APPENDIX 2

2005 PACIFIC SARDINE STOCK ASSESSMENT
AND
STOCK ASSESSMENT REVIEW PANEL REPORT

The 2005 Pacific sardine stock assessment and 2005 harvest guideline were approved at the November 2004 Council meeting and can be found at the Council web page at the link below.

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ASSESSMENT OF THE PACIFIC SARDINE STOCK FOR U.S. MANAGEMENT IN 2005

by

Ray Conser[1], Kevin Hill[1], Paul Crone[1], Nancy Lo[1], and Roberto Felix-Uraga[2]

[1] NOAA Fisheries
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla, California 92037
USA

[2] CICIMAR-IPN
Ave. IPN s/n A.P. 592
Col. Playa Palo Sta. Rita C.P. 230096
La Paz, Baja California Sur
México

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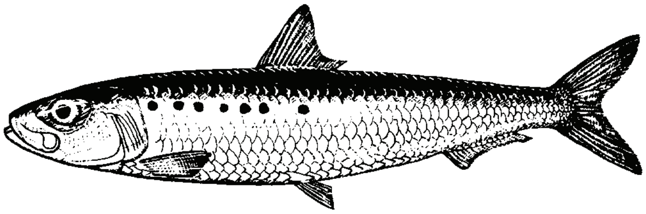

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TABLE OF CONTENTS

ASSESSMENT MODEL

MODEL RESULTS

Appendix I.	ASAP Model Description (Legault and Restrepo 1998).
Appendix II.	ASAP ADMB Template File.
Appendix III.	ASAP Base Run Input File.
Appendix IV.	ASAP Base Run Report File.

LIST OF TABLES

Table 12b. Pacific sardine instantaneous rates of fishing mortality at age (yr^{-1}) for biological years 1983-2005. The biological year begins on July 1st and extends through June 30th of the labeled year.

Table 13. Proposed harvest guideline for Pacific sardine for the 2005 management year. See ‘Harvest Guideline’ section for methods used to derive harvest guideline.

Table 14. Coastwide harvest (mt) of Pacific sardine for calendar years1981 through 2003 (PFMC 2004b).

LIST OF FIGURES

Figure 13. Estimated selectivity for the California fishery (Fishery 1) from the ASAP baseline model. Selectivity was estimated for two periods: 1983-92 and 1993-2005.

Figure 14. Estimated selectivity for the Ensenada, Mexico fishery (Fishery 2) from the ASAP baseline model.

Figure 15. Estimated selectivity for the Oregon, Washington, and British Columbia fishery (Fishery 3) from the ASAP baseline model.

Figure 16. Estimated instantaneous rate of fishing mortality (yr^{-1}) for fully-recruited age(s) for the California fishery (Fishery 1) from the ASAP baseline model.

Figure 17. Estimated instantaneous rate of fishing mortality (yr^{-1}) for fully-recruited age(s) for the Ensenada, Mexico fishery (Fishery 2) from the ASAP baseline model.

Figure 18. Estimated instantaneous rate of fishing mortality (yr^{-1}) for fully-recruited age(s) for the Pacific Northwest fishery (Oregon/Washington/British Columbia; Fishery 3) from the ASAP baseline model.

Figure 19. Estimated instantaneous rate of fishing mortality (yr^{-1}) by age and year for all fisheries combined from the ASAP baseline model.

Figure 20. Sardine recruitment estimates (age 0 abundance in billions) from the ASAP baseline model (triangles) along with a 2-standard error uncertainty envelope.

Figure 21. Sardine spawning stock biomass and recruitment estimates from the baseline model. Year labels indicate the biological year associated with the spawning stock biomass.

Figure 22. Sardine Age 1+ biomass estimates from the ASAP baseline model (triangles) along with a 2-standard deviation uncertainty envelope. Also shown are the corresponding estimates from the CANSAR-TAM model (circles) used for the last stock assessment (Conser et al. 2003).

LIST OF ACRONYMS AND ABBREVIATIONS

ADMB	automatic differentiation model builder (a programming language)
ASAP	age structured assessment program
BC	British Columbia, Canada
CA	California
CANSAR-TAM	catch-at-age analysis for sardine – two area model
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CDFG	California Department of Fish and Game
CICIMAR-IPN	Centro Interdisciplinario de Ciencias Marinas - Instituto Politécnico Nacional
CPS	Coastal Pelagic Species
CPSMT	Coastal Pelagic Species Management Team
CPSAS	Coastal Pelagic Species Advisory Subpanel
CV	coefficient of variation
CWPA	California Wetfish Producers Association
DFO	Department of Fisheries and Oceans - Canada
FMP	fishery management plan
HG	harvest guideline
INP-CRIP	Instituto Nacional de la Pesca - Centro Regional de Investigación Pesquera
MSY	maximum sustainable yield
MX	Mexico
MX-Ensenada	Mexican fishery that lands its product in Ensenada, Baja California
NMFS	National Marine Fisheries Service
NOAA Fisheries	National Oceanic and Atmospheric Administration, National Marine Fisheries Service
OR	Oregon
PFMC	Pacific Fishery Management Council
SAFE	stock assessment and fishery evaluation
SSB	spawning stock biomass
SSC	Scientific and Statistical Committee
SST	sea surface temperature
STAR	Stock Assessment Review (Panel)
STAT	Stock Assessment Team
VPA	virtual population analysis
WA	Washington

PREFACE

A Pacific sardine stock assessment is conducted annually in support of the Pacific Fishery Management Council (PFMC) process that, in part, establishes an annual harvest guideline (quota) for the USA sardine fishery. The last assessment and quota-setting process was completed in November 2003 – setting a 2004 calendar year quota of 122,747 mt. In June 2004, the PFMC, in conjunction with NOAA Fisheries, organized a Stock Assessment Review (STAR) Panel in La Jolla, California, to provide peer review of the methods used for assessment of Pacific sardine and Pacific mackerel. The following assessment report was initially prepared in draft form for the STAR panel's consideration, and is updated here for the PFMC's 2005 management cycle. The STAR Panel report for Pacific sardine (PFMC 2004a) included recommendations for improving the model configuration and input data. Many of these recommendations were incorporated into this updated assessment. Additional data – not available at the time of the STAR meeting – have also been incorporated into this update. These include not only the usual additional year of data associated with assessment updates (e.g. from ongoing fishery-dependent and fishery-independent sampling programs) but also considerable enhancements to the historic catch-at-age data.

EXECUTIVE SUMMARY

A stock assessment of Pacific sardine was conducted using a forward simulation, likelihood-based, age-structured model. The model was developed in AD Model Builder – a high-level programming language based on C++ Libraries. The assessment benefited from a review of the assessment model conducted in June 2004 (STAR Panel). Many of the review recommendations as well as considerable new data have been incorporated into this stock assessment update.

The primary motivation for conducting this assessment annually is to provide the scientific basis for the Pacific Fishery Management Council's (PFMC) sardine management process. This process – centered on an environmentally-based control rule -- establishes U.S. coastwide harvest guidelines (HG) for sardine for the fishing year beginning on January 1st of each year. Based on the sardine biomass estimate from this assessment (1.2 million mt) and current environmental conditions, the PFMC control rule suggests a 2005 HG for U.S. fisheries of 136,179 mt. This HG recommendation is 11% greater than the HG adopted by the PFMC for calendar year 2004.

INTRODUCTION

For stock assessment purposes, many of the world's fisheries may be considered data-limited. However, when a data-limited fishery is economically important, data availability generally improves over time as additional resources are allocated to better assess and manage the stock(s). With sufficient time and resources, these data-limited fisheries tend to become data-rich.

In the case of Pacific sardine off the west coast of North America, the fishery has been economically important since the early part of the 20th century. As large scale fishing operations developed, fisheries data collection programs were established along with biological studies and eventually fisheries independent surveys. The fishery collapsed in the 1950's following dramatic declines in stock biomass and remained at low levels for nearly forty years. Sampling programs remained in place, however, and when the stock began to recover in the late 1980's, an apparent data-rich assessment environment appeared to be in place. But sardine biology and ecology, along with oceanographic changes in the Pacific Ocean, conspired to prove this wrong.

For nearly half a century (mid-1940's through mid-1990's), the sardine population was distributed only from Baja California, Mexico northward to Monterey, California USA. This area represented a substantial contraction of the range occupied by sardine when the stock was at high biomass levels (1930's). Fisheries sampling programs were in place over this reduced geographic range; and annual egg production surveys were established in the early 1980's (Wolf 1988a,b), covering sardine spawning areas in southern and central California. Periodic stock assessments took advantage of this data-rich environment. In the mid-1990's, however, the population began a rapid recovery with concomitant expansion of its range northward through British Columbia, Canada. With some lag, fisheries sampling programs were established in the Pacific Northwest but due to budgetary constraints and logistical difficulties, systematic surveys were only recently launched in this area. Consequently, stock assessments are now much more difficult to carry out due to what has become a data-limited situation.

Currently-used Pacific sardine stock assessment models were designed for the data-rich environment and subsequently, have been modified in order to function in the new data-limited environment. The primary thrust of this paper is go back to basics by examining stock assessment methods that may be better suited from the ground up for contemporary sardine stock assessment and management; and for serving as a flexible framework to take advantage of new data sources as they become available. With regard to the latter, there is a reasonable expectation that over the course of the next few years, there will be significant improvements in the fisheries database, new fisheries-independent surveys, and better understanding of stock structure and the oceanographic constraints that govern suitable sardine habitat and productivity.

BACKGROUND

Scientific Name, Distribution, Stock Structure, Management Units

Biological information about Pacific sardine (*Sardinops sagax caerulea*) is available in Clark and Marr (1955), Ahlstrom (1960), Murphy (1966), MacCall (1979), Leet et al. (2001) and in the references cited below. Other common names for Pacific sardine include California pilchard, pilchard (in Canada), and sardina monterrey (in Mexico).

Sardines, as a group of species, are small pelagic schooling fish that inhabit coastal subtropical and temperate waters. The genus *Sardinops* is found in eastern boundary currents of the Atlantic and Pacific, and in western boundary currents of the Indo-Pacific oceans. Recent studies indicate that sardines in the Alguhas, Benguela, California, Kuroshio, and Peru currents, and off New Zealand and Australia are a single species (*Sardinops sagax*, Parrish et al. 1989), but stocks in different areas of the globe may be different at the subspecies level (Bowen and Grant 1997).

Pacific sardine have at times been the most abundant fish species in the California Current. When the population is large it is abundant from the tip of Baja California (23^o N latitude) to southeastern Alaska (57^o N latitude), and throughout the Gulf of Mexico. In the northern portion of the range, occurrence tends to be seasonal. When sardine abundance is low, as during the 1960s and 1970s, sardine do not occur in commercial quantities north of Point Conception.

It is generally accepted that sardine off the West Coast of North America consists of three subpopulations or stocks. A northern subpopulation (northern Baja California to Alaska), a southern subpopulation (off Baja California), and a Gulf of California subpopulation were distinguished on the basis of serological techniques (Vrooman 1964) and, more recently, a study of temperature-at capture (Felix-Uraga et al., *In Press*). A recent electrophoretic study (Hedgecock et al. 1989) showed, however, no genetic variation among sardine from central and southern California, the Pacific coast of Baja California, or the Gulf of California. A fourth, far northern subpopulation, has also been postulated (Radovich 1982). Although the ranges of the northern and southern subpopulations overlap, the stocks may move north and south at similar times and not overlap significantly. The northern stock is exploited by U.S. fisheries and is included in the Coast Pelagic Species Fishery Management Plan (CPS-FMP; PFMC 1998).

Pacific sardine probably migrated extensively during historical periods when abundance was high, moving north as far as British Columbia in the summer and returning to southern California and northern Baja California in the fall. Tagging studies (Clark and Janssen 1945) indicate that the older and larger fish moved farther north. Migratory patterns were probably complex, and the timing and extent of movement were affected by oceanographic conditions (Hart 1973) and stock biomass. During the 1950s to 1970s, a period of reduced stock size and unfavorably cold sea surface temperatures apparently caused the stock to abandon the northern portion of its range. At present, the combination of increased stock size and warmer sea surface temperatures have resulted in the stock reoccupying areas off northern California, Oregon, Washington, and British Columbia. Abandonment and recolonization of the higher latitude portion of their range has been associated with changes in abundance of sardine populations around the world (Parrish et al. 1989).

Important Features of Life History that Affect Management

Life History

Pacific sardine may reach 41 cm, but are seldom longer than 30 cm. They may live as long as 14 years, but individuals in historical and current California commercial catches are usually younger than five years. In contrast, the most common ages in the historical Canadian sardine fishery were six years to eight years. There is a good deal of regional variation in size-at-age, with size increasing from south to north and from inshore to offshore (Phillips 1948, Hill 1999). Size- and age-at-maturity may decline with a decrease in biomass, but latitude and temperature are likely also important (Butler 1987). At low biomass levels, sardine appear to be fully mature at age one, whereas at high biomass levels only some of the two-year-olds are mature (MacCall 1979).

Age-specific mortality estimates are available for the entire suite of life history stages (Butler et al. 1993). Mortality is high at the egg and yolk sac larvae stages (instantaneous rates in excess of 0.66 d^{-1}). Adult natural mortality rates has been estimated to be $M=0.4.yr^{-1}$ (Murphy 1966; MacCall 1979) and 0.51 yr^{-1} (Clark and Marr 1955). A natural mortality rate of $M=0.4$ yr^{-1} means that 33% of the sardine stock would die each year of natural causes if there were no fishery.

Pacific sardine spawn in loosely aggregated schools in the upper 50 meters of the water column. Spawning occurs year-round in the southern stock and peaks April through August between San Francisco and Magdalena Bay, and January through April in the Gulf of California (Allen et al. 1990). Off California, sardine eggs are most abundant at sea surface temperatures of 13°C to 15°C and larvae are most abundant at 13°C to 16°C. Temperature requirements are apparently flexible, however, because eggs are most common at 22°C to 25° C and in the Gulf of California and at 17°C to 21°C off Southern Baja (Lluch-Belda et al. 1991).

The spatial and seasonal distribution of spawning is influenced by temperature. During periods of warm water, the center of sardine spawning shifts northward and spawning extends over a longer period of time (Butler 1987; Ahlstrom 1960). Recent spawning has been concentrated in the region offshore and north of Point Conception (Lo et al. 1996). Historically, spawning may also have been fairly regular off central California. Spawning was observed off Oregon (Bentley et al. 1996), and young fish were seen in waters off British Columbia in the early fishery (Ahlstrom 1960) and during recent years (Hargreaves et al. 1994). The main spawning area for the historical population off the U.S. was between Point Conception and San Diego, California, out to about 100 miles offshore, with evidence of spawning as far as 250 miles offshore (Hart 1973).

Sardine are oviparous multiple-batch spawners with annual fecundity that is indeterminate and highly age or size dependent. Butler et al. (1993) estimate that two-year-old sardine spawn on average six times per year whereas the oldest sardine spawn 40 times per year. Both eggs and larvae are found near the surface. Sardine eggs are spheroid, have a large perivitelline space, and require about three days to hatch at 15°C.

Sardine are planktivores that consume both phytoplankton and zooplankton. When biomass is high, Pacific sardine may consume a significant proportion of total organic production in the California Current system. Based on an energy budget for sardine developed from laboratory experiments and estimates of primary and secondary production in the California Current, Lasker (1970) estimated that annual energy requirements of the sardine population would have been about 22% of the annual primary production and 220% of the secondary production during 1932 to 1934, a period of high sardine abundance.

Pacific sardine are taken by a variety of predators throughout all life stages. Sardine eggs and larvae are consumed by an assortment of invertebrate and vertebrate planktivores. Although it has not been demonstrated in the field, anchovy predation on sardine eggs and larvae was postulated as a possible mechanism for increased larval sardine mortality from 1951 through 1967 (Butler 1987). There have been few studies about sardine as forage, but juvenile and adult sardine are consumed by a variety of predators, including commercially important fish (e.g., yellowtail, barracuda, bonito, tuna, marlin, mackerel, hake, salmon, and sharks), seabirds (pelicans, gulls, and cormorants), and marine mammals (sea lions, seals, porpoises, and whales). In all probability, sardine are fed on by the same predators (including endangered species) that utilize anchovy. It is also likely that sardine will become more important as prey as their numbers increase. For example, while sardine were abundant during the 1930s, they were a major forage species for both coho and chinook salmon off Washington (Chapman 1936).

Abundance, Recruitment, and Population Dynamics

Extreme natural variability and susceptibility to recruitment overfishing are characteristic of clupeoid stocks like Pacific sardine (Cushing 1971). Estimates of the abundance of sardine from 1780 through 1970 have been derived from the deposition of fish scales in sediment cores from the Santa Barbara basin off southern California (Soutar and Issacs 1969, 1974; Baumgartner et al. 1992). Significant sardine populations existed throughout the period with biomass levels varying widely. Both sardine and anchovy populations tend to vary over periods of roughly 60 years, although sardine have varied more than anchovy. Sardine population declines were characterized as lasting an average of 36 years; recoveries lasted an average of 30 years. Biomass estimates of the sardine population inferred from scale-deposition rates in the 19th and 20th centuries (Soutar and Isaacs 1969; Smith 1978) indicate that the biomass peaked in 1925 at about six million mt.

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

Sardine spawning biomass estimated from catch-at-age analysis averaged 3.5 million mt from 1932 through 1934, fluctuated between 1.2 million mt to 2.8 million mt over the next ten years, then declined steeply during 1945 through 1965, with some short-term reversals following periods of particularly successful recruitment (Murphy 1966; MacCall 1979). During the 1960s and 1970s, spawning biomass levels were thought to be less than about five thousand to ten thousand mt (Barnes et al. 1992). The sardine stock began to increase by an average rate of 27% annually in the early 1980s (Barnes et al. 1992). Recent estimates (Hill et al. 1999; Conser et al. 2003) indicate that the total biomass of sardine age one or older is greater than one million metric tons.

Recruitment success in sardine is generally autocorrelated and affected by environmental processes occurring on long (decadal) time scales. Lluch-Belda et al. (1991) and Jacobson and

MacCall (1995) demonstrated relationships between recruitment success in Pacific sardine and sea surface temperatures measured over relatively long periods (i.e., three years to five years). Their results suggest that equilibrium spawning biomass and potential sustained yield is highly dependent upon environmental conditions associated with elevated sea surface temperature conditions.

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

MacCall (1979) estimated that the average potential population growth rate of sardine was 8.5% during the historical fishery while the population was declining. He concluded that, even with no fishing mortality, the population on average was capable of little more than replacement. Jacobson and MacCall (1995) obtained similar results for cold, unproductive regimes, but also found that the stock was very productive during warmer regimes.

MSY for the historical Pacific sardine population was estimated to be 250,000 mt annually (MacCall 1979; Clark 1939), which is far below the catch of sardine during the peak of the historical fishery. Jacobson and MacCall (1995) found that MSY for sardine depends on environmental conditions, and developed a stock-recruitment model that incorporates a running average of sea-surface temperature measured off La Jolla, California. This stock-recruitment model has been used in recent assessments.

Relevant History of the Fishery

The sardine fishery was first developed in response to demand for food during World War I. Landings increased from 1916 to 1936, and peaked at over 700,000 mt. Pacific sardine supported the largest fishery in the western hemisphere during the 1930s and 1940s, with landings along the coast in British Columbia, Washington, Oregon, California, and Mexico. The fishery declined, beginning in the late 1940s and with some short-term reversals, to extremely low levels in the 1970s. There was a southward shift in the catch as the fishery decreased, with landings ceasing in the northwest in 1947 through 1948, and in San Francisco in 1951 through 1952. Sardine were primarily used for reduction to fish meal, oil, and as canned food, with small quantities taken for live bait. An extremely lucrative dead bait market developed in central California in the 1960s.

In the early 1980s, sardine fishers began to take sardine incidentally with Pacific (chub) mackerel and jack mackerel in the southern California mackerel fishery. Sardine were primarily canned for pet food, although some were canned for human consumption. As sardine continued to increase in abundance, a directed purse-seine fishery was reestablished. Sardine landed in the directed sardine U.S. fisheries are mostly frozen and sold overseas as bait and aquaculture feed, with minor amounts canned or sold fresh for human consumption and animal food. Small quantities are harvested live bait.

Besides San Pedro and Monterey, California, significant Pacific sardine landings are now made in the Pacific northwest and in Baja California, Mexico. Sardine landed in Mexico are used primarily for reduction and canning. Mexico does not currently place catch restrictions on its directed sardine fishery.

Management History

The sardine fishery developed in response to an increased demand for protein products that arose during World War I. The fishery developed rapidly and became so large that by the 1930s sardines accounted for almost 25% of all fish landed in the U.S. (Leet et al. 2001). Coast wide landings exceeded 350,000 mt each season from 1933 through 1934 to 1945 through 1946; 83% to 99% of these landings were made in California, the remainder in British Columbia, Washington, and Oregon. Sardine landings peaked at over 700,000 tons in 1936. In the early 1930s, the state of California implemented management measures including control of tonnage for reduction, case pack requirements, and season restrictions.

In the late 1940s, sardine abundance and landings declined dramatically (MacCall 1979; Radovich 1981). The decline has been attributed to a combination of overfishing and environmental conditions, although the relative importance of the two factors is still open to debate (Clark and Marr 1955; Jacobson and MacCall 1995). Reduced abundance was accompanied by a southward shift in the range of the resource and landings (Radovich 1981). As a result, harvests ceased completely in British Columbia, Washington, and Oregon in the late 1940s, but significant amounts continued to be landed in California through the 1950s.

During 1967, in response to low sardine biomass, the California legislature imposed a two-year moratorium that eliminated directed fishing for sardine, and limited the take to 15% by weight in mixed loads (primarily jack mackerel, Pacific [chub] mackerel and sardines); incidentally-taken sardines could be used for dead bait. In 1969, the legislature modified the moratorium by limiting dead bait usage to 227 mt (250 short tons). From 1967 to 1974, a lucrative fishery developed that supplied dead bait to striped bass anglers in the San Francisco Bay-Delta area. Sardine biomass remained at low levels and, in 1974, legislation was passed to permit incidentally-taken sardines to be used only for canning or reduction. The law also included a recovery plan for the sardine population, allowing a 907 mt (1,000-short ton) directed quota only when the spawning population reached 18,144 mt (20,000 short tons), with increases as the spawning stock increased further.

Management Since Onset of the Recovery

In the late 1970s and early 1980s, CDFG began receiving anecdotal reports about the sighting, setting, and dumping of "pure" schools of juvenile sardines, and the incidental occurrence of sardines in other fisheries, suggesting increased abundance (CDFG 1986). In 1986, the state lifted its 18-year moratorium on sardine harvest on the basis of sea-survey and other data indicating that the spawning biomass had exceeded 18,144 mt (20,000 short tons). CDFG Code allowed for a directed fishery of at least 907 mt once the spawning population had returned to this level. California’s annual directed quota was set at 907 mt (1,000 short tons) during 1986 to

1990; increased to 10,886 mt in 1991, 18,597 mt in 1992, 18,144 mt in 1993, 9,072 mt in 1994, 47,305 mt in 1995, 34,791 mt in 1996, 48,988 mt in 1997, 43,545 mt in 1998, and 120,474 mt in 1999.

Management Under the PFMC CPS Fishery Management Plan (2000-present)

In January 2000, management authority for the U.S. Pacific sardine fishery was transferred to the Pacific Fishery Management Council. Pacific sardine was one of five species included in the federal CPS-FMP (PFMC 1998). The CPS-FMP includes a maximum sustainable yield (MSY) control rule intended to prevent Pacific sardine from being overfished and maintain relatively high and consistent catch levels over a long-term horizon. The harvest formula for sardine is provided at the end of this report (see section '**Harvest Guideline for 2005')**. A thorough description of PFMC management actions for sardine, including harvest guidelines, may be found in the most recent CPS SAFE document (PFMC 2004b).

ASSESSMENT DATA

Biological Parameters

Stock Structure

The stock structure that has been used for Pacific sardine assessment assumes a single stock that extends from northern Baja California, Mexico to British Columbia, Canada and extends well offshore, perhaps 200 nm or more (Hill et al. 1999). More specifically, all USA and Canadian landings are assumed to be taken from the single stock being accessed. Similarly, all sardine landed in Ensenada, Baja California, Mexico are also assumed to be taken from the single stock being accessed. But for stock assessment purposes, sardine landed in Mexican ports south of Ensenada are considered to be part of another stock that may extend from southern Baja California into the Gulf of California. In the future, alternative stock structure scenarios will be explored as ongoing research becomes available.

Length-weight Relationship

The length-weight relationship for Pacific sardine was modeled using fish measured from survey and port samples collected from 1982 to 2004. The following power function was used to determine the relationship between weight (g) and standard length (mm) 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. The estimated coefficients were $a = 0.000001$ and $b = 3.113$ (corrected $R^2 = 0.928$; $n = 86,606$).

Length-at-age Relationship

The von Bertalanffy growth equation was used to derive the relationship between standard length (mm) and age (yr) for Pacific mackerel:

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

where L_A is the length-at-age A, L_∞ (‘L infinity’) is the theoretical maximum size (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 sardine was: L_∞ = 244 mm, K = 0.319, and t_o = -2.503 (corrected R^2 = 0.561; n = 86,606).

Maximum Age and Size

The largest recorded Pacific sardine was 410 mm long (Eschmeyer et al. 1983), but the largest Pacific sardine taken by commercial fishing since 1983 was 288 mm and 323 g. The oldest recorded age for a Pacific sardine was 14 years, but most commercially-caught sardine are typically less than four years old.

Maturity Schedule

The maturity schedule provided in Table 1 was used for all model runs (Hill et al. 1999). The “Coded Age” appears in all model input and output files (such as those in the appendices). The correspondence between “Coded Age” and “True Age” is also provided in the table.

Natural Mortality

Adult natural mortality rates has been estimated to be M=0.4.yr^{-1} (Murphy 1966; MacCall 1979) and 0.51 yr^{-1} (Clark and Marr 1955). A natural mortality rate of M=0.4 yr^{-1} means that 33% of the sardine stock would die each year of natural causes if there were no fishery. Consistent with previous assessments, the instantaneous rate of natural mortality was taken as 0.4 yr^{-1} for all ages and years (Murphy 1966, Deriso et al. 1996, Hill et al. 1999).

Fishery Data

Overview

Following the recommendations of the CPS STAR Panel (PFMC 2004), all fishery inputs were recompiled based on a ‘biological year’ of July (year *x*) through June (year *x*+1). Labeling of inputs and outputs uses the more recent year of the ‘biological’ year (e.g., 2003-04 data are labeled ‘2004’). A complete listing of the ASAP input file may be found in Appendix III. In the input and output files, the sardine fisheries (or Fleets) are assigned numbers are follows:

ASAP Fleet Number	***Corresponding Sardine Fishery***
1	California (primarily San Pedro and Monterey)
2	Ensenada (northern Baja California, Mexico)
3	Pacific Northwest (Oregon, Washington, British Columbia)

Catch-at-age

Pacific sardine are aged by fishery biologists in Mexico, California, and the Pacific Northwest, using annuli in sagittal otoliths. A birth date of July 1 was assumed when assigning ages to California, Oregon, and Washington samples. Ensenada age assignments were adjusted to match this assumption *post-hoc* by subtracting one year of age from fish caught during the first semester of the calendar year. A thorough description of sardine otolith ageing techniques can be found in Yaremko (1996). Sample sizes by fishery and biological year are provided in Table

2.

Catch-at-age data for each fishery are provided in Tables 3-5, and proportions-at-age are displayed in Figures 1-3. Catch-at-age matrices were developed for each fishery using port sample and landings data aggregated by month. 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 (July-June) to provide the catch-at-age (thousands of fish) for each biological year. Individuals five years of age and older were pooled into a ‘plus’ group, and sexes were pooled for the assessment. For years and fisheries where age sampling was carried out, an effective sample size (λ) of 50 was used. For cases with landings but no samples, effective sample size was set to zero.

Historical catch-at-age data (1932-65) were examined for possible use in the modeling (Kohin et al. 2004). Problems with consistency of the ageing during significant parts of the historical period coupled with the lack of indices of abundance for the period, made these data difficult to use in conjunction with data from the contemporary period (1983-2003). While the historical data were not used formally in the modeling, the historical VPA biomass estimates derived from them were used qualitatively for establishing the scale for virgin SSB estimates in the ASAP modeling of the contemporary period.

Fishery weight at age

Mean weights-at-age were calculated for each fishery and biological year by dividing total sampled weight of fish-at-age by the total number of fish-at-age. The current version of ASAP is only configured to accommodate one weight-at-age matrix, so a pooled weight-at-age was calculated by taking a weighted weight-at-age for the three fisheries, using respective landings in each year as a basis for the weighting. Pooled fishery weights-at-age applied in ASAP are provided in Table 6 and Figure 4.

Population weight at age

Because the sardine fisheries do not cover the stocks’ full geographic range (i.e., fishery coverage is generally inshore, whereas the spawning stock extends 200 miles offshore), fishery weight-at-age estimates are often smaller than those of the population as a whole. For the purposes of converting model-based stock numbers at age estimates into stock biomass (Ages 1+) estimates for management, biological samples from fishery-independent sources that span the geographical range of the stock (Table 7) were used to calculate population weights-at-age. Data included survey samples from summer 1998 and spring 2004.

Landings

Annual landings for each fishery are provided in Tables 3-5, and displayed in Figure 5.

Fishery-Independent Data

Overview

In the input and output files, the fisheries-independent indices of abundance are assigned numbers are follows:

Index Number	Corresponding Data	Represents
1	DEPM	SSB
2	Aerial Spotter	Biomass of Ages 0-2

Daily Egg Production Method (DEPM) Spawning Biomass Index (Index 1)

Daily egg production method (DEPM) biomass estimates were available 1986-2004 with several years missing from the series (Table 8). Lo (2003) provides the methodology employed and the sampling constraints. Note in particular that adult samples were not taken on a regular basis and consequently, it was necessary to assume that the adult reproductive parameters were constant for most years in the series. The index was taken to represent sardine SSB. The modeled selectivity pattern was set using the proportion maturity at age (Table 9).

Aerial Spotter Survey (Index 2)

Pilots employed by the fishing fleet to locate Pacific sardine (and other pelagic fish) schools report data for each flight on standardized logbooks and provide them under contract to NOAA Fisheries. Spotter indices for young sardine were calculated as year effects estimated using delta log-normal linear models (Lo et al. 1992). The spotter index covers the period 1986 through 2000 (Table 8). 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. The index was taken to represent the inshore, younger sardine (primarily ages 0-2; Table 9).

ASSESSMENT MODEL

ASAP MODEL

Overview

The Age-structured Assessment Program (ASAP) model (Legault and Restrepo 1998; Appendix I) is based on the AD Model Builder (ADMB) software environment, which is essentially a high-level programming language that utilizes C++ libraries for nonlinear optimization (Otter Research 2001). Further, the ASAP model is maintained through the NOAA Fisheries Toolbox Project (NFT), which includes various fishery-related models that have been customized with graphical user interfaces (GUIs) to enable users to conduct modeling exercises and evaluate results more easily. Further, the ADMB code is provided so that experienced users can make modifications to meet specific needs.

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 underpinnings of ASAP are well established and date back to Fournier and Archibald (1982). However, reliable implementation of such large scale models for fisheries stock assessment has only become practical during the past decade as microprocessors have become powerful enough to handle the computational demands and professional quality optimization software (ADMB) has been developed.

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 (1998; Appendix I).

- 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 and/or catchability can be incorporated via the estimation of random walks.
- Predicted catch in weight and catch-at-age are estimated using the Baronov 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 includes nine likelihood components and a few penalties, given a baseline population model (e.g., see Table 10).
- 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.

Assessment Program with Last Revision Date

ASAP version 1.3.2 (September 2004) was used for all runs presented in this paper. A listing of the ADMB code (template file) is provided in Appendix II.

Likelihood Components and Model Parameters

Parameterization summaries for the baseline ASAP model are provided in Table 11. See also Appendix IV for a complete 'report' file (i.e., output file, including input data, fixed and estimated parameter values, etc.).

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.

MODEL RESULTS

Overview

An ASAP model was developed initially by mimicking (to the extent possible) the structure employed in the last CANSAR-TAM stock assessment (Conser et al 2003). However, as noted above, recent assessments have not used the fisheries data from the northern area (OR+WA+BC) – instead fish were moved from the modeled southern area at fixed transfer rates. In this implementation of ASAP, fisheries data from the northern area were fully incorporated and no assumptions were made regarding sardine migration rates. The initial model configuration was then modified following recommendations of the June 2004 STAR Panel and further examination of model diagnostics. This process resulted in the baseline model described herein.

In the ASAP baseline model, most parameters were freely estimated without strong constraints or penalties. The likelihood components at the optimal solution are provided in Table 10. 132 parameters were estimated (Table 11). Model run times were usually only a few minutes and generally converged without problem, and with a positive-definite Hessian matrix. Limited exploration of the response surface via adjustments to the starting values did not uncover additional local minima. CV's were reasonable for most of the key model parameters including the derived parameters such as SSB (Table 11).

Catch

Model fit to catch data for each fishery is displayed in Figures 6-8. The observed and predicted time series essentially overlay each other, indicating a precise fit to this data source.

Catch-at-age

Model residuals for catch-at-age data are displayed in Figure 9. Residuals for the three fisheries were random, with no obvious trends over age or time.

Indices of Abundance

Model fit to DEPM data is displayed in Figure 10.
Model fit to Aerial Spotter data is displayed in Figure 11.
A comparison of data for the two indices may be found in Figure 12.

Selectivity Estimates

The estimated selectivities (*S*-at-age) for the three respective fisheries are displayed in Figures 13-15. Selectivities for the California fishery were estimated for two periods: 1983-1991 (biological years) when the population was smaller, quotas were lower, a significant portion of landed sardine were captured mixed with schools of jack and Pacific mackerel; and 1992-2005, when the population was larger, quotas were higher, and pure schools of sardine were targeted. Estimated selectivity patterns for the California and Ensenada fisheries were dome-shaped (Figures 13 and 14), with 2 year old fish (coded age 3) being fully selected. Relative paucity of older ages in these two fisheries is likely an artifact of availability (larger, older fish offshore or north of the fishing grounds) as opposed to gear- or market-related causes. Estimated selectivity for the Pacific Northwest fishery is asymptotic (Figure 15), with the oldest two ages being more or less fully selected. Again, this likely reflects the coastwide distribution of sardine population.

Fishing Mortality Rate

Fishing mortality estimates for the three respective fisheries are displayed in Figures 16-18. Combined fishing mortality-at-age is displayed in Figure 19 and Table 12b.

Spawning Stock Biomass

Population SSB from the final model is provided in Table 12a.

Recruitment

Recruitment estimates are presented in Table 12a and displayed in Figure 20.

Stock-recruitment Relationship

The relationship between SSB and recruitment is displayed in Figure 21.

Biomass of Stock for PFMC Management (Ages 1+)

Stock biomass (age 1+) estimates are presented in Table 12a and displayed in Figure 22.

Model Diagnostic Examinations

For the most part, diagnostics were reasonable. In particular, the results were not characterized by the lack of fit in the some abundance indices that appeared in previous assessments.

Areas of Uncertainty

The principal areas of uncertainty are:

1. consistent fishery-independent surveys have been limited to waters off central & southern California;

2. biological sampling of adults has been sparse in offshore waters outside the range of the

USA, Mexican, and Canadian fisheries;

3. stock structure and migration rates are not well understood and require further research efforts.

HARVEST GUIDELINE FOR 2005

The harvest guideline recommended for the USA (California, Oregon, and Washington) Pacific sardine fishery for calendar year 2005 is 136,179 mt. Statistics used to determine this harvest guideline are discussed below and presented in Table 13. To calculate the proposed harvest guideline for 2005, we used the maximum sustainable yield (MSY) control rule defined in Amendment 8 of the Coastal Pelagic Species-Fishery Management Plan, Option J, Table 4.2.5-1, PFMC (1998). This formula is intended to prevent Pacific sardine from being overfished and maintain relatively high and consistent catch levels over a long-term horizon. The Amendment 8 harvest formula for sardine is:

$HG_{2005} = (BIOMASS_{2004} - CUTOFF) \bullet FRACTION \bullet USA\ DISTRIBUTION$

where HG_{2005} is the total USA (California, Oregon, and Washington) harvest guideline recommended for 2005, $BIOMASS_{2004}$ is the estimated July 1,2004 stock biomass (ages 1+) from the current assessment (see above), CUTOFF is the lowest level of estimated biomass at which harvest is allowed (150,000 mt), FRACTION is an environment-based percentage of biomass above the CUTOFF that can be harvested by the fisheries (see below), and USA DISTRIBUTION (87%) is the percentage of $BIOMASS_{2004}$ assumed in USA waters. The value for FRACTION in the MSY control rule for Pacific sardine is a proxy for F_{msy} (i.e., the fishing mortality rate that achieves equilibrium MSY). Given F_{msy} and the productivity of the sardine stock have been shown to increase when relatively warm-ocean conditions persist, the following formula has been used to determine an appropriate (sustainable) FRACTION value:

$FRACTION \text{ or } F_{msy} = 0.248649805(T^2) - 8.190043975(T) + 67.4558326,$

where T is the running average sea-surface temperature at Scripps Pier, La Jolla, California during the three preceding seasons (July-June). Ultimately, under Option J (PFMC 1998), F_{msy} is constrained and ranges between 5% and 15%. Based on the T values observed throughout the period covered by this stock assessment (1983-2004; Table 8), the appropriate F_{msy} exploitation fraction has consistently been 15%; and this remains the case under current oceanic conditions ($T_{2004} = 17.69$ °C). The 2005 USA harvest guideline (136,179 mt) is 11% higher than the 2004 harvest guideline (122,747 mt). Recent fishery practices and market conditions indicate that it may not be constraining with regard to USA fishery landings in 2005 (PFMC 2004b).

However, recent recruitment levels are not well-estimated, resulting in a high degree of uncertainty with respect to recent recruitment. If the actual recruitment in recent years is less than that estimated in the model and/or should the general sea-surface temperature decline continue, it is likely that harvest guidelines in the out years will constrain USA fishery practices and removals. Further when viewed on a stock-wide basis and considering the landings of Mexico and Canada as well as the USA (Table 14), adherence to an implied ‘stock-wide harvest guideline’ may constrain fisheries even without recruitment and sea-surface temperature declines.

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Table 1. Maturity schedule applied in the baseline model to calculate spawning stock biomass.

