0.0683332 0.281801 0.563647 0.827121 0.943572 1 0.589237 0.259853 0.0405972
 0.0683332 0.281801 0.563647 0.827121 0.943572 1 0.589237 0.259853 0.0405972
 0.0683332 0.281801 0.563647 0.827121 0.943572 1 0.589237 0.259853 0.0405972
 0.0683332 0.281801 0.563647 0.827121 0.943572 1 0.589237 0.259853 0.0405972
 0.0683332 0.281801 0.563647 0.827121 0.943572 1 0.589237 0.259853 0.0405972
 0.0683332 0.281801 0.563647 0.827121 0.943572 1 0.589237 0.259853 0.0405972
 0.0683332 0.281801 0.563647 0.827121 0.943572 1 0.589237 0.259853 0.0405972
 0.0683332 0.281801 0.563647 0.827121 0.943572 1 0.589237 0.259853 0.0405972
 0.0683332 0.281801 0.563647 0.827121 0.943572 1 0.589237 0.259853 0.0405972
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 0.271134 1 0.238564 0.144752 0.100711 0.21308 0.271807 0.0246291 0.0322787
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 0.415208 0.743877 0.648101 0.777872 0.917902 1 0.780118 0.70331 0.39342
 0.415208 0.743877 0.648101 0.777872 0.917902 1 0.780118 0.70331 0.39342
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 0.415208 0.743877 0.648101 0.777872 0.917902 1 0.780118 0.70331 0.39342
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 0.415208 0.743877 0.648101 0.777872 0.917902 1 0.780118 0.70331 0.39342
 0.415208 0.743877 0.648101 0.777872 0.917902 1 0.780118 0.70331 0.39342

Fmult by year for each fleet
1929   0.0333487
1930   0.00709957
1931   0.00812264
1932   0.00612334
1933   0.050338
1934   0.103302
1935   0.191034
1936   0.185702
1937   0.171636
1938   0.224226
1939   0.27675
1940   0.33543
1941   0.238939
1942   0.158222
1943   0.270486
1944   0.330101
1945   0.259496
1946   0.377169
1947   0.323211
1948   0.323117
1949   0.460621
1950   0.356753
1951   0.406307
1952   0.332395
1953   0.154091
1954   0.427568
1955   0.426979
1956   0.683296
1957   0.583617
1958   0.280099
1959   0.453926
1960   0.455095
1961   0.556993
1962   0.446467
1963   0.508752
1964   0.664895
1965   0.670565
1966   0.563604
1967   0.121636
1968   0.0904379
1969   0.0357032
1970   0.0246759
1971   0.0237132
1972   0.0247846
1973   0.0113076
1974   0.0163302
1975   0.018266
1976   0.0229416
1977   0.0230206
1978   0.0386454
1979   0.0397026
1980   0.0472041
1981   0.0511151
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1982   0.0431779
1983   0.0567806
1984   0.0727974
1985   0.0815196
1986   0.112646
1987   0.12431
1988   0.138763
1989   0.159096
1990   0.254767
1991   0.284001
1992   0.186588
1993   0.128199
1994   0.154892
1995   0.0680853
1996   0.124947
1997   0.284448
1998   0.541481
1999   0.179172
2000   0.400174
2001   0.221915
2002   0.270912
2003   0.197854
2004   0.135725
2005   0.124693
2006   0.0967215
2007   0.0783117

