Agenda Item F.1
Situation Summary
November 2006

# PACIFIC SARDINE STOCK ASSESSMENT AND HARVEST GUIDELINE FOR 2007

Per the coastal pelagic species (CPS) fishery management plan (FMP) annual cycle, the Council is scheduled to review the Pacific sardine stock assessment and adopt a recommendation to the U.S. Secretary of Commerce for a harvest guideline (HG) and management measures for the 2007 Pacific sardine fishing season. The current HG (which expires December 31, 2006) is 118,937 mt. The results of the most recent stock assessment indicate a 2007 HG recommendation of 152,564 mt. (Agenda Item F.1.b, NMFS Report).

The Council approved and National Marine Fisheries Service (NMFS) has implanted a new long term allocation formula for Pacific sardine as Amendment 11 to the CPS FMP. Under this new allocation framework, the Pacific sardine HG is allocated seasonally in the following manner:

(1) January 1, 35% of the HG to be allocated coastwide;
(2) July 1, 40% of the HG, plus any portion not harvested from the initial allocation, to be reallocated coastwide; and
(3) September 15, the remaining 25% of the HG, plus any portion not harvested from earlier allocations, to be reallocated coastwide.

In addition to approving the 2007 HG, the Council may also consider management measures for the 2007 fishery such as incidental landing allowances and set-asides for incidental sardine landings which may occur in other CPS fisheries should a seasonal allocation be reached.

The Coastal Pelagic Species Management Team (CPSMT), the Coastal Pelagic Species Advisory Subpanel (CPSAS), and the CPS Subcommittee of the Scientific and Statistical Committee (SSC) reviewed the assessment in October 2006, and final CPSMT and CPSAS written statements are included under Agenda Item F.1.d. The full Scientific and Statistical Committee is scheduled to review the assessment at the November meeting and will present their advice to the Council in a supplemental report.

**Council Action:**

**Adopt Pacific Sardine HG and Management Measures for 2007.**

Reference Materials:

1. Agenda Item F.1.b, NMFS Report: Assessment of the Pacific Sardine Population for U.S. Management in 2007.
2. Agenda Item F.1.d, CPSMT Report.
3. Agenda Item F.1.d, CPSAS Report.
4. Agenda Item F.1.d, Supplemental SSC Report.

Agenda Order:

a. Agenda Item Overview — Mike Burner
b. NMFS Report — Kevin Hill
c. Agency and Tribal Comments
d. Reports and Comments of Advisory Bodies
e. Public Comment
f. **Council Action**: Adopt Pacific Sardine HG and Management Measures for 2006

PFMC
10/26/06

# DRAFT

Note: Additions made by NOAA General Counsel are highlighted.

November 17, 2006

The Honorable Magalie Salas
Federal Energy Regulatory Commission
888 First Street, NE
Washington, D.C. 20426

RE: Docket Number P-2082 (Pacific Fishery Management Council's Comments on the Draft Environmental Impact Statement, and Essential Fish Habitat [EFH] Recommendations for the Klamath Hydropower Project).

Dear Secretary Salas:

The Pacific Fishery Management Council (Council) submits these comments regarding the Draft Environmental Impact Statement (DEIS) for Hydropower License for the Klamath Hydroelectric Project (P-2082). Under §305(b)(3)(B) of the Magnuson-Stevens Fishery Conservation and Management Act, the Council is obligated to comment on activities that are likely to substantially affect essential fish habitat (EFH) for salmon. The Council has identified EFH for fall Chinook and coho within the Klamath River below Iron Gate Dam.

First, we reiterate our comments sent in a letter dated April 24, 2006 (enclosed). In that letter, the Council submitted its recommendation that the Federal Energy Regulatory Commission (FERC) order the removal of the lowermost four dams on the Klamath River (Iron Gate, Copco 1 and 2, and JC Boyle Dams). The current draft EIS does not include this option, and, therefore, is inadequate in addressing the full range of reasonable alternatives as required by 40 CFR 1502.14.

FERC replied to the Council's letter on May 12, 2006, noting that "We will consider your April 24, 2006, EFH comments under section 10(a) of the Federal Power Act as we prepare our Draft Environmental Impact Statement (DEIS)… We will look forward to your comments and any EFH recommendations after you've reviewed our DEIS and EFH Assessment."