Coded Age (ASAP)	True Age	% Mature
1	0	30
2	1	53
3	2	91
4	3	97
5	4	99
6	5+	100

Table 2. Pacific sardine landings (mt) and samples (number of fish) for production of fishery catches-at-age (see Tables 3-5).

	-------- CALIFORNIA --------			-------- ENSENADA --------			-- PACIFIC NORTHWEST --		
Biological Year	Landings (mt)	# Fish	Fish per 1,000 mt	Landings (mt)	# Fish	Fish per 1,000 mt	Landings (mt)	# Fish	Fish per 1,000 mt
1982-83	337	941	2,791	150	0	0	0	---	---
1983-84	248	599	2,413	124	0	0	0	---	---
1984-85	397	214	539	3,174	0	0	0	---	---
1985-86	1,191	1,150	965	647	0	0	0	---	---
1986-87	1,548	1,517	980	1,118	0	0	0	---	---
1987-88	3,810	2,855	749	2,077	0	0	0	---	---
1988-89	2,919	1,634	560	1,876	34	18	0	---	---
1989-90	3,659	1,486	406	11,663	170	15	0	---	---
1990-91	5,856	2,344	400	14,746	901	61	0	---	---
1991-92	9,574	2,040	213	25,447	2,179	86	0	---	---
1992-93	24,320	3,683	151	49,890	719	14	4	0	0
1993-94	12,431	1,148	92	19,108	346	18	0	---	---
1994-95	32,902	3,668	111	33,393	494	15	0	---	---
1995-96	29,820	2,626	88	32,835	500	15	23	0	0
1996-97	29,027	4,509	155	36,897	478	13	44	0	0
1997-98	56,172	4,181	74	75,179	485	6	28	0	0
1998-99	51,005	3,177	62	62,333	537	9	563	31	55
1999-00	60,360	2,672	44	49,609	553	11	1,155	178	154
2000-01	52,916	3,196	60	34,681	512	15	17,923	2,006	112
2001-02	52,981	4,283	81	29,436	362	12	25,683	2,581	100
2002-03	60,714	3,216	53	39,814	55	1	36,123	2,834	78
2003-04	29,451	3,572	121	35,723	0	0	39,861	2,215	56

Table 3. Pacific sardine catch-at-age (thousands of fish) and landings (metric tons), 1983-2005 seasons (July-June), for the USA-California fishery (Fishery 1). Landings for 2005 (i.e. 2004-05) were projected.

	Catch-at-Age (thousands)						
Year	0	1	2	3	4	5+	Landings (mt)
1983	0	880	1,261	261	56	8	337
1984	398	740	1,135	78	3	0	248
1985	17	804	1,611	282	0	0	397
1986	19	2,273	4,907	715	40	0	1,191
1987	185	1,167	5,924	2,305	175	26	1,548
1988	38	14,431	9,912	3,757	676	58	3,810
1989	356	4,999	11,193	2,602	786	109	2,919
1990	188	15,741	9,135	1,533	91	0	3,659
1991	1,350	9,506	14,557	10,456	5,050	2,919	5,856
1992	7,452	21,252	28,460	12,301	5,303	5,714	9,574
1993	33,463	147,999	98,106	22,749	5,997	3,354	24,320
1994	26,760	41,603	50,290	30,094	5,058	2,043	12,431
1995	206,712	236,588	64,598	29,723	4,091	868	32,902
1996	84,888	240,038	132,467	12,176	1,793	122	29,820
1997	89,636	96,347	136,744	57,311	7,157	2,119	29,027
1998	49,163	325,948	218,952	97,980	31,395	5,755	56,172
1999	219,059	601,996	183,576	25,483	14,214	1,990	51,005
2000	209,576	729,802	252,952	13,953	5,931	1,325	60,360
2001	173,501	260,540	283,685	157,218	12,562	1,851	52,916
2002	525,651	184,094	148,101	105,555	20,576	6,988	52,981
2003	126,574	568,045	156,788	31,379	10,102	2,505	60,714
2004	398,822	78,957	93,111	20,654	8,127	4,546	29,451
2005	0	0	0	0	0	0	*35,824*

Table 4. Pacific sardine catch-at-age (thousands of fish) and landings (metric tons), 1983-2004 seasons (July-June), for the segment of the Mexican fishery that lands its product in Ensenada, Baja California, Mexico (Fishery 2). Ensenada landings for 2004 and 2005 (i.e. 2003-04 and 2004-05) were based on incomplete data and projected.

	------------------------ Catch-at-Age (thousands) ------------------------						
Year	0	1	2	3	4	5+	Landings (mt)
1983	0	0	0	0	0	0	150
1984	0	0	0	0	0	0	124
1985	0	0	0	0	0	0	3,174
1986	0	0	0	0	0	0	647
1987	0	0	0	0	0	0	1,118
1988	0	0	0	0	0	0	2,077
1989	0	0	0	0	0	0	1,876
1990	30,029	35,488	15,431	4,272	1,887	66	11,663
1991	26,364	41,035	34,641	8,016	1,643	1,440	14,746
1992	20,559	68,135	50,263	41,932	18,599	8,898	25,447
1993	236,304	512,739	53,762	395	263	0	49,890
1994	103,939	69,104	120,215	8,697	0	0	19,108
1995	262,031	174,392	55,347	42,693	5,253	0	33,393
1996	191,289	144,459	85,039	17,658	5,799	0	32,835
1997	39,883	112,217	132,568	46,846	23,194	2,034	36,897
1998	44,799	157,950	266,468	184,200	79,962	23,397	75,179
1999	267,923	285,025	154,083	102,701	64,506	13,703	62,333
2000	306,257	246,127	162,450	81,398	31,978	13,576	49,609
2001	81,157	205,539	65,525	24,266	5,892	1,205	34,681
2002	204,814	130,416	65,163	7,237	1,081	0	29,436
2003	0	0	0	0	0	0	39,814
2004	0	0	0	0	0	0	35,723
2005	0	0	0	0	0	0	35,723

Table 5. Pacific sardine catch-at-age (thousands of fish) and landings (metric tons), 1983-2004 seasons (July-June), for the fisheries off Oregon and Washington, USA and British Columbia, Canada (Fishery 3). Landings for 2005 (i.e. 2004-05) were projected.

	------------------- Catch-at-Age (thousands) --------------------						
Year	0	1	2	3	4	5+	Landings (mt)
1983	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	4
1994	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	23
1997	0	0	0	0	0	0	44
1998	0	0	0	0	0	0	28
1999	0	0	0	0	0	0	563
2000	0	0	3,791	1,937	1,040	2,262	1,155
2001	0	1,814	45,205	48,656	19,198	13,823	17,923
2002	178	3,499	21,320	70,724	44,439	26,569	25,683
2003	0	1,726	6,647	28,202	73,487	87,564	36,123
2004	0	4,639	39,204	37,741	26,634	127,556	39,861
2005	0	0	0	0	0	0	38,158

Table 6. Pacific sardine fishery weight-at-age (kg), 1983-2005 seasons (July-June). Values are weighted estimates based on landings of the three respective fisheries.

	--------------	Fishery	Weight-at-Age (kg)	-----------------		
Year	0	1	2	3	4	5+
1983	0.0685	0.1179	0.1281	0.1548	0.1840	0.1871
1984	0.0692	0.0871	0.1379	0.1539	0.1674	0.1870
1985	0.0830	0.1077	0.1351	0.1485	0.1636	0.1599
1986	0.0738	0.1168	0.1482	0.1702	0.1847	0.1860
1987	0.0539	0.1106	0.1498	0.1641	0.1842	0.1722
1988	0.0867	0.1074	0.1423	0.1685	0.1826	0.1875
1989	0.0690	0.1013	0.1478	0.1691	0.1845	0.1948
1990	0.1087	0.1299	0.1534	0.1612	0.1700	0.1645
1991	0.0824	0.1219	0.1432	0.1524	0.1549	0.1588
1992	0.0593	0.0973	0.1322	0.1465	0.1567	0.1695
1993	0.0545	0.0615	0.0948	0.1227	0.1607	0.1458
1994	0.0473	0.0705	0.0794	0.0822	0.1309	0.1456
1995	0.0503	0.0620	0.0870	0.0953	0.1025	0.1151
1996	0.0574	0.0693	0.0786	0.0958	0.1112	0.1161
1997	0.0634	0.0765	0.1070	0.1143	0.1213	0.1221
1998	0.0491	0.0729	0.0943	0.1141	0.1182	0.1184
1999	0.0417	0.0561	0.0777	0.1024	0.1041	0.1149
2000	0.0502	0.0563	0.0616	0.0638	0.0690	0.0902
2001	0.0540	0.0758	0.0873	0.0940	0.1047	0.1285
2002	0.0404	0.0675	0.0995	0.1154	0.1340	0.1510
2003	0.0540	0.0836	0.1002	0.1131	0.1287	0.1456
2004	0.0466	0.0855	0.0990	0.1115	0.1341	0.1475
2005	0.0466	0.0855	0.0990	0.1115	0.1341	0.1475

Table 7. Pacific sardine population weight-at-age (kg) used to calculate the total stock biomass (Ages 1+) for management.

	------- Population Weight-at-Age (kg) --------				
Year	1	2	3	4	5+
1983	0.1031	0.1467	0.1681	0.1721	0.1791
1984	0.1031	0.1467	0.1681	0.1721	0.1791
1985	0.1031	0.1467	0.1681	0.1721	0.1791
1986	0.1031	0.1467	0.1681	0.1721	0.1791
1987	0.1031	0.1467	0.1681	0.1721	0.1791
1988	0.1031	0.1467	0.1681	0.1721	0.1791
1989	0.1031	0.1467	0.1681	0.1721	0.1791
1990	0.1031	0.1467	0.1681	0.1721	0.1791
1991	0.1031	0.1467	0.1681	0.1721	0.1791
1992	0.1031	0.1467	0.1681	0.1721	0.1791
1993	0.1031	0.1467	0.1681	0.1721	0.1791
1994	0.1031	0.1467	0.1681	0.1721	0.1791
1995	0.1031	0.1467	0.1681	0.1721	0.1791
1996	0.1031	0.1467	0.1681	0.1721	0.1791
1997	0.1031	0.1467	0.1681	0.1721	0.1791
1998	0.1031	0.1467	0.1681	0.1721	0.1791
1999	0.1031	0.1467	0.1681	0.1721	0.1791
2000	0.1031	0.1467	0.1681	0.1721	0.1791
2001	0.1031	0.1467	0.1681	0.1721	0.1791
2002	0.1031	0.1467	0.1681	0.1721	0.1791
2003	0.1031	0.1467	0.1681	0.1721	0.1791
2004	0.1031	0.1467	0.1681	0.1721	0.1791
2005	0.1031	0.1467	0.1681	0.1721	0.1791

Table 8. Pacific sardine time series of survey indices of relative abundance and sea-surface temperature, 1983-2004. The SST is a moving average of monthly SST observations for the three-year period prior to July 1st of the given year.

Year	DEPM (mt)	Aerial Spotter (mt)	SST at SIO Pier (°C)
1983	na	na	17.25
1984	na	na	17.58
1985	na	na	17.80
1986	7,659	22,049	17.87
1987	15,704	11,498	17.71
1988	13,526	55,882	17.55
1989	na	32,929	17.24
1990	na	21,144	17.19
1991	na	40,571	17.35
1992	na	49,065	17.61
1993	na	84,070	17.84
1994	127,102	211,293	17.97
1995	Na	188,924	18.04
1996	83,175	119,731	18.06
1997	409,579	66,943	18.06
1998	313,985	118,492	18.44
1999	282,248	40,506	18.04
2000	1,063,837	48,373	17.73
2001	790,925	na	17.24
2002	206,333	na	17.31
2003	485,121	na	17.50
2004	281,639	na	17.69
2005	na	na	na

Table 9. Selectivities applied to survey data in the ASAP model. See survey sections for details.

	Age					
Survey	0	1	2	3	4	5+
DEPM						
1983-2004	0.30	0.53	0.91	0.97	0.99	1.00
Aerial Spotter						
1983-2004	1.00	1.00	0.59	0.18	0.03	0.00

Table 10. Likelihood components for the baseline model in which 132 parameters were estimated. See text for definitions of fleet (fishery) numbers and index numbers.

Component	**RSS**	**nobs**	**Lambda**	**Likelihood**	**% of Total**
Catch_Fleet_1	0.002610	23	100	0.260966	
Catch_Fleet_2	0.005849	23	100	0.584863	
Catch_Fleet_3	0.121991	23	100	12.199100	
Catch_Fleet_Total	**0.130450**	69	100	**13.045000**	3%
Discard_Fleet_1	0.000000	23	0	0.000000	
Discard_Fleet_2	0.000000	23	0	0.000000	
Discard_Fleet_3	0.000000	23	0	0.000000	
Discard_Fleet_Total	0.000000	69	0	0.000000	
CAA_proportions	N/A	414	50	**219.938000**	53%
Discard_proportions	N/A	414	0	0.000000	
Index_Fit_1	7.761820	13	1	37.066900	
Index_Fit_2	6.366530	15	1	27.745800	
Index_Fit_Total	**14.128300**	28	2	**64.812800**	16%
Selectivity_devs_fleet_1	14.271400	1	0	0.000000	
Selectivity_devs_fleet_2	0.000000	1	100	0.000000	
Selectivity_devs_fleet_3	0.000000	1	100	0.000000	
Selectivity_devs_Total	**14.271400**	3	200	**0.000000**	0%
Catchability_devs_index_1	0.000000	13	10	0.000000	
Catchability_devs_index_2	0.000000	15	10	0.000000	
Catchability_devs_Total	**0.000000**	28	20	**0.000000**	0%
Fmult_fleet_1	6.114370	22	1	6.114370	
Fmult_fleet_2	15.134800	22	1	15.134800	
Fmult_fleet_3	52.899900	22	1	52.899900	
Fmult_fleet_Total	**74.149100**	66	3	**74.149100**	18%
N_year_1	0.000000	5	0	0.000000	
Stock-Recruit_Fit	15.646900	23	1	29.083200	7%
Recruit_devs	15.646900	23	1	15.646900	4%
SRR_steepness	0.017840	1	0	0.000000	
SRR_virgin_stock	0.037199	1	5	0.185994	
Curvature_over_age	19.836700	12	0	0.000000	
Curvature_over_time	28.542800	378	0	0.000000	
F_penalty	2.058300	138	0.001	0.002058	
Mean_Sel_year1_pen	0.000000	18	1000	0.000000	
Max_Sel_penalty	2.718150	1	100	0.000000	
Fmult_Max_penalty	0.000000	?	100	0.000000	
TOTAL	**187.18**	**1760**		**416.86**	100%

Table 11. ASAP parameter estimates and standard deviations for the baseline model. The first 132 parameters are formal model parameters. The remaining are state variables derived from the formal model parameters. See text for definition of coded ages, fisheries, and indices.

Coded Age	Year	Fishery	Index	Parameter	Estimate	Standard Deviation
1	1983	1	1	log_sel_year1	-5.27E+00	1.45E+02
2	1983	1	2	log_sel_year1	-1.81E+00	1.45E+02
3	1983	1	3	log_sel_year1	-4.14E-01	1.45E+02
4	1983	1	4	log_sel_year1	-8.32E-01	1.45E+02
5	1983	1	5	log_sel_year1	-1.60E+00	1.45E+02
6	1983	1	6	log_sel_year1	-2.25E+00	1.45E+02
1	1983	2	7	log_sel_year1	-2.75E+00	2.51E+02
2	1983	2	8	log_sel_year1	-1.96E+00	2.51E+02
3	1983	2	9	log_sel_year1	-1.80E+00	2.51E+02
4	1983	2	10	log_sel_year1	-2.09E+00	2.51E+02
5	1983	2	11	log_sel_year1	-2.34E+00	2.51E+02
6	1983	2	12	log_sel_year1	-3.81E+00	2.51E+02
1	1983	3	13	log_sel_year1	-6.00E+00	9.23E-03
2	1983	3	14	log_sel_year1	-3.41E+00	5.93E-01
3	1983	3	15	log_sel_year1	-1.06E-01	2.20E-01
4	1983	3	16	log_sel_year1	7.60E-01	1.97E-01
5	1983	3	17	log_sel_year1	1.00E+00	1.28E-02
6	1983	3	18	log_sel_year1	7.63E-01	2.11E-01
1	1983	1	19	log_sel_devs_vector	3.54E+00	7.82E-01
2	1983	1	20	log_sel_devs_vector	1.20E+00	7.27E-01
3	1983	1	21	log_sel_devs_vector	-6.87E-02	7.23E-01
4	1983	1	22	log_sel_devs_vector	-2.19E-02	7.39E-01
5	1983	1	23	log_sel_devs_vector	-1.55E-01	8.25E-01
6	1983	1	24	log_sel_devs_vector	-5.23E-01	9.73E-01
1	1983	2	25	log_sel_devs_vector	0.00E+00	7.07E-02
2	1983	2	26	log_sel_devs_vector	0.00E+00	7.07E-02
3	1983	2	27	log_sel_devs_vector	0.00E+00	7.07E-02
4	1983	2	28	log_sel_devs_vector	0.00E+00	7.07E-02
5	1983	2	29	log_sel_devs_vector	0.00E+00	7.07E-02
6	1983	2	30	log_sel_devs_vector	0.00E+00	7.07E-02
1	1983	3	31	log_sel_devs_vector	0.00E+00	7.07E-02
2	1983	3	32	log_sel_devs_vector	0.00E+00	7.07E-02
3	1983	3	33	log_sel_devs_vector	0.00E+00	7.07E-02
4	1983	3	34	log_sel_devs_vector	0.00E+00	7.07E-02
5	1983	3	35	log_sel_devs_vector	0.00E+00	7.07E-02
6	1983	3	36	log_sel_devs_vector	0.00E+00	7.07E-02

Table 11 (continued). ASAP parameter estimates and standard deviations for baseline model.

Coded Age	**Year**	**Fishery**	**Index**	**Parameter**	**Estimate**	**Standard Deviation**
	1983	*1*	37	log_Fmult_year1	-1.32E+00	1.45E+02
	1983	*2*	38	log_Fmult_year1	-1.91E+00	2.51E+02
	1983	*3*	39	log_Fmult_year1	-1.50E+01	1.62E-02
	1984	*1*	40	log_Fmult_devs	-8.94E-01	1.36E-01
	1985	*1*	41	log_Fmult_devs	-6.77E-01	1.31E-01
	1986	*1*	42	log_Fmult_devs	4.40E-01	1.30E-01
	1987	*1*	43	log_Fmult_devs	-3.90E-02	1.30E-01
	1988	*1*	44	log_Fmult_devs	5.59E-01	1.35E-01
	1989	*1*	45	log_Fmult_devs	-8.56E-01	1.25E-01
	1990	*1*	46	log_Fmult_devs	-2.68E-01	1.28E-01
	1991	*1*	47	log_Fmult_devs	1.64E-01	1.18E-01
	1992	*1*	48	log_Fmult_devs	6.22E-08	7.07E-01
	1993	*1*	49	log_Fmult_devs	1.08E+00	1.09E-01
	1994	*1*	50	log_Fmult_devs	-7.08E-01	1.09E-01
	1995	*1*	51	log_Fmult_devs	5.96E-01	1.11E-01
	1996	*1*	52	log_Fmult_devs	-3.93E-01	1.07E-01
	1997	*1*	53	log_Fmult_devs	-2.46E-01	1.05E-01
	1998	*1*	54	log_Fmult_devs	7.98E-01	1.07E-01
	1999	*1*	55	log_Fmult_devs	8.90E-02	1.07E-01
	2000	*1*	56	log_Fmult_devs	2.64E-01	1.09E-01
	2001	*1*	57	log_Fmult_devs	-2.29E-01	1.06E-01
	2002	*1*	58	log_Fmult_devs	1.08E-01	1.11E-01
	2003	*1*	59	log_Fmult_devs	4.10E-03	1.22E-01
	2004	*1*	60	log_Fmult_devs	-7.05E-01	1.22E-01
	2005	*1*	61	log_Fmult_devs	-4.21E-02	1.38E-01
	1984	*2*	62	log_Fmult_devs	-9.24E-01	1.27E-01
	1985	*2*	63	log_Fmult_devs	2.41E+00	1.18E-01
	1986	*2*	64	log_Fmult_devs	-1.91E+00	1.09E-01
	1987	*2*	65	log_Fmult_devs	1.96E-01	1.15E-01
	1988	*2*	66	log_Fmult_devs	3.50E-02	1.21E-01
	1989	*2*	67	log_Fmult_devs	-4.88E-01	1.09E-01
	1990	*2*	68	log_Fmult_devs	1.23E+00	1.11E-01
	1991	*2*	69	log_Fmult_devs	1.49E-01	1.06E-01
	1992	*2*	70	log_Fmult_devs	5.15E-01	1.07E-01
	1993	*2*	71	log_Fmult_devs	8.15E-01	1.07E-01
	1994	*2*	72	log_Fmult_devs	-1.00E+00	1.08E-01
	1995	*2*	73	log_Fmult_devs	1.98E-01	1.09E-01
	1996	*2*	74	log_Fmult_devs	-2.81E-01	1.05E-01
	1997	*2*	75	log_Fmult_devs	-9.85E-02	1.04E-01
	1998	*2*	76	log_Fmult_devs	8.07E-01	1.06E-01
	1999	*2*	77	log_Fmult_devs	-1.78E-02	1.05E-01
	2000	*2*	78	log_Fmult_devs	-7.74E-02	1.07E-01
	2001	*2*	79	log_Fmult_devs	-4.58E-01	1.06E-01
	2002	*2*	80	log_Fmult_devs	-1.13E-01	1.09E-01

Table 11 (continued). ASAP parameter estimates and standard deviations for baseline model.

Coded Age	**Year**	**Fishery**	**Index**	**Parameter**	**Estimate**	**Standard Deviation**
	2003	*2*	81	log_Fmult_devs	2.19E-01	1.19E-01
	2004	*2*	82	log_Fmult_devs	-1.30E-01	1.23E-01
	2005	*2*	83	log_Fmult_devs	-1.64E-01	1.27E-01
	1984	*3*	84	log_Fmult_devs	-5.63E-02	6.55E-01
	1985	*3*	85	log_Fmult_devs	-5.61E-02	6.56E-01
	1986	*3*	86	log_Fmult_devs	-5.53E-02	6.56E-01
	1987	*3*	87	log_Fmult_devs	-5.10E-02	6.56E-01
	1988	*3*	88	log_Fmult_devs	-3.91E-02	6.56E-01
	1989	*3*	89	log_Fmult_devs	-1.68E-02	6.51E-01
	1990	*3*	90	log_Fmult_devs	3.92E-02	6.37E-01
	1991	*3*	91	log_Fmult_devs	1.86E-01	5.98E-01
	1992	*3*	92	log_Fmult_devs	6.36E-01	5.04E-01
	1993	*3*	93	log_Fmult_devs	3.05E+00	3.04E-01
	1994	*3*	94	log_Fmult_devs	-2.86E+00	2.80E-01
	1995	*3*	95	log_Fmult_devs	1.01E-01	3.36E-01
	1996	*3*	96	log_Fmult_devs	4.26E+00	2.49E-01
	1997	*3*	97	log_Fmult_devs	1.68E-01	1.17E-01
	1998	*3*	98	log_Fmult_devs	-5.43E-01	1.09E-01
	1999	*3*	99	log_Fmult_devs	3.09E+00	1.09E-01
	2000	*3*	100	log_Fmult_devs	1.11E+00	1.12E-01
	2001	*3*	101	log_Fmult_devs	2.32E+00	1.06E-01
	2002	*3*	102	log_Fmult_devs	2.37E-01	1.07E-01
	2003	*3*	103	log_Fmult_devs	5.14E-01	1.12E-01
	2004	*3*	104	log_Fmult_devs	1.67E-01	1.19E-01
	2005	*3*	105	log_Fmult_devs	3.50E-03	1.22E-01
1	*1983*		106	log_recruit_devs	-3.40E+00	1.77E-01
1	*1984*		107	log_recruit_devs	3.40E-01	2.02E-01
1	*1985*		108	log_recruit_devs	-1.45E-02	1.94E-01
1	*1986*		109	log_recruit_devs	-6.89E-01	1.93E-01
1	*1987*		110	log_recruit_devs	-6.52E-02	1.71E-01
1	*1988*		111	log_recruit_devs	-1.58E-01	1.62E-01
1	*1989*		112	log_recruit_devs	6.06E-02	1.34E-01
1	*1990*		113	log_recruit_devs	-1.99E-01	1.25E-01
1	*1991*		114	log_recruit_devs	-3.14E-01	1.24E-01
1	*1992*		115	log_recruit_devs	1.19E-01	1.11E-01
1	*1993*		116	log_recruit_devs	-1.62E-01	1.30E-01
1	*1994*		117	log_recruit_devs	5.33E-01	1.12E-01
1	*1995*		118	log_recruit_devs	8.90E-01	1.04E-01
1	*1996*		119	log_recruit_devs	4.37E-01	1.13E-01
1	*1997*		120	log_recruit_devs	2.53E-01	1.18E-01
1	*1998*		121	log_recruit_devs	5.87E-01	1.11E-01
1	*1999*		122	log_recruit_devs	6.55E-01	1.08E-01
1	*2000*		123	log_recruit_devs	1.76E-01	1.19E-01
1	*2001*		124	log_recruit_devs	-1.15E-01	1.40E-01

Table 11 (continued). ASAP parameter estimates and standard deviations for baseline model.

Coded Age	**Year**	**Fishery**	**Index**		**Parameter**	**Estimate**	**Standard Deviation**
1	*2002*			125	log_recruit_devs	5.86E-01	1.43E-01
1	*2003*			126	log_recruit_devs	-3.48E-01	2.22E-01
1	*2004*			127	log_recruit_devs	8.25E-01	1.91E-01
1	*2005*			128	log_recruit_devs	1.74E-03	1.46E-01
	1983		*1*	129	log_q_year1	-1.32E+01	1.98E-01
	1983		*2*	130	log_q_year1	-1.29E+01	1.67E-01
				131	log_SRR_virgin	1.40E+01	1.43E-01
				132	SRR_steepness	6.56E-01	3.80E-02
	1983			133	SSB	6.77E+03	5.40E+02
	1984			134	SSB	1.28E+04	1.59E+03
	1985			135	SSB	2.77E+04	4.10E+03
	1986			136	SSB	4.21E+04	7.01E+03
	1987			137	SSB	6.19E+04	1.08E+04
	1988			138	SSB	1.06E+05	1.95E+04
	1989			139	SSB	1.63E+05	3.10E+04
	1990			140	SSB	2.79E+05	5.25E+04
	1991			141	SSB	3.28E+05	6.09E+04
	1992			142	SSB	3.68E+05	6.59E+04
	1993			143	SSB	3.43E+05	6.12E+04
	1994			144	SSB	3.51E+05	6.57E+04
	1995			145	SSB	4.63E+05	8.07E+04
	1996			146	SSB	5.85E+05	1.01E+05
	1997			147	SSB	7.88E+05	1.34E+05
	1998			148	SSB	7.87E+05	1.27E+05
	1999			149	SSB	6.81E+05	1.11E+05
	2000			150	SSB	5.65E+05	8.93E+04
	2001			151	SSB	6.96E+05	1.21E+05
	2002			152	SSB	7.17E+05	1.36E+05
	2003			153	SSB	7.00E+05	1.43E+05
	2004			154	SSB	7.12E+05	1.62E+05
	2005			155	SSB	7.34E+05	1.76E+05

Table 11 (continued). ASAP parameter estimates and standard deviations for baseline model.

Coded Age	**Year**	**Fishery**	**Index**		**Parameter**	**Estimate**	**Standard Deviation**
1	*1983*			156	recruits	1.46E+05	2.61E+04
1	*1984*			157	recruits	2.56E+05	4.83E+04
1	*1985*			158	recruits	3.29E+05	6.83E+04
1	*1986*			159	recruits	3.36E+05	7.61E+04
1	*1987*			160	recruits	8.91E+05	1.93E+05
1	*1988*			161	recruits	1.10E+06	2.41E+05
1	*1989*			162	recruits	1.98E+06	4.11E+05
1	*1990*			163	recruits	1.95E+06	3.88E+05
1	*1991*			164	recruits	2.23E+06	4.09E+05
1	*1992*			165	recruits	3.65E+06	6.05E+05
1	*1993*			166	recruits	2.87E+06	5.18E+05
1	*1994*			167	recruits	5.61E+06	9.55E+05
1	*1995*			168	recruits	8.08E+06	1.31E+06
1	*1996*			169	recruits	5.59E+06	8.89E+05
1	*1997*			170	recruits	4.94E+06	7.38E+05
1	*1998*			171	recruits	7.35E+06	9.61E+05
1	*1999*			172	recruits	7.86E+06	1.04E+06
1	*2000*			173	recruits	4.73E+06	7.48E+05
1	*2001*			174	recruits	3.39E+06	6.45E+05
1	*2002*			175	recruits	7.16E+06	1.44E+06
1	*2003*			176	recruits	2.83E+06	7.71E+05
1	*2004*			177	recruits	9.11E+06	2.28E+06
1	*2005*			178	recruits	4.01E+06	8.48E+05
6	*1983*			179	plus_group	1.94E+03	0.00E+00
6	*1984*			180	plus_group	3.29E+03	3.71E+01
6	*1985*			181	plus_group	4.24E+03	5.49E+01
6	*1986*			182	plus_group	4.74E+03	9.73E+01
6	*1987*			183	plus_group	5.43E+03	1.49E+02
6	*1988*			184	plus_group	1.88E+04	3.33E+03
6	*1989*			185	plus_group	3.88E+04	7.77E+03
6	*1990*			186	plus_group	6.08E+04	1.28E+04
6	*1991*			187	plus_group	7.67E+04	1.67E+04
6	*1992*			188	plus_group	1.50E+05	3.44E+04
6	*1993*			189	plus_group	2.18E+05	5.14E+04
6	*1994*			190	plus_group	3.29E+05	8.41E+04
6	*1995*			191	plus_group	3.87E+05	1.01E+05
6	*1996*			192	plus_group	4.26E+05	1.12E+05
6	*1997*			193	plus_group	5.57E+05	1.44E+05
6	*1998*			194	plus_group	6.01E+05	1.51E+05
6	*1999*			195	plus_group	8.56E+05	2.11E+05
6	*2000*			196	plus_group	1.19E+06	2.93E+05
6	*2001*			197	plus_group	1.16E+06	2.91E+05
6	*2002*			198	plus_group	1.02E+06	2.67E+05
6	*2003*			199	plus_group	1.03E+06	2.78E+05
6	*2004*			200	plus_group	1.01E+06	2.99E+05
6	*2005*			201	plus_group	8.27E+05	2.76E+05

Table 12a. Pacific sardine population numbers at age, Age 1+ biomass, and spawning stock biomass (SSB) at the beginning of each biological year, 1983-2005. Landings during the course of each biological year are also provided (landings for 2005 are projected). Recruitment is shown as Age 0 population numbers. The biological year begins on July 1st and extends through June 30th of the labeled year. The Age 1+ biomass estimated for 2005 (shaded) serves as the basis for setting a harvest guideline for the U.S. fishery in calendar year 2005 (see Table 13).

	Population Numbers at Age (millions)						**Biomass**	**SSB**	**Landings**
Biological Year	**0**	**1**	**2**	**3**	**4**	**5+**	**Ages 1+**		
							----------	**(1000 mt)**	**----------**
1983	146	15	9	5	3	2	5	4	0.5
1984	256	97	9	5	3	3	13	9	0.4
1985	329	171	63	6	3	4	29	21	4
1986	336	211	103	37	4	5	45	34	2
1987	891	224	138	64	23	5	59	49	3
1988	1,096	592	146	86	41	19	107	79	6
1989	1,978	729	381	87	53	39	162	127	5
1990	1,954	1,319	479	242	56	61	267	202	15
1991	2,229	1,289	846	298	154	77	347	279	21
1992	3,650	1,466	821	521	188	150	418	344	35
1993	2,866	2,348	889	490	321	218	549	429	74
1994	5,609	1,738	1,231	448	267	329	540	453	32
1995	8,078	3,611	1,053	733	276	387	767	598	66
1996	5,594	5,111	2,084	593	434	426	1,084	821	63
1997	4,943	3,597	3,080	1,235	364	557	1,193	986	66
1998	7,346	3,198	2,204	1,860	768	601	1,206	1,033	131
1999	7,859	4,549	1,754	1,171	1,054	856	1,258	1,030	114
2000	4,733	4,857	2,478	924	659	1,191	1,347	1,087	111
2001	3,393	2,907	2,587	1,271	509	1,163	1,189	1,017	106
2002	7,162	2,136	1,648	1,399	705	1,020	1,001	889	108
2003	2,833	4,506	1,204	881	763	1,029	1,105	873	137
2004	9,114	1,771	2,503	622	454	1,011	913	818	105
2005	4,013	5,831	1,052	1,384	331	827	1,194	902	*110*

Table 12b. Pacific sardine instantaneous rates of fishing mortality at age (yr^{-1}) for biological years 1983-2005. The biological year begins on July 1st and extends through June 30th of the labeled year.

	Instantaneous Fishing Mortality Rates at Age (yr^{-1})					
Biological Year	**0**	**1**	**2**	**3**	**4**	**5+**
1983	0.01	0.06	0.20	0.13	0.07	0.03
1984	0.00	0.03	0.08	0.05	0.03	0.01
1985	0.04	0.10	0.14	0.10	0.07	0.02
1986	0.01	0.03	0.07	0.05	0.03	0.01
1987	0.01	0.03	0.07	0.05	0.03	0.01
1988	0.01	0.04	0.12	0.08	0.04	0.02
1989	0.01	0.02	0.05	0.04	0.02	0.01
1990	0.02	0.04	0.07	0.05	0.03	0.01
1991	0.02	0.05	0.09	0.06	0.04	0.01
1992	0.04	0.10	0.12	0.09	0.06	0.01
1993	0.10	0.25	0.29	0.21	0.14	0.04
1994	0.04	0.10	0.12	0.09	0.05	0.01
1995	0.06	0.15	0.17	0.12	0.07	0.02
1996	0.04	0.11	0.12	0.09	0.05	0.01
1997	0.04	0.09	0.10	0.08	0.05	0.01
1998	0.08	0.20	0.23	0.17	0.10	0.03
1999	0.08	0.21	0.24	0.17	0.11	0.03
2000	0.09	0.23	0.27	0.20	0.12	0.04
2001	0.06	0.17	0.21	0.19	0.14	0.07
2002	0.06	0.17	0.23	0.21	0.16	0.09
2003	0.07	0.19	0.26	0.26	0.23	0.14
2004	0.05	0.12	0.19	0.23	0.23	0.15
2005	0.04	0.11	0.18	0.22	0.22	0.15

Table 13. Proposed harvest guideline for Pacific sardine for the 2005 management year. See 'Harvest Guideline' section for methods used to derive harvest guideline.

Stock biomass (age 1+, mt)	Cutoff (mt)	Fraction	U.S. Distribution	Harvest guideline (mt)
1,193,515	150,000	15%	87%	136,179

Table 14. Coastwide harvest (mt) of Pacific sardine for calendar years1981 through 2003 (PFMC 2004b).

Year	Ensenada, Mexico	United States	British Columbia, Canada	Total
1981	0	34	0	34
1982	0	2	0	2
1983	274	1	0	274
1984	0	1	0	1
1985	3,722	6	0	3,728
1986	243	388	0	631
1987	2,432	439	0	2,871
1988	2,035	1,188	0	3,223
1989	6,224	837	0	7,061
1990	11,375	1,664	0	13,040
1991	31,392	7,587	0	38,979
1992	34,568	17,950	0	52,518
1993	32,045	15,345	0	47,390
1994	20,877	11,644	0	32,520
1995	35,396	40,327	25	75,748
1996	39,065	32,553	88	71,706
1997	68,439	43,245	34	111,718
1998	47,812	42,956	745	91,514
1999	58,569	60,039	1,250	119,858
2000	51,173	67,984	1,718	120,875
2001	22,246	75,719	1,600	99,565
2002	43,436	101,988	1,044	146,468
2003	30,537	74,895	954	106,386

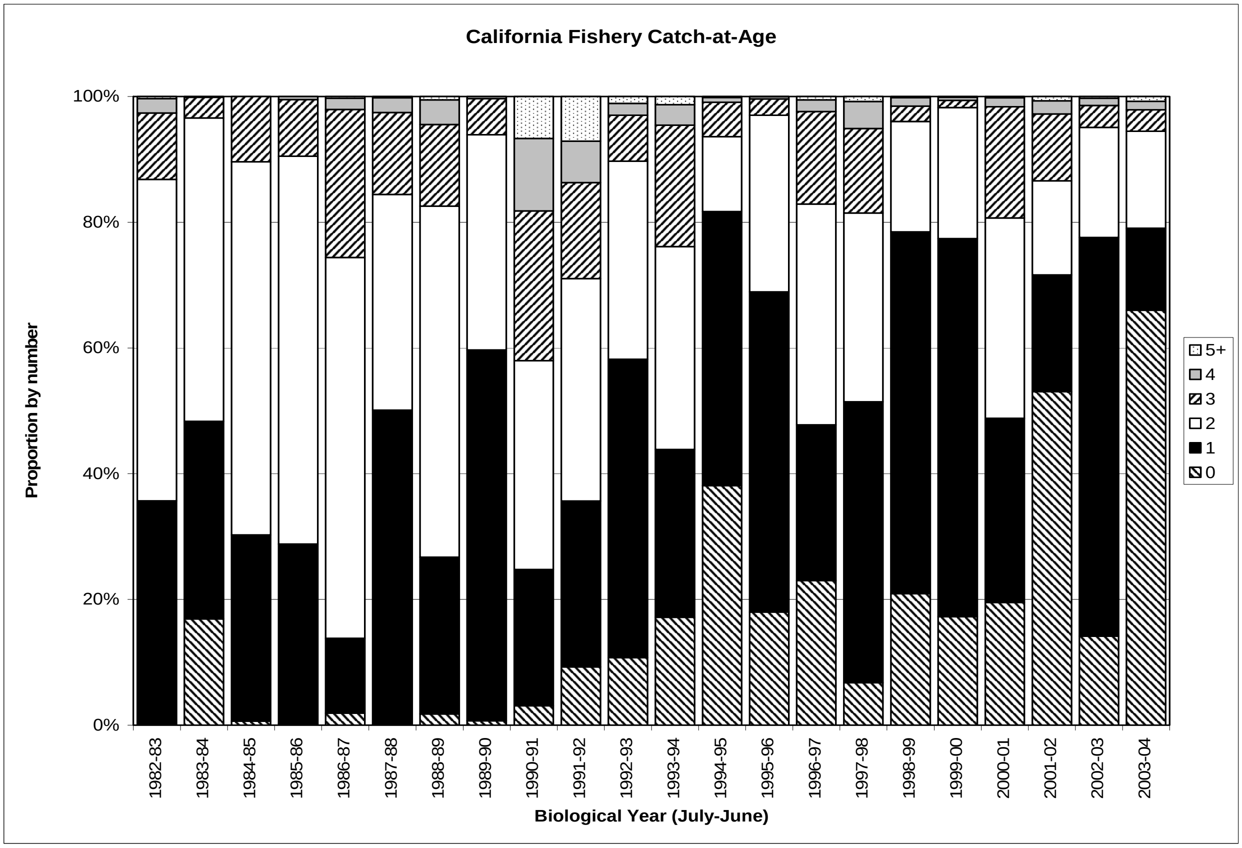

Figure 1. Proportional catch-at-age for the Pacific sardine fishery in California (San Pedro and Monterey) for the biological years 1983-2004 (July-June).