Directed F by age and year for each fleet
 fleet 1 directed F at age
 0.00227883 0.00939769 0.0187969 0.0275834 0.0314669 0.0333487 0.0196503 0.00866577 0.00135387
 0.000485137 0.00200066 0.00400165 0.0058722 0.00669896 0.00709957 0.00418333 0.00184485 0.000288223
 0.000555047 0.00228897 0.0045783 0.00671841 0.0076643 0.00812264 0.00478616 0.00211069 0.000329757
 0.000418427 0.00172556 0.0034514 0.00506474 0.00577781 0.00612334 0.0036081 0.00159117 0.000248591
 0.00343976 0.0141853 0.0283728 0.0416356 0.0474975 0.050338 0.029661 0.0130805 0.00204358
 0.00705893 0.0291105 0.0582256 0.0854429 0.0974725 0.103302 0.0608692 0.0268432 0.00419376
 0.013054 0.0538336 0.107676 0.158008 0.180255 0.191034 0.112565 0.0496408 0.00775546
 0.0126896 0.0523308 0.10467 0.153598 0.175223 0.185702 0.109422 0.0482551 0.00753897
 0.0117284 0.048367 0.0967418 0.141963 0.16195 0.171636 0.101134 0.0446 0.00696793
 0.0153221 0.0631871 0.126385 0.185462 0.211574 0.224226 0.132123 0.0582659 0.00910297
 0.0189112 0.0779883 0.155989 0.228905 0.261133 0.27675 0.163071 0.0719143 0.0112353
 0.022921 0.0945244 0.189064 0.277441 0.316502 0.33543 0.197648 0.0871625 0.0136175
 0.0163275 0.0673333 0.134677 0.197632 0.225456 0.238939 0.140792 0.0620891 0.00970028
 0.0108118 0.044587 0.0891812 0.130869 0.149294 0.158222 0.0932302 0.0411144 0.00642337
 0.0184832 0.0762232 0.152459 0.223725 0.255223 0.270486 0.159381 0.0702867 0.010981
 0.0225568 0.0930225 0.18606 0.273033 0.311474 0.330101 0.194508 0.0857776 0.0134012
 0.0177322 0.073126 0.146264 0.214634 0.244853 0.259496 0.152904 0.0674307 0.0105348
 0.0257732 0.106286 0.21259 0.311964 0.355886 0.377169 0.222242 0.0980085 0.015312
 0.0220861 0.0910812 0.182177 0.267335 0.304973 0.323211 0.190448 0.0839875 0.0131215
 0.0220796 0.0910545 0.182124 0.267257 0.304884 0.323117 0.190393 0.0839629 0.0131177
 0.0314757 0.129803 0.259627 0.380989 0.434629 0.460621 0.271415 0.119694 0.0186999
 0.0243781 0.100533 0.201083 0.295078 0.336622 0.356753 0.210212 0.0927034 0.0144832
 0.0277643 0.114498 0.229014 0.336065 0.38338 0.406307 0.239411 0.10558 0.0164949
 0.0227137 0.0936692 0.187354 0.274931 0.313639 0.332395 0.19586 0.086374 0.0134943
 0.0105296 0.0434231 0.0868531 0.127452 0.145396 0.154091 0.0907964 0.0400411 0.00625569
 0.0292171 0.120489 0.240997 0.35365 0.403441 0.427568 0.251939 0.111105 0.0173581
 0.0291769 0.120323 0.240665 0.353163 0.402885 0.426979 0.251592 0.110952 0.0173342
 0.0466918 0.192553 0.385138 0.565168 0.644739 0.683296 0.402624 0.177557 0.0277399
 0.0398804 0.164463 0.328954 0.482721 0.550684 0.583617 0.343889 0.151655 0.0236932
 0.0191401 0.0789322 0.157877 0.231676 0.264294 0.280099 0.165045 0.0727847 0.0113713
 0.0310182 0.127917 0.255854 0.375451 0.428311 0.453926 0.26747 0.117954 0.0184281
 0.0310981 0.128246 0.256513 0.376419 0.429415 0.455095 0.268159 0.118258 0.0184756
 0.0380611 0.156961 0.313947 0.4607 0.525563 0.556993 0.328201 0.144736 0.0226124
 0.0305085 0.125815 0.25165 0.369282 0.421274 0.446467 0.263075 0.116016 0.0181253
 0.0347647 0.143367 0.286757 0.420799 0.480044 0.508752 0.299776 0.132201 0.0206539
 0.0454344 0.187368 0.374766 0.549948 0.627376 0.664895 0.391781 0.172775 0.0269929
 0.0458219 0.188966 0.377962 0.554638 0.632726 0.670565 0.395122 0.174248 0.0272231
 0.0385129 0.158824 0.317674 0.466169 0.531801 0.563604 0.332097 0.146454 0.0228808
 0.0083118 0.0342772 0.0685599 0.100608 0.114773 0.121636 0.0716726 0.0316076 0.0049381
 0.00617991 0.0254854 0.050975 0.074803 0.0853346 0.0904379 0.0532894 0.0235006 0.00367153
 0.00243972 0.0100612 0.020124 0.0295309 0.0336886 0.0357032 0.0210377 0.0092776 0.00144945
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 0.00495253 0.018266 0.00435762 0.00264405 0.00183959 0.00389211 0.00496483 0.000449875 0.000589603
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 0.118105 0.211594 0.184351 0.221264 0.261095 0.284448 0.221903 0.200055 0.111907
 0.224827 0.402795 0.350935 0.421203 0.497027 0.541481 0.422419 0.380829 0.213029
 0.0743936 0.133282 0.116122 0.139373 0.164462 0.179172 0.139775 0.126013 0.0704897
 0.166155 0.29768 0.259353 0.311284 0.367321 0.400174 0.312183 0.281447 0.157436
 0.0921406 0.165077 0.143823 0.172621 0.203696 0.221915 0.173119 0.156075 0.0873055
 0.112485 0.201525 0.175578 0.210735 0.24867 0.270912 0.211343 0.190535 0.106582
 0.0821507 0.147179 0.12823 0.153905 0.181611 0.197854 0.15435 0.139153 0.0778398
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 0.0325156 0.0582543 0.0507539 0.0609165 0.0718825 0.0783117 0.0610924 0.0550774 0.0308094
Discard F by age and year for each fleet
 fleet 1 Discard F at age
 0 0 0 0 0 0 0 0 0
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Total F
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0.00227883 0.00939769 0.0187969 0.0275834 0.0314669 0.0333487 0.0196503 0.00866577 0.00135387
0.000485137 0.00200066 0.00400165 0.0058722 0.00669896 0.00709957 0.00418333 0.00184485 0.000288223
0.000555047 0.00228897 0.0045783 0.00671841 0.0076643 0.00812264 0.00478616 0.00211069 0.000329757
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Population Numbers at the Start of the Year
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2.55425e+06 1.78441e+06 1.44399e+06 928475 499315 284730 90390.8 49693.9 318885
2.43421e+06 1.54837e+06 1.07983e+06 871825 559378 300538 171300 54563 223427
894967 1.47581e+06 937514 652691 526117 337325 181173 103525 168523
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Proportions of catch at age by fleet
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Year 1 Pred =  0.0903145 0.240889 0.260924 0.219567 0.0797179 0.0463594 0.0379632 0.0177969 0.0064679
Year 2 Obs  =  0 0.0867775 0.446367 0.301453 0.11939 0.0417583 0.00273329 0.00108783 0.000433015
Year 2 Pred =  0.0646665 0.215981 0.278072 0.219666 0.142963 0.0481097 0.0155602 0.00961806 0.00536357
Year 3 Obs  =  0 0.048402 0.505194 0.313014 0.0660961 0.0380708 0.0187757 0.00747368 0.0029743
Year 3 Pred =  0.0565302 0.162734 0.263122 0.248027 0.152097 0.0918997 0.017217 0.00417933 0.00419336
Year 4 Obs  =  0 0.0117399 0.261808 0.474939 0.113249 0.0764021 0.0397449 0.0158206 0.00629655
Year 4 Pred =  0.0577546 0.151409 0.211034 0.249844 0.182814 0.104078 0.0349953 0.00492027 0.00314965
Year 5 Obs  =  0 0.0505403 0.20803 0.348817 0.255576 0.0905435 0.0298707 0.0118901 0.00473207
Year 5 Pred =  0.024622 0.166617 0.210338 0.213592 0.195888 0.132935 0.0424679 0.010783 0.00275625
Year 6 Obs  =  0 0.0307845 0.335587 0.223908 0.256675 0.0975438 0.0356587 0.0141941 0.00564898
Year 6 Pred =  0.0209993 0.0794665 0.25589 0.232301 0.18108 0.153386 0.0589024 0.0144649 0.00351004
Year 7 Obs  =  0 0.0564975 0.0661942 0.320666 0.33166 0.174786 0.03225 0.0128372 0.00510896
Year 7 Pred =  0.0242907 0.0758024 0.134168 0.305027 0.209998 0.150352 0.073097 0.0221231 0.00514107
Year 8 Obs  =  0 0.0193028 0.17522 0.149419 0.283927 0.301928 0.0451043 0.0179539 0.00714533
Year 8 Pred =  0.0687767 0.0899924 0.130104 0.160479 0.273211 0.171794 0.0703317 0.0274772 0.00783416
Year 9 Obs  =  0.001935 0.022218 0.0390255 0.120969 0.239529 0.392018 0.118413 0.0471347 0.0187587
Year 9 Pred =  0.0778695 0.222923 0.135456 0.136808 0.126556 0.196923 0.0706377 0.0231621 0.00966478
Year 10 Obs  =  0.00893818 0.134115 0.370324 0.191463 0.0499225 0.126082 0.0765549 0.0304729 0.0121276
Year 10 Pred =  0.123202 0.212847 0.281569 0.119066 0.0901369 0.0761837 0.068291 0.0197074 0.00899745
Year 11 Obs  =  0.0170716 0.219961 0.224557 0.319107 0.105056 0.0597505 0.0354563 0.0144452 0.00459618
Year 11 Pred =  0.0855346 0.300945 0.237227 0.215318 0.0675413 0.0464963 0.0228096 0.0167795 0.00734877
Year 12 Obs  =  0.0248007 0.143047 0.460585 0.213906 0.131975 0.0194862 0.00531445 0.000885742 0
Year 12 Pred =  0.0602206 0.220093 0.348629 0.185781 0.123751 0.0351275 0.0141538 0.00581812 0.00642533
Year 13 Obs  =  0.007362 0.21227 0.360327 0.332515 0.0752556 0.010634 0.000817962 0.000817962 0
Year 13 Pred =  0.128294 0.154161 0.254938 0.273411 0.106476 0.0640689 0.0104477 0.00352767 0.00467463
Year 14 Obs  =  0 0.463869 0.168609 0.246309 0.100233 0.017871 0.00233102 0.000776952 0
Year 14 Pred =  0.0529238 0.319702 0.177592 0.20378 0.162717 0.0577305 0.0197349 0.00260468 0.00321524
Year 15 Obs  =  0.00444443 0.147556 0.647556 0.109778 0.0773333 0.0106666 0.00177775 0.000888928 0
Year 15 Pred =  0.0558446 0.142243 0.395398 0.152371 0.131013 0.0955613 0.0196991 0.0054372 0.00243249
Year 16 Obs  =  0 0.2375 0.236184 0.403289 0.101316 0.0184211 0.00263156 0 0.000657919
Year 16 Pred =  0.0700053 0.164571 0.188981 0.355688 0.100714 0.0784055 0.0334493 0.0057648 0.00242146
Year 17 Obs  =  0.0373743 0.281744 0.22185 0.163872 0.152851 0.0886441 0.0354577 0.0110205 0.00718732
Year 17 Pred =  0.0635443 0.208211 0.221047 0.171605 0.23599 0.0603542 0.0270946 0.00970296 0.00245144
Year 18 Obs  =  0.0500569 0.253697 0.308305 0.167994 0.10201 0.0652256 0.027683 0.0166857 0.00834285
Year 18 Pred =  0.0599968 0.186392 0.274111 0.196362 0.111944 0.139338 0.0210174 0.00792101 0.00291784
Year 19 Obs  =  0.168217 0.105226 0.236936 0.209019 0.137437 0.079456 0.0429492 0.0157481 0.00501085
Year 19 Pred =  0.194871 0.157399 0.21789 0.213479 0.110591 0.0566773 0.0410664 0.00530765 0.00271813
Year 20 Obs  =  0.0459588 0.62916 0.153724 0.0618066 0.0681458 0.0237718 0.0110936 0.00475437 0.00158485
Year 20 Pred =  0.105107 0.423888 0.153535 0.142823 0.102033 0.0476944 0.0142544 0.00873529 0.00193072
Year 21 Obs  =  0.00763357 0.296619 0.490185 0.123773 0.0414394 0.0267176 0.0109052 0.00163574 0.00109049
Year 21 Pred =  0.0364655 0.256957 0.457007 0.109578 0.0738503 0.0474591 0.0132388 0.00341236 0.00203191
Year 22 Obs  =  0.000981302 0.146222 0.378803 0.380766 0.0706575 0.0117763 0.00883216 0.000981302 0.000981302
Year 22 Pred =  0.0360821 0.108537 0.336065 0.391438 0.0668937 0.0402609 0.0151043 0.00370242 0.00191678
Year 23 Obs  =  0.0285714 0.110989 0.19011 0.327473 0.313187 0.0186814 0.00659342 0.00219771 0.00219771
Year 23 Pred =  0.0473546 0.120755 0.160607 0.329364 0.27721 0.0425667 0.0151349 0.00489899 0.00210768
Year 24 Obs  =  0.0277779 0.0176766 0.108586 0.108586 0.474747 0.25505 0.00505068 0.00252507 0
Year 24 Pred =  0.165195 0.142617 0.161313 0.142126 0.209738 0.158336 0.0141613 0.00435078 0.00216163
Year 25 Obs  =  0.614865 0.114865 0.0743242 0.0765767 0.0315314 0.0450448 0.0427928 0 0
Year 25 Pred =  0.363689 0.278141 0.109853 0.0849917 0.0549826 0.0734611 0.0313854 0.00232153 0.00117478
Year 26 Obs  =  0.0110974 0.764488 0.162762 0.0345253 0.0197287 0 0.00493225 0.00246605 0
Year 26 Pred =  0.0781364 0.59143 0.20427 0.0550414 0.0316917 0.0186662 0.0148841 0.00524611 0.000634005
Year 27 Obs  =  0.219298 0.249123 0.352632 0.150877 0.0157895 0.00175435 0.00350883 0.00175435 0.00526318
Year 27 Pred =  0.140386 0.161464 0.534543 0.120628 0.0232093 0.0119431 0.00415991 0.00292019 0.000746456
Year 28 Obs  =  0.00395652 0.51731 0.212661 0.18002 0.083086 0.00296739 0 0 0
Year 28 Pred =  0.0548108 0.34729 0.16949 0.356973 0.0568782 0.00972831 0.00308377 0.000979606 0.000767143
Year 29 Obs  =  0.0311493 0.123523 0.469388 0.16971 0.13319 0.0472609 0.0204082 0.00537054 0
Year 29 Pred =  0.0751391 0.160732 0.424078 0.127561 0.182896 0.0254821 0.00261971 0.000796867 0.000695175
Year 30 Obs  =  0.363234 0.084164 0.145072 0.233666 0.0996677 0.0454042 0.0287929 0 0
Year 30 Pred =  0.203188 0.183674 0.171752 0.293383 0.0619126 0.0787182 0.00629175 0.000579705 0.000500249
Year 31 Obs  =  0.0265252 0.736074 0.122016 0.0570292 0.0384615 0.0159151 0.00397886 0 0
Year 31 Pred =  0.109102 0.430195 0.172506 0.107591 0.134064 0.0255278 0.0193757 0.00132074 0.000318465
Year 32 Obs  =  0.0327868 0.256148 0.342213 0.204918 0.102459 0.034836 0.0266393 0 0
Year 32 Pred =  0.136798 0.238552 0.408739 0.106313 0.0470917 0.0523123 0.00591269 0.00399228 0.000288296
Year 33 Obs  =  0.099526 0.388626 0.2109 0.199052 0.078199 0.0165877 0.00710899 0 0
Year 33 Pred =  0.1241 0.309742 0.231839 0.254853 0.0468536 0.0184604 0.0123742 0.00126238 0.000516226
Year 34 Obs  =  0.0132497 0.417966 0.225209 0.187863 0.12687 0.0254956 0.00334697 0 0
Year 34 Pred =  0.0427988 0.311952 0.334566 0.159884 0.122859 0.0199926 0.00465224 0.00284283 0.000452208
Year 35 Obs  =  0.00592527 0.142545 0.383941 0.215353 0.184199 0.0591923 0.00884417 0 0
Year 35 Pred =  0.0391637 0.125739 0.396047 0.274275 0.0929693 0.0636488 0.00620356 0.00129149 0.00066197
```

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Year 36 Obs  =  0.0337332 0.187382 0.158354 0.233831 0.266371 0.102963 0.0173653 0 0
Year 36 Pred =  0.0491163 0.13789 0.186441 0.369372 0.178455 0.0534815 0.0224279 0.00202923 0.000787628
Year 37 Obs  =  0.401408 0.0388331 0.0235413 0.0522133 0.169618 0.266398 0.047988 0 0
Year 37 Pred =  0.13748 0.16884 0.19581 0.162227 0.218633 0.0923252 0.016869 0.00683703 0.000978155
Year 38 Obs  =  0.194677 0.427054 0.0769113 0.0616409 0.0523264 0.118213 0.0643685 0.00480818 0
Year 38 Pred =  0.0830409 0.379983 0.195077 0.140024 0.0792079 0.09347 0.0236608 0.00412345 0.00141333
Year 39 Obs  =  0.657835 0.145684 0.0128271 0.0917297 0.0331728 0.0237318 0.0278497 0.00660377 0.000566287
Year 39 Pred =  0.191107 0.182957 0.374194 0.127072 0.0647068 0.0326295 0.0214915 0.00473991 0.00110055
Year 40 Obs  =  0.840647 0.0566066 0.0250615 0.0400243 0.0101157 0.00970434 0.00771655 0.00588063 0.00424303
Year 40 Pred =  0.30691 0.288981 0.130777 0.190527 0.0491876 0.023035 0.00654294 0.00336038 0.000679142
Year 41 Obs  =  0.0137492 0.69875 0.179811 0.0656796 0.0209859 0.0182135 0.00281098 0 0
Year 41 Pred =  0.100998 0.495997 0.223122 0.0727456 0.0811705 0.0193379 0.00505471 0.00110254 0.000472179
Year 42 Obs  =  0.318667 0.681333 0 0 0 0 0 0 0
Year 42 Pred =  0.279183 0.535358 0.152773 0.0207564 0.00319376 0.00658595 0.00188521 7.65984e-05 0.00018752
Year 43 Obs  =  0 0.918346 0.0721092 0.00318711 0.00381488 0.00254325 0 0 0
Year 43 Pred =  0.0752309 0.743233 0.0920483 0.067562 0.0105437 0.0049304 0.00611677 0.000124611 0.000210686
Year 44 Obs  =  0.615382 0.0919161 0.136717 0.148312 0.00432343 0.00334868 0 0 0
Year 44 Pred =  0.44307 0.262596 0.167679 0.0533954 0.0450155 0.0213481 0.00600598 0.000530377 0.000358975
Year 45 Obs  =  0.050081 0.546991 0.153253 0.0329207 0.0749215 0.0883818 0.049331 0.00206004 0.00206004
Year 45 Pred =  0.164863 0.695985 0.0265252 0.0435437 0.015923 0.0408228 0.011651 0.000232955 0.000452674
Year 46 Obs  =  0.669105 0.23874 0.0758828 0.0122035 0.00406887 0 0 0 0
Year 46 Pred =  0.688077 0.20862 0.0570363 0.00555849 0.0104724 0.0116389 0.0179702 0.000364864 0.000262337
Year 47 Obs  =  0.0195705 0.955894 0.0135269 0.00990975 0.000285205 0.000541739 0.000271624 0 0
Year 47 Pred =  0.0748977 0.880615 0.0172685 0.0120986 0.00135361 0.00775097 0.00518598 0.000569657 0.000259612
Year 48 Obs  =  0.875994 0.010291 0.11054 4.70167e-05 0.00144059 0 0.00168696 0 0
Year 48 Pred =  0.88207 0.0626573 0.0476883 0.00239883 0.00192981 0.000656088 0.00226115 0.000107683 0.000231118
Year 49 Obs  =  0.229832 0.762596 0.00161824 0.00595355 0 0 0 0 0
Year 49 Pred =  0.172734 0.814403 0.00373799 0.00731206 0.000422441 0.00103281 0.000211273 5.18197e-05 9.44242e-05
Year 50 Obs  =  0.596692 0.152357 0.231306 0.00942713 0.00813682 0.00208085 0 0 0
Year 50 Pred =  0.62521 0.166492 0.18406 0.00428109 0.0162653 0.00147011 0.00132853 0.000192192 0.000701547
Year 51 Obs  =  0.000203985 0.767831 0.111662 0.113603 0.0016599 0.00504044 0 0 0
Year 51 Pred =  0.0729913 0.687785 0.0886097 0.134904 0.00306872 0.0107166 0.000695152 0.000730366 0.00049975
Year 52 Obs  =  0.397376 0.0209664 0.481455 0.0510616 0.0458306 0.00252993 0.000779936 0 0
Year 52 Pred =  0.353186 0.0843165 0.384429 0.0681795 0.10146 0.00212063 0.00531864 0.000401266 0.000588594
Year 53 Obs  =  0.12455 0.29922 0.0716614 0.451951 0.0312945 0.0200249 0.000493155 0.000804903 0
Year 53 Pred =  0.345226 0.304842 0.0351718 0.220789 0.0382451 0.0522566 0.000784458 0.00229068 0.000394272
Year 54 Obs  =  0.124414 0.279434 0.25634 0.0765293 0.239475 0.0178835 0.00592472 0 0
Year 54 Pred =  0.113403 0.43367 0.184879 0.0293886 0.180227 0.0286641 0.0281024 0.000491266 0.00117599
Year 55 Obs  =  0.0248154 0.0245617 0.387195 0.350854 0.0551877 0.155191 0.00219528 0 0
Year 55 Pred =  0.0789352 0.17405 0.32199 0.188892 0.0293247 0.165136 0.0188774 0.0215418 0.00125311
Year 56 Obs  =  0.0282877 0.00524412 0.0943585 0.481844 0.248019 0.0617107 0.0785911 0.0019442 0
Year 56 Pred =  0.165181 0.109094 0.116166 0.295659 0.169058 0.024061 0.0974815 0.012999 0.0102997
Year 57 Obs  =  0.0308318 0.165781 0.0492178 0.154192 0.475344 0.101534 0.0131711 0.00992887 0
Year 57 Pred =  0.228093 0.195013 0.0620421 0.0909187 0.225167 0.11785 0.0120689 0.057166 0.011681
Year 58 Obs  =  0.138839 0.327844 0.169457 0.0388448 0.0662747 0.188477 0.0547372 0.00753582 0.0079909
Year 58 Pred =  0.250392 0.269633 0.11102 0.0485437 0.0690438 0.156234 0.0589939 0.0070783 0.0290612
Year 59 Obs  =  0.127165 0.506432 0.230247 0.0375036 0.0201527 0.0247659 0.0332249 0.0145325 0.00597554
Year 59 Pred =  0.158839 0.330538 0.170538 0.0966008 0.0408746 0.0529674 0.0864449 0.0384045 0.0247921
Year 60 Obs  =  0.570154 0.0823816 0.196302 0.0713299 0.0154715 0.0105521 0.0139787 0.0225674 0.0172625
Year 60 Pred =  0.469972 0.13914 0.138519 0.098299 0.0537895 0.0207068 0.0193697 0.0372648 0.0229387
Year 61 Obs  =  0.10365 0.76615 0.0397887 0.0318993 0.0214395 0.0129103 0.0120773 0.00411792 0.00796741
Year 61 Pred =  0.163142 0.515182 0.0728391 0.0996988 0.0681905 0.0338849 0.00942832 0.0104223 0.0272124
Year 62 Obs  =  0.180593 0.118733 0.264447 0.0731527 0.103116 0.119672 0.0502753 0.0399953 0.0500162
Year 62 Pred =  0.30197 0.191221 0.288453 0.0558311 0.0731231 0.0451933 0.0163635 0.00541125 0.0224337
Year 63 Obs  =  0.138341 0.467133 0.111522 0.110364 0.0529952 0.0474732 0.0341453 0.0153868 0.0226398
Year 63 Pred =  0.251516 0.326119 0.0970396 0.201108 0.036922 0.043321 0.0194738 0.00848951 0.0160106
Year 64 Obs  =  0.121609 0.329654 0.134973 0.107747 0.116311 0.0885753 0.0611695 0.0287533 0.0112088
Year 64 Pred =  0.229798 0.2991 0.180514 0.074317 0.146623 0.0241396 0.0203854 0.0110389 0.0140841
Year 65 Obs  =  0.568585 0.102906 0.117101 0.0377232 0.0369103 0.0553067 0.0316353 0.0317291 0.0181029
Year 65 Pred =  0.435952 0.199289 0.122633 0.1022 0.0404891 0.0723481 0.00856464 0.008589 0.00993472
Year 66 Obs  =  0.281886 0.418543 0.109505 0.0498703 0.0633214 0.0332717 0.020579 0.016348 0.006675
Year 66 Pred =  0.305996 0.407281 0.0890681 0.0753307 0.0605698 0.0218123 0.0281735 0.00393562 0.00783323
Year 67 Obs  =  0.597211 0.275366 0.0682615 0.0127006 0.00713895 0.0183222 0.00981228 0.00684189 0.00434565
Year 67 Pred =  0.37183 0.287363 0.181413 0.054881 0.0449376 0.0328781 0.00847617 0.0129233 0.00529692
Year 68 Obs  =  0.286794 0.435129 0.124389 0.0595121 0.0370643 0.0254399 0.0135528 0.0106332 0.00748687
Year 68 Pred =  0.231455 0.398044 0.148585 0.128737 0.0378067 0.0283016 0.0149658 0.00451493 0.00759012
Year 69 Obs  =  0.160104 0.328173 0.216088 0.0853181 0.0553272 0.0501796 0.0322665 0.0274253 0.0451183
Year 69 Pred =  0.135703 0.308681 0.255476 0.130102 0.10794 0.0286917 0.0157178 0.00984609 0.00784235
Year 70 Obs  =  0.0907195 0.132568 0.258606 0.158071 0.103525 0.0889858 0.0711439 0.0431607 0.0532205
Year 70 Pred =  0.125739 0.1955 0.20993 0.235833 0.112032 0.0823767 0.016267 0.0108576 0.0114651
Year 71 Obs  =  0.313482 0.077059 0.0700383 0.159918 0.15245 0.116195 0.0508593 0.0347571 0.0252423
Year 71 Pred =  0.263959 0.158443 0.109136 0.164582 0.172659 0.0720026 0.0375944 0.00925011 0.0123728
Year 72 Obs  =  0.366854 0.191166 0.0644712 0.109169 0.128236 0.0826361 0.0354184 0.0142007 0.00784852
Year 72 Pred =  0.357997 0.25442 0.0731106 0.0684691 0.09783 0.0921431 0.0283427 0.0177145 0.00997333
Year 73 Obs  =  0.305678 0.439405 0.0756729 0.0419842 0.0518005 0.0459145 0.0211745 0.0119458 0.00642483
Year 73 Pred =  0.41718 0.310299 0.100568 0.0401636 0.0354203 0.0448957 0.0303637 0.0114355 0.00967429
Year 74 Obs  =  0.110228 0.780057 0.0787162 0.0181348 0.0034718 0.00554983 0.00384275 0 0
Year 74 Pred =  0.210708 0.460218 0.161746 0.0719437 0.0273407 0.0216673 0.0199822 0.0161969 0.0101978
Year 75 Obs  =  0.527677 0.296787 0.102162 0.0375274 0.0131551 0.0129358 0.00656773 0.00189719 0.00129092
Year 75 Pred =  0.388054 0.208582 0.212671 0.103275 0.0437437 0.0149173 0.00852312 0.00945646 0.0107779
Year 76 Obs  =  0.79319 0.120929 0.039149 0.0283708 0.0120824 0.00242117 0.00161412 0.000629423 0.00161412
Year 76 Pred =  0.521106 0.253221 0.0642355 0.0904554 0.0422152 0.0161755 0.00396712 0.00269619 0.00592815
Year 77 Obs  =  0.815607 0.112104 0.0574635 0.00831505 0.00325068 0.00198288 0.00102078 0.000256591 0
Year 77 Pred =  0.549042 0.301727 0.069955 0.0244427 0.0332519 0.0141132 0.00389627 0.0011275 0.00244397
Year 78 Obs  =  0.696374 0.230338 0.0457493 0.018179 0.00532952 0.00194578 0.00161627 0.000468371 0
Year 78 Pred =  0.516518 0.338745 0.0888929 0.0284166 0.00961635 0.0119197 0.00363706 0.001182 0.00107223
Year 79 Obs  =  0 0 0 0 0 0 0 0 0
Year 79 Pred =  0.127849 0.58549 0.184142 0.066599 0.020685 0.00639619 0.00569674 0.00203792 0.00110491

Proportions of Discards at age by fleet
 fleet 1
Year 1 Obs  =  0 0 0 0 0 0 0 0 0
Year 1 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 2 Obs  =  0 0 0 0 0 0 0 0 0
Year 2 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
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Year 3 Obs  =  0 0 0 0 0 0 0 0 0
Year 3 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 4 Obs  =  0 0 0 0 0 0 0 0 0
Year 4 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 5 Obs  =  0 0 0 0 0 0 0 0 0
Year 5 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 6 Obs  =  0 0 0 0 0 0 0 0 0
Year 6 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 7 Obs  =  0 0 0 0 0 0 0 0 0
Year 7 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 8 Obs  =  0 0 0 0 0 0 0 0 0
Year 8 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 9 Obs  =  0 0 0 0 0 0 0 0 0
Year 9 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 10 Obs  =  0 0 0 0 0 0 0 0 0
Year 10 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 11 Obs  =  0 0 0 0 0 0 0 0 0
Year 11 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 12 Obs  =  0 0 0 0 0 0 0 0 0
Year 12 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 13 Obs  =  0 0 0 0 0 0 0 0 0
Year 13 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 14 Obs  =  0 0 0 0 0 0 0 0 0
Year 14 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 15 Obs  =  0 0 0 0 0 0 0 0 0
Year 15 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 16 Obs  =  0 0 0 0 0 0 0 0 0
Year 16 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 17 Obs  =  0 0 0 0 0 0 0 0 0
Year 17 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 18 Obs  =  0 0 0 0 0 0 0 0 0
Year 18 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 19 Obs  =  0 0 0 0 0 0 0 0 0
Year 19 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 20 Obs  =  0 0 0 0 0 0 0 0 0
Year 20 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 21 Obs  =  0 0 0 0 0 0 0 0 0
Year 21 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 22 Obs  =  0 0 0 0 0 0 0 0 0
Year 22 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 23 Obs  =  0 0 0 0 0 0 0 0 0
Year 23 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 24 Obs  =  0 0 0 0 0 0 0 0 0
Year 24 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 25 Obs  =  0 0 0 0 0 0 0 0 0
Year 25 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 26 Obs  =  0 0 0 0 0 0 0 0 0
Year 26 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 27 Obs  =  0 0 0 0 0 0 0 0 0
Year 27 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 28 Obs  =  0 0 0 0 0 0 0 0 0
Year 28 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 29 Obs  =  0 0 0 0 0 0 0 0 0
Year 29 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 30 Obs  =  0 0 0 0 0 0 0 0 0
Year 30 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 31 Obs  =  0 0 0 0 0 0 0 0 0
Year 31 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 32 Obs  =  0 0 0 0 0 0 0 0 0
Year 32 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 33 Obs  =  0 0 0 0 0 0 0 0 0
Year 33 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 34 Obs  =  0 0 0 0 0 0 0 0 0
Year 34 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 35 Obs  =  0 0 0 0 0 0 0 0 0
Year 35 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 36 Obs  =  0 0 0 0 0 0 0 0 0
Year 36 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 37 Obs  =  0 0 0 0 0 0 0 0 0
Year 37 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 38 Obs  =  0 0 0 0 0 0 0 0 0
Year 38 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 39 Obs  =  0 0 0 0 0 0 0 0 0
Year 39 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 40 Obs  =  0 0 0 0 0 0 0 0 0
Year 40 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 41 Obs  =  0 0 0 0 0 0 0 0 0
Year 41 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 42 Obs  =  0 0 0 0 0 0 0 0 0
Year 42 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 43 Obs  =  0 0 0 0 0 0 0 0 0
Year 43 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 44 Obs  =  0 0 0 0 0 0 0 0 0
Year 44 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 45 Obs  =  0 0 0 0 0 0 0 0 0
Year 45 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 46 Obs  =  0 0 0 0 0 0 0 0 0
Year 46 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 47 Obs  =  0 0 0 0 0 0 0 0 0
Year 47 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 48 Obs  =  0 0 0 0 0 0 0 0 0
Year 48 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 49 Obs  =  0 0 0 0 0 0 0 0 0
Year 49 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 50 Obs  =  0 0 0 0 0 0 0 0 0
```

```
Year 50 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 51 Obs  =  0 0 0 0 0 0 0 0 0
Year 51 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 52 Obs  =  0 0 0 0 0 0 0 0 0
Year 52 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 53 Obs  =  0 0 0 0 0 0 0 0 0
Year 53 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 54 Obs  =  0 0 0 0 0 0 0 0 0
Year 54 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 55 Obs  =  0 0 0 0 0 0 0 0 0
Year 55 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 56 Obs  =  0 0 0 0 0 0 0 0 0
Year 56 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 57 Obs  =  0 0 0 0 0 0 0 0 0
Year 57 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 58 Obs  =  0 0 0 0 0 0 0 0 0
Year 58 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 59 Obs  =  0 0 0 0 0 0 0 0 0
Year 59 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 60 Obs  =  0 0 0 0 0 0 0 0 0
Year 60 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 61 Obs  =  0 0 0 0 0 0 0 0 0
Year 61 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 62 Obs  =  0 0 0 0 0 0 0 0 0
Year 62 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 63 Obs  =  0 0 0 0 0 0 0 0 0
Year 63 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 64 Obs  =  0 0 0 0 0 0 0 0 0
Year 64 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 65 Obs  =  0 0 0 0 0 0 0 0 0
Year 65 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 66 Obs  =  0 0 0 0 0 0 0 0 0
Year 66 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 67 Obs  =  0 0 0 0 0 0 0 0 0
Year 67 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 68 Obs  =  0 0 0 0 0 0 0 0 0
Year 68 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 69 Obs  =  0 0 0 0 0 0 0 0 0
Year 69 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 70 Obs  =  0 0 0 0 0 0 0 0 0
Year 70 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 71 Obs  =  0 0 0 0 0 0 0 0 0
Year 71 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 72 Obs  =  0 0 0 0 0 0 0 0 0
Year 72 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 73 Obs  =  0 0 0 0 0 0 0 0 0
Year 73 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 74 Obs  =  0 0 0 0 0 0 0 0 0
Year 74 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 75 Obs  =  0 0 0 0 0 0 0 0 0
Year 75 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 76 Obs  =  0 0 0 0 0 0 0 0 0
Year 76 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 77 Obs  =  0 0 0 0 0 0 0 0 0
Year 77 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 78 Obs  =  0 0 0 0 0 0 0 0 0
Year 78 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 79 Obs  =  0 0 0 0 0 0 0 0 0
Year 79 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15 1e-15

F Reference Points Using Final Year Selectivity Scaled Max=1.0
 refpt           F       slope to plot on SRR
  F0.1     0.561938     13.1564
  Fmax     9.99999     6440.53
  F30%SPR  0.424104     9.64335
  F40%SPR  0.308242     7.2325
  Fmsy     0.123101     4.29711    SSmsy    118603     MSY   20661.9
  Foy      0.0923259     xxxxxx    SSoy    153905     OY   19513.3
  Fcurrent 0.0783117     3.73962

Stock-Recruitment Relationship Parameters
 alpha     = 1.52404e+06
 beta      = 236062
 virgin    = 185424
 steepness = 0.308615
Spawning Stock, Obs Recruits(year+1), Pred Recruits(year+1)
1929  1.16277e+06  2.94343e+06  1.26685e+06
1930  1.06053e+06  2.55425e+06  1.24656e+06
1931  1.02042e+06  2.43421e+06  1.23771e+06
1932  978710  894967  1.22788e+06
1933  883367  583607  1.20265e+06
1934  747106  455935  1.15811e+06
1935  592114  844859  1.08963e+06
1936  451514  716790  1.0008e+06
1937  344994  1.00357e+06  904874
1938  267252  683986  809239
1939  237022  444659  763565
1940  188787  883869  677224
1941  162671  354547  621760
1942  145339  335498  580759
1943  145301  339405  580664
1944  126880  247012  532783
1945  104667  188381  468160
1946  87674.6  550999  412740
1947  68557.4  323971  342998
```

```
1948  59430.2  107598  306518
1949  56177.7  83756.1  292967
1950  49532.7  77089.8  264324
1951  43205.7  210352  235785
1952  35014.5  662508  196857
1953  29896.2  207874  171316
1954  32920  421322  186523
1955  40177.4  151306  221662
1956  46514.6  159643  250870
1957  41765.9  413086  229108
1958  34537.8  246057  194519
1959  35839.6  327459  200884
1960  37545.9  301526  209136
1961  37780.9  95408.9  210264
1962  40440  68648.9  222899
1963  40078.7  55426.6  221197
1964  30919  101160  176498
1965  19681.3  50033.9  117285
1966  14235.1  124302  86675.9
1967  11612.3  324593  71454.9
1968  13447.4  163732  82138.6
1969  20533.4  188980  121957
1970  31397.3  42171.5  178908
1971  41783.9  156853  229192
1972  46056.1  82248.7  248800
1973  49676.8  601704  264959
1974  55446  113283  289878
1975  70293.5  3.52284e+06  349691
1976  95840  1.64842e+06  440080
1977  148673  6.64599e+06  588932
1978  263041  749739  803209
1979  397917  3.33316e+06  956561
1980  472604  3.99148e+06  1.01637e+06
1981  590565  1.10321e+06  1.08881e+06
1982  662372  529493  1.1236e+06
1983  641691  841667  1.11416e+06
1984  623557  1.02532e+06  1.10552e+06
1985  539151  983582  1.05995e+06
1986  459036  481162  1.00646e+06
1987  378397  1.64298e+06  938534
1988  324384  521270  882106
1989  258032  806597  795901
1990  231281  583382  754222
1991  190701  421100  681021
1992  145855  908875  582033
1993  127578  687579  534687
1994  105836  897366  471771
1995  117870  541059  507548
1996  128394  235404  536901
1997  137003  135354  559681
1998  113751  190579  495582
1999  81273.4  255315  390324
2000  64071.2  305743  325345
2001  40163.6  133326  221597
2002  33738.5  233929  190580
2003  39714.3  472241  219475
2004  41169.2  866391  226321
2005  39433  1.34358e+06  218143
2006  56496.3  302694  294308
2007  86777.2       xxxx   409651

average F (ages 4 to 8 unweighted) by year
Projection into Future
Projected NAA
 2 177720 447948 162367 48656.1 12730.1 3600.52 4149.56 3274.45
 2 1.15262 98360.1 250860 89487.8 26358.3 6826.88 1983.86 4200.26
Projected Directed FAA
 0.0511126 0.0915722 0.0797821 0.095757 0.112995 0.123101 0.0960335 0.0865784 0.0484304
 0.0511126 0.0915722 0.0797821 0.095757 0.112995 0.123101 0.0960335 0.0865784 0.0484304
Projected Discard FAA
 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0
Projected Nondirected FAA
 -0 -0 -0 -0 -0 -0 -0 -0 -0
 -0 -0 -0 -0 -0 -0 -0 -0 -0
Projected Catch at Age
 0.07859 12284.4 27120.7 11714 4110.21 1166.25 260.478 271.798 122.066
 0.07859 0.0796717 5955.14 18098.4 7559.47 2414.78 493.887 129.944 156.579
Projected Discards at Age (in numbers)
 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0
Projected Yield at Age
 0.00903785 2849.99 9790.57 5962.43 2938.8 926.004 220.624 249.511 114.132
 0.00903785 0.0184838 2149.8 9212.06 5405.02 1917.34 418.322 119.288 146.401
Year, Total Yield (in weight), Total Discards (in weight), SSB, proj_what, SS/SSmsy
2008  23052.1  0  127581  0  1.07569
2009  19368.3  0  148058  0  1.24834

M =  0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
mature =  0 0.07 0.25 0.47 0.73 1 1 1 1
 0 0.07 0.25 0.47 0.73 1 1 1 1
 0 0.07 0.25 0.47 0.73 1 1 1 1
 0 0.07 0.25 0.47 0.73 1 1 1 1
 0 0.07 0.25 0.47 0.73 1 1 1 1
 0 0.07 0.25 0.47 0.73 1 1 1 1
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 0 0.07 0.25 0.47 0.73 1 1 1 1
 0 0.07 0.25 0.47 0.73 1 1 1 1
Weight at age
 0.074 0.167 0.297 0.402 0.523 0.615 0.704 0.8 0.83
 0.06 0.139 0.301 0.422 0.511 0.603 0.698 0.8 0.83
 0.077 0.114 0.276 0.399 0.527 0.606 0.701 0.8 0.83
 0.058 0.081 0.277 0.379 0.508 0.604 0.711 0.8 0.83
 0.059 0.083 0.2 0.299 0.493 0.585 0.7 0.8 0.83
 0.065 0.142 0.198 0.233 0.431 0.538 0.683 0.8 0.83
 0.079 0.186 0.217 0.251 0.379 0.472 0.629 0.79 0.83
 0.086 0.193 0.284 0.338 0.393 0.453 0.574 0.75 0.82
 0.119 0.176 0.318 0.429 0.461 0.502 0.575 0.74 0.8
 0.124 0.174 0.31 0.448 0.532 0.582 0.633 0.726 0.79
 0.191 0.246 0.363 0.46 0.583 0.68 0.775 0.795 0.878
 0.18 0.26 0.339 0.442 0.527 0.64 0.729 0.834 0.82
 0.115 0.259 0.343 0.439 0.559 0.65 0.806 0.807 0.85
 0.18 0.236 0.373 0.471 0.546 0.626 0.684 0.909 0.83
 0.165 0.292 0.339 0.474 0.574 0.65 0.629 0.881 1
 0.144 0.271 0.379 0.472 0.587 0.66 0.754 0.735 0.948
 0.121 0.234 0.383 0.494 0.611 0.704 0.745 0.819 0.842
 0.125 0.261 0.384 0.487 0.617 0.679 0.736 0.778 0.812
 0.119 0.291 0.4 0.499 0.622 0.709 0.753 0.788 0.818
 0.107 0.227 0.354 0.506 0.616 0.706 0.764 0.895 0.871
 0.109 0.192 0.319 0.456 0.607 0.725 0.799 0.917 0.917
```

0.084 0.249 0.323 0.455 0.564 0.664 0.784 0.799 0.871
0.162 0.255 0.346 0.429 0.569 0.694 0.827 0.835 0.853
0.173 0.297 0.386 0.471 0.568 0.719 0.832 0.988 0.85
0.162 0.296 0.411 0.512 0.603 0.763 0.834 0.85 1.1
0.084 0.257 0.387 0.505 0.585 0.744 0.701 0.879 0.87
0.14 0.253 0.357 0.484 0.583 0.744 0.762 0.778 0.878
0.111 0.248 0.373 0.485 0.598 0.752 0.722 0.91 0.87
0.179 0.31 0.374 0.509 0.602 0.649 0.65 0.7 1
0.176 0.292 0.396 0.488 0.617 0.685 0.775 0.75 0.75
0.132 0.251 0.398 0.51 0.602 0.702 0.754 0.84 0.85
0.102 0.276 0.391 0.507 0.611 0.699 0.768 0.82 0.87
0.144 0.252 0.389 0.495 0.584 0.647 0.817 0.83 0.85
0.276 0.32 0.42 0.54 0.622 0.712 0.782 0.89 0.86
0.197 0.298 0.434 0.538 0.627 0.73 0.743 0.84 0.93
0.181 0.3 0.4 0.503 0.612 0.748 0.812 0.82 0.87
0.109 0.195 0.384 0.501 0.596 0.723 0.735 0.88 0.85
0.149 0.273 0.419 0.525 0.658 0.79 0.833 0.85 0.93
0.166 0.235 0.488 0.51 0.599 0.723 0.869 0.917 0.849
0.138 0.266 0.391 0.562 0.593 0.709 0.902 0.952 1.07
0.103 0.322 0.428 0.505 0.662 0.746 0.907 1 1.1
0.099 0.232 0.402 0.584 0.73 0.837 0.85 1 1.2
0.266 0.282 0.457 0.481 0.74 0.955 0.88 0.9 1.2
0.147 0.266 0.449 0.508 0.552 0.746 1 0.9 1.1
0.119 0.329 0.433 0.609 0.606 0.686 0.758 0.803 0.838
0.107 0.303 0.604 0.74 0.837 0.8 0.8 0.8 1
0.127 0.361 0.517 0.973 1.053 1.029 1.35 0.9 0.9
0.17 0.297 0.672 0.864 1.291 1.223 1.531 1.2 1
0.122 0.322 0.6 0.847 1.063 1.1 1.3 1.5 1.3
0.062 0.334 0.473 0.705 0.908 1.1 1.2 1.4 1.6
0.082 0.189 0.44 0.598 0.81 0.969 1.2 1.3 1.5
0.072 0.176 0.27 0.437 0.598 0.874 1.066 1.3 1.4
0.083 0.19 0.239 0.391 0.597 0.715 0.953 0.929 1.4
0.032 0.151 0.237 0.345 0.516 0.773 0.916 1 1.2
0.049 0.191 0.302 0.39 0.458 0.511 0.688 0.9 1.1
0.12 0.235 0.351 0.396 0.505 0.614 0.638 0.871 0.91
0.157 0.285 0.418 0.461 0.484 0.56 0.612 0.697 0.85
0.148 0.29 0.408 0.508 0.561 0.595 0.63 0.719 0.784
0.133 0.272 0.414 0.523 0.6 0.691 0.717 0.766 0.826
0.101 0.301 0.415 0.576 0.666 0.734 0.806 0.815 0.899
0.104 0.193 0.381 0.542 0.647 0.749 0.757 0.739 0.827
0.094 0.267 0.377 0.554 0.649 0.68 0.749 0.775 0.803
0.071 0.217 0.397 0.514 0.591 0.664 0.724 0.766 0.799
0.087 0.175 0.33 0.459 0.544 0.661 0.691 0.725 0.805
0.073 0.228 0.294 0.408 0.583 0.607 0.72 0.756 0.832
0.1 0.156 0.248 0.361 0.493 0.597 0.644 0.733 0.785
0.081 0.179 0.275 0.431 0.586 0.689 0.74 0.758 0.92
0.105 0.182 0.318 0.471 0.589 0.649 0.674 0.705 0.751
0.149 0.239 0.333 0.446 0.572 0.637 0.719 0.718 0.749
0.139 0.267 0.325 0.419 0.53 0.615 0.631 0.667 0.689
0.148 0.228 0.399 0.509 0.575 0.633 0.688 0.754 0.768
0.114 0.266 0.37 0.55 0.59 0.608 0.646 0.712 0.731
0.103 0.253 0.347 0.534 0.567 0.619 0.617 0.635 0.627
0.133 0.218 0.303 0.412 0.552 0.687 0.656 0.728 0.65
0.125 0.284 0.414 0.603 0.679 0.745 0.809 0.794 0.838
0.159 0.28 0.407 0.596 0.685 0.821 0.926 0.82 0.902
0.106 0.267 0.38 0.463 0.556 0.665 0.737 0.797 0.84
0.115 0.232 0.361 0.509 0.715 0.794 0.847 0.918 0.935
0.115 0.232 0.361 0.509 0.715 0.794 0.847 0.918 0.935