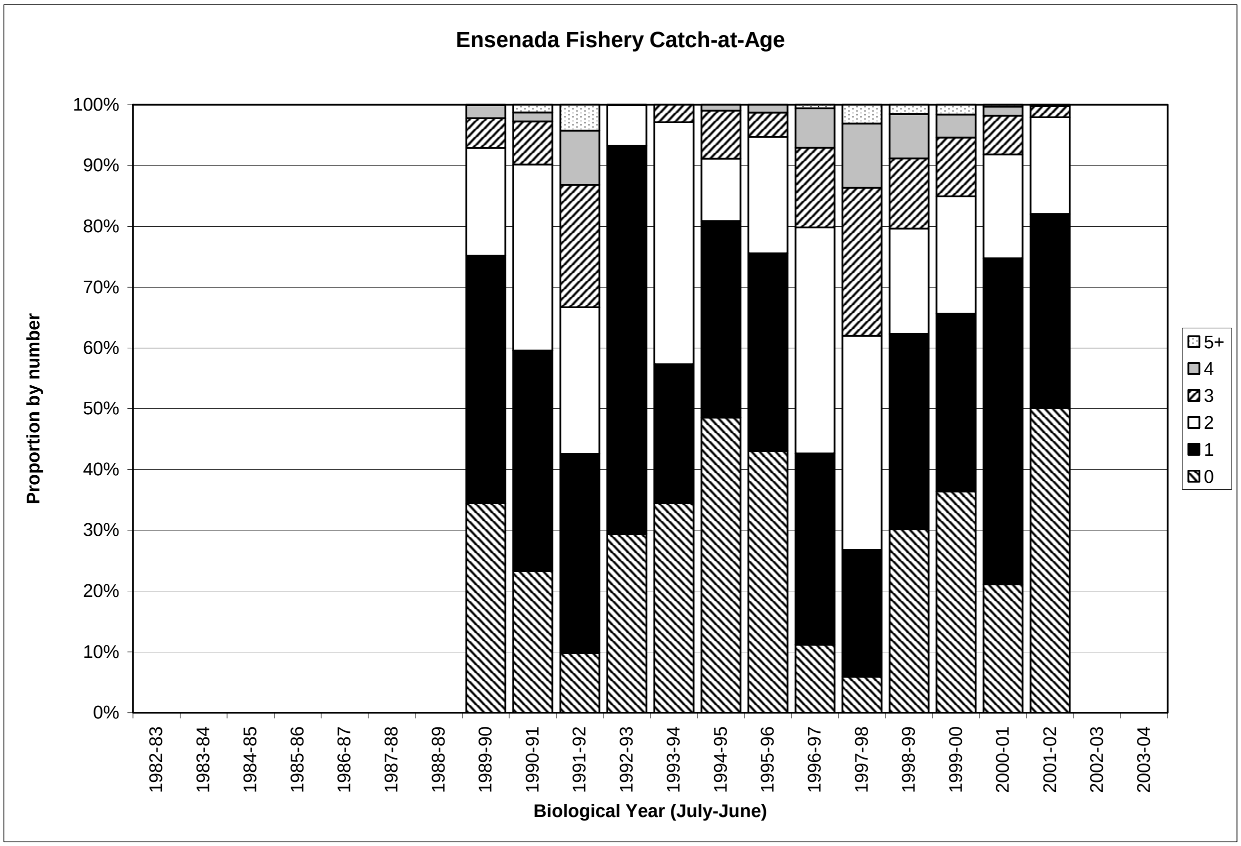

Figure 2. Proportional catch-at-age for the Pacific sardine fishery in Ensenada (Baja California, Mexico) for the biological years 1990-2002 (July-June).

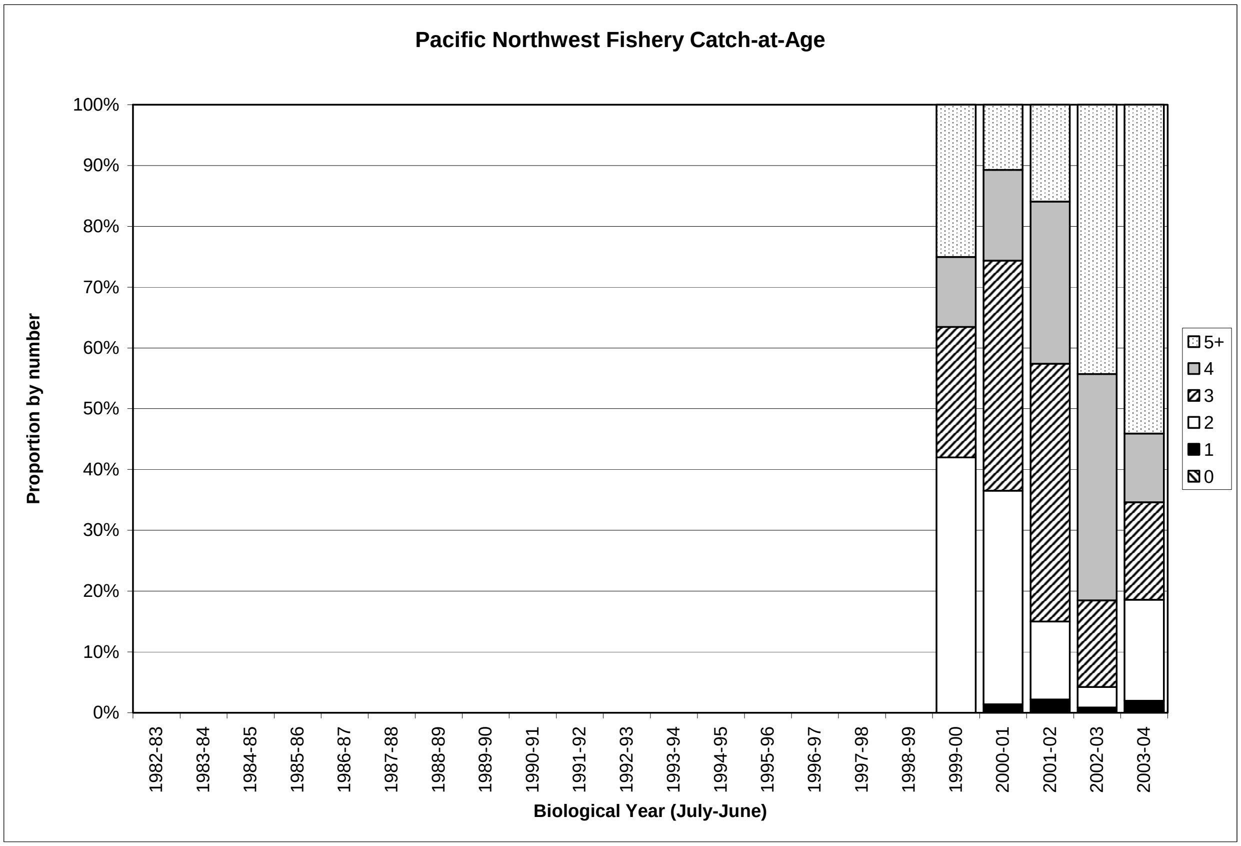

Figure 3. Proportional catch-at-age for the Pacific sardine fishery in the Pacific Northwest (Oregon, Washington, and British Columbia) for the biological years 2000-2004 (July-June).

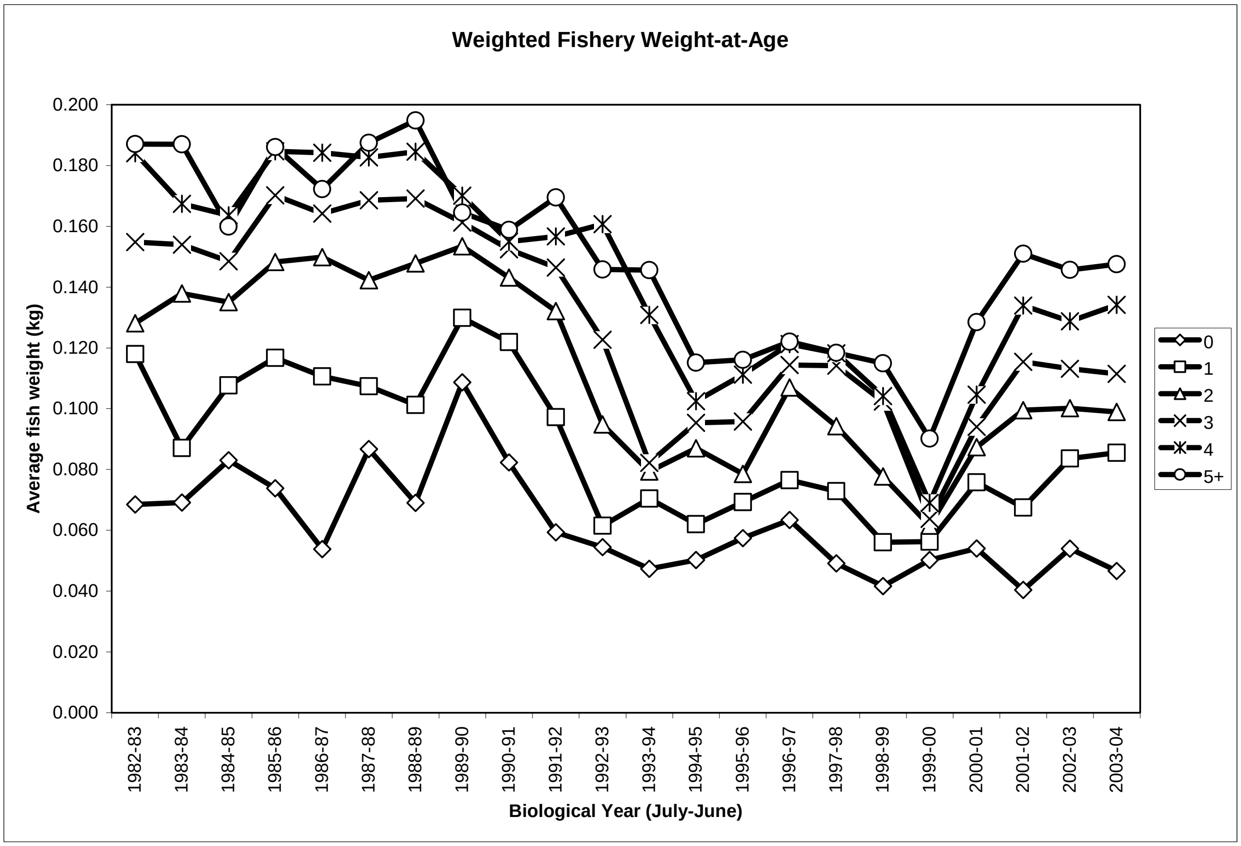

Figure 4. Pooled fishery weight-at-age (kg) of Pacific sardine as applied in the ASAP base model. Whole body weights were averaged across the three fisheries using respective landings to weight the data.

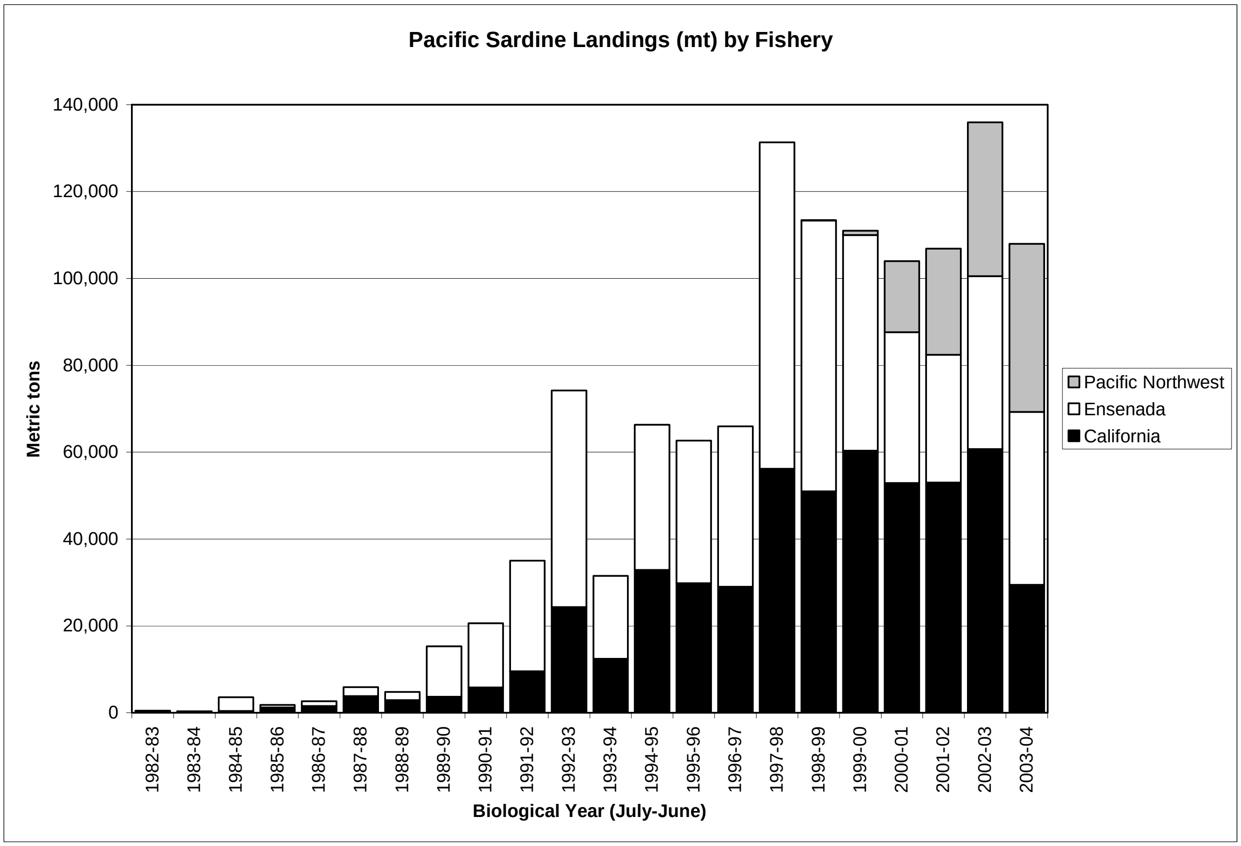

Figure 5. Pacific sardine landings (mt) by fishery for the 1983-2004 biological years (July-June).

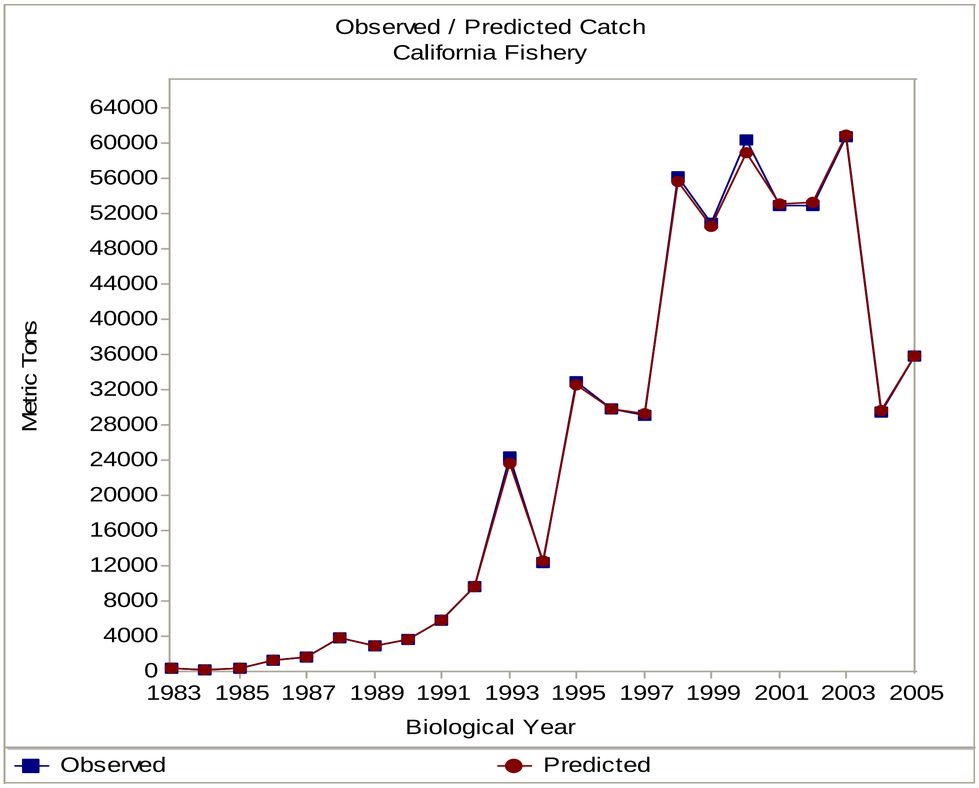

Figure 6. Observed and predicted estimates of total catch (mt) for the California fishery from the ASAP model (1983-05).

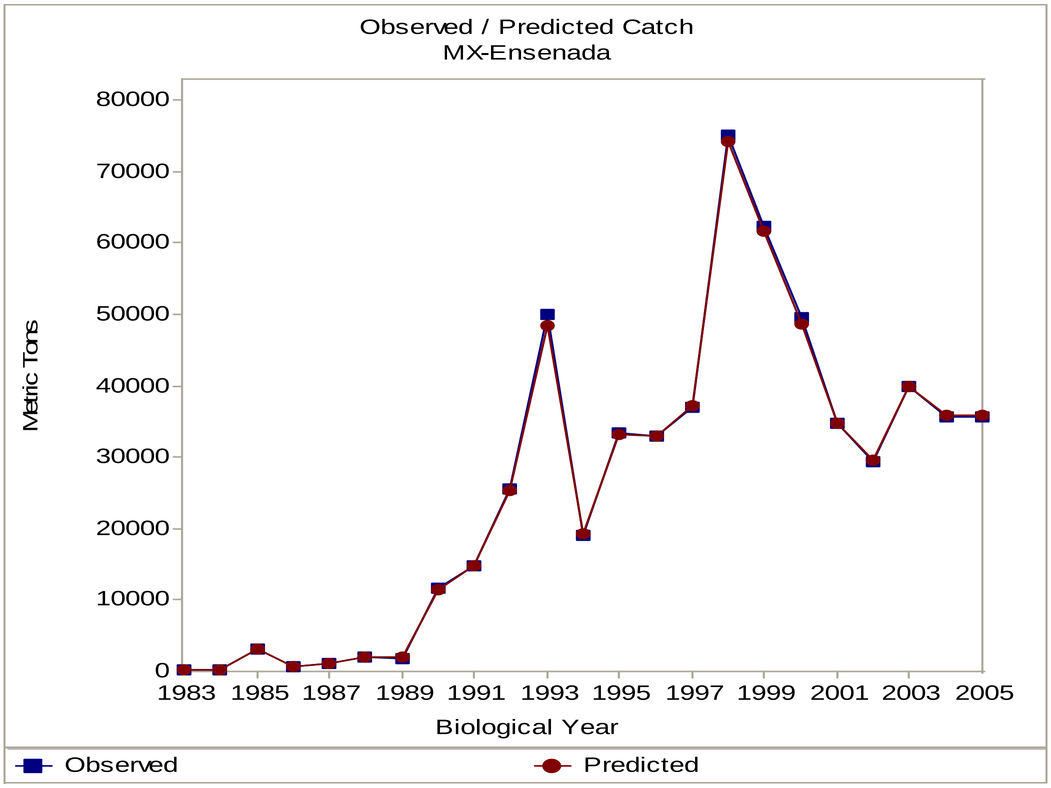

Figure 7. Observed and predicted estimates of total catch (mt) for the Ensenada fishery from the ASAP model (1983-05).

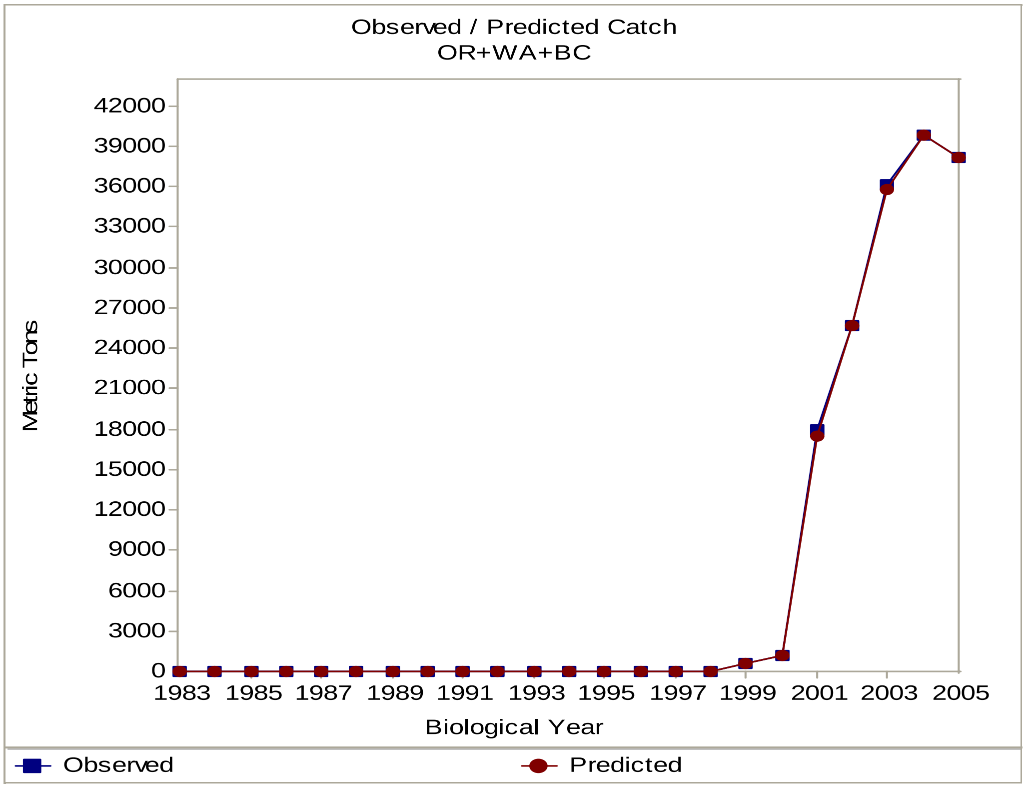

Figure 8. Observed and predicted estimates of total catch (mt) for the Pacific Northwest fishery (Oregon, Washington, and British Columbia) from the ASAP model (1983-05).

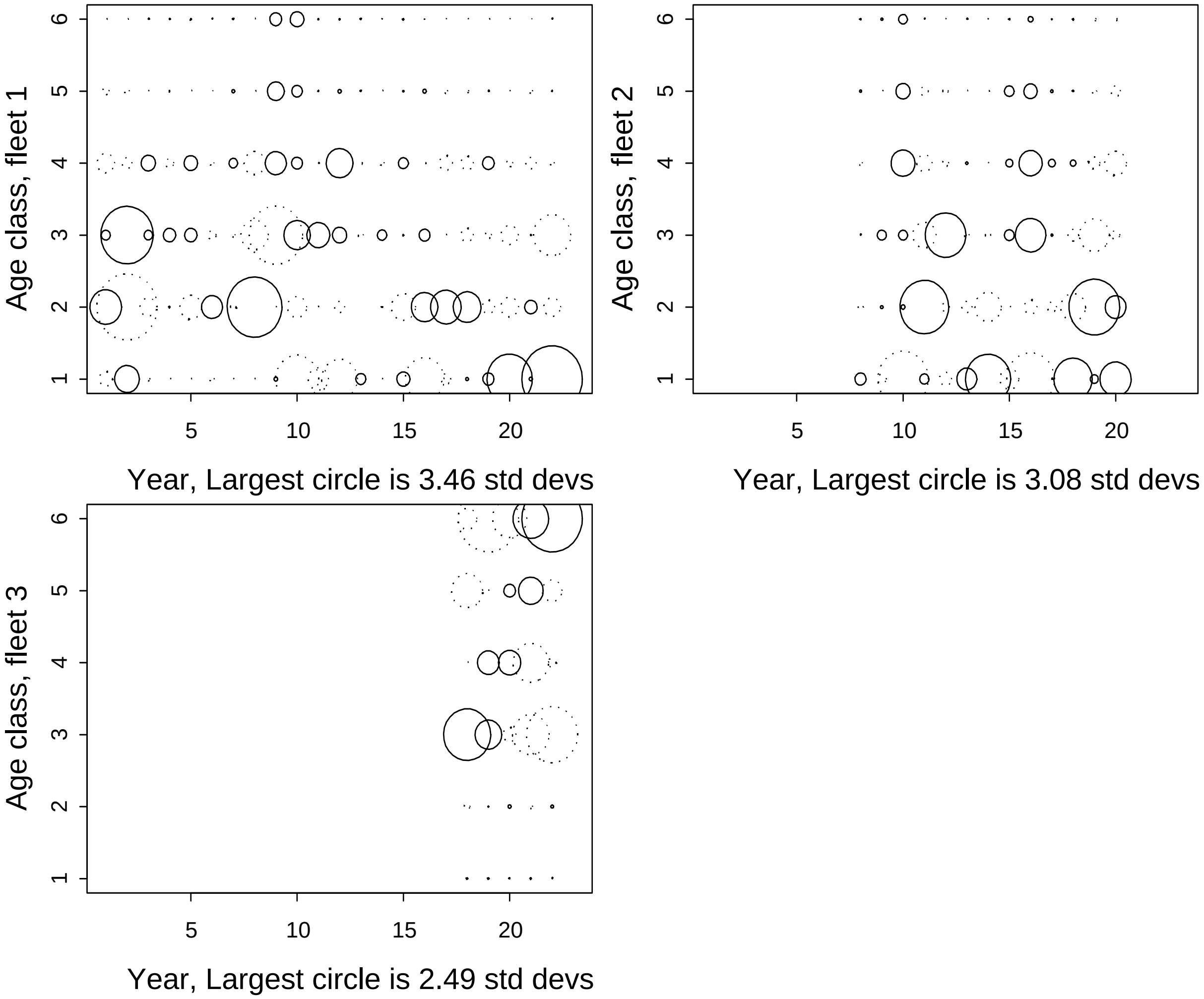

Figure 9. Standardized residuals from ASAP model fit to catch-at-age data for the three sardine fisheries (Fleet-1=CA; Fleet-2=MX; and Fleet-3=ORWABC). Circle size is proportional to the magnitude of the residual. Circles drawn with dotted lines are negative residuals. Coded ages are shown on the ordinate of each plot (coded-age-1=true-age-0, coded-age-2=true-age-1,..…, coded-age-6=true-ages-5+). Biological years are shown on the abscissa of each plot (1=1983, 2=1984, …, 23=2005)

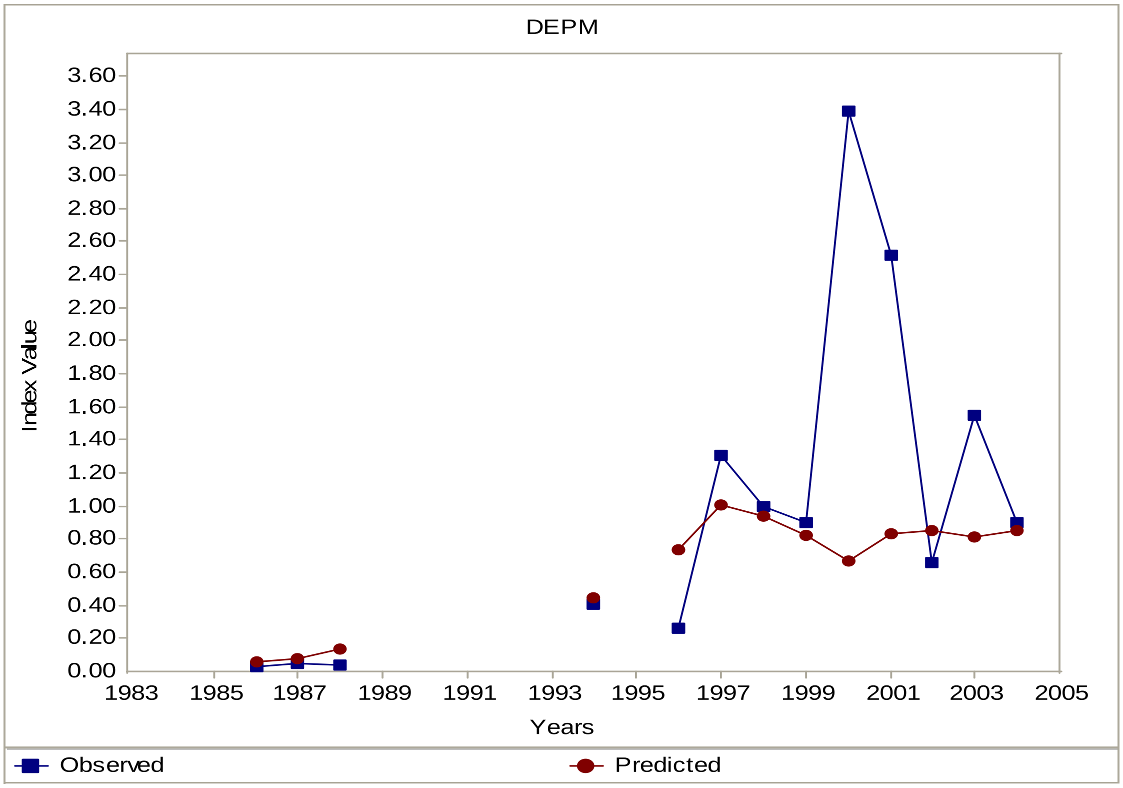

Figure 10. Index of relative abundance of sardine spawning stock biomass (mt) based on the daily egg production method (DEPM) estimates from ichthyoplankton survey data, 1986-2004. Note that no sample data (observed estimates) were available for years 1989-1993 and 1995. The predicted values are estimates from the ASAP baseline model.

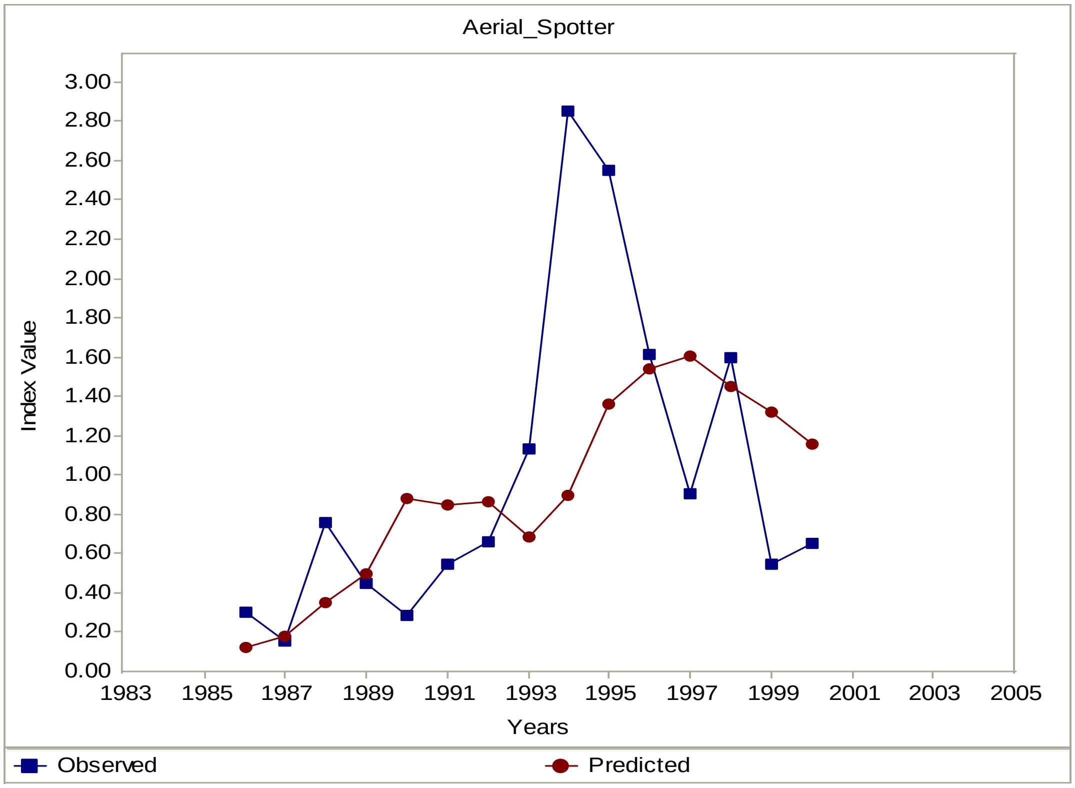

Figure 11. Index of relative abundance of sardine pre-adult biomass (primarily age 0-2 fish) based on aerial spotter plane survey data (1986-2000). Note that no sample data are available for 2001-2004. The predicted values are estimates from the ASAP baseline model.

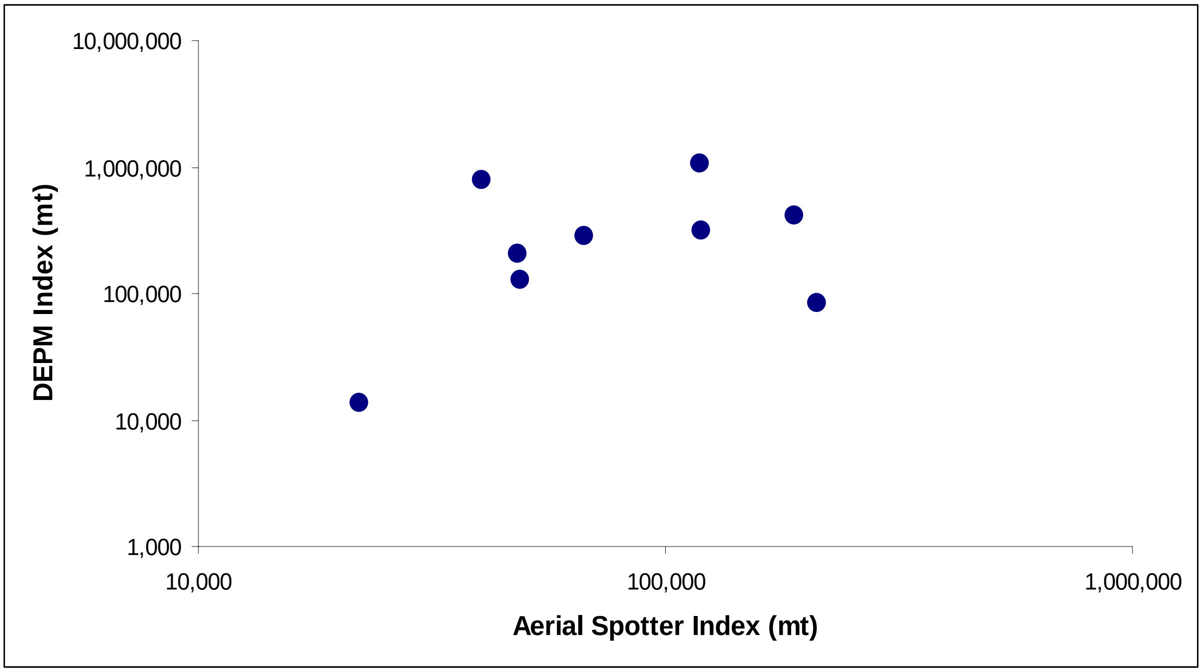

Figure 12. Comparison of observed values for the DEPM survey (index of spawning stock biomass) and Aerial Spotter survey (index of young sardine). For plotting purposes only, the surveys were lagged two years, i.e. the aerial spotter index values were plotted against the DEPM index two years later (both on log scale).

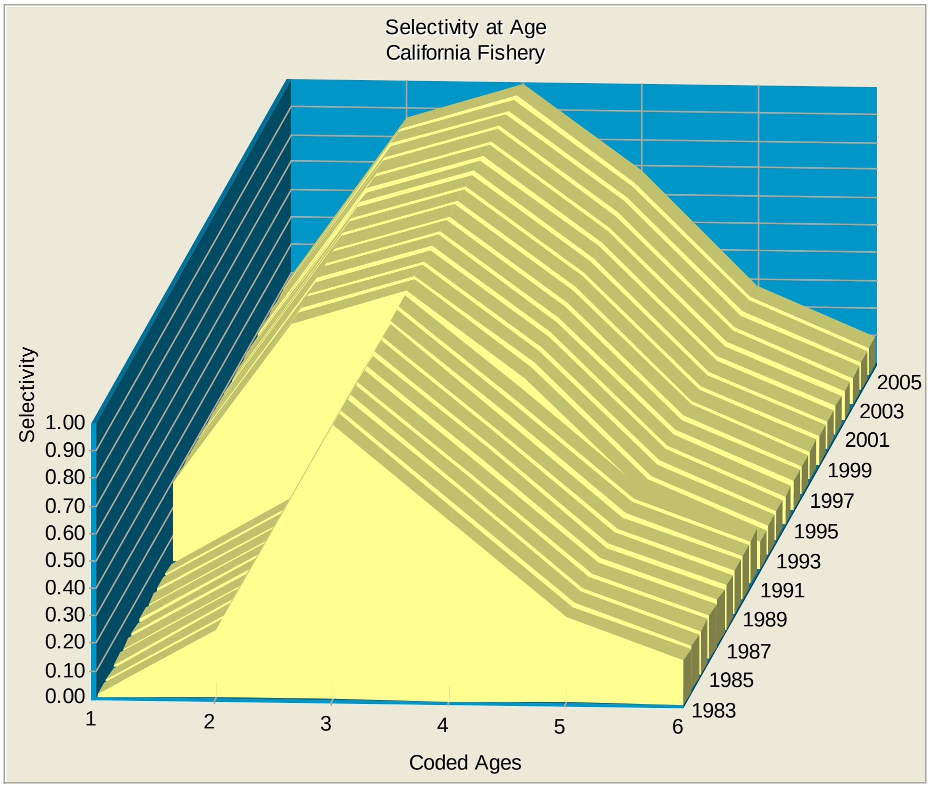

Figure 13. Estimated selectivity for the California fishery (Fishery 1) from the ASAP baseline model. Selectivity was estimated for two periods: 1983-92 and 1993-2005.