Fecundity

0 0.01169 0.07425 0.18894 0.38179 0.615 0.704 0.8 0.83
0 0.00973 0.07525 0.19834 0.37303 0.603 0.698 0.8 0.83
0 0.00798 0.069 0.18753 0.38471 0.606 0.701 0.8 0.83
0 0.00567 0.06925 0.17813 0.37084 0.604 0.711 0.8 0.83
0 0.00581 0.05 0.14053 0.35989 0.585 0.7 0.8 0.83
0 0.00994 0.0495 0.10951 0.31463 0.538 0.683 0.8 0.83
0 0.01302 0.05425 0.11797 0.27667 0.472 0.629 0.79 0.83
0 0.01351 0.071 0.15886 0.28689 0.453 0.574 0.75 0.82
0 0.01232 0.0795 0.20163 0.33653 0.502 0.575 0.74 0.8
0 0.01218 0.0775 0.21056 0.38836 0.582 0.633 0.726 0.79
0 0.01722 0.09075 0.2162 0.42559 0.68 0.775 0.795 0.878
0 0.0182 0.08475 0.20774 0.38471 0.64 0.729 0.834 0.82
0 0.01813 0.08575 0.20633 0.40807 0.65 0.806 0.807 0.85
0 0.01652 0.09325 0.22137 0.39858 0.626 0.684 0.909 0.83
0 0.02044 0.08475 0.22278 0.41902 0.65 0.629 0.881 1
0 0.01897 0.09475 0.22184 0.42851 0.66 0.754 0.735 0.948
0 0.01638 0.09575 0.23218 0.44603 0.704 0.745 0.819 0.842
0 0.01827 0.096 0.22889 0.45041 0.679 0.736 0.778 0.812
0 0.02037 0.1 0.23453 0.45406 0.709 0.753 0.788 0.818
0 0.01589 0.0885 0.23782 0.44968 0.706 0.764 0.895 0.871
0 0.01344 0.07975 0.21432 0.44311 0.725 0.799 0.917 0.917
0 0.01743 0.08075 0.21385 0.41172 0.664 0.784 0.799 0.871
0 0.01785 0.0865 0.20163 0.41537 0.694 0.827 0.835 0.853
0 0.02079 0.0965 0.22137 0.41464 0.719 0.832 0.988 0.85
0 0.02072 0.10275 0.24064 0.44019 0.763 0.834 0.85 1.1
0 0.01799 0.09675 0.23735 0.42705 0.744 0.701 0.879 0.87
0 0.01771 0.08925 0.22748 0.42559 0.744 0.762 0.778 0.878
0 0.01736 0.09325 0.22795 0.43654 0.752 0.722 0.91 0.87
0 0.0217 0.0935 0.23923 0.43946 0.649 0.65 0.7 1
0 0.02044 0.099 0.22936 0.45041 0.685 0.775 0.75 0.75
0 0.01757 0.0995 0.2397 0.43946 0.702 0.754 0.84 0.85
0 0.01932 0.09775 0.23829 0.44603 0.699 0.768 0.82 0.87
0 0.01764 0.09725 0.23265 0.42632 0.647 0.817 0.83 0.85
0 0.0224 0.105 0.2538 0.45406 0.712 0.782 0.89 0.86
0 0.02086 0.1085 0.25286 0.45771 0.73 0.743 0.84 0.93
0 0.021 0.1 0.23641 0.44676 0.748 0.812 0.82 0.87

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 0 0.01365 0.096 0.23547 0.43508 0.723 0.735 0.88 0.85
 0 0.01911 0.10475 0.24675 0.48034 0.79 0.833 0.85 0.93
 0 0.01645 0.122 0.2397 0.43727 0.723 0.869 0.917 0.849
 0 0.01862 0.09775 0.26414 0.43289 0.709 0.902 0.952 1.07
 0 0.02254 0.107 0.23735 0.48326 0.746 0.907 1 1.1
 0 0.01624 0.1005 0.27448 0.5329 0.837 0.85 1 1.2
 0 0.01974 0.11425 0.22607 0.5402 0.955 0.88 0.9 1.2
 0 0.01862 0.11225 0.23876 0.40296 0.746 1 0.9 1.1
 0 0.02303 0.10825 0.28623 0.44238 0.686 0.758 0.803 0.838
 0 0.02121 0.151 0.3478 0.61101 0.8 0.8 0.8 1
 0 0.02527 0.12925 0.45731 0.76869 1.029 1.35 0.9 0.9
 0 0.02079 0.168 0.40608 0.94243 1.223 1.531 1.2 1
 0 0.02254 0.15 0.39809 0.77599 1.1 1.3 1.5 1.3
 0 0.02338 0.11825 0.33135 0.66284 1.1 1.2 1.4 1.6
 0 0.01323 0.11 0.28106 0.5913 0.969 1.2 1.3 1.5
 0 0.01232 0.0675 0.20539 0.43654 0.874 1.066 1.3 1.4
 0 0.0133 0.05975 0.18377 0.43581 0.715 0.953 0.929 1.4
 0 0.01057 0.05925 0.16215 0.37668 0.773 0.916 1 1.2
 0 0.01337 0.0755 0.1833 0.33434 0.511 0.688 0.9 1.1
 0 0.01645 0.08775 0.18612 0.36865 0.614 0.638 0.871 0.91
 0 0.01995 0.1045 0.21667 0.35332 0.56 0.612 0.697 0.85
 0 0.0203 0.102 0.23876 0.40953 0.595 0.63 0.719 0.784
 0 0.01904 0.1035 0.24581 0.438 0.691 0.717 0.766 0.826
 0 0.02107 0.10375 0.27072 0.48618 0.734 0.806 0.815 0.899
 0 0.01351 0.09525 0.25474 0.47231 0.749 0.757 0.739 0.827
 0 0.01869 0.09425 0.26038 0.47377 0.68 0.749 0.775 0.803
 0 0.01519 0.09925 0.24158 0.43143 0.664 0.724 0.766 0.799
 0 0.01225 0.0825 0.21573 0.39712 0.661 0.691 0.725 0.805
 0 0.01596 0.0735 0.19176 0.42559 0.607 0.72 0.756 0.832
 0 0.01092 0.062 0.16967 0.35989 0.597 0.644 0.733 0.785
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 0 0.01673 0.08325 0.20962 0.41756 0.637 0.719 0.718 0.749
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 0 0.01526 0.07575 0.19364 0.40296 0.687 0.656 0.728 0.65
 0 0.01988 0.1035 0.28341 0.49567 0.745 0.809 0.794 0.838
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 0 0.01869 0.095 0.21761 0.40588 0.665 0.737 0.797 0.84
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 0 0.01624 0.09025 0.23923 0.52195 0.794 0.847 0.918 0.935

SSmsy_ratio = 1.05289
Fmsy_ratio =  0.636157
that's all
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A FLEXIBLE FORWARD AGE-STRUCTURED ASSESSMENT PROGRAM

Christopher M. Legault[1], *Victor R. Restrepo*[2]

SUMMARY

This paper documents an age-structured assessment program (ASAP) which incorporates various modeling features that have been discussed by the SCRS in recent years, particularly during meetings of the bluefin tuna species group. The software was developed using the commercial package of AD Model Builder, an efficient too for optimization that uses an automatic differentiation algorithm in order to find a solution quickly using derivatives calculated to within machine precision, even when the number of parameters being estimated is rather large. The model is based on forward computations assuming separability of fishing mortality into year and age components. This assumption is relaxed by allowing for fleet-specific computations and by allowing the selectivity at age to change smoothly over time. The software can also allow the catchability associated with each abundance index to vary smoothly with time. The problem's dimensions (number of ages, years, fleets and abundance indices) are defined at input and limited by hardware only. We illustrate an application of ASAP using data for western Atlantic bluefin tuna.

RÉSUMÉ

Le présent travail documente un programme d'évaluation structuré par âge (ASAP) qui comprend plusieurs facettes de modélisation qui ont été abordées par le SCRS ces dernières années, notamment pendant les sessions du groupe d'espèce thon rouge. Le logiciel a été élaboré au moyen du programme commercial AD Model Builder, qui est un outil efficace d'optimisation utilisant un algorithme différentiel automatique pour arriver rapidement à une solution au moyen de dérivatifs calculés avec une précision quasi-mécanique, même lorsque le nombre de paramètres à estimer est assez important. Le modèle se base sur des calculs forward postulant que la mortalité par pêche peut être ventilée par année et par âge. Ce postulat est rendu plus flexible par le fait qu'il prévoit la réalisation de calculs en fonction de la flottille, ainsi que l'évolution progressive dans le temps de la sélectivité par âge. Le logiciel peut aussi tenir compte de la variation graduelle dans le temps de la capturabilité associée à chaque indice de l'abondance. Les dimensions du problème (nombre d'âges, d'années, de flottilles et d'indices d'abondance) sont définies en tant que données d'entrée et ne sont limitées que par le matériel. Une application de l'ASAP à des données sur le thon rouge de l'Atlantique ouest est présentée à titre d'illustration.

RESUMEN

Este papel documenta un programa de evaluación estructurado por edad (ASAP), que incorpora varias características de modelización discutidas por el SCRS en años recientes, particularmente durante las reuniones del Grupo de especies del atún rojo. Se desarrolló el programa utilizando el paquete comercial AD Model Builder, una eficaz herramienta para la optimización, que utiliza un algoritmo de diferenciación automática para hallar una rápida solución empleando derivados calculados con precisión, incluso cuando el número de parámetros que se estima es amplio. El modelo se basa en cálculos "forward" que asumen la capacidad de separación de la mortalidad por pesca en componentes anuales y por edad. Este supuesto se suaviza permitiendo a lo largo del tiempo el cambio progresivo de los cálculos específicos de la flota y la de la selectividad por clases de edad. El programa también permite que la capturabilidad asociada a cada índice de abundancia varíe gradualmente a lo largo del tiempo. Las dimensiones del problema (números de edades, años, flotas e índices de abundancia) se definen en los datos de entrada y sólo están limitados por el hardware. Se ilustra una aplicación de ASAP que utiliza datos para el atún rojo del Atlántico oeste.

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Introduction

Stock assessment algorithms explain observed data through a statistical estimation procedure based on a number of assumptions. The number and severity of these assumptions are determined by the algorithm and reflect not only the user's paradigms but also the amount and quality of the available data. We present an age-structured assessment program (ASAP) which allows easy comparison of results when certain assumptions are made or relaxed. Specifically, ASAP is a flexible forward program that allows the assumption of separability of gear specific fishing mortality into year and age components to be relaxed and change over time. The assumption of constant catchability coefficients for scaling observed indices of abundance can also be relaxed to change over time. The advantage of this flexibility is an increased ability to fit models and less reliance on assumptions that are thought to be too strict. The disadvantage of such an approach is exactly this ability to explain the data in more (and possibly contradictory) ways through different choices in the amount of variability in the changing parameters. Explicit choices for relative weightings amongst the different parts of the objective function must be made. Slight changes in these parameter weightings in a complex model can produce vastly different results, while a simpler model will be more consistent (not necessarily more accurate) relative to changes in the parameter weightings.

Allowing flexibility in selectivity and catchability greatly increases the number of parameters to be estimated. We use the commercial software package AD Model Builder to estimate the relatively large number of parameters. The software package is based on a C++ library of automatic differentiation code (see Greiwank and Corliss 1991) which allows relatively fast convergence by calculating derivatives to machine precision accuracy. These derivatives are used in a quasi-Newton search routine to minimize the objective function. The array sizes for parameters are defined on input and limited only by hardware. Currently, ASAP is compiled to estimate a maximum of 5,000 parameters, but this can be increased by changing one line of code.

The AD Model Builder software package allows many matrix operations to be programmed easily in its template language and allows for the estimation of parameters to occur in phases. The phases work by estimating only some parameters initially and adding more parameters in a stepwise fashion until all parameters are estimated. When new parameters are added by incrementing the phase, the previously estimated parameters are still estimated, not fixed at the previous values. These phases also allow easy switching between simple and complex models by simply turning on or off phases through the input file. For example, index specific catchability coefficients can be allowed to change or have a constant value over time. An additional feature of the AD Model Builder software is easy likelihood profiling of specified variables, although this can be time consuming for models with large numbers of parameters. We first describe ASAP with all the features and then compare two analyses for bluefin tuna using different levels of complexity in the program.

The Model

Population dynamics

The model's population dynamics follow a standard form common to forward-projection methods such as those of Fournier and Archibald (1982), Deriso et al. (1985), Methot (1998), Ianelli and Fornier (1998), and Porch and Turner (In Press). Catches and fishing mortalities can be modeled as being fleet-specific.