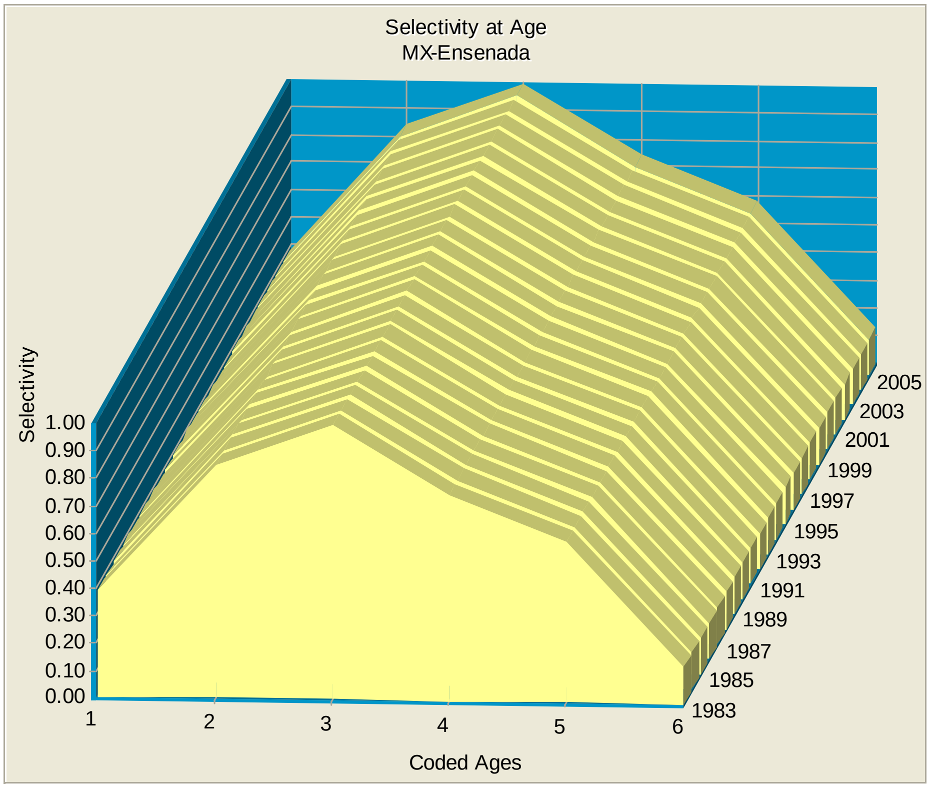

Figure 14. Estimated selectivity for the Ensenada, Mexico fishery (Fishery 2) from the ASAP baseline model.

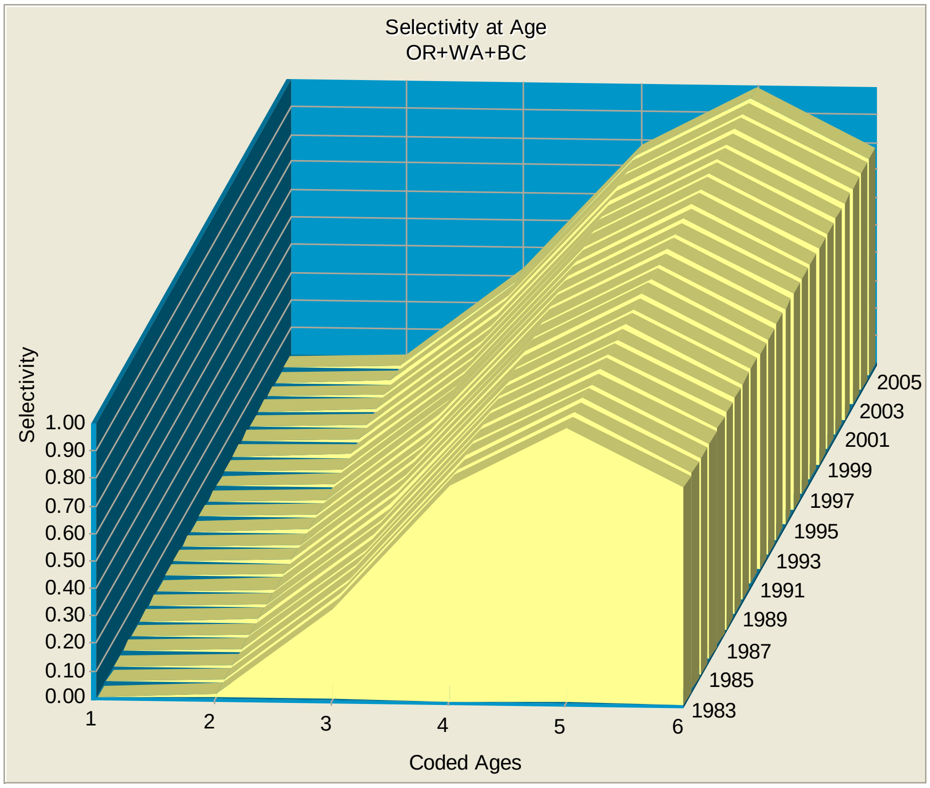

Figure 15. Estimated selectivity for the Oregon, Washington, and British Columbia fishery (Fishery 3) from the ASAP baseline model.

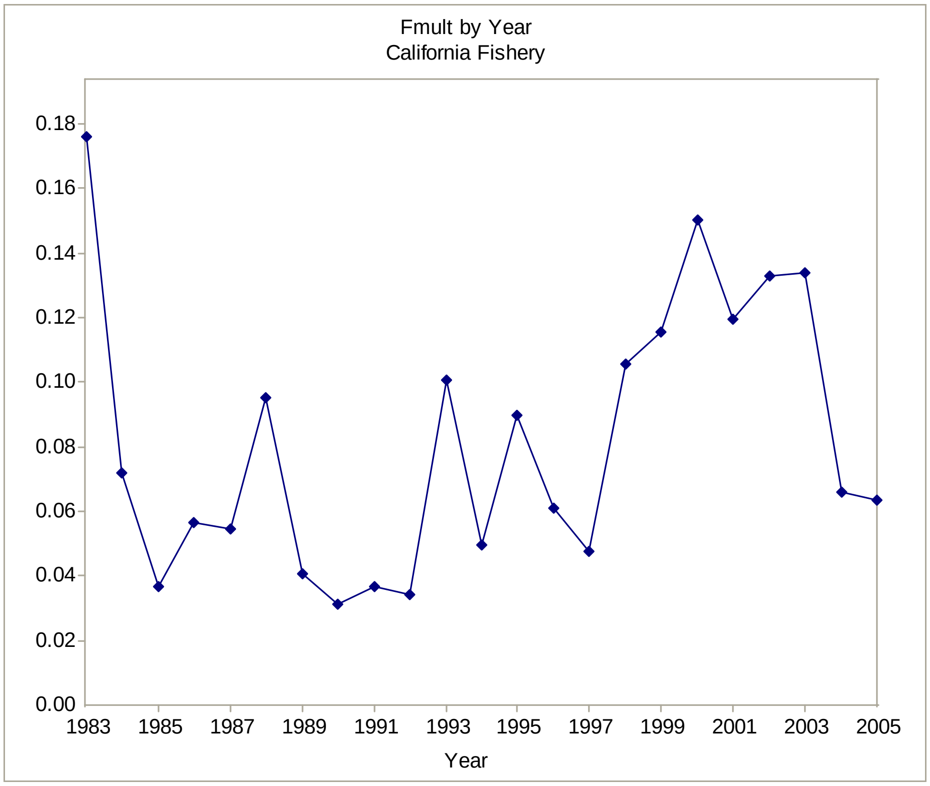

Figure 16. Estimated instantaneous rate of fishing mortality (yr^{-1}) for fully-recruited age(s) for the California fishery (Fishery 1) from the ASAP baseline model.

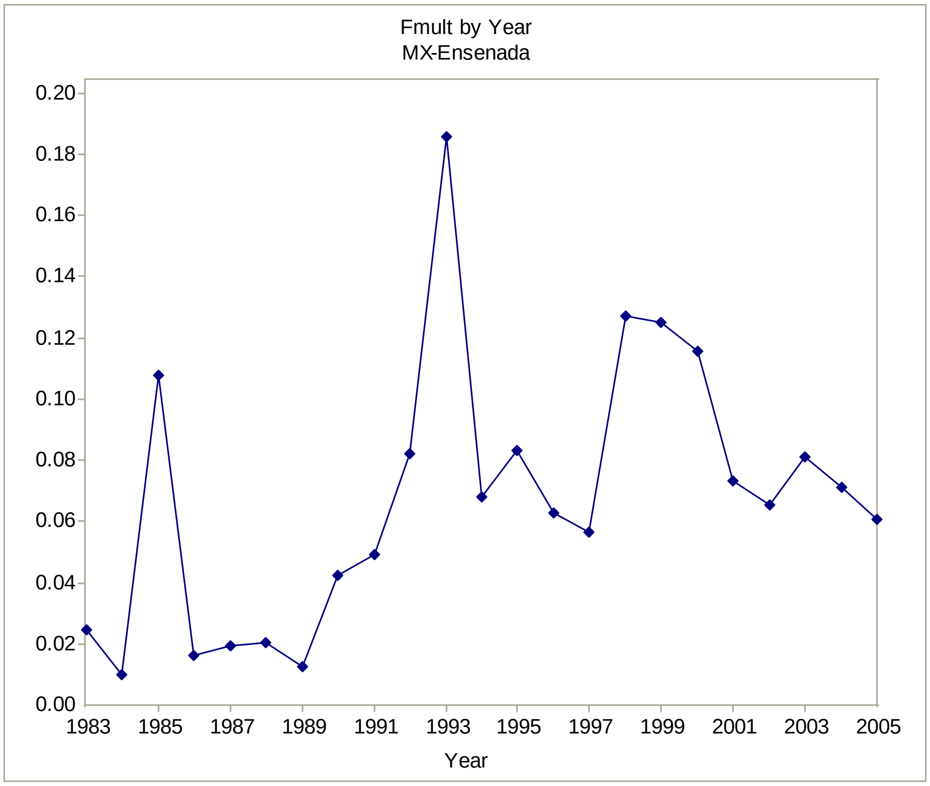

Figure 17. Estimated instantaneous rate of fishing mortality (yr^{-1}) for fully-recruited age(s) for the Ensenada, Mexico fishery (Fishery 2) from the ASAP baseline model.

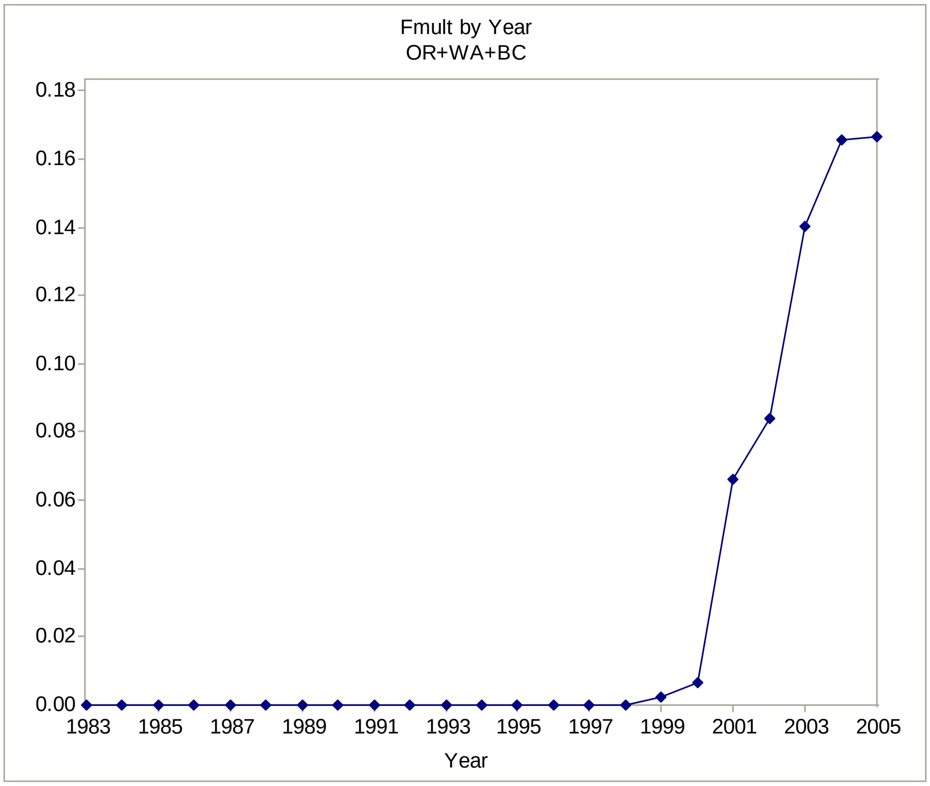

Figure 18. Estimated instantaneous rate of fishing mortality (yr^{-1}) for fully-recruited age(s) for the Pacific Northwest fishery (Oregon/Washington/British Columbia; Fishery 3) from the ASAP baseline model.

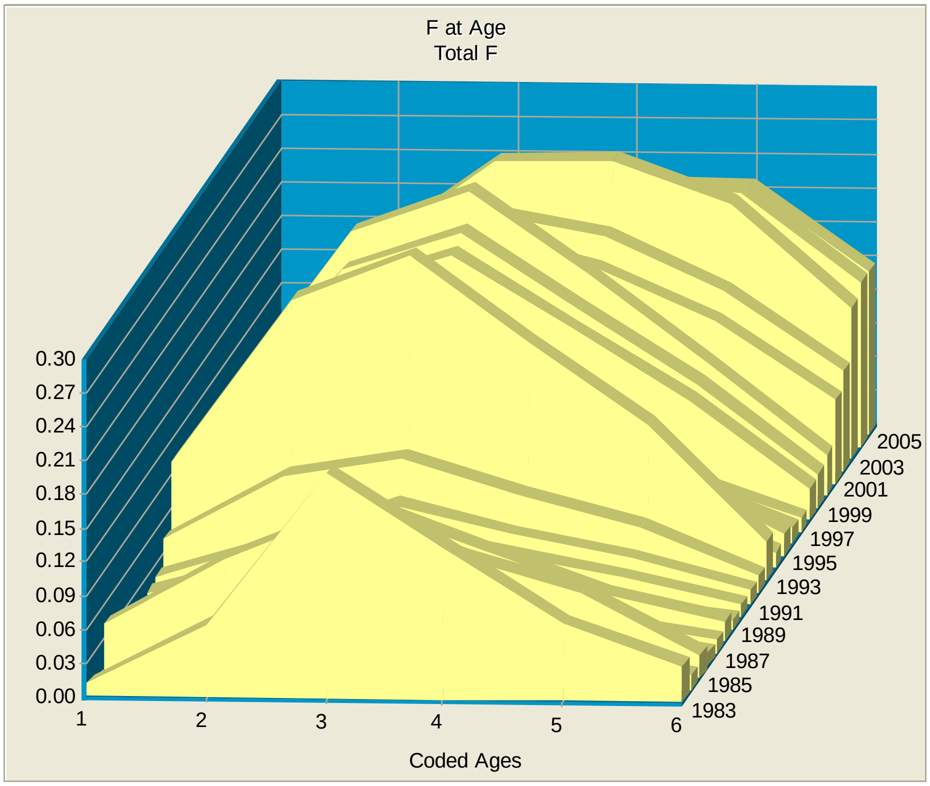

Figure 19. Estimated instantaneous rate of fishing mortality (yr^{-1}) by age and year for all fisheries combined from the ASAP baseline model.

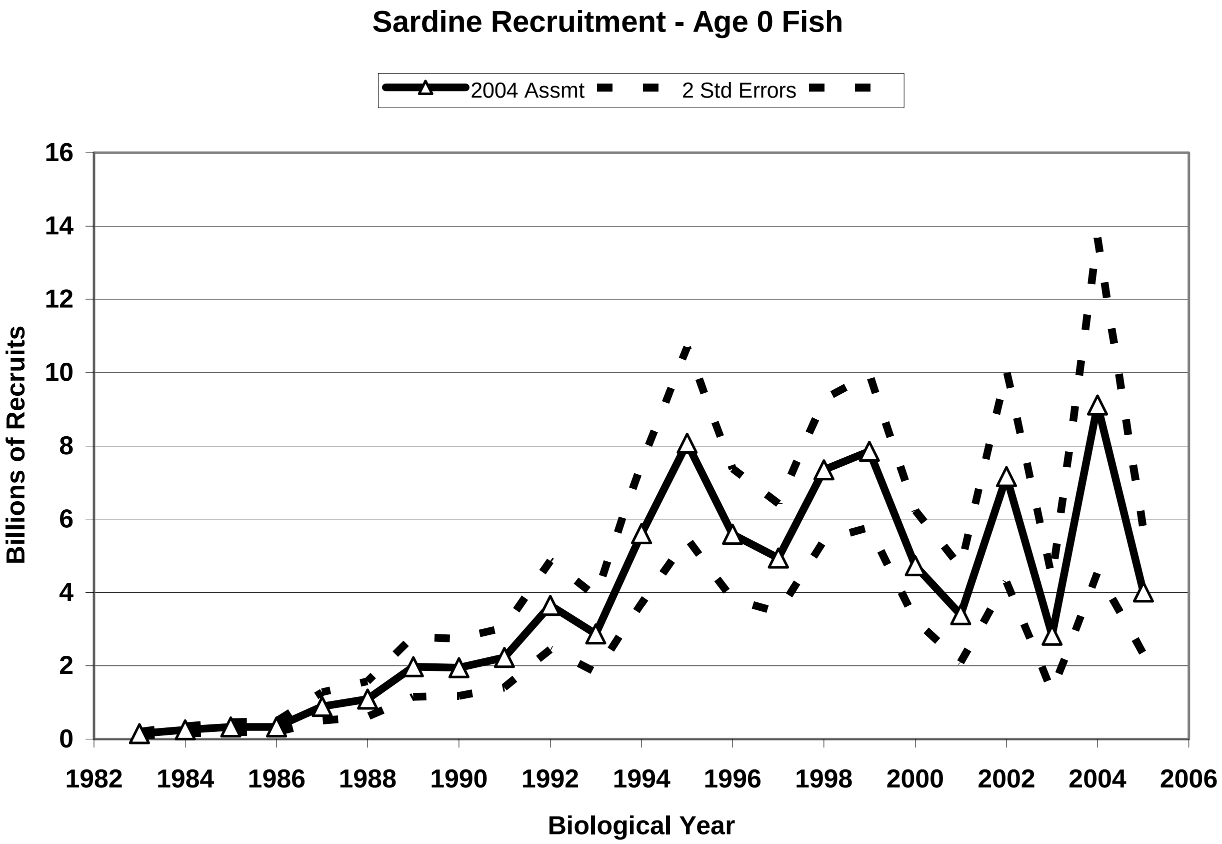

Figure 20. Sardine recruitment estimates (age 0 abundance in billions) from the ASAP baseline model (triangles) along with a 2-standard error uncertainty envelope.

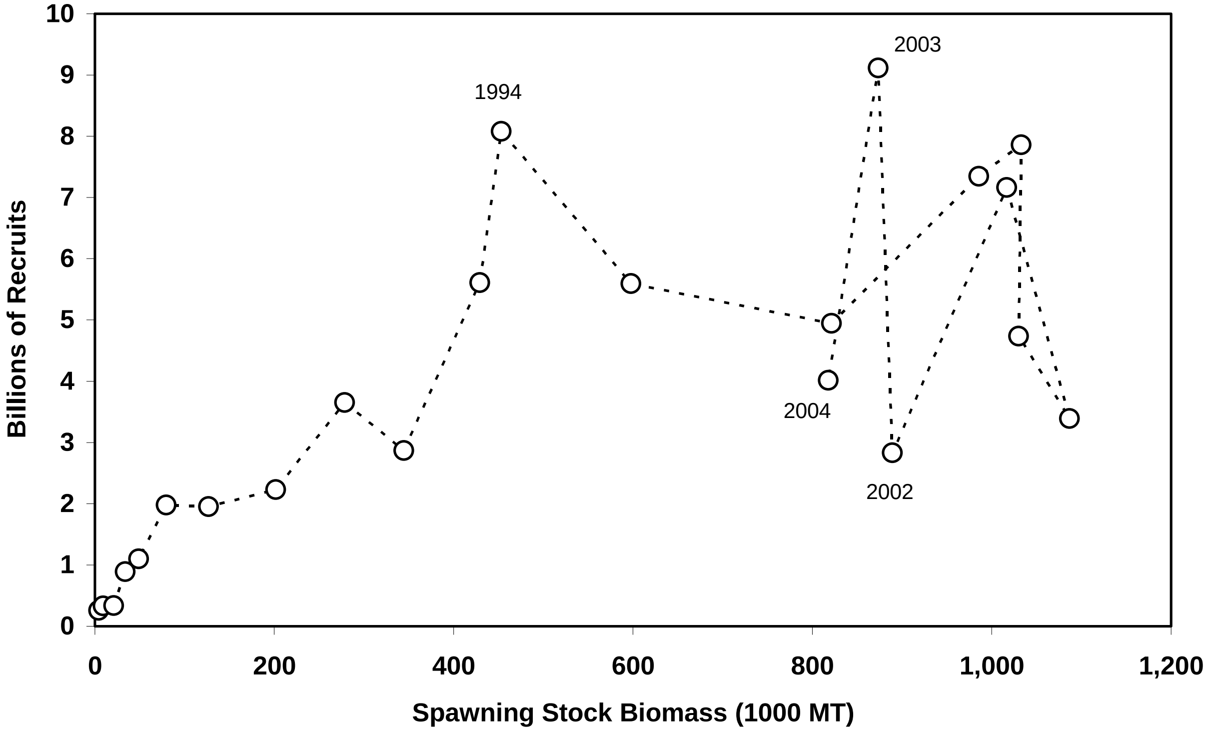

Figure 21. Sardine spawning stock biomass and recruitment estimates from the baseline model. Year labels indicate the biological year associated with the spawning stock biomass.

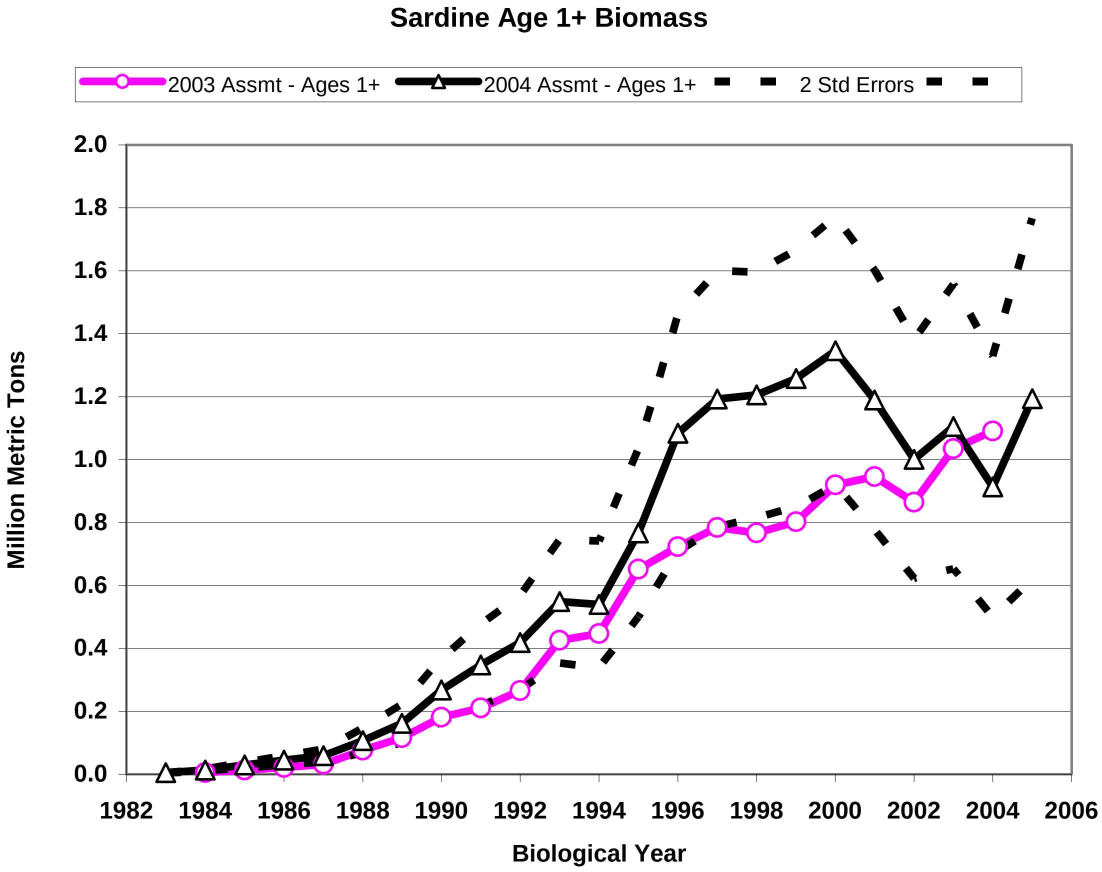

Figure 22. Sardine Age 1+ biomass estimates from the ASAP baseline model (triangles) along with a 2-standard error uncertainty envelope. Also shown are the corresponding estimates from the CANSAR-TAM model (circles) used for the last stock assessment (Conser et al. 2003).

APPENDICES

ICCAT WORKING DOCUMENT
SCRS/98/58

A Flexible Forward Age-Structured Assessment Program

Christopher M. Legault[1] and Victor R. Restrepo[2]

[1] U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
75 Virginia Beach Dr., Miami, Florida, 33149, USA

[2] University of Miami
Rosenstiel School of Marine and Atmospheric Science
Cooperative Unit for Fisheries Education and Research
4600 Rickenbacker Causeway, Miami, Florida 33149, USA

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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 AD Model Builder, an efficient tool 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.

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,

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

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 ($Fmult_{y,g}$)

$$F_{a,y,g} = S_{a,y,g} Fmult_{y,g} \ . \tag{2}$$

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

$$Ftot_{a,y} = \sum_{g} F_{a,y,g} \tag{3}$$

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

$$Z_{a,y} = Ftot_{a,y} + M_{a,y} \ . \tag{4}$$

The catch by age, year and fleet is

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

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

The yield by age, year and fleet is

$$Y_{a,y,g} = C_{a,y,g} W_{a,y} \tag{6}$$

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

$$P_{a,y,g} = \frac{C_{a,y,g}}{\sum_{a} C_{a,y,g}} . \tag{7}$$

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

$$N_{1,y} = \overline{N}_1 e^{u_y} \tag{8}$$

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

$$\begin{aligned} N_{a,1} &= N_{1,1} e^{-\sum_{i=1}^{a-1} Z_{i,1}} e^{y_a} \qquad for\, a < A \\ N_{a,1} &= \frac{N_{1,1} e^{-\sum_{i=1}^{a-1} Z_{i,1}}}{1 - e^{-Z_{A,1}}} e^{y_a} \qquad for\, a = A \end{aligned} \tag{9}$$

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

$$\begin{aligned} N_{a,y} &= N_{a-1,y-1} e^{-Z_{a-1,y-1}} \qquad\qquad\qquad for\ a < A \\ N_{a,y} &= N_{a-1,y-1} e^{-Z_{a-1,y-1}} + N_{a,y-1} e^{-Z_{a,y-1}} \qquad for\ a = A . \end{aligned} \tag{10}$$

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

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

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

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

Time-varying parameters

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

$$S_{a,y+t,g} = S_{a,y,g} e^{e_{a,y,g}} \tag{13}$$

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

$$q_{u,y+1} = q_{u,y}e^{w_{u,y}} \ , \tag{14}$$

as do the fleet specific fishing mortality rate multipliers

$$Fmult_{y+1,g} = Fmult_{y,g}e^{h_{y,g}} \tag{15}$$

where $?_{u,y}$~N(0,s_{qu}^2) and $?_{y,g}$~N(0,s_{Fg}^2).

Parameter estimation

The number of parameters estimated depends upon the values of t_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*-1)*AG* + (*Y*-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 t_g values.

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

$$L_1 = \ l_1[\ln(\sum_a Y_{a,y,g}) - \ln(\sum_a \hat{Y}_{a,y,g})]^2 \ ; \tag{16}$$

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

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

and indices of abundance (lognormally distributed)

$$L_3 = \sum_g \ l_{3,g} \sum_y [\ln(I_{y,g}) - \ln(\hat{I}_{y,g})]^2 / 2s_{y,g}^2 + \ln(s_{y,g}) \ , \tag{18}$$

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 (?) 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 ? equal to the inverse of the assumed variance for each component

$$L_4 = \sum_g l_{4,g} \sum_a \sum_y e_{a,y,g}^2 \qquad (selectivity) \tag{19}$$

$$L_5 = \sum_u l_{5,u} \sum_y w_{u,y}^2 \qquad (catchability) \tag{20}$$

$$L_6 = \sum_g l_{6,g} \sum_y h_{y,g}^2 \qquad (F\ multipliers) \tag{21}$$

$$L_7 = l_7 \sum_y u_y^2 \qquad (recruitment) \tag{22}$$

$$L_8 = l_8 \sum_y y_y^2 \qquad (N\ year 1)\,. \tag{23}$$

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

$$L_9 = l_9 \sum_y [\ln(N_{1,y}) - \ln\left(\frac{a\ SSB_{y-1}}{b + SSB_{y-1}}\right)]^2 \tag{24}$$

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

$$r_1 = l_{r1} \sum_y \sum_g \sum_{a(g_{start})}^{a(g_{end})-2} (S_{a,y,g} - 2S_{a+1,y,g} + S_{a+2,y,g})^2 \tag{25}$$

and over time

$$r_2 = l_{r2} \sum_a \sum_g \sum_{y=1}^{Y-2} (S_{a,y,g} - 2S_{a,y+1,g} + S_{a,y+2,g})^2\,. \tag{26}$$

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

$$L = L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7 + L_8 + L_9 + r_1 + r_2\,. \tag{27}$$

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_y/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

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

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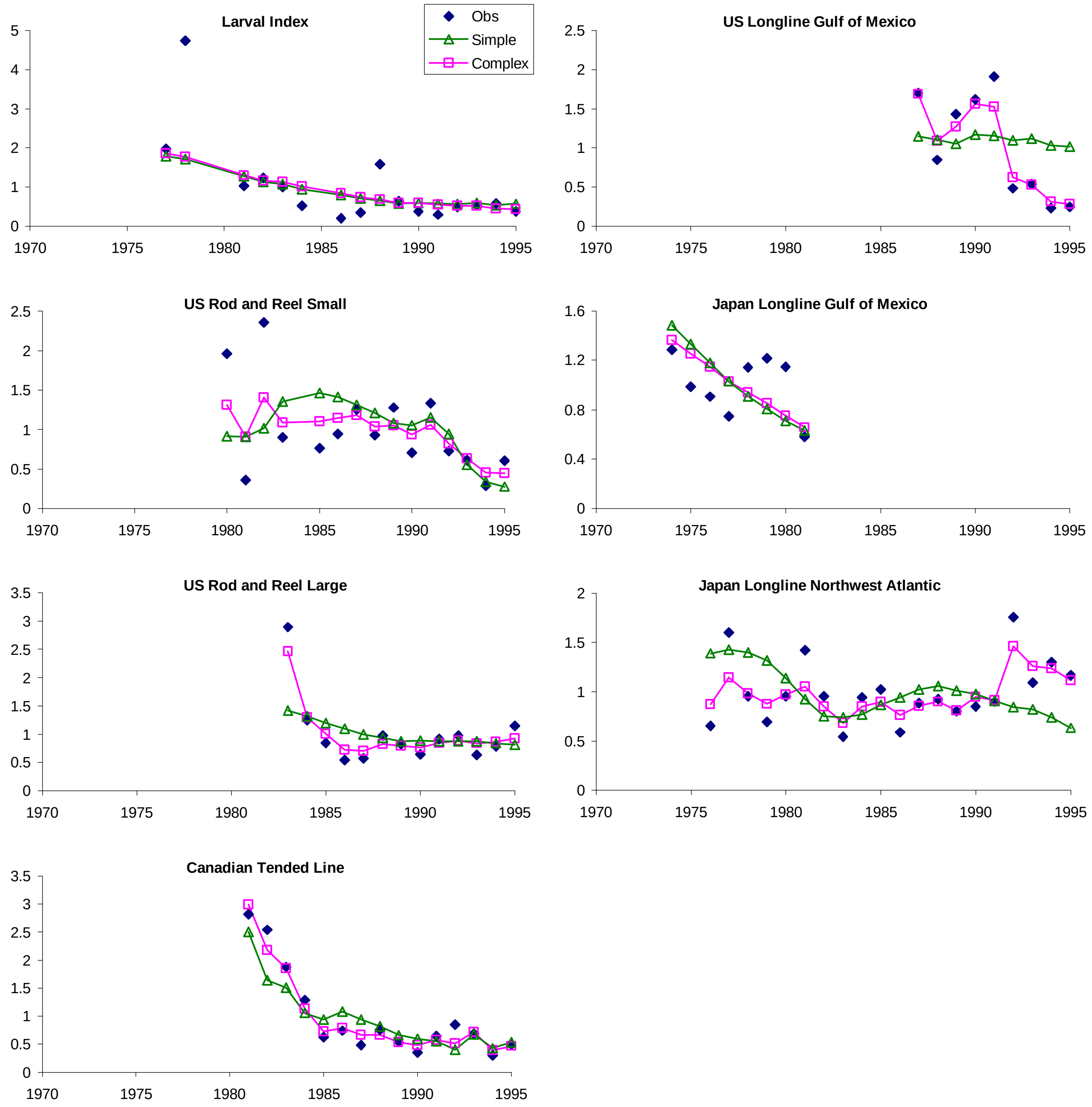
Table 1. Likelihood function components for two ASAP analyses. nobs=number of observations in that component, ?=weight given to that component, RSS=residual sum of squared deviations, L=likelihood value

			Simple		**Complex**	
Component	nobs	?	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**



Larval Index

US Longline Gulf of Mexico

US Rod and Reel Small

Japan Longline Gulf of Mexico

US Rod and Reel Large

Japan Longline Northwest Atlantic

Canadian Tended Line

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

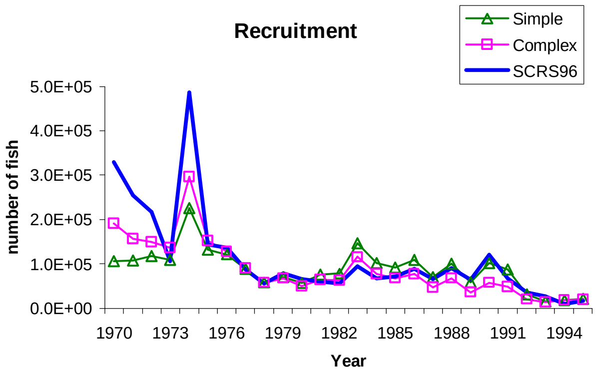


Figure 2. Estimated recruitment from two ASAP analyses and the SCRS 1996 assessment.

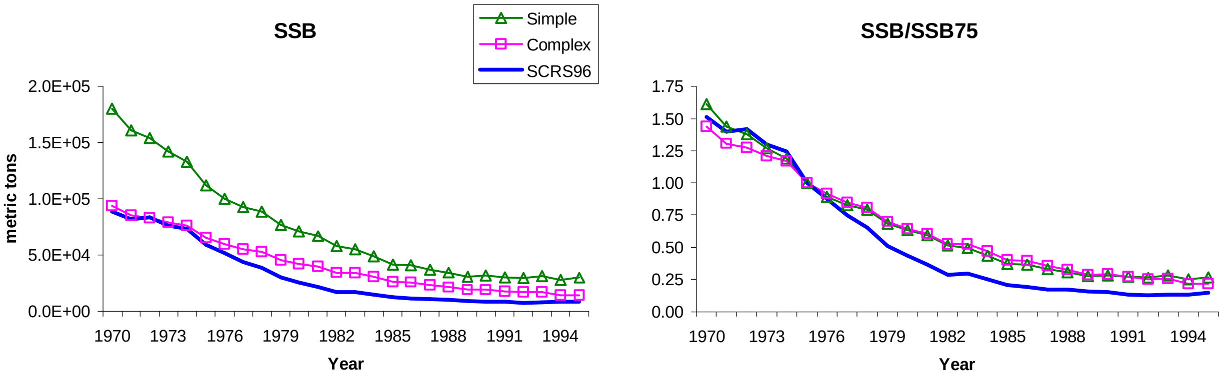


Figure 3. Spawning stock biomass (SSB) from two ASAP analyses and SCRS 1996.

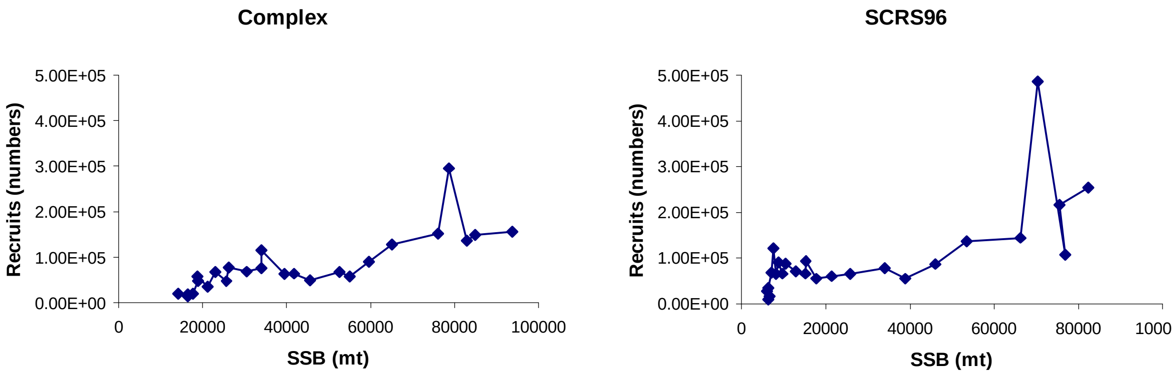


Figure 4. Complex ASAP analysis and SCRS 1996 stock-recruitment relationships.