Let a = age, 1...A,
y = year, 1...Y
g = fleet 1....G
u = abundance index series, 1....U

Selectivity (S) at age within a year by a fleet can be limited to a range of ages and averages one, as opposed to having a maximum of one,

$$\frac{\sum_{a(g_{start})}^{a(g_{end})} S_{a,y,g}}{a(g_{end}) - a(g_{start}) + 1} = 1.0 \qquad (1)$$

where $a(g_{start})$ and $a(g_{end})$ denote the starting and ending ages for the gear's selectivity. The output of the program makes the simple conversion from averaging one to having a maximum of one in order to simplify comparisons with other models.

Fishing mortality is modeled as the product of the selectivity at age within a year by a fleet and a year and fleet specific fishing mortality multiplier ($Fmult_{y,g}$)

$$F_{a,y,g} = S_{a,y,g} Fmult_{y,g} . \qquad (2)$$

Total fishing mortality at age and year is the sum of the fleet specific fishing mortality rates

$$Ftot_{a,y} = \sum_{g} F_{a,y,g} \qquad (3)$$

and adding the natural mortality rate (M) produces the total mortality rate

$$Z_{a,y} = Ftot_{a,y} + M_{a,y} . \qquad (4)$$

The catch by age, year and fleet is

$$C_{a,y,g} = \frac{N_{a,y} F_{a,y,g} (1 - e^{-Z_{a,y}})}{Z_{a,y}} \qquad (5)$$

where N denotes population abundance at the start of the year.

The yield by age, year and fleet is

$$Y_{a,y,g} = C_{a,y,g} W_{a,y} \qquad (6)$$

where $W_{a,y}$ denotes weight of an individual fish of age a in year y.

The proportion of catch at age within a year for a fleet is

$$P_{a,y,g} = \frac{C_{a,y,g}}{\sum_a C_{a,y,g}}. \quad (7)$$

The forward projections begin by computing recruitment as deviations from an average value

$$N_{1,y} = \overline{N}_1 e^{\upsilon_y} \quad (8)$$

where υ_y~N(0,σ_{Ny}^2) and the other numbers at age in the first year as deviations from equilibrium

$$N_{a,1} = N_{1,1} e^{-\sum_{i=1}^{a-1} Z_{i,1}} e^{\psi_a} \quad for\ a < A$$
$$N_{a,1} = \frac{N_{1,1} e^{-\sum_{i=1}^{a-1} Z_{i,1}}}{1 - e^{-Z_{A,1}}} e^{\psi_a} \quad for\ a = A \quad (9)$$

where ψ_a~N(0,σ_{Na}^2). The remaining population abundance at age and year is then computed

$$N_{a,y} = N_{a-1,y-1} e^{-Z_{a-1,y-1}} \quad for\ a < A$$
$$N_{a,y} = N_{a-1,y-1} e^{-Z_{a-1,y-1}} + N_{a,y-1} e^{-Z_{a,y-1}} \quad for\ a = A. \quad (10)$$

Predicted indices of abundance ($\hat{I}$) are a measure of the population scaled by catchability coefficients (q) and selectivity at age (S)

$$\hat{I}_{u,y} = q_{u,y} \sum_{a(u_{start})}^{a(u_{end})} S_{u,a,y} N^*_{a,y} \quad (11)$$

where $a(u_{start})$ and $a(u_{end})$ are the index specific starting and ending ages, respectively, and N^* corresponds to the population abundance in either numbers or weight at a specific time during the year. The abundance index selectivity at age can either be input or linked to a specific fleet. If the latter is chosen, the age range can be smaller than that of the fleet and the annual selectivity patterns are rescaled to equal 1.0 for a specified age (a_{ref})such that the catchability coefficient is linked to this age

$$S_{u,a,y} = \frac{S_{a,y,g}}{S_{a_{ref},y,g}}. \quad (12)$$

Time-varying parameters

Fleet specific selectivity and catchability patterns are allowed to vary over time in the model. Changes in selectivity occur each τ_g years through a random walk for every age in a given fleet

$$S_{a,y+\tau,g} = S_{a,y,g} e^{\varepsilon_{a,y,g}} \quad (13)$$

where $\varepsilon_{a,y,g}$~N(0,σ_{Sg}^2) and are then rescaled to average one following equation (1). If τ_g is greater than one, then the selectivity at age for the fleet is the same as previous values until τ_g years elapse. The catchability coefficients also follow a random walk

$$q_{u,y+1} = q_{u,y} e^{\omega_{u,y}}, \quad (14)$$

as do the fleet specific fishing mortality rate multipliers

$$Fmult_{y+1,g} = Fmult_{y,g} e^{h_{y,g}} \quad (15)$$

where $\omega_{u,y}$~N(0,σ_{qu}^2) and $\eta_{y,g}$~N(0,σ_{Fg}^2).

Parameter estimation

The number of parameters estimated depends upon the values of τ_g and whether or not changes in selectivity or catchability are considered. When time varying selectivity and catchability are not considered the following parameters are estimated: Y recruits, A-1 population abundance in first year, YG fishing mortality rate multipliers, AG selectivities (if all ages selected by all gears), U catchabilities, and 2 stock recruitment parameters. Inclusion of time varying selectivity and catchability can increase the number of parameters to be estimated by a maximum of $(Y\text{-}1)AG$ + $(Y\text{-}1)U$. Sensitivity analyses can be conducted to determine the tradeoffs between number of parameters estimated and goodness of fit caused by changes in the τ_g values.

The likelihood function to be minimized includes the following components (ignoring constants): total catch in weight by fleet (lognormally distributed)

$$L_1 = \lambda_1[\ln(\sum_a Y_{a,y,g}) - \ln(\sum_a \hat{Y}_{a,y,g})]^2; \quad (16)$$

catch proportions in numbers of fish by fleet (multinomially distributed)

$$L_2 = -\sum_y \sum_g \lambda_{2,y,g} \sum_a P_{a,y,g} \ln(\hat{P}_{a,y,g}) - P_{a,y,g} \ln(P_{a,y,g}); \quad (17)$$

and indices of abundance (lognormally distributed)

$$L_3 = \sum_g \lambda_{3,g} \sum_y [\ln(I_{y,g}) - \ln(\hat{I}_{y,g})]^2 / 2\sigma^2_{y,g} + \ln(\sigma_{y,g}), \quad (18)$$

where variables with a hat are estimated by the model and variables without a hat are input as observations. The second term in the catch proportion summation causes the likelihood to equal zero for a perfect fit. The sigmas in equation 18 are input by the user and can optionally be set to all equal 1.0 for equal weighting of all index points. The weights (λ) assigned to each component of the likelihood function correspond to the inverse of the variance assumed to be associated with that component. Note that the year and fleet subscripts for the catch proportion lambdas allow zero weights to be assigned to specific year and fleet combinations such that only the total catch in weight by that fleet and year would be incorporated in the objective function. Priors for the variances of the time varying parameters are also included in the likelihood by setting λ equal to the inverse of the assumed variance for each component

$$L_4 = \sum_g \lambda_{4,g} \sum_a \sum_y \varepsilon^2_{a,y,g} \qquad (selectivity) \qquad (19)$$

$$L_5 = \sum_u \lambda_{5,u} \sum_y \omega^2_{u,y} \qquad (catchability) \qquad (20)$$

$$L_6 = \sum_g \lambda_{6,g} \sum_y \eta^2_{y,g} \qquad (F\ multipliers) \qquad (21)$$

$$L_7 = \lambda_7 \sum_y \upsilon^2_y \qquad (recruitment) \qquad (22)$$

$$L_8 = \lambda_8 \sum_y \psi^2_y \qquad (N\ year1). \qquad (23)$$

Additionally, there is a prior for fitting a Beverton and Holt type stock-recruitment relationship

$$L_9 = \lambda_9 \sum_y [\ln(N_{1,y}) - \ln\left(\frac{\alpha\, SSB_{y-1}}{\beta + SSB_{y-1}}\right)]^2 \qquad (24)$$

where SSB denotes the spawning stock biomass and α and β are parameters to be estimated. Penalties are used to determine the amount of curvature allowed in the fleet selectivity patterns, both at age

$$\rho_1 = \lambda_{p1} \sum_y \sum_g \sum_{a(g_{start})}^{a(g_{end})-2} (S_{a,y,g} - 2S_{a+1,y,g} + S_{a+2,y,g})^2 \qquad (25)$$

and over time

$$\rho_2 = \lambda_{p2} \sum_a \sum_g \sum_{y=1}^{Y-2} (S_{a,y,g} - 2S_{a,y+1,g} + S_{a,y+2,g})^2 . \qquad (26)$$

The function to be minimized is then the sum of the likelihoods and penalties

$$L = L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7 + L_8 + L_9 + \rho_1 + \rho_2 . \qquad (27)$$

An additional penalty is utilized in early phases of the minimization to keep the average total fishing mortality rate close to the natural morality rate. This penalty ensures the population abundance estimates do not get exceedingly large during early phases of the minimization. The final penalty added to the objective function forces the parameters for fleet selectivities in the first year to average 1.0. This penalty prevents multiple parameter sets from having the same objective function value, which would cause difficulty for the minimization routine. Each component of the objective function is reported in the output file along with the corresponding number of observations, weight assigned to that component, and residual sum of squared deviations (if appropriate).

Additional Features

The model optionally does some additional computations once the likelihood function has been minimized. These "extras" do not impact the solution, they are merely provided for reference. Each fleet can be designated as either directed or nondirected for the projections and F reference point calculations, with the option to modify the nondirected F in the future. The directed fleets are combined to form an overall selectivity pattern that is used to solve for common fishing mortality rate reference points ($F_{0.1}$, F_{max}, $F_{30\%SPR}$, $F_{40\%SPR}$ and F_{msy}) and compared to the terminal year F estimate. The inverse of the SPR for each of these points is also given so replacement lines corresponding to these reference values can be plotted on the spawner-recruit relationship. Projections are computed using either the stock-recruitment relationship or input values to generate future recruitment. The projections for each successive year can be made using either a total catch in weight or the application of a static $F_{X\%SPR}$, where X is input. A reference year is also input that allows comparison of the spawning stock biomass (SSB) in the terminal year and that in the final projection year as SSB_t/SSB_{ref}. Likelihood profiles for these SSB ratios can optionally be generated.

Example: Western Atlantic Bluefin Tuna

Two analyses of western Atlantic bluefin tuna data using ASAP are presented here. The first analysis (simple) did not allow selectivity and catchability to change over time (225 parameters estimated). The second analysis (complex) used the full complexity allowed by the model, with fleet selectivities allowed to change every two years and index catchabilities allowed to change every year (914 parameters estimated). In both analyses the model was structured for years 1970-1995, ages 1-10+, five fleets, and seven tuning indices (each point input with a variance) with all likelihood component weightings equal between the analyses. The natural mortality rate was set at 0.14 for all ages (for data details see Restrepo and Legault In Press). The number of observations associated with, and the weights given to, each part of the likelihood function are shown in Table 1. In this example, the weights assigned to each component were chosen arbitrarily. In an actual assessment, these weights will need to be selected by the assessment working group.

The overall fit of the complex analysis was better than the simple analysis (lower objective function value) as expected due to the greater number of parameters (Table 1). The complex analysis fits the indices better than the simple analysis, especially the US Rod and Reel Large, US Longline Gulf of Mexico, and the Japan Longline Gulf of Mexico indices. (Figure 1). Recruitment estimates from the two analyses are similar to the estimates from the 1996 SCRS assessment, which used virtual population analysis (VPA) with the main differences occurring in the early years of the time series (Figure 2). The estimates of spawning stock biomass (SSB) differ between the analyses, the complex one is similar in magnitude to the SCRS96 results, while the simple analysis estimates larger values (Figure 3). However, standardizing the SSB trends (dividing by the SSB in 1975) produces similar trends for all three analyses (Figure 3). The resulting stock-recruitment relationship is shown in figure 4. The total fishing mortality rates by year and age differ in both magnitude and pattern, with the complex analysis more closely matching the 1996 SCRS assessment (Figure 5). These differences in F are due to the assumptions about selectivity, fixed for the simple analysis and allowed to vary for the complex one (Figure 6). Note in particular the large change in selectivity of the purse seine fleet, mainly young fish in the early years and old fish in recent years. The catchability values also reflect the difference in assumptions, constant for the simple analysis and allowed to vary in the complex analysis (Figure 7). Note the large lambda given to the larval index causes the catchability coefficients to vary only slightly in the complex analysis. The catch at age proportions are fit relatively well in both analyses, the input and effective sample sizes are similar, even though this is the largest part of the total likelihood. The estimated effective sample size can be computed as

$$Effective\, N_g = \frac{\sum_a \sum_y \hat{p}_{a,y,g}(1-\hat{p}_{a,y,g})}{\sum_a \sum_y (p_{a,y,g} - \hat{p}_{a,y,g})^2} \qquad (28)$$

(for details see McAllister and Ianelli, 1997 Appendix 2).

Discussion

The flexibility afforded by ASAP is a continuation of the trend in stock assessment programs from the relatively simple structure of Fournier and Archibald (1982) to the more flexible structure found in Methot (1998), Ianelli and Fournier (1998), and Porch and Turner (In Press). In fact, ASAP is based on the same logic as these more flexible programs, but combines the advantages of the AD Model Builder software with the more general input flexibility of stock synthesis and CATCHEM. J. Ianelli (NMFS, Seattle, pers. comm.) also provided guidance in the formulation of certain model components, specifically the logic of linking fleet specific indices with a specific age in the tuning process (see equation 12). The distinguishing feature between this approach and that found in virtual population analysis (VPA) (Gavaris 1988, Powers and Restrepo 1992) is that VPA assumes the catch at age is measured without error, while ASAP assumes the observed catch at age varies about its true value.

The flexibility of ASAP can also cause problems however. Slight changes in the weights assigned to each likelihood component can produce different results, both in magnitude and trend. The large number of parameters, in the complex model especially, required the solutions in each phase to progress towards a satisfactory region in the solution space. If any phase led the solution away from this region, the final result will not be believable (e.g. total F<1e-5). This problem was not found in multiple tests using simulated data that did not contain errors or only small observation errors. Thus, the ability to fit highly complex models depends upon the quality of the data available, especially the consistency between the catch at age and the tuning indices. Nevertheless, the flexible nature of ASAP allows for easy exploration of the data to determine what level of complexity can appropriately be modeled.

Acknowledgments

The conclusions presented here are entirely the authors' and are not necessarily endorsed by NMFS or UM. We are grateful to Jim Ianelli, Clay Porch, Joe Powers, Gerry Scott and Steve Turner for helpful discussions.

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Table 1. Likelihood function components for two ASAP analyses. nobs=number of observations in that component, λ=weight given to that component, RSS=residual sum of squared deviations, L=likelihood value

			Simple		Complex	
Component	nobs	λ	RSS	L	RSS	L
Total Catch in Weight						
Rod and Reel	26	100.5	0.0005	0.0479	0.0001	0.0147
Japan Longline	26	100.5	0.0015	0.1558	0.0003	0.0322
Other Longline	26	100.5	0.0001	0.0069	0.0001	0.0070
Purse Seine	26	100.5	0.0002	0.0183	0.0039	0.3913
Other	26	100.5	0.0001	0.0065	0.0000	0.0026
Total	130	100.5	0.0023	0.2353	0.0045	0.4477
Catch at Age Proportions	1300	N/A	N/A	874.40	N/A	396.47
Index Fits						
Larval Index	16	1	5.26	11.95	5.29	11.61
US Rod and Reel Small	15	1	3.95	9.33	2.02	-1.02
Canadian Tended Line	15	1	2.08	3.05	0.64	-5.95
US Rod and Reel Large	13	1	1.76	1.22	0.39	-5.74
US Longline Gulf of Mexico	9	1	6.13	15.26	0.31	-3.79
Japan Longline Gulf of Mexico	8	1	0.74	1.10	0.58	1.05
Japan Longline NW Atlantic	20	1	3.22	9.51	0.58	-9.19
Total	96	7	23.15	51.43	9.80	-13.02
Selectivity Deviations						
Rod and Reel	12	0.1	0	0	2.52	0.25
Japan Longline	12	0.1	0	0	4.42	0.44
Other Longline	12	0.1	0	0	3.56	0.36
Purse Seine	12	0.1	0	0	8.74	0.87
Other	12	0.1	0	0	3.00	0.30
Total	60	0.5	0	0	22.25	2.22
Catchability Deviations						
Larval Index	16	1000	0	0	0.00	0.29
US Rod and Reel Small	15	6.7	0	0	0.51	3.43
Canadian Tended Line	15	6.7	0	0	0.37	2.45
US Rod and Reel Large	13	6.7	0	0	0.18	1.20
US Longline Gulf of Mexico	9	6.7	0	0	0.21	1.39
Japan Longline Gulf of Mexico	8	6.7	0	0	0.00	0.03
Japan Longline NW Atlantic	20	6.7	0	0	0.35	2.35
Total	96	1040.2	0	0	1.62	11.14
Fmult Deviations						
Rod and Reel	25	0.1	5.26	0.53	5.01	0.50
Japan Longline	25	0.1	21.44	2.14	19.67	1.97
Other Longline	25	0.1	24.30	2.43	23.97	2.40
Purse Seine	25	0.1	5.24	0.52	8.07	0.81
Other	25	0.1	5.60	0.56	6.84	0.68
Total	125	0.1	61.84	6.18	63.56	6.36
Recruitment	26	0.01	10.14	0.10	14.51	0.15
N in Year 1	9	1.44	3.34	4.82	3.08	4.43
Stock-Recruit Fit	25	0.001	9.47	0.01	3.94	0.00
Selectivity Curvature over Age	40	1.44	12.03	17.32	17.19	24.76
Selectivity Curvature over Time	1200	1.44	0	0	52.03	74.92
F penalty	260	0.001	3.0E-01	3.0E-4	2.3E-02	2.3E-02
Mean Sel Year 1 Penalty	50	1	4.5E-12	4.5E-12	4.7E-12	4.7E-12
Objective Function Value				954.50		507.87

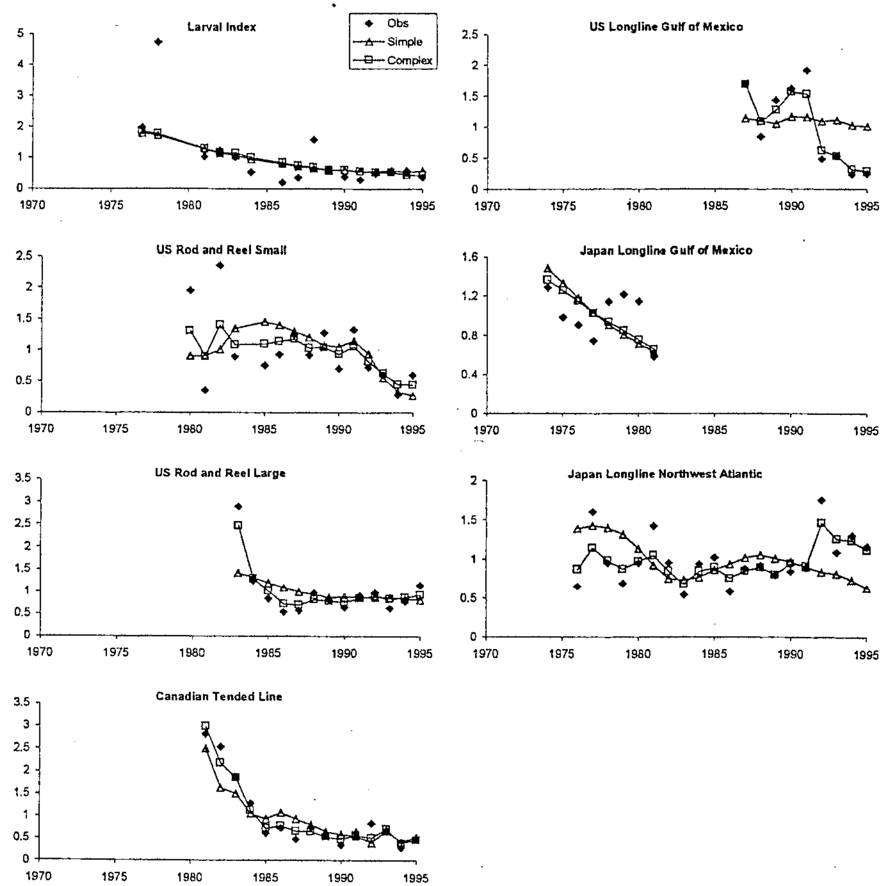

Figure 1. Observed and predicted indices for the simple and complex ASAP analyses.

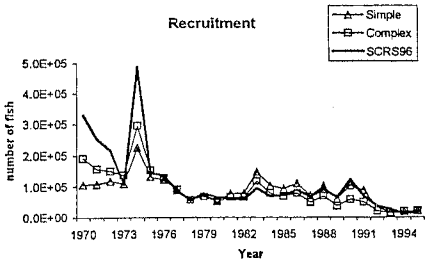

Figure 2. Estimated recruitment from two ASAP analyses and the SCRS 1996 assessment.

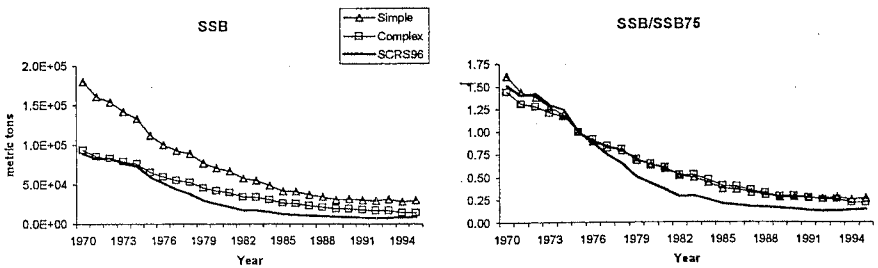

Figure 3. Spawning stock biomass (SSB) from two ASAP analyses and SCRS 1996.

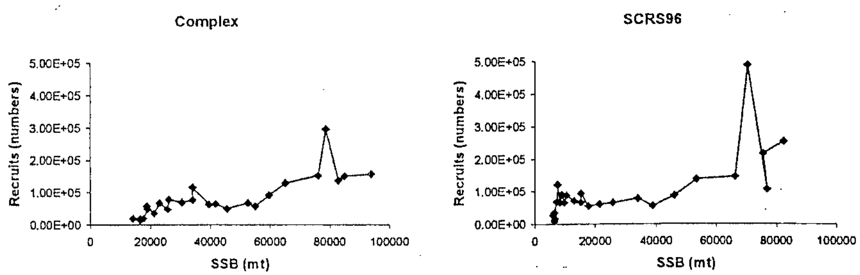

Figure 4. Complex ASAP analysis and SCRS 1996 stock-recruitment relationships.

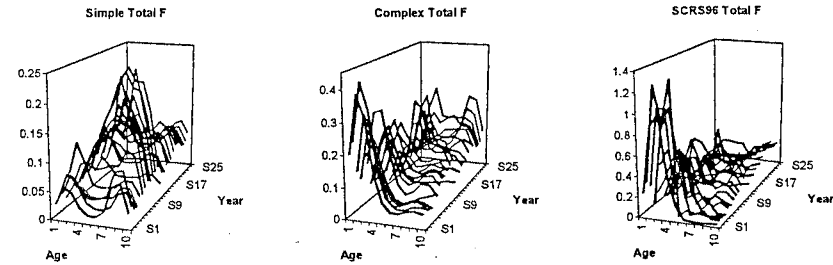

Figure 5. Estimated fishing mortality rates by age and year for two ASAP analyses and SCRS 1996.

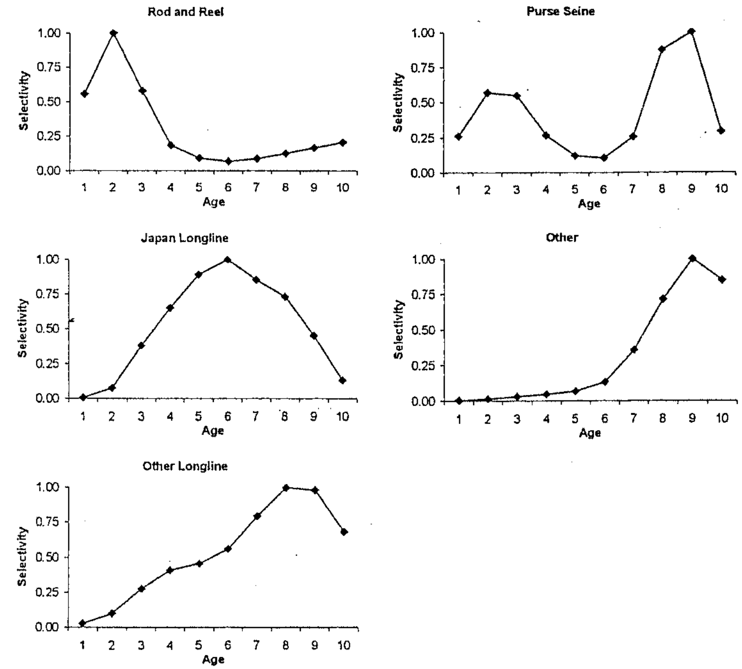

Figure 6a. Selectivity at age for the simple ASAP analysis, constant over all years for each fleet.

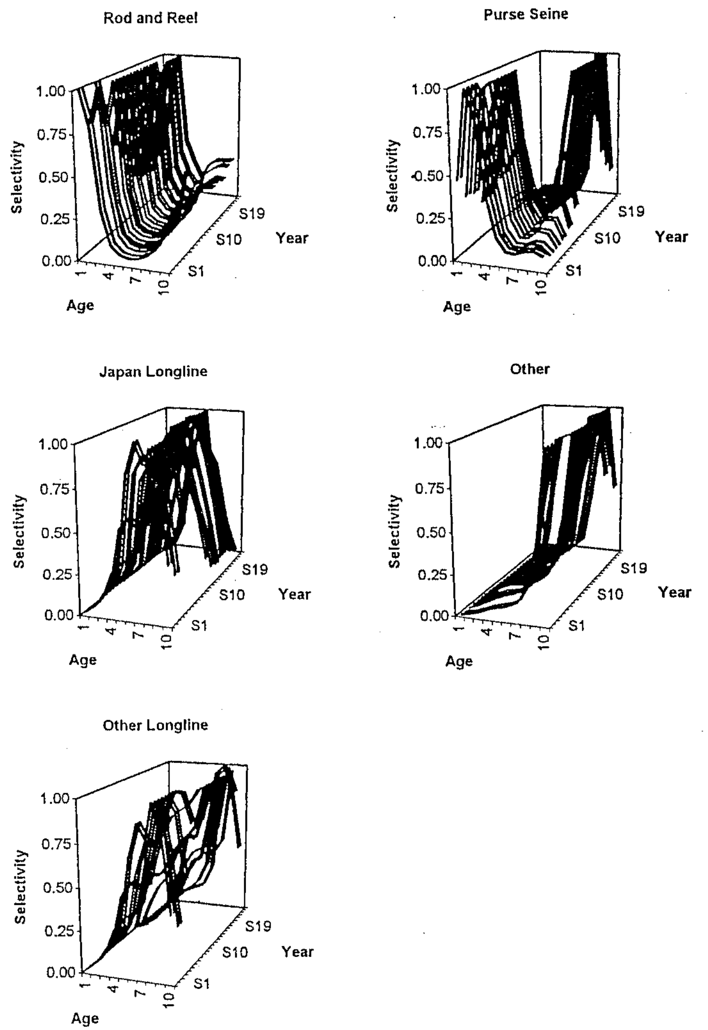

Figure 6b. Selectivity at age for the complex ASAP analysis.

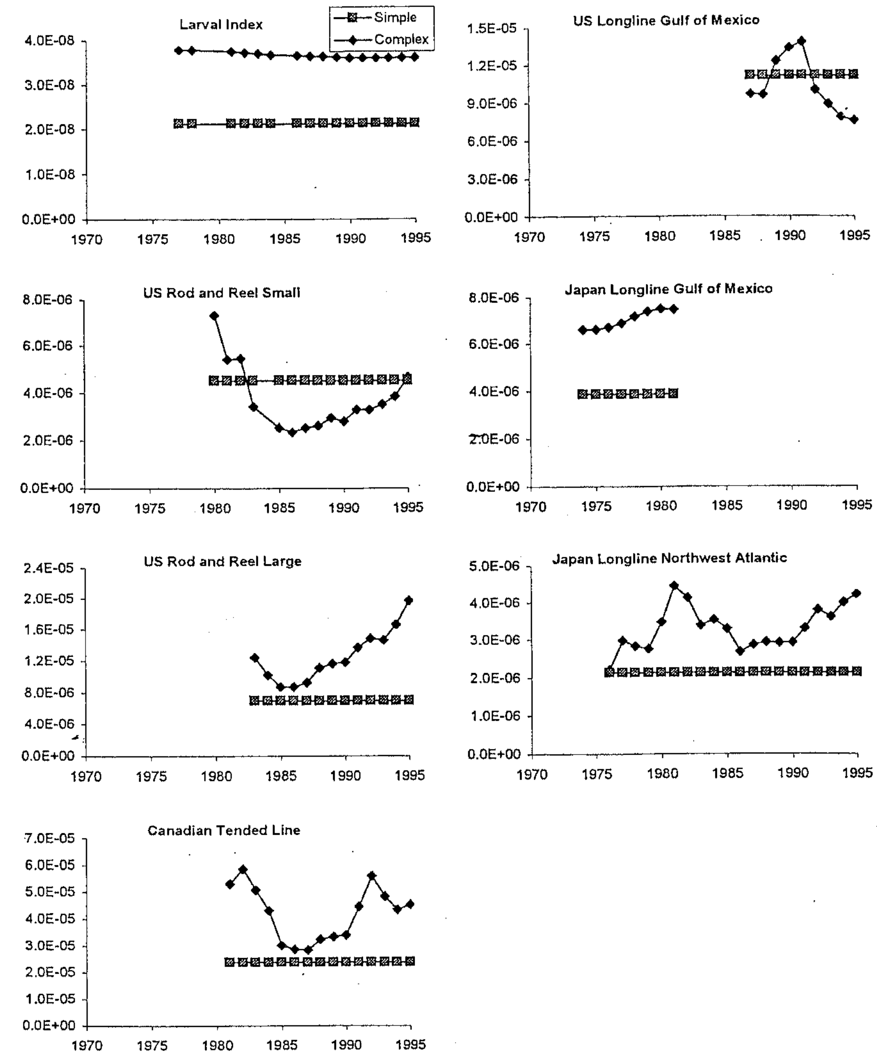

Figure 7. Catchability for each tuning index from the two ASAP analyses.

Pacific Mackerel

STAR Panel Meeting Report

NOAA / Southwest Fisheries Science Center
La Jolla, California
May 1-4, 2007

STAR Panel
Tom Jagielo, Washington Department of Fish of Wildlife (Chair)
André Punt, University of Washington (SSC representative)
Malcolm Haddon, University of Tasmania (CIE)

PFMC
Diane Pleschner-Steele (CPSAS)
Dale Sweetnam, SWFSC (CPSMT)

STAT
Emmanis Dorval, NOAA / SWFSC
Kevin Hill, NOAA / SWFSC
Nancy Lo, NOAA / SWFSC
Jennifer McDaniel, NOAA / SWFSC

1) Overview

The Pacific Mackerel STAR Panel (Panel) met at the Southwest Fisheries Science Center, La Jolla, CA Laboratory from May 1-4, 2007 to review a draft assessment by the Stock Assessment Team (STAT) for Pacific Mackerel. The Panel was originally scheduled to conclude on May 3rd, however, additional time was needed and the Panel also met on the morning of May 4th. Introductions were made (see list of attendees, Appendix 1), and the Panel chair (Tom Jagielo) reviewed the Terms of Reference for CPS assessments with respect to how the STAR Panel would be conducted. Draft assessment documents, model input and output files, and extensive background material (previous assessments, previous STAR Panel reports, SSC statements, etc.) were provided to the Panel in advance of the meeting on an FTP site, which served as a timely and convenient means to distribute the material for review. The Panel chair thanked the STAT for providing the draft assessment approximately one week prior to the meeting, which provided sufficient time for review. A file server was provided at the meeting room to provide common access to all presentation material and the additional model runs that were conducted during the course of the Panel meeting.