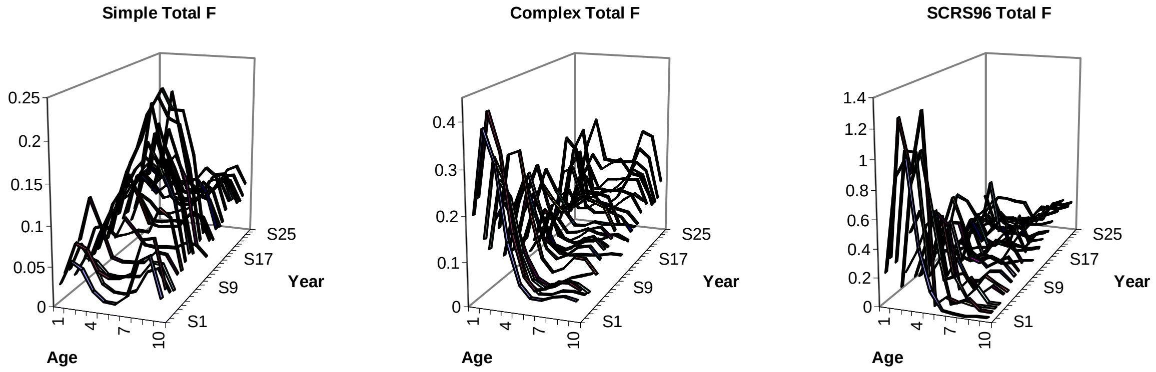


Figure 5. Estimated fishing mortality rates by age and year for two ASAP analyses and SCRS 1996.

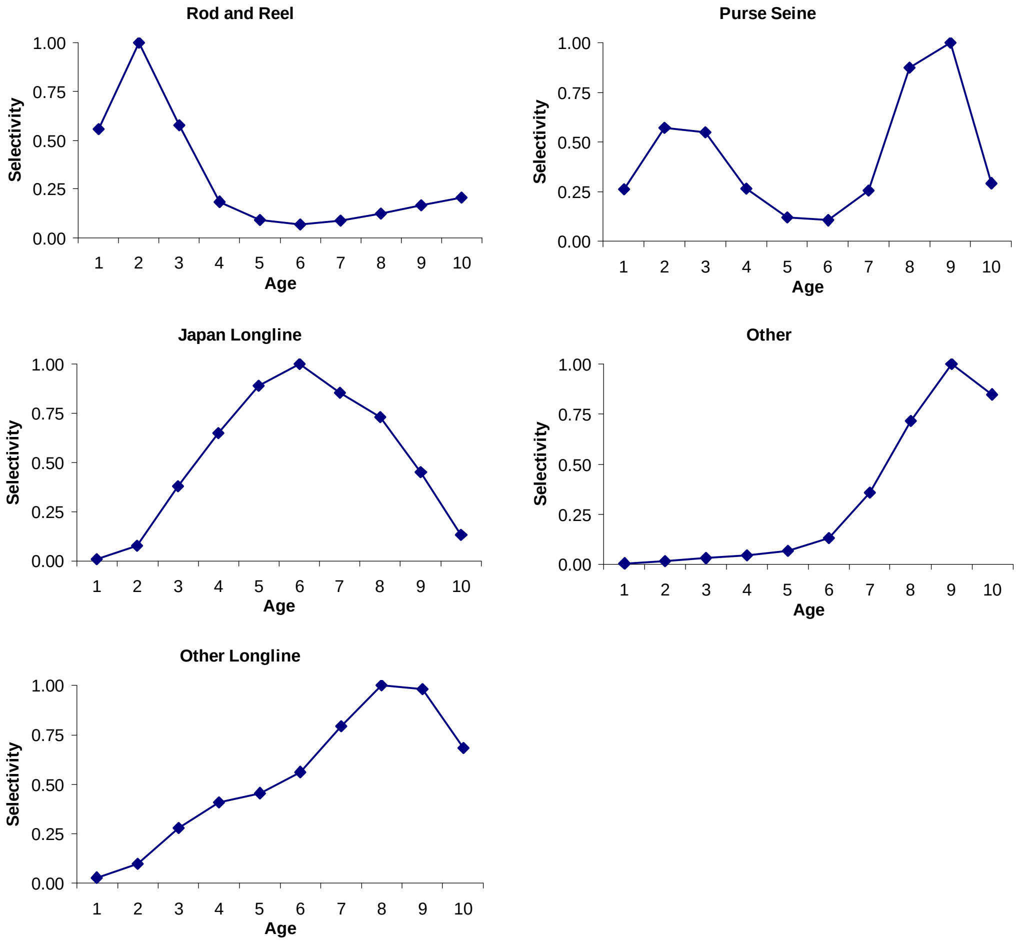
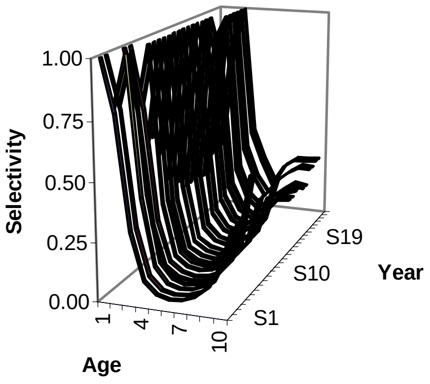
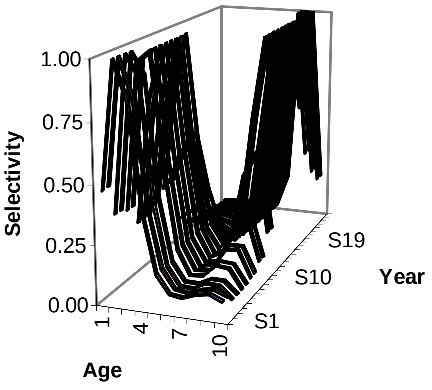


Figure 6a. Selectivity at age for the simple ASAP analysis, constant over all years for each fleet.

Rod and Reel



Purse Seine



Japan Longline

Other

Other Longline

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

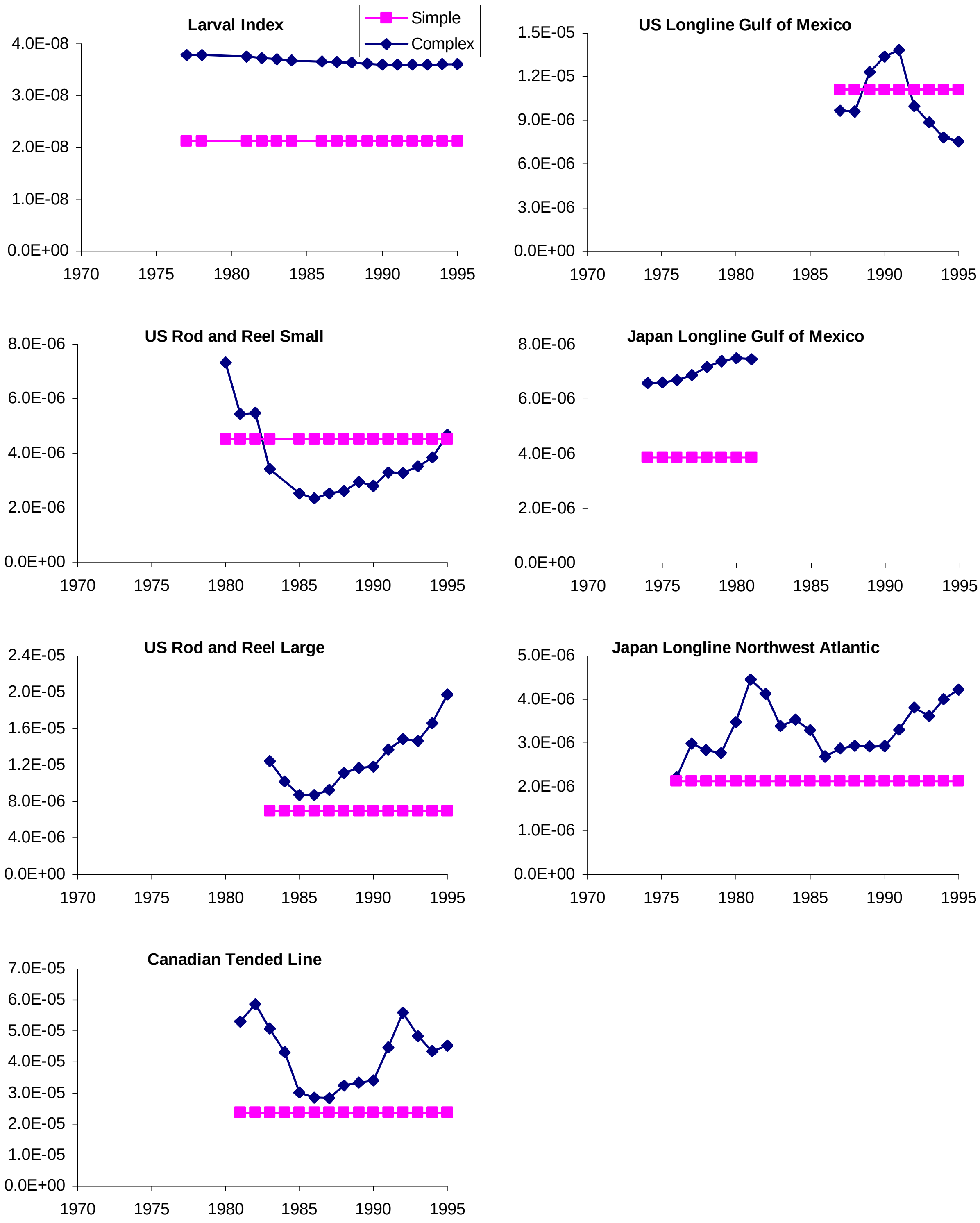


Figure 7. Catchability for each tuning index from the two ASAP analyses.

APPENDIX II

ASAP ADMB TEMPLATE FILE (BASELINE MODEL)

```
// ASAP (Age Structured Assessment Program)
// by Christopher Legault and Victor Restrepo


TOP_OF_MAIN_SECTION
// set buffer sizes
  arrmblsize=5000000;
//  gradient_structure::set_GRADSTACK_BUFFER_SIZE(9000000);
//  gradient_structure::set_CMPDIF_BUFFER_SIZE(90000000);
  gradient_structure::set_MAX_NVAR_OFFSET(50000);
  gradient_structure::set_NUM_DEPENDENT_VARIABLES(5000);


DATA_SECTION
  int iyear
  int iage
  int ifleet
  int ind
  int i
  int j
  int iloop
  init_int nyears
  init_int year1
  init_int nages
  init_vector M(1,nages)
  init_number isfecund
  init_matrix mature(1,nyears,1,nages)
  init_matrix WAA(1,nyears,1,nages)
  matrix fecundity(1,nyears,1,nages)
 LOCAL_CALCS
  if (isfecund==1)
     fecundity=mature;
  else
     fecundity=elem_prod(WAA,mature);
 END_CALCS
  init_int nfleets
  init_ivector sel_start_age(1,nfleets)
  init_ivector sel_end_age(1,nfleets)
  init_ivector sel_est_start_age(1,nfleets)
  init_ivector sel_est_end_age(1,nfleets)
  init_vector release_mort(1,nfleets)
  init_ivector dim_sel_fleet(1,nfleets)
  init_matrix fleet_sel_change_year(1,nfleets,1,dim_sel_fleet)
  init_matrix CAA_ini(1,nyears*nfleets,1,nages+1)
  init_matrix Discard_ini(1,nyears*nfleets,1,nages+1)
  init_matrix proportion_release_ini(1,nyears*nfleets,1,nages)
  3darray CAA_obs(1,nfleets,1,nyears,1,nages)
  3darray Discard_obs(1,nfleets,1,nyears,1,nages)
  3darray proportion_release(1,nfleets,1,nyears,1,nages)
  3darray CAA_prop_obs(1,nfleets,1,nyears,sel_start_age,sel_end_age)
  3darray Discard_prop_obs(1,nfleets,1,nyears,sel_start_age,sel_end_age)
  matrix sum_p_lnp(1,nfleets,1,nyears)
  matrix sum_Discard_p_lnp(1,nfleets,1,nyears)
  matrix Catch_tot_fleet_obs(1,nfleets,1,nyears)
  matrix Discard_tot_fleet_obs(1,nfleets,1,nyears)
  matrix CAA_prop_obs_sum(1,nfleets,1,nyears)
  matrix Discard_prop_obs_sum(1,nfleets,1,nyears)
 LOCAL_CALCS
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     for (iyear=1;iyear<=nyears;iyear++)
     {
         CAA_obs(ifleet,iyear)(1,nages)=CAA_ini((ifleet-1)*nyears+iyear)(1,nages);
         Discard_obs(ifleet,iyear)(1,nages)=Discard_ini((ifleet-
1)*nyears+iyear)(1,nages);
```

```
         proportion_release(ifleet,iyear)=proportion_release_ini((ifleet-
1)*nyears+iyear)(1,nages);
         Catch_tot_fleet_obs(ifleet,iyear)=CAA_ini((ifleet-1)*nyears+iyear,nages+1);
         Discard_tot_fleet_obs(ifleet,iyear)=Discard_ini((ifleet-
1)*nyears+iyear,nages+1);
     }
  }
  CAA_prop_obs=0.0;
  Discard_prop_obs=0.0;
  sum_p_lnp=0.0;
  sum_Discard_p_lnp=0.0;
  CAA_prop_obs_sum=0.0;
  Discard_prop_obs_sum=0.0;
  for (iyear=1;iyear<=nyears;iyear++)
  {
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
       if (Catch_tot_fleet_obs(ifleet,iyear)>0.0)
       {
          for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
             CAA_prop_obs_sum(ifleet,iyear)+=CAA_obs(ifleet,iyear,iage);
          if (CAA_prop_obs_sum(ifleet,iyear)==0.0)
          {
             CAA_prop_obs(ifleet,iyear)=0.0;
          }
          else
          {

CAA_prop_obs(ifleet,iyear)=CAA_obs(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet
))/CAA_prop_obs_sum(ifleet,iyear);
          }
       }
       for (iage=1;iage<=nages;iage++)
       {
          if(CAA_prop_obs(ifleet,iyear,iage)>1.0e-15)

sum_p_lnp(ifleet,iyear)+=CAA_prop_obs(ifleet,iyear,iage)*log(CAA_prop_obs(ifleet,iyear,ia
ge));
       }
       if (Discard_tot_fleet_obs(ifleet,iyear)>0.0)
       {
          for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
             Discard_prop_obs_sum(ifleet,iyear)+=Discard_obs(ifleet,iyear,iage);
          if (Discard_prop_obs_sum(ifleet,iyear)==0.0)
          {
             Discard_prop_obs(ifleet,iyear)=0.0;
          }
          else
          {

Discard_prop_obs(ifleet,iyear)=Discard_obs(ifleet,iyear)(sel_start_age(ifleet),sel_end_ag
e(ifleet))/Discard_prop_obs_sum(ifleet,iyear);
          }
       }
       for (iage=1;iage<=nages;iage++)
       {
          if(Discard_prop_obs(ifleet,iyear,iage)>1.0e-15)

sum_Discard_p_lnp(ifleet,iyear)+=Discard_prop_obs(ifleet,iyear,iage)*log(Discard_prop_obs
(ifleet,iyear,iage));
       }
    }
  }
 END_CALCS
  init_int nindices
  init_int index_weight_flag // 1=equal, 2=input
  init_vector index_units(1,nindices) // 1=biomass, 2=numbers
  init_vector index_month(1,nindices) // -1=average pop
  init_ivector index_start_age(1,nindices)
  init_ivector index_end_age(1,nindices)
  init_ivector index_fix_age(1,nindices)
```

```
  init_ivector index_sel_choice(1,nindices) // -1=fixed
  init_matrix index_ini(1,nyears*nindices,1,3+nages)
  ivector index_nobs(1,nindices)
 LOCAL_CALCS
  for (ind=1;ind<=nindices;ind++)
  {
     j=0;
     for (iyear=1;iyear<=nyears;iyear++)
     {
         if (index_ini((ind-1)*nyears+iyear,2)>-999.)
             j+=1;
     }
     index_nobs(ind)=j;
  }
 END_CALCS
  matrix index_time(1,nindices,1,index_nobs)
  matrix index_obs(1,nindices,1,index_nobs)
  matrix index_cv(1,nindices,1,index_nobs)
  matrix index_sigma2(1,nindices,1,index_nobs)
  matrix index_sigma(1,nindices,1,index_nobs)
  3darray index_sel_input(1,nindices,1,nyears,1,nages)
  vector index_mean(1,nindices)
 LOCAL_CALCS
  for (ind=1;ind<=nindices;ind++)
  {
     j=0;
     for (iyear=1;iyear<=nyears;iyear++)
     {
         i=(ind-1)*nyears+iyear;
         index_sel_input(ind,iyear)=--(--(--index_ini(i)(4,3+nages)));
         if (index_ini(i,2)>-999.)
         {
             j+=1;
             index_time(ind,j)=index_ini(i,1)-year1+1;
             index_obs(ind,j)=index_ini(i,2);
             index_cv(ind,j)=index_ini(i,3);
             if (index_weight_flag==1)
             {
                 index_sigma2(ind,j)=1.0;
             }
             else
             {
                 index_sigma2(ind,j)=log(index_cv(ind,j)*index_cv(ind,j)+1.0);
             }
             index_sigma(ind,j)=sqrt(index_sigma2(ind,j));
         }
     }
     index_mean(ind)=mean(index_obs(ind));
     index_obs(ind)/=index_mean(ind);       // rescale indices so mean=1
  }
 END_CALCS
//  init_int test_value
// !! cout << "test value = " << test_value << endl;
// !! cout << "asap2 read in" << endl;
// !! ad_comm::change_datafile_name("phase.ctl");
  init_int phase_sel_year1
  init_int phase_sel_devs
  init_int phase_Fmult_year1
  init_int phase_Fmult_devs
  init_int phase_recruit_devs
  init_int phase_N_year1_devs
  init_int phase_q_year1
  init_int phase_q_devs
  init_int phase_SRR
  init_int phase_steepness
  init_vector recruit_CV(1,nyears)
  vector recruit_sigma2(1,nyears)
  vector recruit_sigma(1,nyears)
 LOCAL_CALCS
  for (iyear=1;iyear<=nyears;iyear++)
  {
```

```
    recruit_sigma2(iyear)=log(recruit_CV(iyear)*recruit_CV(iyear)+1.0);
    recruit_sigma(iyear)=sqrt(recruit_sigma2(iyear));
  }
 END_CALCS
  init_vector lambda_ind(1,nindices)
  init_number lambda_catch_tot
  init_number lambda_Discard_tot
  init_matrix lambda_catch_ini(1,nyears,1,nfleets)
  init_matrix lambda_Discard_ini(1,nyears,1,nfleets)
  matrix lambda_catch(1,nfleets,1,nyears)
  matrix lambda_Discard(1,nfleets,1,nyears)
 LOCAL_CALCS
  for(iyear=1;iyear<=nyears;iyear++)
  {
   for(ifleet=1;ifleet<=nfleets;ifleet++)
   {
     lambda_catch(ifleet,iyear)=lambda_catch_ini(iyear,ifleet);
     lambda_Discard(ifleet,iyear)=lambda_Discard_ini(iyear,ifleet);
   }
  }
 END_CALCS
  init_vector lambda_Fmult_devs(1,nfleets)
  init_number lambda_N_year1_devs
  init_number lambda_recruit_devs
  init_vector lambda_q_devs(1,nindices)
  init_vector lambda_sel_devs(1,nfleets)
  init_number lambda_curve_sel_at_age
  init_number lambda_curve_sel_over_time
  init_number lambda_steepness
  init_number lambda_log_virgin_S
  init_vector NAA_year1_ini(1,nages)
  init_vector log_Fmult_year1_ini(1,nfleets)
  init_vector log_q_year1_ini(1,nindices)
  init_number log_SRR_virgin_ini
  init_number steepness_ini
  init_matrix select_year1_ini(1,nages,1,nfleets)
  init_number where_extras
  init_number ignore_guesses
  number delta
//  init_int test_value3
// !! cout << "test value3 = " << test_value3 << endl;
// !! cout << "phase.ctl read in   " << endl;
// !! ad_comm::change_datafile_name("project.ctl");
  init_int year_SSB
  init_ivector directed_fleet(1,nfleets)
  init_number nfinalyear
  int nprojyears
 !! nprojyears=nfinalyear-year1-nyears+1;
  init_matrix project_ini(1,nprojyears,1,5)
  vector proj_recruit(1,nprojyears)
  ivector proj_what(1,nprojyears)
  vector proj_target(1,nprojyears)
  vector proj_F_nondir_mult(1,nprojyears)
 LOCAL_CALCS
  for (iyear=1;iyear<=nprojyears;iyear++)
  {
    proj_recruit(iyear)=project_ini(iyear,2);
    proj_what(iyear)=project_ini(iyear,3);
    proj_target(iyear)=project_ini(iyear,4);
    proj_F_nondir_mult(iyear)=project_ini(iyear,5);
  }
 END_CALCS
//  init_int test_value2
// !! cout << "test value2 = " << test_value2 << endl;
// !! cout << "project.ctl read in   " << endl;


PARAMETER_SECTION
  init_bounded_matrix log_sel_year1(1,nfleets,sel_est_start_age,sel_est_end_age,-
6.,1.,phase_sel_year1)
  3darray log_sel_devs(1,nfleets,1,dim_sel_fleet,sel_est_start_age,sel_est_end_age)
```

```
!! int ns=size_count(log_sel_devs);
 init_bounded_vector log_sel_devs_vector(1,ns,-15.,15.,phase_sel_devs)
 init_bounded_vector log_Fmult_year1(1,nfleets,-15.,15.,phase_Fmult_year1)
 init_bounded_matrix log_Fmult_devs(1,nfleets,2,nyears,-15.,15.,phase_Fmult_devs)
 init_bounded_dev_vector log_recruit_devs(1,nyears,-15.,15.,phase_recruit_devs)
 init_bounded_vector log_N_year1_devs(2,nages,-15.,15.,phase_N_year1_devs)
 init_bounded_vector log_q_year1(1,nindices,-30,5,phase_q_year1)
 init_bounded_matrix log_q_devs(1,nindices,2,index_nobs,-15.,15.,phase_q_devs)
 init_bounded_number log_SRR_virgin(-1.0,200,phase_SRR)
 init_bounded_number SRR_steepness(0.20001,1.0,phase_steepness)
 matrix log_Fmult(1,nfleets,1,nyears)
 matrix NAA(1,nyears,1,nages)
 matrix temp_NAA(1,nyears,1,nages)
 matrix FAA_tot(1,nyears,1,nages)
 matrix Z(1,nyears,1,nages)
 matrix S(1,nyears,1,nages)
 matrix Catch_tot_fleet_pred(1,nfleets,1,nyears)
 matrix Discard_tot_fleet_pred(1,nfleets,1,nyears)
 3darray CAA_pred(1,nfleets,1,nyears,1,nages)
 3darray Discard_pred(1,nfleets,1,nyears,1,nages)
 3darray CAA_prop_pred(1,nfleets,1,nyears,sel_start_age,sel_end_age)
 3darray Discard_prop_pred(1,nfleets,1,nyears,sel_start_age,sel_end_age)
 3darray FAA_by_fleet_dir(1,nfleets,1,nyears,1,nages)
 3darray FAA_by_fleet_Discard(1,nfleets,1,nyears,1,nages)
 3darray log_sel(1,nfleets,1,nyears,sel_start_age,sel_end_age)
 3darray sel_by_fleet(1,nfleets,1,nyears,1,nages)
 vector temp_sel_over_time(1,nyears)
 number temp_sel_fix
 vector temp_sel_max(1,nfleets)
 number sel_max_pen
 number temp_Fmult_max
 number Fmult_max_pen
 matrix q_by_index(1,nindices,1,index_nobs)
 matrix temp_sel(1,nyears,1,nages)
 matrix index_pred(1,nindices,1,index_nobs)
 number ntemp
 number SRR_S0
 number SRR_virgin
 number SRR_rnot
 number SRR_alpha
 number SRR_beta
 vector SRR_pred_recruits(1,nyears+1)
 number RSS_SRR
 number RSS_SRR_sigma
 number likely_SRR_sigma
 vector RSS_sel_devs(1,nfleets)
 vector RSS_catch_tot_fleet(1,nfleets)
 vector RSS_Discard_tot_fleet(1,nfleets)
 number likely_catch
 number likely_Discard
 vector RSS_ind(1,nindices)
 vector RSS_ind_sigma(1,nindices)
 vector likely_ind(1,nindices)
 number fpenalty
 number sel_centered_pen
 vector Fmult_pen(1,nfleets)
 number N_year1_pen
 number recruit_pen
 vector q_pen(1,nindices)
 vector sel_devs_pen(1,nfleets)
 number curve_sel_at_age
 number curve_sel_over_time
 number nobs_curve_age
 number nobs_curve_time
 matrix effective_sample_size(1,nfleets,1,nyears)
 matrix effective_Discard_sample_size(1,nfleets,1,nyears)
 vector temp_Fmult(1,nfleets)
 sdreport_vector SSB(1,nyears)
 sdreport_vector recruits(1,nyears)
 sdreport_vector plus_group(1,nyears)
 vector final_year_total_sel(1,nages)
```

```
  vector dir_F(1,nages)
  vector Discard_F(1,nages)
  vector proj_nondir_F(1,nages)
  vector proj_dir_sel(1,nages)
  vector proj_Discard_sel(1,nages)
  matrix proj_NAA(1,nprojyears,1,nages)
  vector proj_Fmult(1,nprojyears)
  vector Ftemp(1,nages)
  vector Ztemp(1,nages)
  vector proj_SSB(1,nprojyears)
  number SSBtemp
  number denom
  matrix proj_F_dir(1,nprojyears,1,nages)
  matrix proj_F_Discard(1,nprojyears,1,nages)
  matrix proj_F_nondir(1,nprojyears,1,nages)
  matrix proj_Z(1,nprojyears,1,nages)
  matrix proj_catch(1,nprojyears,1,nages)
  matrix proj_Discard(1,nprojyears,1,nages)
  matrix proj_yield(1,nprojyears,1,nages)
  vector proj_total_yield(1,nprojyears)
  vector proj_total_Discard(1,nprojyears)
  vector output_prop_obs(1,nages)
  vector output_prop_pred(1,nages)
  vector output_Discard_prop_obs(1,nages)
  vector output_Discard_prop_pred(1,nages)
  number temp_sum
  number temp_sum2
  number A
  number B
  number C
  number f
  number z
  number SPR_Fmult
  number YPR_Fmult
  number SPR_virgin
  number SPR
  number SPRatio
  number YPR
  number S_F
  number R_F
  number slope_origin
  number slope
  number F30SPR
  number F40SPR
  number Fmsy
  number Foy
  number F01
  number Fmax
  number Fcurrent
  number F30SPR_slope
  number F40SPR_slope
  number Fmsy_slope
  number F01_slope
  number Fmax_slope
  number Fcurrent_slope
  number SSmsy
  number SSoy
  number OY
  sdreport_number MSY
  sdreport_number SSB_ratio
  sdreport_number proj_SSB_ratio
  sdreport_number SSmsy_ratio
  sdreport_number Fmsy_ratio
  number SSB_ratiop
  number proj_SSB_ratiop
  likeprof_number MSYp


  objective_function_value obj_fun

PRELIMINARY_CALCS_SECTION                  // this section requires ;
```

```
  if (ignore_guesses==0)
  {
    NAA(1)=NAA_year1_ini;
    log_Fmult_year1=log_Fmult_year1_ini;
    log_q_year1=log_q_year1_ini;
    log_SRR_virgin=log_SRR_virgin_ini;
    SRR_steepness=steepness_ini;
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
      for (iage=sel_est_start_age(ifleet);iage<=sel_est_end_age(ifleet);iage++) // last
age set to last age-1
         log_sel_year1(ifleet,iage)=log(select_year1_ini(iage,ifleet));
    }
  }
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     if(sel_start_age(ifleet)<sel_est_start_age(ifleet))
     {
        for (iage=sel_start_age(ifleet);iage<sel_est_start_age(ifleet);iage++)
        {
           for (iyear=1;iyear<=nyears;iyear++)
              sel_by_fleet(ifleet,iyear,iage)=select_year1_ini(iage,ifleet);
        }
     }
     if(sel_end_age(ifleet)>sel_est_end_age(ifleet))
     {
        for (iage=sel_est_end_age(ifleet)+1;iage<=sel_end_age(ifleet);iage++)
        {
           for (iyear=1;iyear<=nyears;iyear++)
              sel_by_fleet(ifleet,iyear,iage)=select_year1_ini(iage,ifleet);
        }
     }
  }
  ntemp=1.0;
  SRR_S0=0.0;
  for (iage=1;iage<nages;iage++)
  {
     SRR_S0+=ntemp*fecundity(1,iage);
     ntemp*=mfexp(-M(iage));
  }
  ntemp/=(1.0-mfexp(-M(nages)));
  SRR_S0+=ntemp*fecundity(1,nages);
  delta=0.00001;


PROCEDURE_SECTION                          // this section requires ;
  get_SRR();
  fill_seldevs();
  get_selectivity();
  get_mortality_rates();
  get_numbers_at_age();
  get_predicted_catch();
  get_q();
  get_predicted_indices();
  compute_the_objective_function();
  if (where_extras==1)
  {
    if (last_phase())
    {
       get_proj_sel();
       get_Fref();
       project_into_future();
    }
  }


FUNCTION fill_seldevs
  if (active(log_sel_devs_vector))
  {
     j=0;
     for (ifleet=1;ifleet<=nfleets;ifleet++)
```

```
     {
       for (i=1;i<=dim_sel_fleet(ifleet);i++)
       {
          for (iage=sel_est_start_age(ifleet);iage<=sel_est_end_age(ifleet);iage++)
          {
             j++;
             log_sel_devs(ifleet,i,iage)=log_sel_devs_vector(j);
          }
       }
     }
  }


FUNCTION get_selectivity
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {

log_sel(ifleet,1)(sel_est_start_age(ifleet),sel_est_end_age(ifleet))=log_sel_year1(ifleet
)(sel_est_start_age(ifleet),sel_est_end_age(ifleet));
  }
  if (active(log_sel_devs_vector))
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
     {
         i=1;
         for (iyear=2;iyear<=nyears;iyear++)
         {
             if ((iyear+year1-1-fleet_sel_change_year(ifleet,i))==0)
             {

log_sel(ifleet,iyear)(sel_est_start_age(ifleet),sel_est_end_age(ifleet))=log_sel(ifleet,i
year-
1)(sel_est_start_age(ifleet),sel_est_end_age(ifleet))+log_sel_devs(ifleet,i)(sel_est_star
t_age(ifleet),sel_est_end_age(ifleet));
                 i++;
                 if (i>dim_sel_fleet(ifleet))
                    i=dim_sel_fleet(ifleet);
             }
             else
             {

log_sel(ifleet,iyear)(sel_est_start_age(ifleet),sel_est_end_age(ifleet))=log_sel(ifleet,i
year-1)(sel_est_start_age(ifleet),sel_est_end_age(ifleet));
             }
         }
     }
  }
  else
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
     {
         for (iyear=2;iyear<=nyears;iyear++)

log_sel(ifleet,iyear)(sel_est_start_age(ifleet),sel_est_end_age(ifleet))=log_sel(ifleet,i
year-1)(sel_est_start_age(ifleet),sel_est_end_age(ifleet));
     }
  }
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     for (iyear=1;iyear<=nyears;iyear++)
     {
         for (iage=sel_est_start_age(ifleet);iage<=sel_est_end_age(ifleet);iage++)
             sel_by_fleet(ifleet,iyear,iage)=mfexp(log_sel(ifleet,iyear,iage));
     }
  }


FUNCTION get_mortality_rates
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     log_Fmult(ifleet,1)=log_Fmult_year1(ifleet);
```

```
     if (active(log_Fmult_devs))
     {
         for (iyear=2;iyear<=nyears;iyear++)
             log_Fmult(ifleet,iyear)=log_Fmult(ifleet,iyear-
1)+log_Fmult_devs(ifleet,iyear);
     }
     else
     {
         for (iyear=2;iyear<=nyears;iyear++)
             log_Fmult(ifleet,iyear)=log_Fmult_year1(ifleet);
     }
  }
  FAA_tot=0.0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     for (iyear=1;iyear<=nyears;iyear++)
     {
       for (iage=1;iage<=nages;iage++)
       {

FAA_by_fleet_dir(ifleet,iyear,iage)=(mfexp(log_Fmult(ifleet,iyear))*sel_by_fleet(ifleet,i
year,iage))*(1.0-proportion_release(ifleet,iyear,iage));

FAA_by_fleet_Discard(ifleet,iyear,iage)=(mfexp(log_Fmult(ifleet,iyear))*sel_by_fleet(ifle
et,iyear,iage))*(proportion_release(ifleet,iyear,iage)*release_mort(ifleet));
       }
     }
     FAA_tot+=FAA_by_fleet_dir(ifleet)+FAA_by_fleet_Discard(ifleet);
  }
  for (iyear=1;iyear<=nyears;iyear++)
     Z(iyear)=FAA_tot(iyear)+M;
  S=mfexp(-1.0*Z);


FUNCTION get_numbers_at_age
  SRR_pred_recruits(1)=SRR_rnot;
  NAA(1,1)=SRR_pred_recruits(1)*mfexp(log_recruit_devs(1));
  if (phase_N_year1_devs>0)
  {
    for (iage=2;iage<=nages;iage++)
       NAA(1,iage)=NAA(1,iage-1)*mfexp(-1.0*M(iage-1));
    NAA(1,nages)/=(1.0-mfexp(-1.0*M(nages)));
    for (iage=2;iage<=nages;iage++)
       NAA(1,iage)*=mfexp(log_N_year1_devs(iage));
  }
  SSB(1)=NAA(1)*fecundity(1);
  for (iyear=2;iyear<=nyears;iyear++)
  {
     SRR_pred_recruits(iyear)=SRR_alpha*SSB(iyear-1)/(SRR_beta+SSB(iyear-1));
     NAA(iyear,1)=SRR_pred_recruits(iyear)*mfexp(log_recruit_devs(iyear));
     for (iage=2;iage<=nages;iage++)
         NAA(iyear,iage)=NAA(iyear-1,iage-1)*S(iyear-1,iage-1);
     NAA(iyear,nages)+=NAA(iyear-1,nages)*S(iyear-1,nages);
     SSB(iyear)=NAA(iyear)*fecundity(iyear);
  }
  SRR_pred_recruits(nyears+1)=SRR_alpha*SSB(nyears)/(SRR_beta+SSB(nyears));
  for (iyear=1;iyear<=nyears;iyear++)
  {
    recruits(iyear)=NAA(iyear,1);
    plus_group(iyear)=NAA(iyear,nages);
  }
  if (SSB(year_SSB-year1+1)>0.0)
  {
    SSB_ratio=SSB(nyears)/SSB(year_SSB-year1+1);
  }
  else
  {
    SSB_ratio=-1.0;
  }
  SSB_ratiop=SSB_ratio;
  if (SSmsy>0.0)
```

```
    SSmsy_ratio=SSB(nyears)/SSmsy;


FUNCTION get_predicted_catch
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     CAA_pred(ifleet)=elem_prod(elem_div(FAA_by_fleet_dir(ifleet),Z),elem_prod(1.0-
S,NAA));

Discard_pred(ifleet)=elem_prod(elem_div(FAA_by_fleet_Discard(ifleet),Z),elem_prod(1.0-
S,NAA));
  }

  for (iyear=1;iyear<=nyears;iyear++)
  {
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
       CAA_prop_pred(ifleet,iyear)=0.0;
       Discard_prop_pred(ifleet,iyear)=0.0;

Catch_tot_fleet_pred(ifleet,iyear)=sum(CAA_pred(ifleet,iyear)(sel_start_age(ifleet),sel_e
nd_age(ifleet)));

Discard_tot_fleet_pred(ifleet,iyear)=sum(Discard_pred(ifleet,iyear)(sel_start_age(ifleet)
,sel_end_age(ifleet)));
       if (Catch_tot_fleet_pred(ifleet,iyear)>0.0)

CAA_prop_pred(ifleet,iyear)=CAA_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifle
et))/Catch_tot_fleet_pred(ifleet,iyear);
       if (Discard_tot_fleet_pred(ifleet,iyear)>0.0)

Discard_prop_pred(ifleet,iyear)=Discard_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_
age(ifleet))/Discard_tot_fleet_pred(ifleet,iyear);

Catch_tot_fleet_pred(ifleet,iyear)=CAA_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_a
ge(ifleet))*WAA(iyear)(sel_start_age(ifleet),sel_end_age(ifleet));

Discard_tot_fleet_pred(ifleet,iyear)=Discard_pred(ifleet,iyear)(sel_start_age(ifleet),sel
_end_age(ifleet))*WAA(iyear)(sel_start_age(ifleet),sel_end_age(ifleet));
       for (iage=1;iage<=nages;iage++)
       {
          if (CAA_prop_pred(ifleet,iyear,iage)<1.e-15)
             CAA_prop_pred(ifleet,iyear,iage)=1.0e-15;
          if (Discard_prop_pred(ifleet,iyear,iage)<1.e-15)
             Discard_prop_pred(ifleet,iyear,iage)=1.0e-15;
       }
    }
  }


FUNCTION get_q
  for (ind=1;ind<=nindices;ind++)
  {
     q_by_index(ind,1)=mfexp(log_q_year1(ind));
     if (active(log_q_devs))
     {
         for (i=2;i<=index_nobs(ind);i++)
             q_by_index(ind,i)=q_by_index(ind,i-1)*mfexp(log_q_devs(ind,i));
     }
     else
     {
         for (i=2;i<=index_nobs(ind);i++)
             q_by_index(ind,i)=q_by_index(ind,1);
     }
  }


FUNCTION get_predicted_indices
  for (ind=1;ind<=nindices;ind++)
  {
     if (index_sel_choice(ind)==-1)
```

```
     {
         temp_sel=index_sel_input(ind);
     }
     else
     {
         temp_sel=sel_by_fleet(index_sel_choice(ind));
         for (iyear=1;iyear<=nyears;iyear++)
         {
             temp_sel_fix=temp_sel(iyear,index_fix_age(ind));
             temp_sel(iyear)/=temp_sel_fix;
         }
     }
     if (index_month(ind)==-1)
     {
         temp_NAA=elem_prod(NAA,elem_div(1.0-S,Z));
     }
     else
     {
         temp_NAA=elem_prod(NAA,mfexp(-1.0*(index_month(ind)/12.0)*Z));
     }
     if (index_units(ind)==1)
     {
         temp_NAA=elem_prod(temp_NAA,WAA);
     }
     for (i=1;i<=index_nobs(ind);i++)
     {
         j=index_time(ind,i);
         index_pred(ind,i)=q_by_index(ind,i)*sum(elem_prod(
             temp_NAA(j)(index_start_age(ind),index_end_age(ind)) ,
             temp_sel(j)(index_start_age(ind),index_end_age(ind))));
     }

  }


FUNCTION get_SRR
  SRR_virgin=mfexp(log_SRR_virgin);
  SRR_rnot=SRR_virgin/SRR_S0;
  SRR_alpha=4.0*SRR_steepness*SRR_rnot/(5.0*SRR_steepness-1.0);
  SRR_beta=SRR_virgin*(1.0-SRR_steepness)/(5.0*SRR_steepness-1.0);


FUNCTION get_proj_sel
  dir_F=0.0;
  Discard_F=0.0;
  proj_nondir_F=0.0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     if (directed_fleet(ifleet)==1)
     {
        dir_F+=FAA_by_fleet_dir(ifleet,nyears);
        Discard_F+=FAA_by_fleet_Discard(ifleet,nyears);
     }
     else
     {
        proj_nondir_F+=FAA_by_fleet_dir(ifleet,nyears);
     }
  }
  proj_dir_sel=dir_F/max(dir_F);
  proj_Discard_sel=Discard_F/max(dir_F);


FUNCTION get_Fref
  get_SPR_virgin();
  A=0.0;
  B=5.0;
  for (iloop=1;iloop<=20;iloop++)
  {
     C=(A+B)/2.0;
     SPR_Fmult=C;
     get_SPR();
```

```
     if (SPR/SPR_virgin<0.30)
     {
        B=C;
     }
     else
     {
        A=C;
     }
  }
  F30SPR=C;
  F30SPR_slope=1.0/SPR;
  A=0.0;
  B=5.0;
  for (iloop=1;iloop<=20;iloop++)
  {
     C=(A+B)/2.0;
     SPR_Fmult=C;
     get_SPR();
     if (SPR/SPR_virgin<0.40)
     {
        B=C;
     }
     else
     {
        A=C;
     }
  }
  F40SPR=C;
  F40SPR_slope=1.0/SPR;
  A=0.0;
  B=3.0;
  for (iloop=1;iloop<=20;iloop++)
  {
    C=(A+B)/2.0;
    SPR_Fmult=C+delta;
    get_SPR();
    S_F=SRR_alpha*SPR-SRR_beta;
    R_F=S_F/SPR;
    YPR_Fmult=C+delta;
    get_YPR();
    slope=R_F*YPR;
    SPR_Fmult=C;
    get_SPR();
    S_F=SRR_alpha*SPR-SRR_beta;
    R_F=S_F/SPR;
    YPR_Fmult=C;
    get_YPR();
    slope-=R_F*YPR;
//    slope/=delta; only care pos or neg
    if(slope>0.0)
    {
       A=C;
    }
    else
    {
       B=C;
    }
  }
  Fmsy=C;
  SSmsy=S_F;
  MSY=YPR*R_F;
  MSYp=MSY;
  SPR_Fmult=Fmsy;
  get_SPR();
  Fmsy_slope=1.0/SPR;
    Foy=Fmsy*0.75;
    SPR_Fmult=Foy;
    get_SPR();
    SSoy=SRR_alpha*SPR-SRR_beta;
    R_F=SSoy/SPR;
    YPR_Fmult=Foy;
```

```
    get_YPR();
    OY=R_F*YPR;
  YPR_Fmult=delta;
  get_YPR();
  slope_origin=YPR/delta;
  A=0.0;
  B=5.0;
  for (iloop=1;iloop<=20;iloop++)
  {
     C=(A+B)/2.0;
     YPR_Fmult=C+delta;
     get_YPR();
     slope=YPR;
     YPR_Fmult=C;
     get_YPR();
     slope-=YPR;
     slope/=delta;
     if (slope<0.10*slope_origin)
     {
        B=C;
     }
     else
     {
        A=C;
     }
  }
  F01=C;
  SPR_Fmult=F01;
  get_SPR();
  F01_slope=1.0/SPR;
  A=0.0;
  B=10.0;
  for (iloop=1;iloop<=20;iloop++)
  {
     C=(A+B)/2.0;
     YPR_Fmult=C+delta;
     get_YPR();
     slope=YPR;
     YPR_Fmult=C;
     get_YPR();
     slope-=YPR;
     slope/=delta;
     if (slope<0.0)
     {
        B=C;
     }
     else
     {
        A=C;
     }
  }
  Fmax=C;
  SPR_Fmult=Fmax;
  get_SPR();
  Fmax_slope=1.0/SPR;
  Fcurrent=max(FAA_tot(nyears)-proj_nondir_F-Discard_F);
  SPR_Fmult=Fcurrent;
  get_SPR();
  Fcurrent_slope=1.0/SPR;
  if (Fmsy>0.0)
    Fmsy_ratio=Fcurrent/Fmsy;


FUNCTION get_YPR
  YPR=0.0;
  ntemp=1.0;
  for (iage=1;iage<nages;iage++)
  {
    f=YPR_Fmult*proj_dir_sel(iage);
    z=M(iage)+f+proj_nondir_F(iage)+YPR_Fmult*proj_Discard_sel(iage);
    YPR+=ntemp*f*WAA(nyears,iage)*(1.0-mfexp(-1.0*z))/z;
```

```
    ntemp*=mfexp(-1.0*z);
  }
  f=YPR_Fmult*proj_dir_sel(nages);
  z=M(nages)+f+proj_nondir_F(nages)+YPR_Fmult*proj_Discard_sel(nages);
  ntemp/=(1.0-mfexp(-1.0*z));
  YPR+=ntemp*f*WAA(nyears,nages)*(1.0-mfexp(-1.0*z))/z;


FUNCTION project_into_future
  get_SPR_virgin();
  for (iyear=1;iyear<=nprojyears;iyear++)
  {
    proj_F_nondir(iyear)=proj_nondir_F*proj_F_nondir_mult(iyear);
    if (proj_recruit(iyear)<0.0)  // use stock-recruit relationship
    {
       if (iyear==1)
       {
          proj_NAA(iyear,1)=SRR_alpha*SSB(nyears)/(SRR_beta+SSB(nyears));
       }
       else
       {
          proj_NAA(iyear,1)=SRR_alpha*proj_SSB(iyear-1)/(SRR_beta+proj_SSB(iyear-1));
       }
    }
    else
    {
       proj_NAA(iyear,1)=proj_recruit(iyear);
    }
    if (iyear==1)
    {
       for (iage=2;iage<=nages;iage++)
          proj_NAA(1,iage)=NAA(nyears,iage-1)*S(nyears,iage-1);
       proj_NAA(1,nages)+=NAA(nyears,nages)*S(nyears,nages);
    }
    else
    {
       for (iage=2;iage<=nages;iage++)
          proj_NAA(iyear,iage)=proj_NAA(iyear-1,iage-1)*mfexp(-1.0*proj_Z(iyear-1,iage-
1));
       proj_NAA(iyear,nages)+=proj_NAA(iyear-1,nages)*mfexp(-1.0*proj_Z(iyear-1,nages));
    }
    if (proj_what(iyear)==1) // match directed yield
    {
       proj_Fmult(iyear)=3.0;  // first check to see if catch possible
       proj_F_dir(iyear)=proj_Fmult(iyear)*proj_dir_sel;
       proj_F_Discard(iyear)=proj_Fmult(iyear)*proj_Discard_sel;
       proj_Z(iyear)=M+proj_F_nondir(iyear)+proj_F_dir(iyear)+proj_F_Discard(iyear);

proj_catch(iyear)=elem_prod(elem_div(proj_F_dir(iyear),proj_Z(iyear)),elem_prod(1.0-
mfexp(-1.0*proj_Z(iyear)),proj_NAA(iyear)));

proj_Discard(iyear)=elem_prod(elem_div(proj_F_Discard(iyear),proj_Z(iyear)),elem_prod(1.0
-mfexp(-1.0*proj_Z(iyear)),proj_NAA(iyear)));
       proj_yield(iyear)=elem_prod(proj_catch(iyear),WAA(nyears));
       proj_total_yield(iyear)=sum(proj_yield(iyear));
       proj_total_Discard(iyear)=sum(elem_prod(proj_Discard(iyear),WAA(nyears)));
       if (proj_total_yield(iyear)>proj_target(iyear))  // if possible, what F needed
       {
          proj_Fmult(iyear)=0.0;
          for (iloop=1;iloop<=20;iloop++)
          {
             Ftemp=proj_Fmult(iyear)*proj_dir_sel;
             denom=0.0;
             for (iage=1;iage<=nages;iage++)
             {

Ztemp(iage)=M(iage)+proj_F_nondir(iyear,iage)+proj_Fmult(iyear)*proj_Discard_sel(iage)+Ft
emp(iage);
                denom+=proj_NAA(iyear,iage)*WAA(nyears,iage)*proj_dir_sel(iage)*(1.0-
mfexp(-1.0*Ztemp(iage)))/Ztemp(iage);
             }
```

```
         proj_Fmult(iyear)=proj_target(iyear)/denom;
      }
   }
}
else
{
 if (proj_what(iyear)==2)      // match F%SPR
 {
   A=0.0;
   B=5.0;
   for (iloop=1;iloop<=20;iloop++)
   {
      C=(A+B)/2.0;
      SPR_Fmult=C;
      get_SPR();
      SPRatio=SPR/SPR_virgin;
      if (SPRatio<proj_target(iyear))
      {
         B=C;
      }
      else
      {
         A=C;
      }
   }
   proj_Fmult(iyear)=C;
 }
 else
 {
  if (proj_what(iyear)==3)   // project Fmsy
  {
    proj_Fmult=Fmsy;
  }
  else
  {
    if (proj_what(iyear)==4) // project Fcurrent
    {
        proj_Fmult=Fcurrent;
    }
    else
    {
       if (proj_what(iyear)==5) // project input F
       {
           proj_Fmult=proj_target(iyear);
       }
       else               // project default MSY (6) or OY (7) control rule
       {
           if(iyear==1)
           {
              SSBtemp=SSB(nyears);
           }
           else
           {
              SSBtemp=proj_SSB(iyear-1);
           }
           if((M(nages)+(SSBtemp/SSmsy))<=1)
           {
                proj_Fmult=Fmsy*(SSBtemp/SSmsy)/(1.0-M(nages));
           }
           else
           {
                proj_Fmult=Fmsy;
           }
           if (proj_what(iyear)==7)
                proj_Fmult*=0.75;
       }
    }
  }
 }
}
proj_F_dir(iyear)=proj_Fmult(iyear)*proj_dir_sel;
```

```
    proj_F_Discard(iyear)=proj_Fmult(iyear)*proj_Discard_sel;
    proj_Z(iyear)=M+proj_F_nondir(iyear)+proj_F_dir(iyear)+proj_F_Discard(iyear);
    proj_catch(iyear)=elem_prod(elem_div(proj_F_dir(iyear),proj_Z(iyear)),elem_prod(1.0-
mfexp(-1.0*proj_Z(iyear)),proj_NAA(iyear)));

proj_Discard(iyear)=elem_prod(elem_div(proj_F_Discard(iyear),proj_Z(iyear)),elem_prod(1.0
-mfexp(-1.0*proj_Z(iyear)),proj_NAA(iyear)));
    proj_yield(iyear)=elem_prod(proj_catch(iyear),WAA(nyears));
    proj_total_yield(iyear)=sum(proj_yield(iyear));
    proj_total_Discard(iyear)=sum(elem_prod(proj_Discard(iyear),WAA(nyears)));
    proj_SSB(iyear)=proj_NAA(iyear)*fecundity(nyears);
  }
  proj_SSB_ratio=proj_SSB(nprojyears)/SSB(year_SSB-year1+1);
  proj_SSB_ratiop=proj_SSB_ratio;


FUNCTION get_SPR_virgin
  ntemp=1.0;
  SPR_virgin=0.0;
  for (iage=1;iage<nages;iage++)
  {
    SPR_virgin+=ntemp*fecundity(nyears,iage);
    ntemp*=mfexp(-1.0*(M(iage)));
  }
  ntemp/=(1.0-mfexp(-1.0*(M(nages))));
  SPR_virgin+=ntemp*fecundity(nyears,nages);

FUNCTION get_SPR
  ntemp=1.0;
  SPR=0.0;
  for (iage=1;iage<nages;iage++)
  {
    SPR+=ntemp*fecundity(nyears,iage);

z=M(iage)+proj_nondir_F(iage)+SPR_Fmult*proj_dir_sel(iage)+SPR_Fmult*proj_Discard_sel(iag
e);
    ntemp*=mfexp(-1.0*z);
  }

z=M(nages)+proj_nondir_F(nages)+SPR_Fmult*proj_dir_sel(nages)+SPR_Fmult*proj_Discard_sel(
nages);
  ntemp/=(1.0-mfexp(-1.0*z));
  SPR+=ntemp*fecundity(nyears,nages);


FUNCTION compute_the_objective_function
// residuals and likelihoods
  for (ind=1;ind<=nindices;ind++)
  {
     RSS_ind(ind)=0.0;
     RSS_ind_sigma(ind)=0.0;
     for (i=1;i<=index_nobs(ind);i++)
     {
         RSS_ind(ind)+=square(log(index_obs(ind,i)+0.0001)-
log(index_pred(ind,i)+0.0001));
         RSS_ind_sigma(ind)+=((square(log(index_obs(ind,i)+0.0001)-
log(index_pred(ind,i)+0.0001)))/index_sigma2(ind,i))+log(index_sigma(ind,i));
     }
     likely_ind(ind)=0.5*lambda_ind(ind)*RSS_ind_sigma(ind);
  }
  obj_fun=sum(likely_ind);
  likely_catch=0.0;
  likely_Discard=0.0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    RSS_catch_tot_fleet(ifleet)=norm2(log(Catch_tot_fleet_obs(ifleet)+1.0)-
log(Catch_tot_fleet_pred(ifleet)+1.0));
    RSS_Discard_tot_fleet(ifleet)=norm2(log(Discard_tot_fleet_obs(ifleet)+1.0)-
log(Discard_tot_fleet_pred(ifleet)+1.0));
    for (iyear=1;iyear<=nyears;iyear++)
    {
```

```
       temp_sum=0.0;
       temp_sum2=0.0;
       for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
       {

temp_sum+=CAA_prop_obs(ifleet,iyear,iage)*log(CAA_prop_pred(ifleet,iyear,iage));
          if(proportion_release(ifleet,iyear,iage)>0.0)

temp_sum2+=Discard_prop_obs(ifleet,iyear,iage)*log(Discard_prop_pred(ifleet,iyear,iage));
       }
       likely_catch+=-1.0*lambda_catch(ifleet,iyear)*(temp_sum-sum_p_lnp(ifleet,iyear));
       likely_Discard+=-1.0*lambda_Discard(ifleet,iyear)*(temp_sum2-
sum_Discard_p_lnp(ifleet,iyear));
    }
  }
  obj_fun+=lambda_catch_tot*sum(RSS_catch_tot_fleet);
  obj_fun+=lambda_Discard_tot*sum(RSS_Discard_tot_fleet);
  obj_fun+=likely_catch;
  obj_fun+=likely_Discard;
// stock-recruitment relationship
  RSS_SRR=0.0;
  RSS_SRR_sigma=0.0;
  for (iyear=1;iyear<=nyears;iyear++)
  {
     RSS_SRR+=square(log(recruits(iyear)+0.001)-log(SRR_pred_recruits(iyear)+0.001));
     RSS_SRR_sigma+=((square(log(recruits(iyear)+0.001)-
log(SRR_pred_recruits(iyear)+0.001)))/recruit_sigma2(iyear))+log(recruit_sigma(iyear));
  }
  likely_SRR_sigma=0.5*lambda_recruit_devs*RSS_SRR_sigma;
  obj_fun+=likely_SRR_sigma;
  obj_fun+=lambda_steepness*square(log(steepness_ini)-log(SRR_steepness));
  obj_fun+=lambda_log_virgin_S*square(log_SRR_virgin_ini-log_SRR_virgin);
// penalties
  if (last_phase())
  {
    fpenalty=0.001*square(log(mean(FAA_tot))-log(mean(M)));
  }
  else
  {
    fpenalty=100.0*square(log(mean(FAA_tot))-log(mean(M)));
  }
  for (ifleet=1;ifleet<=nfleets;ifleet++)
    Fmult_pen(ifleet)=lambda_Fmult_devs(ifleet)*norm2(log_Fmult_devs(ifleet));
  N_year1_pen=lambda_N_year1_devs*norm2(log_N_year1_devs);
  recruit_pen=lambda_recruit_devs*norm2(log_recruit_devs);
  for (ind=1;ind<=nindices;ind++)
    q_pen(ind)=lambda_q_devs(ind)*norm2(log_q_devs(ind));
  obj_fun+=fpenalty+sum(Fmult_pen)+N_year1_pen+recruit_pen+sum(q_pen);
// penalty for first year selectivity not centered on 1
  sel_centered_pen=0.0;
  obj_fun+=sel_centered_pen;
// curvature penalties
  curve_sel_at_age=0.0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    if ((sel_end_age(ifleet)-sel_start_age(ifleet))>2)
    {
      curve_sel_at_age+=norm2(first_difference(first_difference(log_sel(ifleet,1))));
      if (active(log_sel_devs_vector));
      {
         for (i=1;i<=dim_sel_fleet(ifleet);i++)

curve_sel_at_age+=norm2(first_difference(first_difference(log_sel_devs(ifleet,i))));
      }
    }
  }
  obj_fun+=lambda_curve_sel_at_age*curve_sel_at_age;
  curve_sel_over_time=0.0;
  if (active(log_sel_devs_vector));
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
```

```
     {
       RSS_sel_devs(ifleet)=norm2(log_sel_devs(ifleet));
       sel_devs_pen(ifleet)=lambda_sel_devs(ifleet)*RSS_sel_devs(ifleet);
     }
     obj_fun+=sum(sel_devs_pen);
     for (ifleet=1;ifleet<=nfleets;ifleet++)
     {
        for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
        {
           for (iyear=1;iyear<=nyears;iyear++)
              temp_sel_over_time(iyear)=log_sel(ifleet,iyear,iage);

curve_sel_over_time+=norm2(first_difference(first_difference(temp_sel_over_time)));
        }
     }
  }
  obj_fun+=lambda_curve_sel_over_time*curve_sel_over_time;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
    temp_sel_max(ifleet)=max(mfexp(log_sel_year1(ifleet)));
  if (max(temp_sel_max)<=100)
  {
      sel_max_pen=0.0;
  }
  else
  {
      sel_max_pen=100.*(max(temp_sel_max)-100.0)*(max(temp_sel_max)-100.);
  }
  obj_fun+=sel_max_pen;
  Fmult_max_pen=0.0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    for (iyear=1;iyear<=nyears;iyear++)
    {
       temp_Fmult_max=mfexp(log_Fmult(ifleet,iyear))*temp_sel_max(ifleet);
       if(temp_Fmult_max>5.0)
          Fmult_max_pen+=1000.*(temp_Fmult_max-5.0)*(temp_Fmult_max-5.0);
    }
  }
  obj_fun+=Fmult_max_pen;


REPORT_SECTION                             // this section requires ;
  if (where_extras==2)
  {
    get_proj_sel();
    get_Fref();
    project_into_future();
  }
  report << "obj_fun        = " << obj_fun << endl;
  report << "Component          RSS      nobs  Lambda  Likelihood" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
    report << "  Catch_Fleet_" << ifleet << "        " << RSS_catch_tot_fleet(ifleet) <<
"   " << nyears << "   " << lambda_catch_tot << "   " <<
lambda_catch_tot*RSS_catch_tot_fleet(ifleet) << endl;
  report << "Catch_Fleet_Total     " << sum(RSS_catch_tot_fleet) << "   " <<
nfleets*nyears << "   " << lambda_catch_tot << "   " <<
lambda_catch_tot*sum(RSS_catch_tot_fleet) << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
    report << "  Discard_Fleet_" << ifleet << "        " << RSS_Discard_tot_fleet(ifleet)
<< "   " << nyears << "   " << lambda_Discard_tot << "   " <<
lambda_Discard_tot*RSS_Discard_tot_fleet(ifleet) << endl;
  report << "Discard_Fleet_Total     " << sum(RSS_Discard_tot_fleet) << "   " <<
nfleets*nyears << "   " << lambda_Discard_tot << "   " <<
lambda_Discard_tot*sum(RSS_Discard_tot_fleet) << endl;
  report << "CAA_proportions   " << "   N/A        " << "    " <<
size_count(CAA_prop_obs) << "    see_below      " << likely_catch << endl;
  report << "Discard_proportions   " << "   N/A        " << "    " <<
size_count(Discard_prop_obs) << "    see_below      " << likely_Discard << endl;
  for (ind=1;ind<=nindices;ind++)
    report << "  Index_Fit_" << ind << "         " << RSS_ind(ind) << "   " <<
index_nobs(ind) << "   " << lambda_ind(ind) << "   " << likely_ind(ind) << endl;
```

```
  report << "Index_Fit_Total     " << sum(RSS_ind) << "   " << sum(index_nobs) << "   "
<< sum(lambda_ind) << "   " << sum(likely_ind) << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
    report << "  Selectivity_devs_fleet_" << ifleet << "   " << RSS_sel_devs(ifleet) << "
" << dim_sel_fleet(ifleet) << "   " << lambda_sel_devs(ifleet) << "  " <<
sel_devs_pen(ifleet) << endl;
  report << "Selectivity_devs_Total   " << sum(RSS_sel_devs) << "  " <<
sum(dim_sel_fleet) << "   " << sum(lambda_sel_devs) << "  " << sum(sel_devs_pen) << endl;
  for (ind=1;ind<=nindices;ind++)
    report << "  Catchability_devs_index_" << ind << "  "  << norm2(log_q_devs(ind)) << "
" << index_nobs(ind) << "  " << lambda_q_devs(ind) << "  " << q_pen(ind) << endl;
  report << "Catchability_devs_Total  "  << norm2(log_q_devs) << "  " << sum(index_nobs)
<< "  " << sum(lambda_q_devs) << "  " << sum(q_pen) << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
    report << "  Fmult_fleet_" << ifleet << "     " << norm2(log_Fmult_devs(ifleet)) << "
" << nyears-1 << "   " << lambda_Fmult_devs(ifleet) << "  " << Fmult_pen(ifleet) << endl;
  report << "Fmult_fleet_Total   " << norm2(log_Fmult_devs) << "   " << nfleets*(nyears-
1) << "   " << sum(lambda_Fmult_devs) << "  " << sum(Fmult_pen) << endl;
  report << "N_year_1            " << norm2(log_N_year1_devs) << "   " << nages-1 << "
" << lambda_N_year1_devs << "   " << N_year1_pen << endl;
  report << "Stock-Recruit_Fit   " << RSS_SRR << "  " << nyears << "   " <<
lambda_recruit_devs << "   "  << likely_SRR_sigma << endl;
  report << "Recruit_devs        " << norm2(log_recruit_devs) << "   " << nyears << "   "
<< lambda_recruit_devs << "   " << lambda_recruit_devs*norm2(log_recruit_devs) << endl;
  report << "SRR_steepness       " << square(log(steepness_ini)-log(SRR_steepness)) << "
" << "     1 " << lambda_steepness << "   " <<
lambda_steepness*square(log(steepness_ini)-log(SRR_steepness)) << endl;
  report << "SRR_virgin_stock    " << square(log_SRR_virgin_ini-log_SRR_virgin) << "  "
<< "    1 " << lambda_log_virgin_S << "  " <<
lambda_log_virgin_S*square(log_SRR_virgin_ini-log_SRR_virgin) << endl;
  nobs_curve_age=0.0;
  nobs_curve_time=0.0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    if (sel_end_age(ifleet)-sel_start_age(ifleet)>2)
    {
       if (phase_sel_devs>0)
       {
          nobs_curve_age+=(sel_end_age(ifleet)-sel_start_age(ifleet)-
1)*dim_sel_fleet(ifleet);
       }
       else
       {
          nobs_curve_age+=(sel_end_age(ifleet)-sel_start_age(ifleet)-1);
       }
    }
    nobs_curve_time+=(sel_end_age(ifleet)-sel_start_age(ifleet)+1)*(nyears-2);
  }
  report << "Curvature_over_age  " << curve_sel_at_age << "   " << nobs_curve_age << "
" << lambda_curve_sel_at_age << "   " << lambda_curve_sel_at_age*curve_sel_at_age <<
endl;
  report << "Curvature_over_time " << curve_sel_over_time << "   " << nobs_curve_time <<
"   " << lambda_curve_sel_over_time << "   " <<
lambda_curve_sel_over_time*curve_sel_over_time << endl;
  report << "F_penalty           " << fpenalty/0.001 << "    " << nyears*nages << "
0.001     " << fpenalty << endl;
  report << "Mean_Sel_year1_pen  " << sel_centered_pen/1000. << "   " << sum(sel_end_age-
sel_start_age+1) << "      1000  " << sel_centered_pen << endl;
  report << "Max_Sel_penalty     " << max(temp_sel_max) << "   " << "     1 " << "
100 " << sel_max_pen << endl;
  report << "Fmult_Max_penalty   " << Fmult_max_pen/100. << "   " << "     ? " << "
100 " << Fmult_max_pen << endl;
  report << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     for (iyear=1;iyear<=nyears;iyear++)
     {
       effective_sample_size(ifleet,iyear)=CAA_prop_pred(ifleet,iyear)*(1.0-
CAA_prop_pred(ifleet,iyear))/norm2(CAA_prop_obs(ifleet,iyear)-
CAA_prop_pred(ifleet,iyear));
```

```
       effective_Discard_sample_size(ifleet,iyear)=Discard_prop_pred(ifleet,iyear)*(1.0-
Discard_prop_pred(ifleet,iyear))/norm2(Discard_prop_obs(ifleet,iyear)-
Discard_prop_pred(ifleet,iyear));
     }
  }
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << " Input and Estimated effective sample sizes for fleet " << ifleet <<
endl;
     for (iyear=1;iyear<=nyears;iyear++)
        report << iyear+year1-1 << "  " << lambda_catch(ifleet,iyear) << "  " <<
effective_sample_size(ifleet,iyear) << endl;
     report << " Total  " << sum(lambda_catch(ifleet)) << "  " <<
sum(effective_sample_size(ifleet)) << endl;
  }
  report << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << " Input and Estimated effective Discard sample sizes for fleet " << ifleet
<< endl;
     for (iyear=1;iyear<=nyears;iyear++)
        report << iyear+year1-1 << "  " << lambda_Discard(ifleet,iyear) << "  " <<
effective_Discard_sample_size(ifleet,iyear) << endl;
     report << " Total  " << sum(lambda_Discard(ifleet)) << "  " <<
sum(effective_Discard_sample_size(ifleet)) << endl;
  }
  report << endl;
  report << "Observed and predicted total fleet catch by year" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    report << " fleet " << ifleet << " total catches" << endl;
    for (iyear=1;iyear<=nyears;iyear++)
    {
      report << iyear+year1-1 << "  " << Catch_tot_fleet_obs(ifleet,iyear) << "  " <<
Catch_tot_fleet_pred(ifleet,iyear) << endl;
    }
  }
  report << "Observed and predicted total fleet Discards by year" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    report << " fleet " << ifleet << " total Discards" << endl;
    for (iyear=1;iyear<=nyears;iyear++)
    {
      report << iyear+year1-1 << "  " << Discard_tot_fleet_obs(ifleet,iyear) << "  " <<
Discard_tot_fleet_pred(ifleet,iyear) << endl;
    }
  }
  report << endl << "Index data" << endl;
  for (ind=1;ind<=nindices;ind++)
  {
     report << "index number " << ind << endl;
     report << "units = " << index_units(ind) << endl;
     report << "month = " << index_month(ind) << endl;
     report << "starting and ending ages for selectivity = " << index_start_age(ind) << "
" << index_end_age(ind) << endl;
     report << "selectivity choice = " << index_sel_choice(ind) << endl;
     report << " year, sigma2, obs index, pred index" << endl;
     for (j=1;j<=index_nobs(ind);j++)
         report << index_time(ind,j)+year1-1 << "  " << index_sigma2(ind,j) << "  " <<
index_obs(ind,j) << "  " << index_pred(ind,j) << endl;
  }
  report << endl;
  report << "Selectivity by age and year for each fleet rescaled so max=1.0" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << " fleet " << ifleet << " selectivity at age" << endl;
     for (iyear=1;iyear<=nyears;iyear++)
       report << sel_by_fleet(ifleet,iyear)/max(sel_by_fleet(ifleet,iyear)) << endl;
  }
  report << endl;
  report << "Fmult by year for each fleet" << endl;
```

```
  for (iyear=1;iyear<=nyears;iyear++)
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)

temp_Fmult(ifleet)=mfexp(log_Fmult(ifleet,iyear))*max(sel_by_fleet(ifleet,iyear));
     report << iyear+year1-1 << "  " << temp_Fmult << endl;
  }
  report << endl;
  report << "Directed F by age and year for each fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << " fleet " << ifleet << " directed F at age" << endl;
     for (iyear=1;iyear<=nyears;iyear++)
         report << FAA_by_fleet_dir(ifleet,iyear) << endl;
  }
  report << "Discard F by age and year for each fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << " fleet " << ifleet << " Discard F at age" << endl;
     for (iyear=1;iyear<=nyears;iyear++)
         report << FAA_by_fleet_Discard(ifleet,iyear) << endl;
  }
  report << "Total F" << endl;
  for (iyear=1;iyear<=nyears;iyear++)
     report << FAA_tot(iyear) << endl;
  report << endl;
  report << "Population Numbers at the Start of the Year" << endl;
  for (iyear=1;iyear<=nyears;iyear++)
     report << NAA(iyear) << endl;
  report << "q by index" << endl;
  for (ind=1;ind<=nindices;ind++)
  {
     report << " index " << ind << " q over time" << endl;
     for (i=1;i<=index_nobs(ind);i++)
     {
         j=index_time(ind,i);
         report << j+year1-1 << "  " << q_by_index(ind,i) << endl;
     }
  }
  report << endl;
  report << "Proportions of catch at age by fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    report << " fleet " << ifleet << endl;
    for (iyear=1;iyear<=nyears;iyear++)
    {
       output_prop_obs=0.0;
       output_prop_pred=0.0;

output_prop_obs(sel_start_age(ifleet),sel_end_age(ifleet))=CAA_prop_obs(ifleet,iyear);

output_prop_pred(sel_start_age(ifleet),sel_end_age(ifleet))=CAA_prop_pred(ifleet,iyear);
       report << "Year " << iyear << " Obs  = " << output_prop_obs << endl;
       report << "Year " << iyear << " Pred = " << output_prop_pred << endl;
    }
  }
  report << endl;
  report << "Proportions of Discards at age by fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    report << " fleet " << ifleet << endl;
    for (iyear=1;iyear<=nyears;iyear++)
    {
       output_Discard_prop_obs=0.0;
       output_Discard_prop_pred=0.0;

output_Discard_prop_obs(sel_start_age(ifleet),sel_end_age(ifleet))=Discard_prop_obs(iflee
t,iyear);

output_Discard_prop_pred(sel_start_age(ifleet),sel_end_age(ifleet))=Discard_prop_pred(ifl
eet,iyear);
```

```
       report << "Year " << iyear << " Obs  = " << output_Discard_prop_obs << endl;
       report << "Year " << iyear << " Pred = " << output_Discard_prop_pred << endl;
    }
  }
  report << endl;
  report << "F Reference Points Using Final Year Selectivity Scaled Max=1.0" << endl;
  report << " refpt           F       slope to plot on SRR" << endl;
  report << "  F0.1     " << F01 << "     " << F01_slope << endl;
  report << "  Fmax     " << Fmax << "     " << Fmax_slope << endl;
  report << "  F30%SPR  " << F30SPR << "     " << F30SPR_slope << endl;
  report << "  F40%SPR  " << F40SPR << "     " << F40SPR_slope << endl;
  report << "  Fmsy     " << Fmsy << "     " << Fmsy_slope << "    SSmsy    " << SSmsy <<
"     MSY   " << MSY << endl;
  report << "  Foy      " << Foy << "     " << "xxxxxx" << "    SSoy    " << SSoy << "
OY   " << OY << endl;
  report << "  Fcurrent " << Fcurrent << "     " << Fcurrent_slope << endl;
  report << endl;
  report << "Stock-Recruitment Relationship Parameters" << endl;
  report << " alpha     = " << SRR_alpha << endl;
  report << " beta      = " << SRR_beta << endl;
  report << " virgin    = " << SRR_virgin << endl;
  report << " steepness = " << SRR_steepness << endl;
  report << "Spawning Stock, Obs Recruits(year+1), Pred Recruits(year+1)" << endl;
  for (iyear=1;iyear<nyears;iyear++)
    report << iyear+year1-1 << "  " << SSB(iyear) << "  " << recruits(iyear+1) << "  "
<< SRR_pred_recruits(iyear+1) << endl;
  report << nyears+year1-1 << "  " << SSB(nyears) << "       xxxx   " <<
SRR_pred_recruits(nyears+1) << endl;
  report << endl;
  report << "average F (ages 4 to 8 unweighted) by year" << endl;
  report << "Projection into Future" << endl;
  report << "Projected NAA" << endl;
  report << proj_NAA << endl;
  report << "Projected Directed FAA" << endl;
  report << proj_F_dir << endl;
  report << "Projected Discard FAA" << endl;
  report << proj_F_Discard << endl;
  report << "Projected Nondirected FAA" << endl;
  report << proj_F_nondir << endl;
  report << "Projected Catch at Age" << endl;
  report << proj_catch << endl;
  report << "Projected Discards at Age (in numbers)" << endl;
  report << proj_Discard << endl;
  report << "Projected Yield at Age" << endl;
  report << proj_yield << endl;
  report << "Year, Total Yield (in weight), Total Discards (in weight), SSB, proj_what,
SS/SSmsy" << endl;
  for (iyear=1;iyear<=nprojyears;iyear++)
    report << year1+nyears-1+iyear << "  " << proj_total_yield(iyear) << "  " <<
proj_total_Discard(iyear) << "  " << proj_SSB(iyear) << "  " << proj_what(iyear) << "  "
<< proj_SSB(iyear)/SSmsy << endl;
  report << endl;
  report << "M = " << M << endl;
  report << "mature = " << mature << endl;
  report << "Weight at age" << endl;
  report << WAA << endl;
  report << "Fecundity" << endl;
  report << fecundity << endl;
  report << endl;
  report << "SSmsy_ratio = " << SSmsy_ratio << endl;
  report << "Fmsy_ratio =  " << Fmsy_ratio << endl;
  report << "that's all" << endl;


RUNTIME_SECTION
  convergence_criteria 1.0e-4
  maximum_function_evaluations 800,1600,10000
```