Emannis Dorval, with assistance from Kevin Hill, led the presentation on assessment methodology. Nancy Lo gave presentations on candidate indices for the stock abundance based on: 1) an aerial spotter program GAM analysis (Appendix I to the draft assessment report), and 2) CalCOFI larval production data (Appendix II to the draft assessment report).

The previous mackerel assessment, used for PFMC management decisions for the period July 1, 2005 to June 30, 2006, used a forward-projection age-structured assessment program (ASAP) model to estimate Pacific mackerel biomass. During the meeting, the Panel reviewed an updated ASAP model, and an alternative model in SS2 provided by the STAT. Initial discussion focused on resolving differences between outputs coming from the two models.

To demonstrate continuity from the previous assessment, the STAT presented revised models in which the ASAP formulation mimicked a comparable SS2 model as closely as possible (see also Section 2 below). The discussion focused on how best to model time changing weight-at-age using SS2, after it was noted that similar estimates of 1+ biomass and recruitment could be obtained from SS2 and ASAP if these two assessment packages were based on the same set of specifications.

Despite the relatively close agreement of many of the outputs from the ASAP and SS2 model runs, detailed scrutiny of the diagnostics and outputs from the SS2 modelling runs revealed that the SS2 model invariably ran up against the harvest rate limit (0.9 and 0.95) in a number of years. Attempts to mitigate this problem were unsuccessful. This was considered to be a critical factor which prevented acceptance of the SS2 implementation. The Panel and the STAT agreed that an updated version of the ASAP model should form the basis for the 2007 assessment.

The Panel commended the STAT for their excellent presentations, well-written and complete documentation, and their willingness to respond to the Panel's requests for additional analyses.

2) Discussion and Requests Made to the STAT during the Meeting

1. The selectivity pattern for the CPFV index is based on fitting the length-frequency data for all recreational modes. The length-frequency data for the CPFV fleet should be compared with the length-frequency data from the other recreational modes to test the assumption that the selectivity pattern for the CPFV fleet is the same as that for the remaining recreational fleets. **Response**. Ultimately, the model chosen as the basecase was framed as an age-structured model obviating the need for this comparison.
2. The CalCOFI indices are based on four methods for estimating the mortality rate and the initial number of larvae (methods “1” – “4”). Methods “3” and “4” are used in cases in which it was impossible to estimate the values for these parameters using weighted non-linear regression. A sensitivity test should be conducted in which the index values based on methods “3 and “4” (which should be the least reliable) are omitted. **Response**: Given the time spent on trying to get the SS2 model to operate successfully, insufficient time remained to attempt this sensitivity analysis.
3. The CalCOFI indices are based on data for the “core” area off southern California, but mackerel spawn from Baja through to northern California. The larval densities for Mexico and the “core” area should be plotted for the years for which data on larval abundance are available for both areas. **Response**. Larval density of mackerel off Mexico is substantially higher than off the “core” area (Fig. 1a). The results of a regression of average larval densities on those for the “core” area (Fig. 1b) indicate that the CALCOFI indices for the “core” area may be able to detect years when larval abundance is high, but the relationship between the larval density for the “core” area and for the region including both Mexico and the “core” area is weak (r^2~0.1) when the two highest larval densities are ignored.
4. The design of the survey used to extend the spotter plane index covers different areas and with different design than the historical (opportunistic) surveys. In addition, estimating the tonnage per block and the proportion positives using models that include a smoothing spline on year leads to temporal correlation among the year-factors. This is inconsistent with the assumptions related to how indices of abundance are included in ASAP and SS2 assessments. Repeat the construction of the spotter plane index using a GLM model in which the survey data (2004 and 2005, years with survey data) and the data for 2003 (low number of trips) are ignored, and in which the smoothing splines on year in the models for the proportion positive and tonnes per block are replaced by a year factor. **Response**. The revised spotter plane index exhibited substantially more inter-annual variability, and the coefficients of variation for the indices were higher. The STAT replaced the original GAM index with the GLM index.
5. Examine the implications of moving from an assessment based on ASAP to one based on SS2. As a first step in this process, apply ASAP and SS2 based on model configurations that are as similar as possible so that the impact of a change in platform can be examined. This can be achieved using the following specifications for ASAP and SS2:

   ASAP configuration:

   - Set the weight-at-age in the fishery to the weight-at-age in the population.

- Rescale the catch-at-age data so that the product of catch-at-age and weight-at-age (now based on that for the population) equals the total catch for each year.

SS2 configuration:

- Omit length-based selectivity – assume that selectivity is independent of length.
- Assume age-based selectivity – estimate a selectivity parameter for each age (selectivity option 14).
- Use the catch-at-age data included in the ASAP model (no length data).
- Set weight-at-age to that used in ASAP (not time-varying).
- Have one selectivity pattern only (not time-varying).
- Set selectivity for the spotter and CPFV indices to those used in ASAP.
- Set the recreational catch to 0.0001 for all years.

Response. The STAT conducted the requested analysis, setting the CVs for the ASAP run to the "tuned" values based on the SS2 analyses and setting $\sigma_R = 0.8$. The results from ASAP and SS2 were very similar for the years 1967-2004 but differed slightly for the first years of the assessment period and substantially for the years 2005 onward. The differences between the results for SS2 and ASAP after 2004 were due to the use of the forecast option in SS2, which led to recruitments substantially in excess of those expected under the deterministic stock-recruitment relationship. The Panel agreed that SS2 and ASAP lead to adequately similar results when using the same data, but the SS2 forecast file needs to be corrected for the projections beyond 2004.

6. The recreational catches are included as weights and not numbers in the SS2 assessment. The catches-in-weight are calculated from the catches-in-number under the assumption that each fish weighs 1lb on average. However, SS2 is capable of using catch data entered as catch-in-numbers. Conduct a sensitivity test in which the recreational catches are included in the assessment in the form of catch-in-numbers rather than of catch-in-weight. **Response**. The request became irrelevant once the updated ASAP model was chosen as the assessment platform.
7. The SS2 run presented to the Panel had five time blocks for length-at-age and weight-at-length. Provide the basis for the time-blocking of the growth curves by plotting the annual length-weight relationships for each block. **Response**. The STAT provided the Panel with plots of length versus weight for each year from 1962. There are between-year differences in the length-weight relationship, but it was not possible to identify a preferred time block structure.
8. Run SS2 with pre-specified year-specific growth curves and year-specific length-weight regressions. The CV of length-at-age should be based on the averages over time and the age-specific selectivity pattern for the commercial fishery should be set to three double-normal functions (one for each selectivity epoch). **Response**. The STAT provided the Panel with several runs in which the CV of length-at-age was set to 0.166 for age 0 animals and 0.05 for age 11 animals (the maximum across years), in which $\sigma_R = 0.8$ (selected by comparing the RMSE for the recruitment residuals and the pre-specified value for σ_R), and in which the CVs assigned to the indices

were tuned. The peak abundance is highly sensitive to the value assumed for σ_R. All of the analyses provided to the Panel led to exploitation rates in the 1950s, 1960s, and/or 1990s that exceeded the value permissible value (0.9 and 0.95). After many additional analyses, the Panel and STAT agreed that it would not be possible to base an assessment of Pacific mackerel on SS2 and all additional analyses were based on ASAP.

9. There are concerns with all three potential indices of abundance as they may be in conflict to some extent. Repeat the assessment in which the model is fitted to each index independently. **Response**. The STAT provided results for the ASAP analyses. The different time series are in conflict in some years. For example, the CalCOFI index exhibits an increase in the years 1996 and 1997 whereas the other indices either do not exhibit an increase or show a decline. The stock size exhibits an upturn in the last three or four years of the assessment period. This disappears when the CPFV time series is omitted and only the CalCOFI time series is used (Figure 3).
10. The three indices should be plotted together to provide a visual comparison of where the indices may be in conflict or where each contributes information to the model fit. **Response.** The STAT team produced a graph with an adequate interpretation.
11. Sensitivity runs were requested to examine the impact of varying the natural mortality rate between 0.35 and 0.7yr^{-1}. **Response.** The STAT produced graphs of initial and 1+ biomass which exhibited the expected behaviour; some instability in the model fitting was detected with M between 0.55 and 0.6yr^{-1}. In addition, a table of the likelihood components for the range of M values was produced to aid in the identification of which factors are most influenced by M (Figure 4).

The commercial fleet has failed to take a large proportion of the recommended Harvest Guidelines since 2001. Higher fuel costs that were not matched by comparable increases in price for product were presented as part of the explanation in conjunction with the limited availability of fish close to port. As a result of the increased fuel prices, the area of the fishery has contracted closer to shore, which may have influenced the age composition in recent years by increasing the proportion of 0+ and 1+ fish in the catches. This contraction in area has been exacerbated by spotter plane effort being redirected to higher value fisheries such as tuna.

The results from the 2007 runs based on ASAP are most similar to those from the ADEPT model conducted for assessments prior to 2006 in terms of biomass trends since 1975 (Figure 2). However, there are major differences in biomass trajectories for the years prior to 1950. The results for the 2006 and 2007 ASAP runs differ markedly in terms of biomass in the peak years, in the years prior to 1950 and in recent years. Part of the explanation for this difference is that σ_R has been increased which leads to higher biomass than in the past and because selectivity is estimated for three, rather than one epoch. The increase in biomass in the last three years is a consequence of fitting to the CPFV index; runs without this index lead to markedly less optimistic values.

3) Technical Merits and/or Deficiencies of the Assessment

It was decided to base the 2007 assessment on an ASAP model that includes three selectivity epochs and a higher value for σ_R. Unlike SS2, this model did not lead to diagnostics that were clearly problematical. However, the ASAP is not capable of including more than one fleet so the recreational catches could not be independently modelled. In addition, the ASAP model uses the same weight-at-age for the catch as for the population, which implies that any stock recruitment relationship may be biased. In order to estimate selectivity for a relative abundance index, ASAP requires that the index be associated with a particular fishery. This means there are difficulties estimating the selectivity for the larval abundance and spotter plane indices.

The Panel accepts that the ASAP E1-base model can be used as the basis for management advice and advices that the runs based on all indices included and M=0.35 and M=0.70 be used in order to bracket uncertainty.

4) Areas of Disagreement

There were no major areas of agreement between the STAT and Panel.

5) Unresolved Problems and Major Uncertainties

Problems unresolved at the end of the meeting form the basis for some of the research recommendations in Section 6. The background to three of the main issues are given here.

1) While the best estimates of the landings off Mexico are included in the assessment, there is a continuing lack of size- and age-composition data from these catches. The 2004 STAR Panel recommended that efforts be made to obtain biological sampling data and especially catch-at-age data from the Mexican fraction of the fishery. The SWFSC began the process of acquiring this information by organizing a US-Mexico workshop in 2007 and obtaining commitments for data provision in time for future assessments. The size and age composition data from the San Pedro fishery are presently assumed to be representative of the whole stock. In addition, two of the indices of relative abundance used in the assessment (the CalCOFI larval survey and the CPFV recreational data) only relate to the Southern Californian Bight. The spawning area is known to extend south to the tip of Baja California. Obtaining data from the Mexican fishery, including the Mexican larval surveys (IMECOCAL) might help remove this important source of uncertainty.
2) There is currently no true fishery-independent index of relative abundance for the whole stock and there are concerns with the three indices used in the present assessment.
    a. The CalCOFI larval surveys are often relatively poor at finding Pacific mackerel larvae. Whether these surveys and the estimates of larval production at hatching constitute representative estimates of the spawning stock size of mackerel is uncertain, especially because the area surveyed is only a fraction of the total spawning region. Obtaining access to the Mexican larval survey data (IMECOCAL) may help solve this problem. In addition, the occurrence of larvae can be limited to one or two size classes in years of relatively low abundance, which compromises the estimation of the larval production at hatching for those years.
    b. The aerial spotter index, up until 2002, provides an opportunistic method for estimating relative abundance. The structure of the index includes an estimate

of area based on the number of 10’ x 10’ blocks surveyed, but this number varies from year to year, and includes coastal blocks which are not strictly 10’ x 10’. This acts as a source of uncertainty among years. A further problem with the spotter plane index of abundance is that the design of the sampling changed after 2002. Specifically, a fishery-independent aerial survey was begun in 2004 using a grid search pattern with the added freedom to search for more fish if a school of fish is found. However, the adherence of the pilots to the sampling grid has yet to become stable. The very different sampling strategy used prior to 2003 means that it is questionable whether this new time series can be combined in a meaningful way with the earlier one.

c. The CPFV index is based on the logbook data from the CPFV fleet for California (although limited data do exist for Mexico). Given that it is fishery-dependent data, its use in the assessment as an index of stock abundance is predicated on the assumption that catchability has not changed over time. While this is a concern for all indices of abundance based on fishery-dependent data, the fact that mackerel is not a target species for the CPFV fleet suggests that this assumption may be acceptable in this case.

3) Ageing error rates (see Table 1) indicate substantial imprecision and /or bias, particularly for the younger age-classes (0 and 1), which currently constitute a large fraction of the catch. The impact of this error rate will only become apparent once an ageing error matrix is included in the assessment.

6) Research Recommendations

A. One of the major uncertainties associated with the assessment is that no account is taken of ageing error. SS2 can include an age-reading error matrix. The data from age-reading studies should be used to construct an age-reading error matrix for inclusion in future (SS2) assessments. However, there are currently very few otoliths that have been read multiple times so additional readings need to be made. In the longer-term, an age validation study should be conducted for Pacific mackerel. Such a study should compare age readings based on whole and sectioned otoliths and consider a marginal increment analysis.

B. The next assessment should continue to examine the possibility of using SS2 as the assessment platform. The analyses presented to the Panel suggested that ASAP and SS2 lead to similar outcomes when configured in a similar manner. However, SS2 deals better with indices that are not tied directly to a fishery, can include age-reading error, and allows weight-at-age in the catch to differ from weight-at-age in the population. In principle, it should be easier to represent uncertainty using the MCMC algorithm for assessments based on SS2.

C. The construction of the spotter plane index is based on the assumption that blocks are random within region (the data for each region is a “visit” by a spotter plane to a block in that region). The distribution of density-per-block should be plotted or a random effects model fitted in which block is nested within region to evaluate this assumption (e.g. examine whether certain blocks are consistently better or worse than the average).

D. The data on catches come from several sources. The catch history from 1926-27 to 2006-07 should be documented in a single report.

E. Conduct a study to update the information used to determine maturity-at-length (and maturity-at-age).
F. A large fraction of the catch is taken off Mexico. In particular, catches of mackerel have been as large as those off California in recent years. Efforts should continue to be made to obtain length, age and biological data from the Mexican fisheries for inclusion in stock assessments. Survey data (IMECOCAL program) should be obtained and analyses conducted to determine whether these data could be combined with the CalCOFI data to construct a coastwide index of larval abundance.
G. The SS2 assessment is based on fitting to age-composition data for the commercial fishery. Future SS2 assessments should consider fitting to the length composition and the conditional age-at-length information. This will require estimating time-varying growth curves and may require multiple time-steps within each year.
H. The CalCOFI data should be reviewed further to examine the extent to which CalCOFI indices for the "core" area can be used to provide information on the abundance of the coastwide stock.
I. There are uncertainties regarding the early biological and fishery data. The Panel reiterates the recommendation of the 2004 STAR Panel that consideration should be given to initiating the assessment model in a more recent year (e.g. 1978).
J. The concern of the 2004 STAR Panel that fishery-based weights are used to estimate population parameters has still not been addressed. Future assessments should attempt to estimate a population growth curve in order, for example, to estimate the time-trajectories of 1+ and spawning biomass.

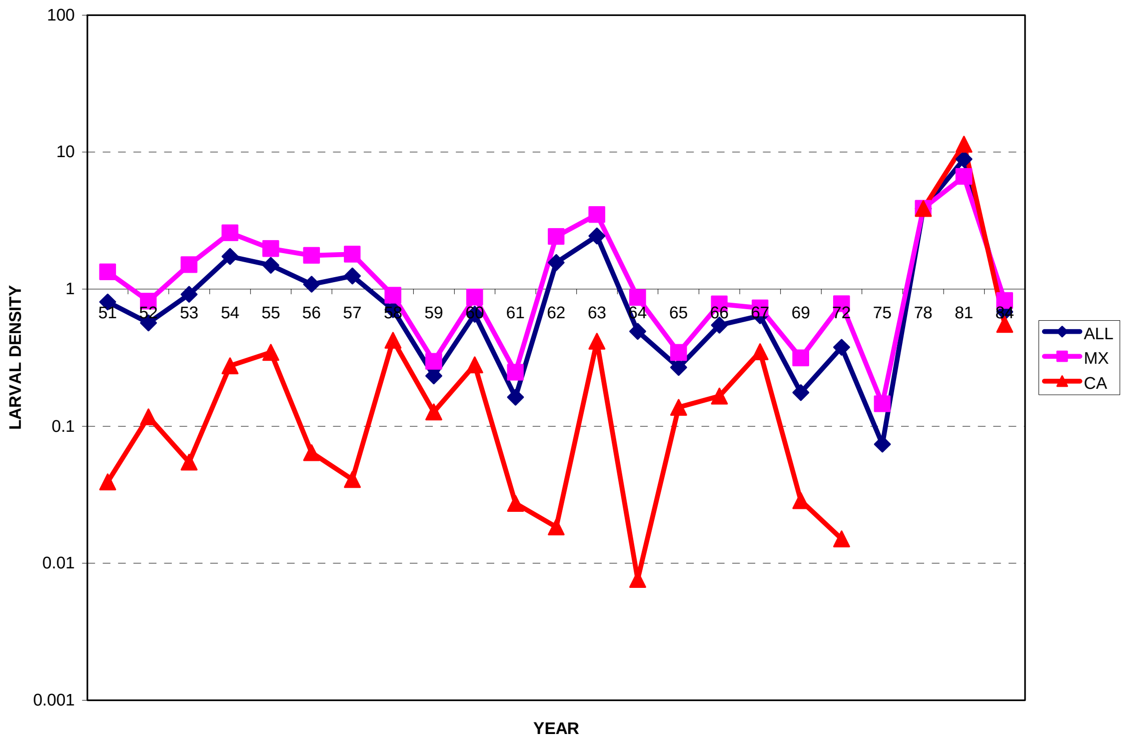

Figure 1a. Coastwide larval densities (diamonds), larval densities off Mexico (squares), and larval densities for the "core" area (results based on CalCOFI surveys that covered Mexico and the "core" area (1951-1984)).

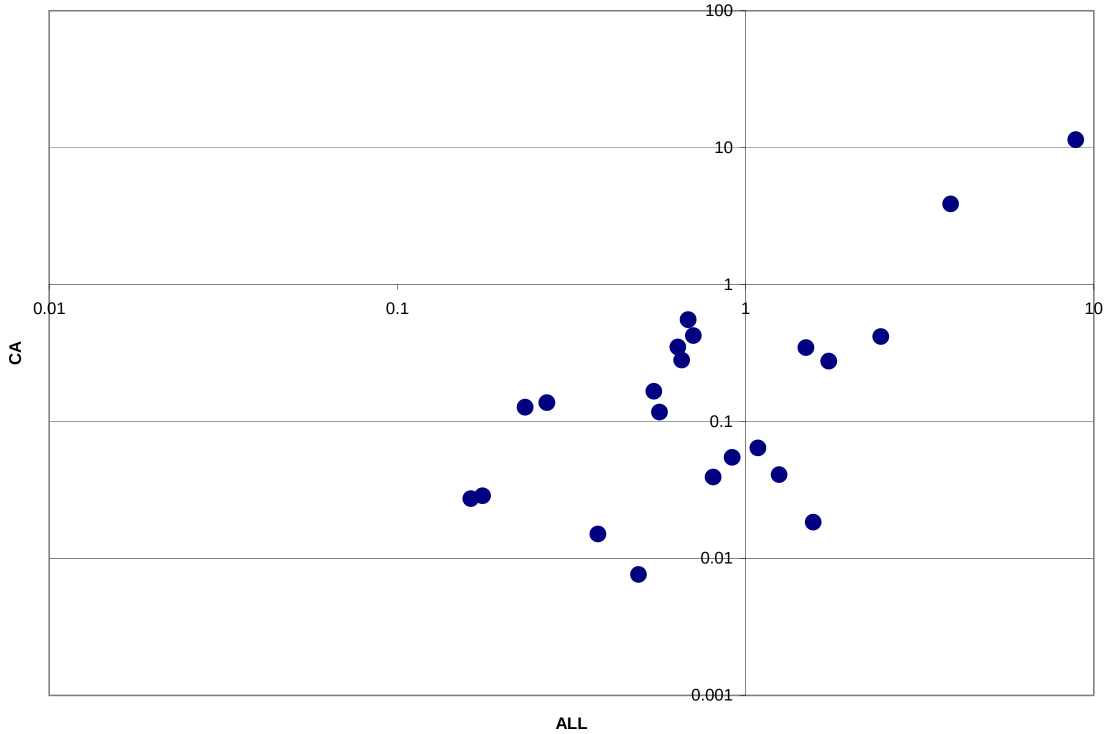

Figure 1b. Average larval densities (Mexico and the “core” area) versus larval densities for the “core” area based on CalCOFI surveys that covered Mexico and the “core” area (1951-1984).

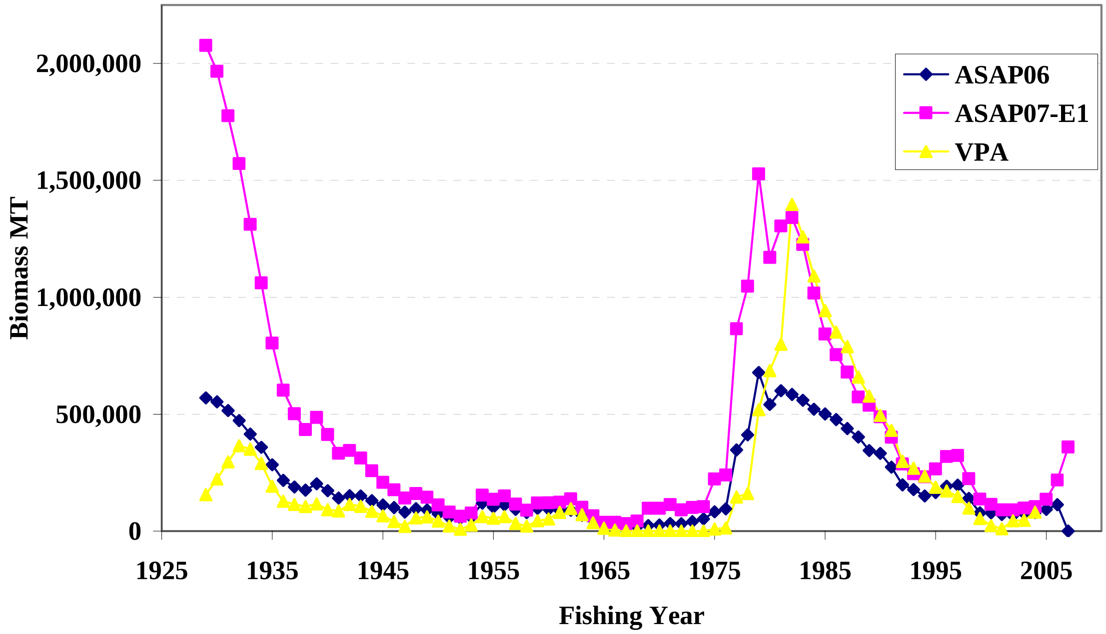

Figure 2. Estimated biomass (age 1+ fish, B in mt) of Pacific mackerel generated from the VPA (2006 assessment), and the ASAP-BaseCase model for the 2007 assessment.

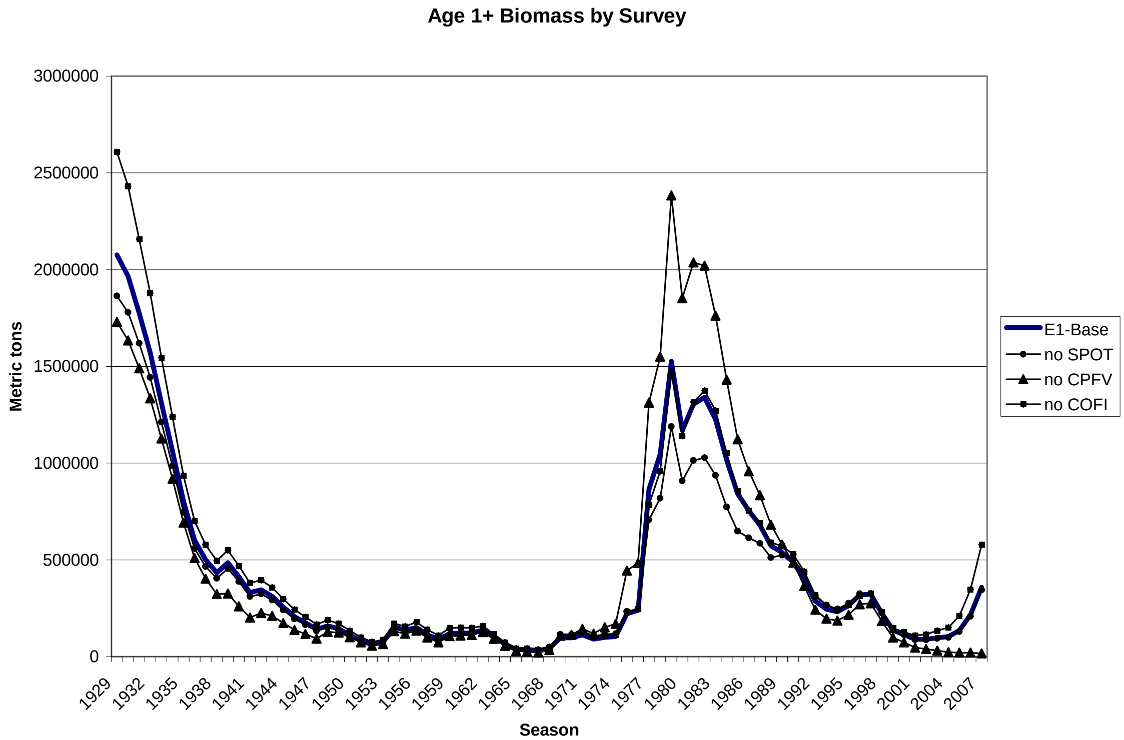

Figure 3. Sensitivity of Base-Case ASAP Model to Indices of Abundance.

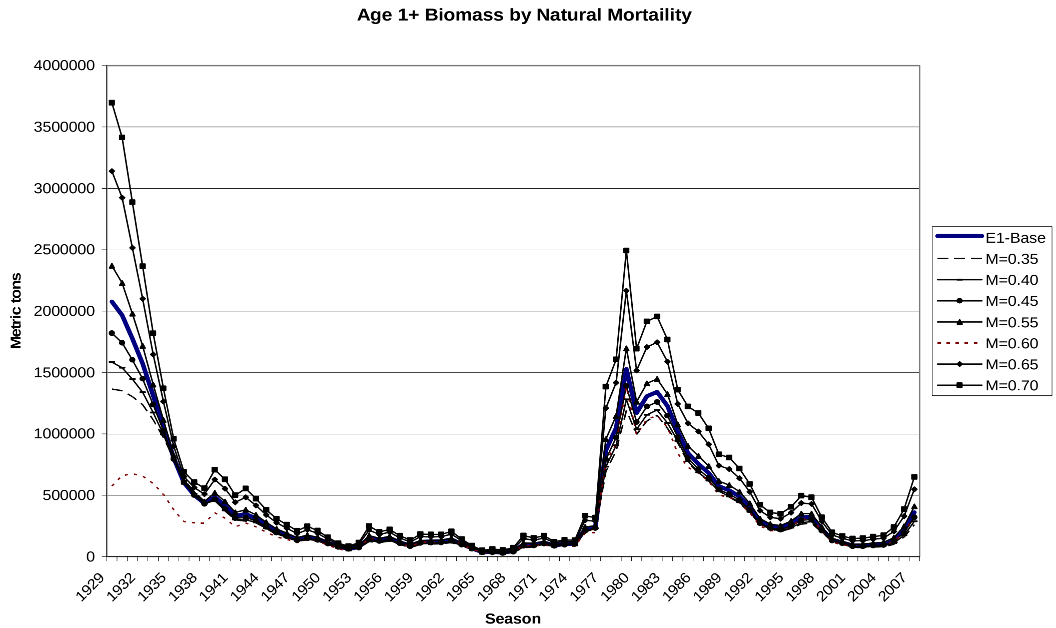

Figure 4. Sensitivity of Base-Case ASAP Model to Natural Mortality.

Table 1
Measures of age-reading error

	Age							
	0	1	2	3	4	5	6	7+
APE	0.298	0.276	0.158	0.150	0.139	0.112	0.111	0.096
CV	0.888	0.758	0.447	0.423	0.408	0.338	0.343	0.286

Appendix 1

STAR Panel Members in Attendance

Mr. Tom Jagielo (Chair), SSC - Washington Department of Fish and Wildlife
Dr. André Punt, SSC - University of Washington
Dr. Malcolm Haddon, CIE - University of Tasmania
Mr. Dale Sweetnam, CPSMT - California Department of Fish and Game
Ms. Diane Pleschner-Steele, CPSAS - California Wetfish Producers Association

STAT Members in Attendance

Dr. Emmanis Dorval, NMFS, Southwest Fisheries Science Center (SWFSC)
Dr Kevin Hill, NMFS, SWFSC
Dr. Nancy Lo, NMFS, SWFSC
Ms. Jennifer McDaniel, NMFS, SWFSC

Others in Attendance

Mr. Mike Burner, Pacific Fishery Management Council
Dr. Ray Conser, NMFS, SWFSC
Dr. Paul Crone, NMFS, SWFSC
Dr. Sam Herrick, NMFS, SWFSC
Mr. Jason Larese, NMFS, SWFSC
Dr. Mark Maunder, Inter-American Tropical Tuna Commission (IATTC)
Dr. Kevin Piner, NMFS, SWFSC
Mr. Alexandre Silva, IATTC

Agenda Item F.2.c
Supplemental SSC Report
June 2007

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON PACIFIC MACKEREL STOCK ASSESSMENT AND HARVEST GUIDELINE FOR 2007-2008

Dr. Emannis Dorval presented a clear and detailed overview of the Pacific mackerel stock assessment to the Scientific and Statistical Committee (SSC). The assessment was technically sound, and the modeling approach taken was not greatly different from previous assessments of this stock. The SSC endorses the Stock Assessment and Review (STAR) Panel conclusions that this assessment represents the best available science and can form the basis for Council decision-making.

Like previous versions, this stock assessment was done using the Age-structured Assessment Program (ASAP) modeling framework. An attempt was made to implement the assessment in SS2, but the Stock Assessment Team and the STAR Panel were not satisfied with the results: they could not determine why the model was unable to fit portions of the early catch history. It may be possible to resolve this issue in time to review an SS2 modeling methodology for Pacific mackerel during the September sardine STAR Panel meeting. The SS2 methodology could then be used in the future for Pacific mackerel but would not affect the current assessment or the 2007-2008 harvest guideline.

Opportunities to improve the Pacific mackerel assessment are limited due to fundamental problems – (1) lack of a cooperative agreement between Mexico and the United States and (2) lack of a reliable index of abundance. The STAR Panel report does a good job of describing these problems. The most likely remedies are to negotiate a formal agreement with Mexico to collect and share catch and abundance data and to develop a more reliable stock-wide abundance index.

All of the current abundance indices have problems that limit their usefulness for this assessment. Potential improvements could involve the use of acoustic or LIDAR surveys. If technical issues can be solved such surveys may be used to produce an abundance index over the entire range of the stock and provide data to improve the stock assessment in a relatively short time frame. It would also be desirable to combine acoustic or LIDAR surveys with an improved implementation of the egg and larval surveys. These techniques could be applied to sardine as well as mackerel.

PFMC
06/12/07