APPENDIX III

ASAP INPUT FILE (BASELINE MODEL)

```
# Sardine Assmt, Nov 2004, Run12-0
# Number of Years
   23
# First Year
   1983
# Number of Ages
   6
# Natural Mortality Rate by Age
   0.4   0.4   0.4   0.4   0.4   0.4
# Fecundity Option
   0
# Maturity Vector
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
   0.30   0.53   0.91   0.97   0.99   1.00
# Weight at Age Vector
   0.069   0.118   0.128   0.155   0.184   0.187
   0.069   0.087   0.138   0.154   0.167   0.187
   0.083   0.108   0.135   0.149   0.164   0.160
   0.074   0.117   0.148   0.170   0.185   0.186
   0.054   0.111   0.150   0.164   0.184   0.172
   0.087   0.107   0.142   0.169   0.183   0.188
   0.069   0.101   0.148   0.169   0.185   0.195
   0.109   0.130   0.153   0.161   0.170   0.165
   0.082   0.122   0.143   0.152   0.155   0.159
   0.059   0.097   0.132   0.147   0.157   0.170
   0.055   0.062   0.095   0.123   0.161   0.146
   0.047   0.071   0.079   0.082   0.131   0.146
   0.050   0.062   0.087   0.095   0.103   0.115
   0.057   0.069   0.079   0.096   0.111   0.116
   0.063   0.077   0.107   0.114   0.121   0.122
   0.049   0.073   0.094   0.114   0.118   0.118
   0.042   0.056   0.078   0.102   0.104   0.115
   0.050   0.056   0.062   0.064   0.069   0.090
   0.054   0.076   0.087   0.094   0.105   0.129
   0.040   0.068   0.100   0.115   0.134   0.151
   0.054   0.084   0.100   0.113   0.129   0.146
   0.047   0.086   0.099   0.112   0.134   0.148
   0.047   0.086   0.099   0.112   0.134   0.148
# Number of Fleets
   3
#$FLEET-1
#$FLEET-2
#$FLEET-3
```

```
# Selectivity Start Age
   1   1   1
# Selectivity End Age
   6   6   6
# Selectivity Est. Start Age
   1   1   1
# Selectivity Est. End Age
   6   6   6
# Release Mortality
   0.0   0.0   0.0
# Number of Selectivity Changes by Fleet
   1   1   1
# Selectivity Change Years
   1992
   1983
   1983
# Fleet 1 Catch at Age - Last Column is Total Weight
         0   880.221   1261.22   260.784    56.087      8.37     337.2
   397.787   739.688  1135.352    77.765     2.678         0    248.21
     16.92   804.455  1611.199   281.504         0         0    396.98
    19.231  2273.313  4906.908   715.091    39.525         0   1191.13
   185.492  1166.523  5923.665   2305.29   174.521    26.432    1548.2
    37.625  14431.15  9911.578  3756.561   675.538    58.138   3810.27
   355.855  4998.951   11192.7  2602.285   786.324   108.958   2918.96
   187.655  15741.01  9135.113  1533.479    90.619         0   3658.77
  1350.244  9506.095  14557.12  10455.88  5050.183  2918.672    5855.6
  7452.161  21251.57  28460.45  12301.09  5302.827  5713.787   9574.24
  33462.91  147998.5   98106.2  22749.35  5996.735  3354.074  24319.88
   26759.9  41603.32  50290.38   30093.8  5057.721   2043.36  12431.23
  206711.6  236588.4  64598.47  29722.69  4090.601   868.406  32902.42
  84888.08  240038.1  132467.1   12175.5   1792.65   122.233  29819.73
  89636.04  96347.18    136744  57311.31  7156.756  2118.914  29026.82
  49163.05  325948.3  218952.2  97980.32  31395.21  5755.492  56172.34
    219059  601996.1  183575.6  25482.61  14214.17  1990.487  51005.23
  209576.1  729802.1  252952.5  13952.99  5930.858  1324.889  60360.46
  173501.2  260539.8  283684.8    157218  12562.37  1851.277  52915.64
  525651.3  184093.6  148100.6  105554.8  20576.32  6988.182  52980.69
  126574.3  568044.8    156788  31379.39  10102.01  2504.878  60713.59
  398822.5  78956.51  93110.77  20653.57  8127.187  4546.108  29451.19
         0         0         0         0         0         0  35824.41
# Fleet 2 Catch at Age - Last Column is Total Weight
         0         0         0         0         0         0     149.5
         0         0         0         0         0         0     124.1
         0         0         0         0         0         0    3174.2
         0         0         0         0         0         0     647.3
         0         0         0         0         0         0    1118.4
         0         0         0         0         0         0    2076.8
         0         0         0         0         0         0    1875.7
  30029.45  35487.88  15431.27  4272.482  1886.625    65.765   11663.2
  26363.59  41035.27  34640.76  8015.582  1643.472   1439.99   14746.3
   20558.6  68134.92   50262.9  41931.73  18598.96  8898.497   25447.3
  236304.2  512738.5  53762.27   395.449   262.804         0   49889.8
  103939.1  69103.66  120214.5  8696.735         0         0   19108.4
  262030.7  174391.7   55347.2  42693.03  5252.599         0   33392.7
  191289.1  144459.2   85039.3  17658.26  5798.779         0   32834.8
  39883.29  112217.4  132568.1  46845.84  23193.53  2034.223  36897.22
   44798.8  157949.9  266467.9    184200  79962.45  23396.89  75179.37
  267923.2  285025.4    154083  102701.5  64506.02  13702.69   62333.2
  306256.8  246126.9  162450.1  81397.97  31977.57  13575.79   49609.1
  81157.16  205539.5  65524.56  24265.99  5892.003  1204.692   34680.8
  204813.6  130415.9  65163.32  7236.996  1081.285         0   29435.7
         0         0         0         0         0         0   39814.3
         0         0         0         0         0         0   35722.9
         0         0         0         0         0         0   35722.9
# Fleet 3 Catch 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      4.08
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0     22.68
         0         0         0         0         0         0     43.54
         0         0         0         0         0         0     28.03
         0         0         0         0         0         0    562.84
         0         0  3791.341  1936.884  1040.338  2262.108   1154.59
         0  1814.186  45205.46  48655.74  19197.64   13822.8  17922.96
   178.242   3499.27  21320.47   70723.7  44438.68  26569.15  25682.92
         0  1726.259  6646.805  28201.98  73487.37   87563.8  36122.98
         0   4639.48  39203.62  37740.66   26634.5  127555.9  39860.69
         0         0         0         0         0         0  38158.47
# 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
# Fleet 2 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
# Fleet 3 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
# 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
# Fleet 2 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
# Fleet 3 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
# Number of Indices
   2
#$DEPM
#$Aerial_Spotter
# Index Weight Flag
   2
# Index Units
   1   1
# Index Month
   10   -1
# Index Start Age
   1   1
# Index End Age
   6   6
# Index Fix Age
   -1   -1
# Index Selectivity Choice
   -1   -1
# Index Data - Year, Index, CV, Selectivity
# INDEX - 1
    1983      -999       0.3       0.3      0.53      0.91      0.97      0.99         1
    1984      -999       0.3       0.3      0.53      0.91      0.97      0.99         1
    1985      -999       0.3       0.3      0.53      0.91      0.97      0.99         1
    1986      7659       0.3       0.3      0.53      0.91      0.97      0.99         1
    1987     15704       0.3       0.3      0.53      0.91      0.97      0.99         1
    1988     13526       0.3       0.3      0.53      0.91      0.97      0.99         1
    1989      -999       0.3       0.3      0.53      0.91      0.97      0.99         1
    1990      -999       0.3       0.3      0.53      0.91      0.97      0.99         1
    1991      -999       0.3       0.3      0.53      0.91      0.97      0.99         1
    1992      -999       0.3       0.3      0.53      0.91      0.97      0.99         1
    1993      -999       0.3       0.3      0.53      0.91      0.97      0.99         1
    1994    127102       0.3       0.3      0.53      0.91      0.97      0.99         1
    1995      -999       0.3       0.3      0.53      0.91      0.97      0.99         1
    1996     83175       0.3       0.3      0.53      0.91      0.97      0.99         1
    1997    409579       0.3       0.3      0.53      0.91      0.97      0.99         1
    1998    313985       0.3       0.3      0.53      0.91      0.97      0.99         1
    1999    282248       0.3       0.3      0.53      0.91      0.97      0.99         1
    2000   1063837       0.3       0.3      0.53      0.91      0.97      0.99         1
    2001    790925       0.3       0.3      0.53      0.91      0.97      0.99         1
    2002    206333       0.3       0.3      0.53      0.91      0.97      0.99         1
    2003    485121       0.3       0.3      0.53      0.91      0.97      0.99         1
    2004    281639       0.3       0.3      0.53      0.91      0.97      0.99         1
    2005      -999       0.3       0.3      0.53      0.91      0.97      0.99         1
# INDEX - 2
    1983      -999       0.3         1         1      0.59      0.18      0.03         0
    1984      -999       0.3         1         1      0.59      0.18      0.03         0
    1985      -999       0.3         1         1      0.59      0.18      0.03         0
    1986     22049       0.3         1         1      0.59      0.18      0.03         0
    1987     11498       0.3         1         1      0.59      0.18      0.03         0
    1988     55882       0.3         1         1      0.59      0.18      0.03         0
    1989     32929       0.3         1         1      0.59      0.18      0.03         0
    1990     21144       0.3         1         1      0.59      0.18      0.03         0
```

```
    1991     40571       0.3         1         1      0.59      0.18      0.03         0
    1992     49065       0.3         1         1      0.59      0.18      0.03         0
    1993     84070       0.3         1         1      0.59      0.18      0.03         0
    1994    211293       0.3         1         1      0.59      0.18      0.03         0
    1995    188924       0.3         1         1      0.59      0.18      0.03         0
    1996    119731       0.3         1         1      0.59      0.18      0.03         0
    1997     66943       0.3         1         1      0.59      0.18      0.03         0
    1998    118492       0.3         1         1      0.59      0.18      0.03         0
    1999     40506       0.3         1         1      0.59      0.18      0.03         0
    2000     48373       0.3         1         1      0.59      0.18      0.03         0
    2001      -999       0.3         1         1      0.59      0.18      0.03         0
    2002      -999       0.3         1         1      0.59      0.18      0.03         0
    2003      -999       0.3         1         1      0.59      0.18      0.03         0
    2004      -999       0.3         1         1      0.59      0.18      0.03         0
    2005      -999       0.3         1         1      0.59      0.18      0.03         0
# 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
   0.5
   0.5
   0.5
   0.5
   0.5
   0.5
   0.5
   0.5
   0.5
   0.5
   0.5
   0.5
   0.5
   0.5
   0.5
   0.5
   0.5
   0.5
   0.49
   0.485
   0.455
   0.265
   0.15
#Lambda for Each Index (cv=0.4)
   1   1
# Lambda for Total Catch in Weight
   100
# Lambda for Total Discards at Age
   0
# Lambda for Catch at Age by Year & Fleet
        50         0         0
        50         0         0
        50         0         0
        50         0         0
```

```
        50         0         0
        50         0         0
        50         0         0
        50        50         0
        50        50         0
        50        50         0
        50        50         0
        50        50         0
        50        50         0
        50        50         0
        50        50         0
        50        50         0
        50        50         0
        50        50        50
        50        50        50
        50        50        50
        50         0        50
        50         0        50
         0         0         0
# Lambda for Discards at Age by Year & Fleet
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
# Lambda for F mult Deviations by Fleet
   1   1   1
# Lambda for N in 1st Year Deviations
   0
# Lambda for Recruitment Deviations
   1
# Lambda for Catchability Deviations by Index
   10   10
# Lambda for Selectivity Deviations by Fleet
   0   100   100
# 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
   5
# NAA for Year 1
  25000  15000  9000  5400  3240  1944
# Log of F mult in 1st year by Fleet
   -0.7   -0.7   -5
# log of Catchability in 1st year by index
   0   0
# Initial log of Virgin Stock Size
   13.8
# Initial Steepness
   0.75
```

```
# Selectivity at Age in 1st Year by Fleet
      0.25      0.25      0.25
       0.5       0.5       0.5
      0.75      0.75      0.75
         1         1         1
         1         1         1
         1         1         1
# Where to do Extras
   2
# Ignore Guesses
   0
# Projection Control Data
# Year for SSB ratio Calculation
   1989
# Fleet Directed Flag
   1   1   1
# Final Year of Projections
   2007
# Year Projected Recruits, What Projected, Target, non- directed F mult
      2006        -1         2         0         1
      2007        -1         2         0         1
# Test Value
   -23456
#####
# ---- FINIS ----
```

APPENDIX IV

ASAP REPORT FILE (BASELINE MODEL)

```
obj_fun        = 416.863
Component          RSS      nobs  Lambda  Likelihood
  Catch_Fleet_1        0.00260966   23   100   0.260966
  Catch_Fleet_2        0.00584863   23   100   0.584863
  Catch_Fleet_3        0.121991   23   100   12.1991
Catch_Fleet_Total     0.13045   69   100   13.045
  Discard_Fleet_1        0   23   0   0
  Discard_Fleet_2        0   23   0   0
  Discard_Fleet_3        0   23   0   0
Discard_Fleet_Total     0   69   0   0
CAA_proportions      N/A            414    see_below      219.938
Discard_proportions      N/A            414    see_below      0
  Index_Fit_1         7.76182   13   1   37.0669
  Index_Fit_2         6.36653   15   1   27.7458
Index_Fit_Total     14.1283   28   2   64.8128
  Selectivity_devs_fleet_1   14.2714  1   0  0
  Selectivity_devs_fleet_2   0  1   100  0
  Selectivity_devs_fleet_3   0  1   100  0
Selectivity_devs_Total   14.2714  3   200  0
  Catchability_devs_index_1  0  13  10  0
  Catchability_devs_index_2  0  15  10  0
Catchability_devs_Total  0  28  20  0
  Fmult_fleet_1     6.11437   22   1  6.11437
  Fmult_fleet_2     15.1348   22   1  15.1348
  Fmult_fleet_3     52.8999   22   1  52.8999
Fmult_fleet_Total   74.1491   66   3  74.1491
N_year_1            0   5   0   0
Stock-Recruit_Fit   15.6469  23   1   29.0832
Recruit_devs        15.6469   23   1   15.6469
SRR_steepness       0.0178402       1 0   0
SRR_virgin_stock    0.0371989      1 5  0.185994
Curvature_over_age  19.8367   12   0   0
Curvature_over_time 28.5428   378   0   0
F_penalty           2.0583    138     0.001     0.0020583
Mean_Sel_year1_pen  0   18      1000  0
Max_Sel_penalty     2.71815        1       100 0
Fmult_Max_penalty   0        ?       100 0

 Input and Estimated effective sample sizes for fleet 1
1983  50  18.6145
1984  50  3.54776
1985  50  41.209
1986  50  107.504
1987  50  32.5449
1988  50  52.1526
1989  50  183.132
1990  50  6.65055
1991  50  6.95447
1992  50  9.42741
1993  50  30.9706
1994  50  13.4081
1995  50  208.454
1996  50  238.943
1997  50  35.7675
1998  50  13.8795
1999  50  24.8583
2000  50  26.4505
2001  50  65.9703
2002  50  11.971
2003  50  88.3217
2004  50  5.72036
2005  0  1.39629
 Total  1100  1227.85
 Input and Estimated effective sample sizes for fleet 2
1983  0  1.01672
```

```
1984  0  1.31114
1985  0  1.82665
1986  0  2.22987
1987  0  2.04157
1988  0  1.92774
1989  0  2.10234
1990  50  187.2
1991  50  173.21
1992  50  8.47704
1993  50  10.3855
1994  50  18.4878
1995  50  60.2985
1996  50  11.8162
1997  50  50.4268
1998  50  7.94869
1999  50  207.75
2000  50  15.0038
2001  50  9.67996
2002  50  17.2892
2003  0  2.01884
2004  0  2.25569
2005  0  1.68627
 Total  650  796.39
 Input and Estimated effective sample sizes for fleet 3
1983  0  2.83514
1984  0  3.68504
1985  0  1.48904
1986  0  1.64649
1987  0  2.12599
1988  0  2.68083
1989  0  2.44139
1990  0  2.32099
1991  0  2.48668
1992  0  2.5144
1993  0  2.96126
1994  0  3.03632
1995  0  2.89935
1996  0  3.01332
1997  0  2.52639
1998  0  2.50219
1999  0  2.92104
2000  50  17.1421
2001  50  15.1754
2002  50  34.5979
2003  50  14.8497
2004  50  9.28233
2005  0  2.39681
 Total  250  137.53

 Input and Estimated effective Discard sample sizes for fleet 1
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
 Total  0  2.3e+16
 Input and Estimated effective Discard sample sizes for fleet 2
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
 Total  0  2.3e+16
 Input and Estimated effective Discard sample sizes for fleet 3
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
 Total  0  2.3e+16

Observed and predicted total fleet catch by year
 fleet 1 total catches
1983  337.2  334.206
1984  248.21  248.385
1985  396.98  401.677
1986  1191.13  1186.36
1987  1548.2  1558.32
1988  3810.27  3754.91
1989  2918.96  2935.49
1990  3658.77  3669.32
1991  5855.6  5836.6
1992  9574.24  9658.63
1993  24319.9  23708.6
1994  12431.2  12591.4
1995  32902.4  32491.5
1996  29819.7  29825.6
1997  29026.8  29276.2
```

```
1998  56172.3  55587.8
1999  51005.2  50565.5
2000  60360.5  58921.4
2001  52915.6  53067.4
2002  52980.7  53390.4
2003  60713.6  61032.7
2004  29451.2  29727.5
2005  35824.4  35841.2
 fleet 2 total catches
1983  149.5  148.063
1984  124.1  128.391
1985  3174.2  3043.73
1986  647.3  661.436
1987  1118.4  1116.97
1988  2076.8  2066.28
1989  1875.7  1907.9
1990  11663.2  11514.4
1991  14746.3  14754.7
1992  25447.3  25373.3
1993  49889.8  48358.8
1994  19108.4  19333.7
1995  33392.7  33160.7
1996  32834.8  32853
1997  36897.2  37137.8
1998  75179.4  74180.7
1999  62333.2  61616.1
2000  49609.1  48735.7
2001  34680.8  34778.9
2002  29435.7  29641
2003  39814.3  39936.6
2004  35722.9  35810.9
2005  35722.9  35783.1
 fleet 3 total catches
1983  0  0.00127235
1984  0  0.0013728
1985  0  0.00278858
1986  0  0.00656737
1987  0  0.0110373
1988  0  0.0150764
1989  0  0.0241065
1990  0  0.0394729
1991  0  0.0705899
1992  0  0.175544
1993  4.08  3.71299
1994  0  0.196949
1995  0  0.239898
1996  22.68  21.6873
1997  43.54  43.2169
1998  28.03  29.1409
1999  562.84  551.814
2000  1154.59  1168.48
2001  17923  17493.7
2002  25682.9  25624.5
2003  36123  35740.8
2004  39860.7  39819.9
2005  38158.5  38158.5
Observed and predicted total fleet Discards by year
 fleet 1 total Discards
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
 fleet 2 total Discards
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
 fleet 3 total Discards
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

Index data
index number 1
units = 1
month = 10
starting and ending ages for selectivity = 1  6
selectivity choice = -1
 year, sigma2, obs index, pred index
1986  0.0861777  0.0243987  0.0552026
1987  0.0861777  0.050027  0.0812122
1988  0.0861777  0.0430888  0.13835
1994  0.0861777  0.404899  0.448899
```

```
1996  0.0861777  0.264964  0.739491
1997  0.0861777  1.30476  1.00426
1998  0.0861777  1.00024  0.93932
1999  0.0861777  0.899136  0.819597
2000  0.0861777  3.38898  0.666353
2001  0.0861777  2.51959  0.831876
2002  0.0861777  0.657299  0.854109
2003  0.0861777  1.54541  0.808884
2004  0.0861777  0.897196  0.85133
index number 2
units = 1
month = -1
starting and ending ages for selectivity = 1  6
selectivity choice = -1
 year, sigma2, obs index, pred index
1986  0.0861777  0.297565  0.120965
1987  0.0861777  0.155173  0.17656
1988  0.0861777  0.754163  0.351276
1989  0.0861777  0.444398  0.500555
1990  0.0861777  0.285352  0.877194
1991  0.0861777  0.547532  0.843692
1992  0.0861777  0.662164  0.86373
1993  0.0861777  1.13458  0.687421
1994  0.0861777  2.85153  0.897309
1995  0.0861777  2.54965  1.3615
1996  0.0861777  1.61585  1.53912
1997  0.0861777  0.903439  1.60372
1998  0.0861777  1.59913  1.44951
1999  0.0861777  0.546654  1.32071
2000  0.0861777  0.652825  1.15386

Selectivity by age and year for each fleet rescaled so max=1.0
 fleet 1 selectivity at age
 0.00774466 0.247414 1 0.65851 0.305843 0.159418
 0.00774466 0.247414 1 0.65851 0.305843 0.159418
 0.00774466 0.247414 1 0.65851 0.305843 0.159418
 0.00774466 0.247414 1 0.65851 0.305843 0.159418
 0.00774466 0.247414 1 0.65851 0.305843 0.159418
 0.00774466 0.247414 1 0.65851 0.305843 0.159418
 0.00774466 0.247414 1 0.65851 0.305843 0.159418
 0.00774466 0.247414 1 0.65851 0.305843 0.159418
 0.00774466 0.247414 1 0.65851 0.305843 0.159418
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 0.286196 0.876516 1 0.69005 0.280673 0.101244
 fleet 2 selectivity at age
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
```

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 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 0.386047 0.850146 1 0.749561 0.585058 0.133851
 fleet 3 selectivity at age
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706
 0.000911958 0.012182 0.330843 0.786269 1 0.788706

Fmult by year for each fleet
1983   0.175895 0.0244442 8.31513e-07
1984   0.0719351 0.00970456 7.8601e-07
1985   0.0365517 0.107821 7.43136e-07
1986   0.0567397 0.0159944 7.03145e-07
1987   0.0545679 0.0194557 6.68153e-07
1988   0.0953942 0.0201483 6.42555e-07
1989   0.0405431 0.0123705 6.31826e-07
1990   0.0310187 0.0422573 6.57107e-07
1991   0.0365342 0.0490255 7.91631e-07
1992   0.0341075 0.0820826 1.49532e-06
1993   0.100637 0.185404 3.16102e-05
1994   0.0495936 0.0680329 1.81641e-06
1995   0.0900389 0.0829072 2.01036e-06
1996   0.060799 0.0626018 0.000142622
1997   0.0475318 0.0567286 0.000168784
1998   0.105554 0.127082 9.80952e-05
1999   0.115381 0.124843 0.00215197
2000   0.150272 0.11555 0.00653566
2001   0.119565 0.0730846 0.0661806
2002   0.13319 0.0652872 0.0839075
2003   0.133738 0.0812727 0.140244
2004   0.0660778 0.0713598 0.165717
2005   0.0633538 0.060586 0.166298

Directed F by age and year for each fleet
 fleet 1 directed F at age
 0.00136225 0.0435188 0.175895 0.115828 0.0537963 0.0280408
 0.000557113 0.0177978 0.0719351 0.04737 0.0220009 0.0114678
 0.000283081 0.00904341 0.0365517 0.0240697 0.0111791 0.00582701
 0.00043943 0.0140382 0.0567397 0.0373637 0.0173535 0.00904534
 0.00042261 0.0135009 0.0545679 0.0359335 0.0166892 0.00869912
 0.000738796 0.0236019 0.0953942 0.0628181 0.0291757 0.0152076
 0.000313993 0.0100309 0.0405431 0.0266981 0.0123998 0.00646331
 0.000240229 0.00767446 0.0310187 0.0204261 0.00948686 0.00494494
 0.000282945 0.00903908 0.0365342 0.0240582 0.0111738 0.00582422
 0.00976142 0.0298958 0.0341075 0.0235359 0.00957306 0.00345318
```

```
 0.0288019 0.0882102 0.100637 0.0694447 0.0282462 0.0101889
 0.0141935 0.0434696 0.0495936 0.034222 0.0139196 0.00502104
 0.0257687 0.0789206 0.0900389 0.0621313 0.0252715 0.00911589
 0.0174004 0.0532913 0.060799 0.0419543 0.0170647 0.00615553
 0.0136034 0.0416624 0.0475318 0.0327993 0.0133409 0.00481231
 0.0302091 0.0925197 0.105554 0.0728375 0.0296262 0.0106867
 0.0330215 0.101133 0.115381 0.0796186 0.0323843 0.0116816
 0.0430072 0.131716 0.150272 0.103695 0.0421773 0.0152141
 0.0342191 0.104801 0.119565 0.0825061 0.0335588 0.0121053
 0.0381185 0.116743 0.13319 0.091908 0.037383 0.0134847
 0.0382751 0.117223 0.133738 0.0922856 0.0375366 0.0135401
 0.0189112 0.0579183 0.0660778 0.045597 0.0185463 0.00668997
 0.0181316 0.0555307 0.0633538 0.0437173 0.0177817 0.00641419
 fleet 2 directed F at age
 0.00943662 0.0207811 0.0244442 0.0183224 0.0143013 0.00327187
 0.00374642 0.00825029 0.00970456 0.00727416 0.00567773 0.00129896
 0.0416239 0.0916633 0.107821 0.0808182 0.0630814 0.0144319

 0.00617458 0.0135976 0.0159944 0.0119888 0.00935764 0.00214086
 0.00751082 0.0165402 0.0194557 0.0145832 0.0113827 0.00260416
 0.0077782 0.017129 0.0201483 0.0151024 0.0117879 0.00269686
 0.00477558 0.0105167 0.0123705 0.00927241 0.00723743 0.00165579
 0.0163133 0.0359249 0.0422573 0.0316745 0.024723 0.00565617
 0.0189262 0.0416789 0.0490255 0.0367476 0.0286828 0.0065621
 0.0316878 0.0697822 0.0820826 0.0615259 0.0480231 0.0109868
 0.0715748 0.157621 0.185404 0.138972 0.108472 0.0248165
 0.0262639 0.0578379 0.0680329 0.0509948 0.0398032 0.00910624
 0.0320061 0.0704832 0.0829072 0.062144 0.0485055 0.0110972
 0.0241673 0.0532207 0.0626018 0.0469239 0.0366257 0.0083793
 0.0218999 0.0482277 0.0567286 0.0425216 0.0331896 0.00759317
 0.0490596 0.108038 0.127082 0.0952556 0.0743503 0.01701
 0.0481952 0.106135 0.124843 0.0935773 0.0730403 0.0167103
 0.0446077 0.0982343 0.11555 0.0866117 0.0676034 0.0154664
 0.0282141 0.0621326 0.0730846 0.0547814 0.0427588 0.00978243
 0.025204 0.0555037 0.0652872 0.0489368 0.0381968 0.00873874
 0.0313751 0.0690937 0.0812727 0.0609189 0.0475493 0.0108784
 0.0275483 0.0606663 0.0713598 0.0534886 0.0417496 0.00955156
 0.0233891 0.051507 0.060586 0.0454129 0.0354464 0.00810948
 fleet 3 directed F at age
 7.58305e-10 1.01295e-08 2.751e-07 6.53793e-07 8.31513e-07 6.5582e-07
 7.16808e-10 9.57515e-09 2.60046e-07 6.18015e-07 7.8601e-07 6.19931e-07
 6.77709e-10 9.05286e-09 2.45861e-07 5.84305e-07 7.43136e-07 5.86116e-07
 6.41239e-10 8.56569e-09 2.3263e-07 5.52861e-07 7.03145e-07 5.54575e-07
 6.09327e-10 8.13942e-09 2.21053e-07 5.25348e-07 6.68153e-07 5.26976e-07
 5.85983e-10 7.82759e-09 2.12585e-07 5.05221e-07 6.42555e-07 5.06787e-07
 5.76199e-10 7.69689e-09 2.09035e-07 4.96785e-07 6.31826e-07 4.98325e-07
 5.99254e-10 8.00486e-09 2.17399e-07 5.16663e-07 6.57107e-07 5.18265e-07
 7.21934e-10 9.64363e-09 2.61905e-07 6.22435e-07 7.91631e-07 6.24365e-07
 1.36367e-09 1.82159e-08 4.94715e-07 1.17572e-06 1.49532e-06 1.17937e-06
 2.88272e-08 3.85075e-07 1.0458e-05 2.48542e-05 3.16102e-05 2.49312e-05
 1.65649e-09 2.21274e-08 6.00946e-07 1.42819e-06 1.81641e-06 1.43261e-06
 1.83337e-09 2.44902e-08 6.65115e-07 1.58069e-06 2.01036e-06 1.58559e-06
 1.30066e-07 1.73742e-06 4.71856e-05 0.000112139 0.000142622 0.000112487
 1.53924e-07 2.05612e-06 5.58409e-05 0.000132709 0.000168784 0.000133121
 8.94587e-08 1.19499e-06 3.24541e-05 7.71292e-05 9.80952e-05 7.73683e-05
 1.9625e-06 2.62152e-05 0.000711963 0.00169203 0.00215197 0.00169727
 5.96024e-06 7.96172e-05 0.00216227 0.00513878 0.00653566 0.00515471
 6.03539e-05 0.00080621 0.0218954 0.0520357 0.0661806 0.052197
 7.65201e-05 0.00102216 0.0277602 0.0659739 0.0839075 0.0661784
 0.000127896 0.00170845 0.0463987 0.110269 0.140244 0.110611
 0.000151127 0.00201876 0.0548263 0.130298 0.165717 0.130702
 0.000151657 0.00202584 0.0550186 0.130755 0.166298 0.131161
Discard F by age and year for each fleet
 fleet 1 Discard F 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
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 0 0 0 0 0 0
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 fleet 2 Discard F at age
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 fleet 3 Discard F at age
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 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
Total F
 0.0107989 0.0643 0.200339 0.134152 0.0680984 0.0313134
 0.00430353 0.0260481 0.0816399 0.0546448 0.0276794 0.0127673
 0.041907 0.100707 0.144373 0.104888 0.0742612 0.0202595
 0.00661402 0.0276358 0.0727343 0.049353 0.0267118 0.0111868
 0.00793343 0.0300411 0.0740238 0.0505173 0.0280726 0.0113038
```

```
 0.00851699 0.0407309 0.115543 0.077921 0.0409643 0.0179049
 0.00508957 0.0205476 0.0529138 0.035971 0.0196379 0.0081196
 0.0165536 0.0435994 0.0732762 0.0521011 0.0342105 0.0106016
 0.0192091 0.0507179 0.08556 0.0608064 0.0398573 0.0123869
 0.0414492 0.099678 0.116191 0.085063 0.0575976 0.0144412
 0.100377 0.245831 0.286052 0.208441 0.13675 0.0350303
 0.0404574 0.101307 0.117627 0.0852183 0.0537246 0.0141287
 0.0577748 0.149404 0.172947 0.124277 0.073779 0.0202147
 0.0415678 0.106514 0.123448 0.0889904 0.053833 0.0146473
 0.0355035 0.0898921 0.104316 0.0754537 0.0466993 0.0125386
 0.0792688 0.200559 0.232668 0.16817 0.104075 0.027774
 0.0812187 0.207294 0.240936 0.174888 0.107577 0.0300892
 0.0876209 0.23003 0.267984 0.195446 0.116316 0.0358353
 0.0624936 0.16774 0.214545 0.189323 0.142498 0.0740847
 0.063399 0.173269 0.226238 0.206819 0.159487 0.0884018
 0.0697781 0.188025 0.261409 0.263474 0.22533 0.13503
 0.0466106 0.120603 0.192264 0.229384 0.226013 0.146944
 0.0416723 0.109064 0.178959 0.219886 0.219527 0.145684

Population Numbers at the Start of the Year
 145722 15000 9000 5400 3240 1944
 255617 96631.1 9428.62 4937.63 3165.3 3291.79
 328664 170609 63108.3 5824.72 3133.78 4242.4
 336375 211269 103407 36615.8 3515.64 4737.03
 890745 223993 137757 64452.9 23362.4 5434.49
 1.0964e+06 592366 145703 85752.9 41075.8 18828.7
 1.97752e+06 728706 381227 87010.6 53172.9 38826
 1.95441e+06 1.31884e+06 478532 242374 56264.2 60765.2
 2.22875e+06 1.28857e+06 846329 298105 154220 76749.2
 3.65033e+06 1.46555e+06 821041 520791 188037 150151
 2.86591e+06 2.34754e+06 889190 489989 320629 218196
 5.60863e+06 1.73761e+06 1.23064e+06 447761 266651 328681
 8.07849e+06 3.61051e+06 1.05254e+06 733380 275625 386623
 5.59378e+06 5.11118e+06 2.08433e+06 593484 434149 425591
 4.94305e+06 3.59695e+06 3.07996e+06 1.23491e+06 363951 556901
 7.34642e+06 3.19785e+06 2.20383e+06 1.86004e+06 767623 601483
 7.85944e+06 4.54917e+06 1.75404e+06 1.17061e+06 1.05383e+06 855836
 4.73345e+06 4.85737e+06 2.47849e+06 924026 658783 1.19103e+06
 3.39258e+06 2.90674e+06 2.58692e+06 1.27082e+06 509431 1.16338e+06
 7.16193e+06 2.13635e+06 1.64756e+06 1.39923e+06 704930 1.02028e+06
 2.83257e+06 4.50587e+06 1.20421e+06 880783 762695 1.02892e+06
 9.11369e+06 1.77075e+06 2.50266e+06 621523 453655 1.01069e+06
 4.01299e+06 5.83088e+06 1.05211e+06 1.38416e+06 331222 827483
q by index
 index 1 q over time
1986  1.89598e-06
1987  1.89598e-06
1988  1.89598e-06
1994  1.89598e-06
1996  1.89598e-06
1997  1.89598e-06
1998  1.89598e-06
1999  1.89598e-06
2000  1.89598e-06
2001  1.89598e-06
2002  1.89598e-06
2003  1.89598e-06
2004  1.89598e-06
 index 2 q over time
1986  2.48497e-06
1987  2.48497e-06
1988  2.48497e-06
1989  2.48497e-06
1990  2.48497e-06
1991  2.48497e-06
1992  2.48497e-06
1993  2.48497e-06
1994  2.48497e-06
1995  2.48497e-06
1996  2.48497e-06
1997  2.48497e-06
```

```
1998  2.48497e-06
1999  2.48497e-06
2000  2.48497e-06

Proportions of catch at age by fleet
 fleet 1
Year 1 Obs  =  0 0.356844 0.511302 0.105723 0.0227378 0.00339322
Year 1 Pred =  0.0640073 0.205326 0.467993 0.190535 0.0547284 0.0174098
Year 2 Obs  =  0.169036 0.314323 0.482457 0.0330455 0.00113799 0
Year 2 Pred =  0.050245 0.600684 0.230883 0.0806176 0.0243047 0.0132665
Year 3 Obs  =  0.00623416 0.296401 0.593645 0.10372 0 0
Year 3 Pred =  0.0233116 0.376249 0.551411 0.0341235 0.00864758 0.0062565
Year 4 Obs  =  0.00241776 0.285805 0.616905 0.0899026 0.00496916 0
Year 4 Pred =  0.014464 0.287391 0.556804 0.131242 0.00591432 0.0041839
Year 5 Obs  =  0.0189627 0.119253 0.605573 0.235668 0.0178412 0.00270213
Year 5 Pred =  0.0281677 0.223969 0.54552 0.169908 0.028903 0.00353192
Year 6 Obs  =  0.00130323 0.499856 0.343311 0.130117 0.0233988 0.00201374
Year 6 Pred =  0.0234825 0.399288 0.383518 0.151225 0.0342223 0.00826479
Year 7 Obs  =  0.0177527 0.249386 0.558377 0.129822 0.0392278 0.00543565
Year 7 Pred =  0.0237084 0.277096 0.577189 0.0874334 0.025005 0.00956813
Year 8 Obs  =  0.00703147 0.589819 0.342294 0.0574598 0.00339551 0
Year 8 Pred =  0.0153315 0.326384 0.472138 0.15902 0.0172876 0.00983924
Year 9 Obs  =  0.0308006 0.216845 0.332065 0.238511 0.115201 0.0665783
Year 9 Pred =  0.0122963 0.223818 0.584688 0.137173 0.0332802 0.00874381
Year 10 Obs  =  0.0925943 0.264054 0.353626 0.152843 0.0658885 0.0709947
Year 10 Pred =  0.297762 0.356435 0.226099 0.100387 0.0149305 0.0043875
Year 11 Obs  =  0.107367 0.47486 0.314778 0.0729923 0.0192408 0.0107617
Year 11 Pred =  0.205166 0.481913 0.204559 0.0805265 0.0221394 0.00569488
Year 12 Obs  =  0.171705 0.266947 0.322688 0.193097 0.0324528 0.0131112
Year 12 Pred =  0.342653 0.316131 0.253538 0.0646085 0.0158786 0.00719101
Year 13 Obs  =  0.380979 0.436043 0.119058 0.0547803 0.00753916 0.00160051
Year 13 Pred =  0.332542 0.436463 0.143621 0.0705992 0.011045 0.00572889
Year 14 Obs  =  0.180045 0.509112 0.280958 0.0258238 0.00380215 0.000259252
Year 14 Pred =  0.187864 0.510228 0.235551 0.0470179 0.0142184 0.00511997
Year 15 Obs  =  0.230241 0.247479 0.351243 0.147211 0.018383 0.00544268
Year 15 Pred =  0.167057 0.363076 0.35235 0.0987876 0.0120004 0.00672957
Year 16 Obs  =  0.067421 0.446998 0.300266 0.134368 0.0430546 0.00789294
Year 16 Pred =  0.252756 0.318861 0.247116 0.148163 0.0256074 0.00749712
Year 17 Obs  =  0.209362 0.575347 0.175449 0.0243546 0.0135849 0.00190237
Year 17 Pred =  0.255579 0.427816 0.185376 0.087944 0.0332038 0.0100807
Year 18 Obs  =  0.172698 0.601383 0.208442 0.0114978 0.00488724 0.00109176
Year 18 Pred =  0.158567 0.467168 0.267389 0.0710599 0.0213601 0.014456
Year 19 Obs  =  0.195086 0.292953 0.318977 0.176777 0.0141252 0.00208159
Year 19 Pred =  0.140808 0.352127 0.350064 0.120022 0.0199892 0.0169903
Year 20 Obs  =  0.530444 0.185772 0.149451 0.106517 0.0207639 0.0070519
Year 20 Pred =  0.312627 0.271618 0.23335 0.137951 0.0288792 0.0155747
Year 21 Obs  =  0.141362 0.634408 0.175105 0.0350454 0.0112822 0.00279752
Year 21 Pred =  0.124448 0.57446 0.169488 0.0854644 0.0306187 0.0155206
Year 22 Obs  =  0.660065 0.130676 0.154102 0.0341824 0.0134508 0.00752397
Year 22 Pred =  0.369464 0.212498 0.331676 0.0558991 0.0166207 0.0138424
Year 23 Obs  =  0 0 0 0 0 0
Year 23 Pred =  0.141138 0.608876 0.12142 0.108215 0.0105345 0.00981537
 fleet 2
Year 1 Obs  =  0 0 0 0 0 0
Year 1 Pred =  0.678804 0.150104 0.0995672 0.0461419 0.0222735 0.00310995
Year 2 Obs  =  0 0 0 0 0 0
Year 2 Pred =  0.506087 0.417071 0.0466537 0.0185426 0.00939472 0.00225079
Year 3 Obs  =  0 0 0 0 0 0
Year 3 Pred =  0.378888 0.421546 0.179794 0.0126648 0.0053938 0.00171283
Year 4 Obs  =  0 0 0 0 0 0
Year 4 Pred =  0.296761 0.406464 0.229183 0.061489 0.00465676 0.00144592
Year 5 Obs  =  0 0 0 0 0 0
Year 5 Pred =  0.472619 0.259047 0.183625 0.0650998 0.0186108 0.000998193
Year 6 Obs  =  0 0 0 0 0 0
Year 6 Pred =  0.369184 0.432728 0.120961 0.054291 0.0206476 0.00218864
Year 7 Obs  =  0 0 0 0 0 0
Year 7 Pred =  0.412276 0.332159 0.201356 0.0347191 0.0166868 0.00280257
Year 8 Obs  =  0.344479 0.407095 0.177018 0.0490113 0.0216422 0.000754415
Year 8 Pred =  0.296189 0.434655 0.182985 0.0701524 0.0128168 0.00320178
Year 9 Obs  =  0.23302 0.362699 0.30618 0.0708474 0.0145262 0.0127277
Year 9 Pred =  0.279389 0.350559 0.266514 0.0711722 0.029019 0.00334641
```

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Year 10 Obs  =  0.0986565 0.326966 0.241201 0.201222 0.0892526 0.0427021
Year 10 Pred =  0.358799 0.308829 0.201978 0.0974108 0.027802 0.00518172
Year 11 Obs  =  0.294107 0.638161 0.0669132 0.000492181 0.000327089 0
Year 11 Pred =  0.253927 0.428872 0.187691 0.0802583 0.0423437 0.00690814
Year 12 Obs  =  0.344222 0.228855 0.398122 0.0288015 0 0
Year 12 Pred =  0.407175 0.270115 0.223352 0.061825 0.0291581 0.00837509
Year 13 Obs  =  0.485498 0.323118 0.102549 0.0791029 0.00973217 0
Year 13 Pred =  0.399504 0.377032 0.127913 0.0683003 0.0205051 0.00674557
Year 14 Obs  =  0.430594 0.325179 0.191424 0.039749 0.0130531 0
Year 14 Pred =  0.236539 0.461934 0.219871 0.0476729 0.027665 0.0063183
Year 15 Obs  =  0.111799 0.314561 0.371607 0.131316 0.0650148 0.00570222
Year 15 Pred =  0.210391 0.328788 0.328972 0.100188 0.023355 0.00830662
Year 16 Obs  =  0.0591969 0.208714 0.352109 0.243401 0.105662 0.0309165
Year 16 Pred =  0.303989 0.275749 0.220333 0.143498 0.0475929 0.00883742
Year 17 Obs  =  0.301735 0.320996 0.173528 0.115662 0.0726467 0.015432
Year 17 Pred =  0.306952 0.369451 0.165052 0.0850549 0.0616244 0.0118662
Year 18 Obs  =  0.363818 0.292387 0.192983 0.0966968 0.0379878 0.0161274
Year 18 Pred =  0.198927 0.421416 0.248684 0.0717886 0.0414099 0.0177747
Year 19 Obs  =  0.211576 0.53584 0.170822 0.0632612 0.0153604 0.00314062
Year 19 Pred =  0.176513 0.3174 0.325328 0.121161 0.0387229 0.020875
Year 20 Obs  =  0.501121 0.319091 0.159436 0.0177069 0.0026456 0
Year 20 Pred =  0.366972 0.229256 0.203066 0.130401 0.0523857 0.0179185
Year 21 Obs  =  0 0 0 0 0 0
Year 21 Pred =  0.156635 0.519895 0.158147 0.0866232 0.0595535 0.0191461
Year 22 Obs  =  0 0 0 0 0 0
Year 22 Pred =  0.433433 0.179251 0.288461 0.0528085 0.0301315 0.0159161
Year 23 Obs  =  0 0 0 0 0 0
Year 23 Pred =  0.180483 0.559855 0.115107 0.111436 0.0208173 0.0123019
 fleet 3
Year 1 Obs  =  0 0 0 0 0 0
Year 1 Pred =  0.011333 0.0152013 0.232811 0.342078 0.269064 0.129513
Year 2 Obs  =  0 0 0 0 0 0
Year 2 Pred =  0.0167493 0.0837279 0.216244 0.272502 0.224968 0.185809
Year 3 Obs  =  0 0 0 0 0 0
Year 3 Pred =  0.00903939 0.0610047 0.600747 0.13417 0.0931086 0.10193
Year 4 Obs  =  0 0 0 0 0 0
Year 4 Pred =  0.00429219 0.0356602 0.464239 0.394911 0.048733 0.0521646
Year 5 Obs  =  0 0 0 0 0 0
Year 5 Pred =  0.00650776 0.0216366 0.354111 0.398043 0.185418 0.0342843
Year 6 Obs  =  0 0 0 0 0 0
Year 6 Pred =  0.00572898 0.0407324 0.262886 0.374105 0.231831 0.0847169
Year 7 Obs  =  0 0 0 0 0 0
Year 7 Pred =  0.00633212 0.0309455 0.433126 0.236788 0.185439 0.107369
Year 8 Obs  =  0 0 0 0 0 0
Year 8 Pred =  0.00384805 0.0342537 0.332948 0.404711 0.120481 0.103759
Year 9 Obs  =  0 0 0 0 0 0
Year 9 Pred =  0.00277504 0.0211209 0.370739 0.313907 0.20855 0.0829088
Year 10 Obs  =  0 0 0 0 0 0
Year 10 Pred =  0.00335905 0.0175377 0.264823 0.404951 0.188325 0.121004
Year 11 Obs  =  0 0 0 0 0 0
Year 11 Pred =  0.00225413 0.0230934 0.233347 0.316367 0.271974 0.152965
Year 12 Obs  =  0 0 0 0 0 0
Year 12 Pred =  0.00396209 0.0159434 0.304384 0.267139 0.205291 0.20328
Year 13 Obs  =  0 0 0 0 0 0
Year 13 Pred =  0.00483708 0.0276905 0.216903 0.367211 0.179635 0.203724
Year 14 Obs  =  0 0 0 0 0 0
Year 14 Pred =  0.00260569 0.0308666 0.339215 0.233196 0.220504 0.173613
Year 15 Obs  =  0 0 0 0 0 0
Year 15 Pred =  0.00161362 0.0152961 0.353364 0.341208 0.129605 0.158913
Year 16 Obs  =  0 0 0 0 0 0
Year 16 Pred =  0.00198642 0.0109299 0.201641 0.416377 0.22502 0.144045
Year 17 Obs  =  0 0 0 0 0 0
Year 17 Pred =  0.00223045 0.0162843 0.167969 0.274442 0.323997 0.215077
Year 18 Obs  =  0 0 0.419829 0.214478 0.115201 0.250492
Year 18 Pred =  0.00138374 0.0177813 0.242269 0.221742 0.208417 0.308408
Year 19 Obs  =  0 0.0140967 0.351258 0.378068 0.149171 0.107407
Year 19 Pred =  0.00097224 0.0106046 0.25096 0.296338 0.154323 0.286802
Year 20 Obs  =  0.00106905 0.0209877 0.127875 0.424182 0.266532 0.159355
Year 20 Pred =  0.0021498 0.00814661 0.166606 0.339215 0.222047 0.261835
Year 21 Obs  =  0 0.00873497 0.0336332 0.142704 0.37185 0.443078
Year 21 Pred =  0.00101204 0.0203759 0.143106 0.248527 0.27841 0.308569
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Year 22 Obs  =  0 0.0196776 0.166276 0.160071 0.112966 0.541009
Year 22 Pred =  0.00341631 0.0085701 0.318427 0.184829 0.171839 0.312919
Year 23 Obs  =  0 0 0 0 0 0
Year 23 Pred =  0.00157039 0.0295487 0.14027 0.430557 0.131058 0.266996

Proportions of Discards at age by fleet
 fleet 1
Year 1 Obs  =  0 0 0 0 0 0
Year 1 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 2 Obs  =  0 0 0 0 0 0
Year 2 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 3 Obs  =  0 0 0 0 0 0
Year 3 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 4 Obs  =  0 0 0 0 0 0
Year 4 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 5 Obs  =  0 0 0 0 0 0
Year 5 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 6 Obs  =  0 0 0 0 0 0
Year 6 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 7 Obs  =  0 0 0 0 0 0
Year 7 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 8 Obs  =  0 0 0 0 0 0
Year 8 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 9 Obs  =  0 0 0 0 0 0
Year 9 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 10 Obs  =  0 0 0 0 0 0
Year 10 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 11 Obs  =  0 0 0 0 0 0
Year 11 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 12 Obs  =  0 0 0 0 0 0
Year 12 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 13 Obs  =  0 0 0 0 0 0
Year 13 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 14 Obs  =  0 0 0 0 0 0
Year 14 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 15 Obs  =  0 0 0 0 0 0
Year 15 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 16 Obs  =  0 0 0 0 0 0
Year 16 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 17 Obs  =  0 0 0 0 0 0
Year 17 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 18 Obs  =  0 0 0 0 0 0
Year 18 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 19 Obs  =  0 0 0 0 0 0
Year 19 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 20 Obs  =  0 0 0 0 0 0
Year 20 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 21 Obs  =  0 0 0 0 0 0
Year 21 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 22 Obs  =  0 0 0 0 0 0
Year 22 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 23 Obs  =  0 0 0 0 0 0
Year 23 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
 fleet 2
Year 1 Obs  =  0 0 0 0 0 0
Year 1 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 2 Obs  =  0 0 0 0 0 0
Year 2 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 3 Obs  =  0 0 0 0 0 0
Year 3 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 4 Obs  =  0 0 0 0 0 0
Year 4 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 5 Obs  =  0 0 0 0 0 0
Year 5 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15

Year 6 Obs  =  0 0 0 0 0 0
Year 6 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 7 Obs  =  0 0 0 0 0 0
Year 7 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 8 Obs  =  0 0 0 0 0 0
Year 8 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
```

```
Year 9 Obs  =  0 0 0 0 0 0
Year 9 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 10 Obs  =  0 0 0 0 0 0
Year 10 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 11 Obs  =  0 0 0 0 0 0
Year 11 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 12 Obs  =  0 0 0 0 0 0
Year 12 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 13 Obs  =  0 0 0 0 0 0
Year 13 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 14 Obs  =  0 0 0 0 0 0
Year 14 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 15 Obs  =  0 0 0 0 0 0
Year 15 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 16 Obs  =  0 0 0 0 0 0
Year 16 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 17 Obs  =  0 0 0 0 0 0
Year 17 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 18 Obs  =  0 0 0 0 0 0
Year 18 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 19 Obs  =  0 0 0 0 0 0
Year 19 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 20 Obs  =  0 0 0 0 0 0
Year 20 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 21 Obs  =  0 0 0 0 0 0
Year 21 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 22 Obs  =  0 0 0 0 0 0
Year 22 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 23 Obs  =  0 0 0 0 0 0
Year 23 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
 fleet 3
Year 1 Obs  =  0 0 0 0 0 0
Year 1 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 2 Obs  =  0 0 0 0 0 0
Year 2 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 3 Obs  =  0 0 0 0 0 0
Year 3 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 4 Obs  =  0 0 0 0 0 0
Year 4 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 5 Obs  =  0 0 0 0 0 0
Year 5 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 6 Obs  =  0 0 0 0 0 0
Year 6 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 7 Obs  =  0 0 0 0 0 0
Year 7 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 8 Obs  =  0 0 0 0 0 0
Year 8 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 9 Obs  =  0 0 0 0 0 0
Year 9 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 10 Obs  =  0 0 0 0 0 0
Year 10 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 11 Obs  =  0 0 0 0 0 0
Year 11 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 12 Obs  =  0 0 0 0 0 0
Year 12 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 13 Obs  =  0 0 0 0 0 0
Year 13 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 14 Obs  =  0 0 0 0 0 0
Year 14 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 15 Obs  =  0 0 0 0 0 0
Year 15 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 16 Obs  =  0 0 0 0 0 0
Year 16 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 17 Obs  =  0 0 0 0 0 0
Year 17 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 18 Obs  =  0 0 0 0 0 0
Year 18 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 19 Obs  =  0 0 0 0 0 0
Year 19 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 20 Obs  =  0 0 0 0 0 0
Year 20 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
```

```
Year 21 Obs  =  0 0 0 0 0 0
Year 21 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 22 Obs  =  0 0 0 0 0 0
Year 22 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 23 Obs  =  0 0 0 0 0 0
Year 23 Pred =  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     0.722404     11.9572
  Fmax     3.91421     31.7346
  F30%SPR  1.26181     16.229
  F40%SPR  0.747342     12.1717
  Fmsy     0.622579     11.0784    SSmsy    273056     MSY   102482
  Foy      0.466934     xxxxxx    SSoy    340684     OY   99949.3
  Fcurrent 0.219886     7.17956

Stock-Recruitment Relationship Parameters
 alpha     = 5.01855e+06
 beta      = 179948
 virgin    = 1.19406e+06
 steepness = 0.656227
Spawning Stock, Obs Recruits(year+1), Pred Recruits(year+1)
1983  6768.48  255617  181922
1984  12807.4  328664  333452
1985  27731.7  336375  670131
1986  42058  890745  950739
1987  61855  1.0964e+06  1.28378e+06
1988  106076  1.97752e+06  1.86119e+06
1989  162859  1.95441e+06  2.38418e+06
1990  278750  2.22875e+06  3.04976e+06
1991  328100  3.65033e+06  3.241e+06
1992  367590  2.86591e+06  3.3692e+06
1993  342720  5.60863e+06  3.29072e+06
1994  351123  8.07849e+06  3.31806e+06
1995  463296  5.59378e+06  3.6146e+06
1996  584754  4.94305e+06  3.83759e+06
1997  788207  7.34642e+06  4.08576e+06
1998  786565  7.85944e+06  4.08418e+06
1999  681294  4.73345e+06  3.96997e+06
2000  564563  3.39258e+06  3.80556e+06
2001  695754  7.16193e+06  3.98729e+06
2002  716527  2.83257e+06  4.01118e+06
2003  700241  9.11369e+06  3.99254e+06
2004  711966  4.01299e+06  4.00603e+06
2005  733922       xxxx   4.03036e+06

average F (ages 4 to 8 unweighted) by year
Projection into Future
Projected NAA
 4.03036e+06 2.58019e+06 3.5047e+06 589691 744685 657745
 4.04783e+06 1.04735e+06 144838 40145.4 2663.4 19447.1
Projected Directed FAA
 0.94759 2.48 4.06935 5 4.99183 3.31273
 0.94759 2.48 4.06935 5 4.99183 3.31273
Projected Discard FAA
 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
Projected Catch at Age
 2.09757e+06 2.09711e+06 3.15448e+06 543544 686300 572555
 2.10666e+06 851259 130365 37003.8 2454.58 16928.4
Projected Discards at Age (in numbers)
 0 0 0 0 0 0
 0 0 0 0 0 0
Projected Yield at Age
 98585.8 180352 312293 60876.9 91964.2 84738.1
 99013.2 73208.3 12906.1 4144.42 328.914 2505.4
Year, Total Yield (in weight), Total Discards (in weight), SSB, proj_what, SS/SSmsy
```

```
2006  828810  0  750371  2  2.74805
2007  192106  0  125454  2  0.459444

M =  0.4 0.4 0.4 0.4 0.4 0.4
mature =  0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
Weight at age
 0.069 0.118 0.128 0.155 0.184 0.187
 0.069 0.087 0.138 0.154 0.167 0.187
 0.083 0.108 0.135 0.149 0.164 0.16
 0.074 0.117 0.148 0.17 0.185 0.186
 0.054 0.111 0.15 0.164 0.184 0.172
 0.087 0.107 0.142 0.169 0.183 0.188
 0.069 0.101 0.148 0.169 0.185 0.195
 0.109 0.13 0.153 0.161 0.17 0.165
 0.082 0.122 0.143 0.152 0.155 0.159
 0.059 0.097 0.132 0.147 0.157 0.17
 0.055 0.062 0.095 0.123 0.161 0.146
 0.047 0.071 0.079 0.082 0.131 0.146
 0.05 0.062 0.087 0.095 0.103 0.115
 0.057 0.069 0.079 0.096 0.111 0.116
 0.063 0.077 0.107 0.114 0.121 0.122
 0.049 0.073 0.094 0.114 0.118 0.118
 0.042 0.056 0.078 0.102 0.104 0.115
 0.05 0.056 0.062 0.064 0.069 0.09
 0.054 0.076 0.087 0.094 0.105 0.129
 0.04 0.068 0.1 0.115 0.134 0.151
 0.054 0.084 0.1 0.113 0.129 0.146
 0.047 0.086 0.099 0.112 0.134 0.148
 0.047 0.086 0.099 0.112 0.134 0.148
Fecundity
 0.0207 0.06254 0.11648 0.15035 0.18216 0.187
 0.0207 0.04611 0.12558 0.14938 0.16533 0.187
 0.0249 0.05724 0.12285 0.14453 0.16236 0.16
 0.0222 0.06201 0.13468 0.1649 0.18315 0.186
 0.0162 0.05883 0.1365 0.15908 0.18216 0.172
 0.0261 0.05671 0.12922 0.16393 0.18117 0.188
 0.0207 0.05353 0.13468 0.16393 0.18315 0.195
 0.0327 0.0689 0.13923 0.15617 0.1683 0.165
 0.0246 0.06466 0.13013 0.14744 0.15345 0.159
 0.0177 0.05141 0.12012 0.14259 0.15543 0.17
 0.0165 0.03286 0.08645 0.11931 0.15939 0.146
 0.0141 0.03763 0.07189 0.07954 0.12969 0.146
 0.015 0.03286 0.07917 0.09215 0.10197 0.115
 0.0171 0.03657 0.07189 0.09312 0.10989 0.116
 0.0189 0.04081 0.09737 0.11058 0.11979 0.122
 0.0147 0.03869 0.08554 0.11058 0.11682 0.118
 0.0126 0.02968 0.07098 0.09894 0.10296 0.115
 0.015 0.02968 0.05642 0.06208 0.06831 0.09
 0.0162 0.04028 0.07917 0.09118 0.10395 0.129
```

```
 0.012 0.03604 0.091 0.11155 0.13266 0.151
 0.0162 0.04452 0.091 0.10961 0.12771 0.146
 0.0141 0.04558 0.09009 0.10864 0.13266 0.148
 0.0141 0.04558 0.09009 0.10864 0.13266 0.148

SSmsy_ratio = 2.88987
Fmsy_ratio =  0.353185
that's all
```

Pacific Sardine

STAR Panel Meeting Report

NOAA / Southwest Fisheries Science Center
La Jolla, California
June 21-24, 2004

STAR Panel
Tom Barnes, California Department of Fish and Game (Chair)
André Punt, University of Washington (SSC Representative, Rapporteur)
Rodolfo Serra, IFOP, Valparaiso, Chile
John Wheeler, Department of Fisheries and Oceans, Canada (CIE)

PFMC
Brian Culver, Washington Department of Fish and Wildlife, CPSMT
Diane Pleschner-Steele CPSAS

STAT
Ray Conser, NOAA / Southwest Fisheries Science Center
Kevin Hill, NOAA / Southwest Fisheries Science Center
Suzanne Kohin, NOAA / Southwest Fisheries Science Center
Nancy Lo, NOAA / Southwest Fisheries Science Center

1. **Overview**

The STAR Panel (hereafter the Panel) reviewed the assessment documents prepared by the STAT for Pacific sardine. The entire STAT was available to present and discuss aspects of the report.

The Panel focused exclusively on assessment models for Pacific sardine. The Terms of Reference for CPS STAR panels includes consideration of management recommendations. The Harvest Guideline for Pacific sardine is currently based on the catch control rule specified in the CPS Fishery Management Plan. The STAR Panel did not review the basis for this catch control rule but noted that the SSC has identified that a future STAR Panel could evaluate the catch control rule for Pacific sardine (and Pacific mackerel). Public comment on the issue on the control rule (verbal and written) was presented to the Panel. The written public comment will be forwarded to the Council.

The "wetfish" purse-seine fleet in California historically has taken CPS (market squid, Pacific sardine, northern anchovy, Pacific mackerel, jack mackerel, bonito), and tunas on an opportunistic basis. The fishery has progressed from one focused primarily on squid and Pacific mackerel in the early 1980s to one that focuses substantially on squid and sardine, although the fishery still relies to some degree on all target species. A CPS purse-seine fishery focused primarily on sardine has developed in the Pacific northwest in recent years.

The results from the assessment models presented to the Panel were preliminary and based on data through 2003. The Panel did not focus on the consequences of the results, and instead focused on the most appropriate framework for conducting future assessments of Pacific sardine. The first occasion that any new assessment for Pacific sardine could be used to provide management advice will be November 2004.

The STAT provided results for two assessment frameworks: CANSAR-TAM (catch-at-age analysis for sardine – two area model) and ASAP (age structured assessment program). CANSAR-TAM has provided the basis for the assessment of Pacific sardine since 1998. CANSAR-TAM is an extension to the CAGEAN approach to fisheries stock assessment that explicitly allows for migration of the northern component of the Pacific sardine population from southern California to the Pacific northwest. The assessment relies on indices of abundance for southern California to infer the status of the total population size.

The migration model underlying CANSAR-TAM is simple, and the values for the parameters related to migration are largely arbitrary. The treatment of the fisheries in Pacific northwest in CANSAR-TAM is also *ad hoc*. In contrast, ASAP is a multi-fleet model that can deal relatively straightforwardly with the component of the population in the Pacific northwest, both in terms of its contribution to the spawning biomass and to the catches. Both the STAT and Panel agreed that ASAP provides a more defensible basis for conducting assessments of Pacific sardine.

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. Requests made and comments to the STAT during the meeting (Table 1 provides a summary of the alternative models considered during the workshop).

a) **Assemble a table of the sample sizes on which the catch-at-age matrix is based**. The sample sizes for the USA-California fishery range from 432 (1984) to 3887 (1995). The Panel agreed that, given that the sample sizes are all fairly large, and the fact that there are several sources of uncertainty associated with the catch-at-age data other than sampling error, there is no need to assign year-specific weights to the catch age-composition data when fitting the population dynamics model.

b) **Examine the implications of different assumptions about selectivity in the USA-California using "bubble plots" of residuals.** The residual patterns for the baseline case in the assessment document provide no evidence for trends in residuals within cohorts but several "runs" of residuals within age-classes are evident. The Panel highlighted the continuing importance of reviewing the residuals about the fits to the catch age-composition data, particularly once these data have been revised.

c) **Examine the trends in *q* for the CalCOFI percent positive index and the spawning area index.** There are noteworthy trends in *q* (increasing for the percent positive index / decreasing for the spawning area index). These trends were expected given percent positive indices will saturate at high population size while square miles of spawning area would under-estimate spawning stock size if there is a "basin effect". See Section 3.2 for further discussion in terms of the utility of these indices for tuning purposes.

d) **Examine the sensitivity of the results to setting the population weights-at-age from 1990 equal to the weights-at-age in the catch.** The results of this sensitivity test were broadly similar to those for the baseline case. The most notable difference between the results of this sensitivity test and those from the baseline case were that the estimates of recruitment for 1990-99 were greater for baseline case. The Panel and the STAT agreed that this was expected given that the fishery weights-at-age are higher than the population weights-at-age for these years. The value of a sensitivity test along these lines will be enhanced once the assessment software can include separate fishery and population weight-at-age matrices.

e) **Plot indices against each other in the form of an X-Y plot.** These plots suggest that the relationships among the DEPM (Daily Egg Production Method), CalCOFI percent positive and spawning area indices are, in general, not linear. There does appear, however, to be a linear relationship between the DEPM and spotter plane indices, even though these indices relate to different components of the population.

f) **Conduct a sensitivity test in which the only abundance indices are the DEPM estimates and the spotter plane index.** The results of this sensitivity test were not statistically different to those for the baseline case, although the variances were slightly larger owing to the reduction in the number of data points. The Panel agreed that this sensitivity analysis should form the baseline case for the November 2004 assessment.

g) Conduct a preliminary evaluation of estimation uncertainty using the Markov chain Monte Carlo (MCMC) module.

The results of a preliminary application of the MCMC algorithm (1,000,000 cycles) indicated evidence for lack of convergence (see Fig. 1). The Panel advised the STAT to examine the .COR matrix from ADMB and to use this to guide how the model should be re-parameterized in future to reduce the correlations among the model parameters. It is likely that modifying the parameterization of selectivity in the first year should lead to reduced correlation among the selectivity parameters.

h). **Examine the sensitivity of the results of the assessment to having a single selectivity pattern for entire 1983-2003 period and to there being three periods of selectivity (1983-91, 1992-97, and 1998-2003).**

The fit to the data deteriorates markedly if selectivity for the southern California fishery is assumed to be time-invariant, providing support for having at least two periods of fishery selectivity. There is little improvement in fit if three periods of fishery selectivity are assumed for the southern California fishery. The Panel agreed that the baseline case for the November 2004 assessment should include two selectivity periods for the southern California fishery.

3. Technical merits and/or deficiencies of the assessment

The STAT identified three areas of considerable (but largely unquantifiable) uncertainty in its initial presentation to the Panel:

- Stock structure and migration are not well understood
- Fishery-independent data are limited to central and southern California, even though spawning occurs off Mexico and limited spawning has been reported to the north.
- The biological data for the Mexican, Canadian and Pacific northwest fisheries are limited.

3.1 Stock structure

There are several hypotheses regarding the stock structure of Pacific sardine. The current stock assessment is based on the working hypothesis that Pacific sardine off northern Mexico, southern California, northern California and the Pacific northwest constitute a single biological stock with substantial mixing / migration. However, there is considerable uncertainty regarding this hypothesis. Evidence that may support an alternative stock structure hypothesis includes:

- The presence in the Pacific northwest of some spawning and some zero-year-old fish.
- The marked differences in mean weight-at-age among fish in the Pacific northwest and those off southern California (the fish tend to be much larger and have higher weight-at-age off the Pacific northwest).

There is also uncertainty regarding the relationship between the fish found offshore of where the fishery off California is prosecuted and those elsewhere, and between the Mexican fish and those elsewhere. The Panel emphasized the considerable importance of research to resolve issues related to stock structure, and to develop abundance indices for areas in addition to southern California. The latter aspect is as important as the former because, if data are collected which provide support for an alternative stock structure hypothesis (e.g. separate California and Pacific northwest stocks), abundance data for the Pacific northwest will be required to conduct an assessment for the population in this area. Even if additional data confirm the present working hypothesis, there is still considerable value in obtaining abundance information for regions other than for which the DEPM and spotter plane indices are available.

The importance of resolving stock structure uncertainty was also emphasized during the period of public comment.

The Panel, the STAT and members of the public identified several areas of research which might shed light on the issue of stock structure (see Section 6.1). It was agreed that for the present time, the assessment should be based on a single coastwide assessment.

3.2 Input data

The variant of the assessment presented initially to the Panel included four indices of abundance: a) the CalCOFI percent positive index, b) the DEPM index, c) the spawning area index, and d) the spotter plane index (see Table 1 for the basic data for the first three indices). The STAR panel noted that the three fishery-independent indices are correlated with each other because they are based on the some of the same underlying data and that the DEPM estimates of abundance are correlated among years because of the way the biological information for 1994 is used to construct the DEPM estimates for several years.

The Panel noted that the DEPM estimates used in the assessment are based on biological data (from which the estimates of daily fecundity per gram are computed) from 1994 and 2002[1]. Although the estimates of fecundity per gram are fairly similar for 1994 and 2002, the values for the biological parameters that are used to estimate fecundity per gram differ markedly between 1994 and 2002. For example, percentage spawning was 7% for 1994 and 17% for 2002. The Panel agreed that biological data for use in the DEPM should be collected more routinely in the future than has been the case in the past.

There is an overlap between the data on which the DEPM estimates are based and the data on which the spawning area and CalCOFI percent positive indices are based. Furthermore, unless allowance is made for time-varying catchability, the fit of the model to the latter two indices is very poor. The Panel and STAT considered three ways to resolve this problem:

- Ignore the CalCOFI percent positive and the spawning area indices and base the assessment solely on the DEPM and spotter plane indices.
- Include the CalCOFI percent positive and the spawning area indices in the assessment but restrict them to years for which the assumption that these indices

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[1] Data for 2004 are still being processed so were not available to the Panel.

are linearly proportional to abundance appears to be most valid (e.g. prior to 1998 for the CalCOFI index and after 1998 for the spawning area index).

- Use a mixed effects model to fill in years with no DEPM data.

The Panel and STAT agreed that the assessment to be presented to the Council in November 2004 should be based on ignoring the CalCOFI percent positive and the spawning area indices.

The Panel and STAT were concerned about relying substantially on the DEPM estimates when it is known that these can vary markedly from one year to the next. The Panel agreed that an attempt should be made to extend the DEPM method so that constraints are placed on the extent to which the estimate of P_0 (the number of eggs spawned) can vary over time to avoid biologically unrealistic changes in this quantity. One approach that could be investigated is to force a time-series structure on the values for P_0 over time.

3.3 Biological data

The model makes use of the weight-at-age data for the population (in addition to that for the fishery). Weight-at-age in the catches off southern California are lower than weight-at-age in the population because the larger individuals appear to be located outside the areas that are fished primarily. Survey data are used to infer post-1990 population weight-at-age. However, this is a crude approach and efforts should be made to include data on weight-at-age from the fisheries in the Pacific northwest when constructing population weight-at-age. This problem can not, however, be resolved easily without sampling of offshore and northern areas to determine the relative proportion of the population in different areas, such as through the use of a synoptic survey of the entire west coast.

3.4 Other

The catch control rule relies on the estimate of 1+ biomass for the start of the last year of the assessment period. The STAT currently bases this estimate on population weight-at-age. However, the alternative of basing it on the fishery weight-at-age may be more appropriate. This issue should be considered when the catch control rule is reviewed at a future STAR Panel.

The weightings given to the various data sources and penalties (the lambdas) impact the sizes of the variances calculated using asymptotic (Hessian and delta method) and Bayesian approaches. The Panel noted that it would be desirable to develop an overall scaling parameter so that the residuals about the data are not over-dispersed relative to the variances implied by the lambda values.

4. Areas of disagreement

There were no areas of major disagreement between the STAT and the Panel[2].

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[3] The Panel was unable to reach agreement on the correct way to pronounce certain letters of the Latin and Greek alphabets. The Panel therefore recommends that future Panels include not only LANs but also translators who can translate from American "English" into English as it is used elsewhere.

5. Unresolved problems and major uncertainties

Problems unresolved at the end of the meeting form the basis for the recommendations in Sections 6.0 - 6.3.

6. Recommendations

The following recommendations are not given in priority order.

6.0 General

The Tri-national Sardine Forum should be utilized to share fishery, survey and biological information among researchers in Mexico, Canada, and the U.S. The long-term benefits of this forum will be greatly enhanced if it can be formalized through international arrangements.

6.1 Stock structure

a) Growth data for Mexico, southern California, northern California, the Pacific northwest and the offshore areas should be collected and analyzed to quantitatively evaluate differences in growth among areas. This evaluation would need to account for differences between Mexico and the U.S. on how birthdates are assigned, and the impact of spawning on growth.

b) The timing and magnitude of spawning off California and the Pacific northwest should be examined.

c) The likelihood of various stock structure hypotheses should be examined using existing tagging data and additional tagging experiments or (preferably) techniques such as analyses of trace element composition.

d) Information which could be used in an assessment of the Pacific northwest component of a single coastwide population or of a separate Pacific northwest stock should be obtained. Synoptic surveys of Pacific sardine on the entire west coast have the potential to provide such information as well as the basic data needed to address research questions 1) and 2) above.

6.2 Data and monitoring needs

a) The Panel endorsed the aerial survey which started during 2004 and emphasized the value and importance of a rigorous survey protocol. It suggested that the surveys be augmented to estimate schooling areas and distinguish schools. It also supported the collection of data (e.g. bearing and distance to schools) which could be used in line transect-type estimation methods. ‘Sea-truthing’ of the species identification of the aerial surveys will enhance the value of any resulting index of abundance.

b) An aerial survey program should be started in the Pacific northwest. Such a survey program would provide data for a component of the population currently not surveyed. However, it would take several years before any index based on such a survey could be included in the assessments.

c) The current abundance indices provide data which can be used to fit a population dynamics model. However, alternative methods for indexing the population (e.g. acoustics) should continue to be evaluated. Acoustic methods are a qualitatively different approach to indexing relative abundance and are the primary fishery-independent method for obtaining abundance indices for many of the world’s major pelagic fish stocks. Acoustic methods have been applied to northern anchovy off California. Acoustic data have the potential to provide information on the relative abundance of the populations off southern California and the Pacific northwest.

d) The catch-at-age data should be updated so that ages are defined in terms of a calendar year lifecycle (if the model continues to be based on a calendar year). At present the catch-at-age matrix combines animals from different cohorts into the same age-class because no account is taken of the assumed 1 July birthdate.
e) Biological data for use in the DEPM must be collected and analyzed more routinely in the future than has been the case in the past.
f) The DEPM method should be extended so that constraints are placed on the extent to which the estimates of P_0 vary over time.
g) The impact of environmental variability on the CalCOFI percent positive data should be examined.
h) The data on maturity-at-age should be reviewed to assess whether there have been changes over time in maturity-at-age, specifically whether maturity may be density-dependent.
i) The algorithm used to determine the catch proportion-at-age data from the raw data collected from the fishery should be documented and included in the assessment report.

6.3 Modeling and assessment issues

a) The November 2004 assessment for Pacific sardine should be based on an extension of ASAP in which:
    - allowance is made for fleet-specific weights-at-age (specifically the fishery weights-at-age for the fishery in the Pacific northwest);
    - spawning biomass is defined in terms of the numbers at the end of the year;
    - explicitly include a zero age-class;
    - a log-normal bias-correction factor is included in the component of the objective function related to deviations about the stock-recruitment relationship; and
    - parameter uncertainty is quantified using the MCMC algorithm.
b) The data on which the November 2004 assessment will be based will differ from those on which the analyses reviewed during the Panel meeting:
    - only the DEPM and spotter plane indices will be used as abundance indices when fitting the model;
    - the latest fishery and abundance index data will be included in the assessment;
    - substantial additional catch-at-age data for the Mexican fisheries for 1983-2002 will be included in the assessment;
    - additional catch-at-age data for the fisheries in the northwest will be included in the assessment; and
    - the DEPM estimate will be enhanced using new biological data.
c) An attempt should be made move from a model that is based on a calendar year to one based on a biological year. This may improve the fits of the model to catch-at-age data but may lead to the catch-at-age data being overweighted relative to the abundance indices.
d) The extent of ageing error should be quantified and included in future assessments.

e) The sensitivity of the results of the assessment to the assumption that recruitment is related to spawning biomass by a Ricker stock-recruitment relationship should be examined.
f) The sensitivity of the results of the assessment to the weight assigned to each data point / abundance index (e.g. equal weight, weight based on the sampling standard error) should be explored.
g) Environmental covariates should be considered when fitting the stock-recruitment relationship.
h) Confidence intervals for the data should be added to the time-series plots which compare observed *versus* model-predicted values.
i) The values for the lambdas should be chosen so that these are consistent with variances of the residuals.
j) Data that may be included in assessments for years beyond November 2004:
    - additional indices of abundance for Oregon / British Columbia / Mexico.
    - the results of the new spotter plane index (if the new index can be related to the historical index).
    - an index based on the spawning volume for Pacific sardine (if such an index can be developed).
k) Sensitivity should be examined to different southern boundaries for the "stock" (i.e. if there is a separate stock off northern Mexico, how does it mix with the stock(s) exploited in the U.S.).

Table 1. Sardine models considered during the STAR Panel

Run	Description	Number of Parameters	Total Likelihood	SSB Virgin (1000 MT)	SSB 2003 (1000 MT)	Recruits 2003 (Billions)
R06-9	Baseline in paper	131	381	2,038	1,490	9.4
R08-0	Remove 2 indices: CalCOFI and Spawn Area. New Baseline	129	281	2,100	1,609	9.9
R08-1	Use USA-CA fishery WAA as population WAA. R08-0 is still new baseline	129	268	1,628	1,836	8.2
R08-2	No time varying selex R08-0 is still new baseline	111	359	1,676	1,365	13.7
R08-3	3 selex blocks for USA-CA 1983-92 / 1993-97 / 1998-2003 R08-0 is still new baseline ???	135	276	2,086	1,510	7.8

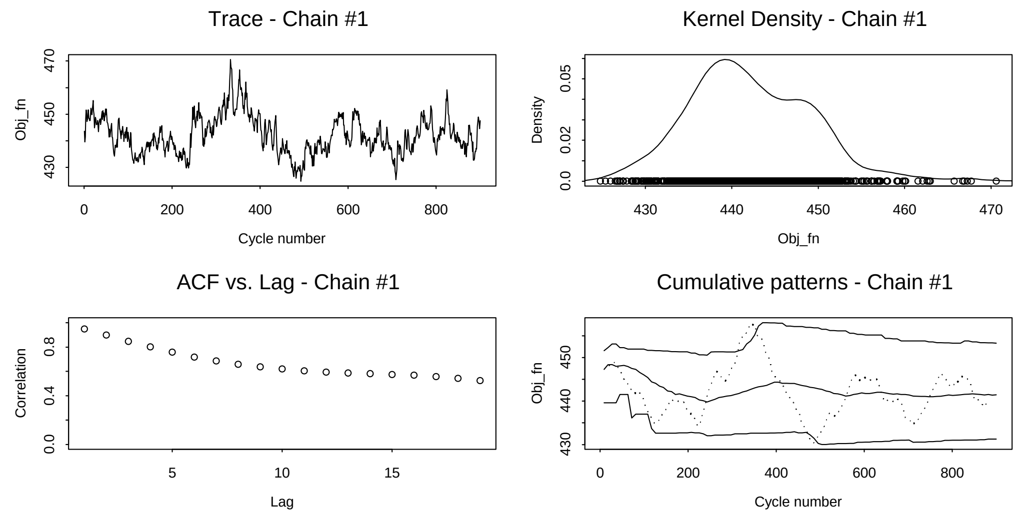
Table 2. Raw data used to construct the DEPM estimates and the indices of abundance based on the positive stations in the CalCOFI surveys and the spawning area.

Year	P_0	Z	**Area (km^2)**	**SSB (CV)**	**Positive Stations**	**Spawning Area index**	**Spotter Plane**
1983					-	40	-
1984					4.9	480	-
1985					3.8	760	-
1986				7,659	1.9	1,260	22,049
1987				15,704	4.0	2,120	11,498
1988				13,526	7.9	3,120	55,882
1989					7.2	3,720	32,929
1990					3.7	1,760	21,144
1991					16.7	5,550	40,571
1992					8.8	9,697	49,065
1993					6.1	7,685	84,070
1994	0.193 (0.21)	0.12 (0.91)	380,175	127,102 (0.32)	17.8	24,539	211,293
1995	-	-	-	-	13.4	23,816	188,924
1996	0.415 (0.42)	0.105 (4.15)	235,960	83,176 (0.48)*	28.0	25,890	119,731
1997	2.77 (0.21)	0.35 (0.14)	174,096	409,579 (0.31)*	27.3	40,591	66,943
1998	2.279 (0.34)	0.255 (0.37)	162,253	313,986 (0.41)*	24.3	33,446	118,492
1999	1.092 (0.35)	0.10 (0.6)	304,191	282,248 (0.42)*	16.7	55,171	50,506
2000	4.235 (0.4)	0.42 (0.73)	295,759	1,063,837 (0.67)*	7.8	32,784	48,373
2001	2.898 (0.39)	0.37 (0.21)	321,386	790,925 (0.45)*	12.5	31,663	-
2002	0.728 (0.17)	0.4 (0.15)	325,082	206,333 (0.35)	7.1	61,753	-
2003	1.52 (0.18)	0.48 (0.08)	365,906	485,121 (0.36)	14.2	41,702	-

* $CV = (CV^2(P_0) + 0.054 CV_{1994}^2)^{1/2}$

Figure 1. Example MCMC diagnostics for two model outputs. The panels for each quantity show the trace, the posterior density function (estimated using a normal kernel density), the correlation at different lags, the 50-point moving average against cycle number (dotted line in the rightmost panels), and the running mean and running 95% probability intervals (solid lines in the rightmost panels).

(a) The objective function



(b) The second selectivity parameter