We note with disappointment that the DEIS contains no alternative for the removal of all four lower Klamath dams. Instead, FERC's proposed final action is unclear. Although FERC is mandated to follow prescriptions submitted to it by the Secretaries of Commerce and the Interior under Section 18 of the Federal Power Act, it has failed to include the preliminary prescriptions for fishways in its "Staff Alternative." Similarly, FERC has failed to include many of the preliminary 4(e) conditions in its "Staff Alternative." These conditions were based upon facts that were affirmed by an Administrative Law Judge in September 2006. FERC needs to clearly lay out a preferred alternative that includes these terms and conditions which, when finalized, will be mandatory.

The Council requests that FERC augment its analysis of the removal of two dams (Iron Gate and Copco 1) with a full analysis of the removal of the lowermost four dams. In addition, we strongly urge FERC to modify its "Staff Alternative" to reflect the mandatory conditions placed upon the new license by the Departments of the Interior and Commerce.

The Council believes that FERC's analysis is inadequate. On page 5-88, FERC addresses EFH issues as they relate to the Klamath River Hydroelectric Project. This analysis reiterates the measures that PacifiCorp and FERC propose in the DEIS, and then, comparing with today's extremely impaired baseline, states that the proposed action will "not adversely affect EFH." We believe that this analysis misses the point – that the current facilities and operations have caused and will continue to cause, through the term of any license, the degradation of EFH below the Klamath River Hydroelectric Project, and that operations should be mitigated to avoid adverse effects to EFH.

The Council further notes that of the five additional measures proposed by FERC (in addition to PacifiCorp's proposed measures), four are requirements for PacifiCorp to make maps or plans with no obligation to implement any actual measures to improve EFH downstream. This is unacceptable. Measures to protect or enhance EFH must encompass real actions, not simply more plans and studies.

As the near-shutdown of ocean fisheries demonstrated this year, Klamath stock abundance affects economies up and down the coast. Thus, the economic consequences that result from the degradation of EFH located below the Klamath Hydroelectric Project can be quite large. Thus, it is important to address effects to EFH completely, and to fully explore ways to mitigate for such impacts.

In summary, the Council requests that FERC add a *four* dam removal scenario to its analysis, and further, based upon the recommendations of numerous individuals, agencies, and other organizations, select the removal option as the preferred alternative. Volitional, or other fish passage scenarios without dam removal, do nothing to address serious water quality problems that FERC's own analyses show impact anadromous fish. We anticipate a new draft EIS that includes the requested analyses will soon be available for further review. Thank you for the opportunity to comment.

Sincerely,

DRAFT

Pacific Fishery Management Council

Enc: April 24, 2006 letter from PFMC to FERC

PFMC-11/16/06

Agenda Item F.1.b
Supplemental NMFS PowerPoint Presentation
November 2006

# ASSESSMENT OF THE PACIFIC SARDINE (*Sardinops sagax caerulea*) POPULATION FOR U.S. MANAGEMENT IN 2007

by

Kevin T. Hill[1], Nancy C. H. Lo[1], Beverly J. Macewicz[1], and Roberto Felix-Uraga[2]

[1] NOAA Fisheries
Southwest Fisheries Science Center
La Jolla, California, USA

[2] CICIMAR-IPN
La Paz, Baja California Sur, México

# ***Acknowledgements***

**INP-Ensenada**

Celia Eva-Cotero

Alfredo Cota

Walterio Garcia-Franco

**SEMARNAP-Ensenada**

Jesús Garcia Esquivel

**CICIMAR-La Paz**

Roberto Felix-Uraga

Casimiro Quiñonez

**SWFSC**

David Griffith

Ron Dotson

Amy Hays

Bill Watson

Sue Manion

**SIO**

Melissa Carter

**CDFG**

Leeanne Laughlin

Valerie Taylor

Kelly O'Reilly

Travis Tanaka

Dianna Porzio

Kim Penttila

Brianna Brady

Alia Al-Humaidhi

Sonia Torres

**ODFW**

Jill Smith

Keith Matteson

Sheryl Manley

**WDFW**

Carol Henry

Sandra Rosenfield

Jennifer Topping

**DFO-Canada**

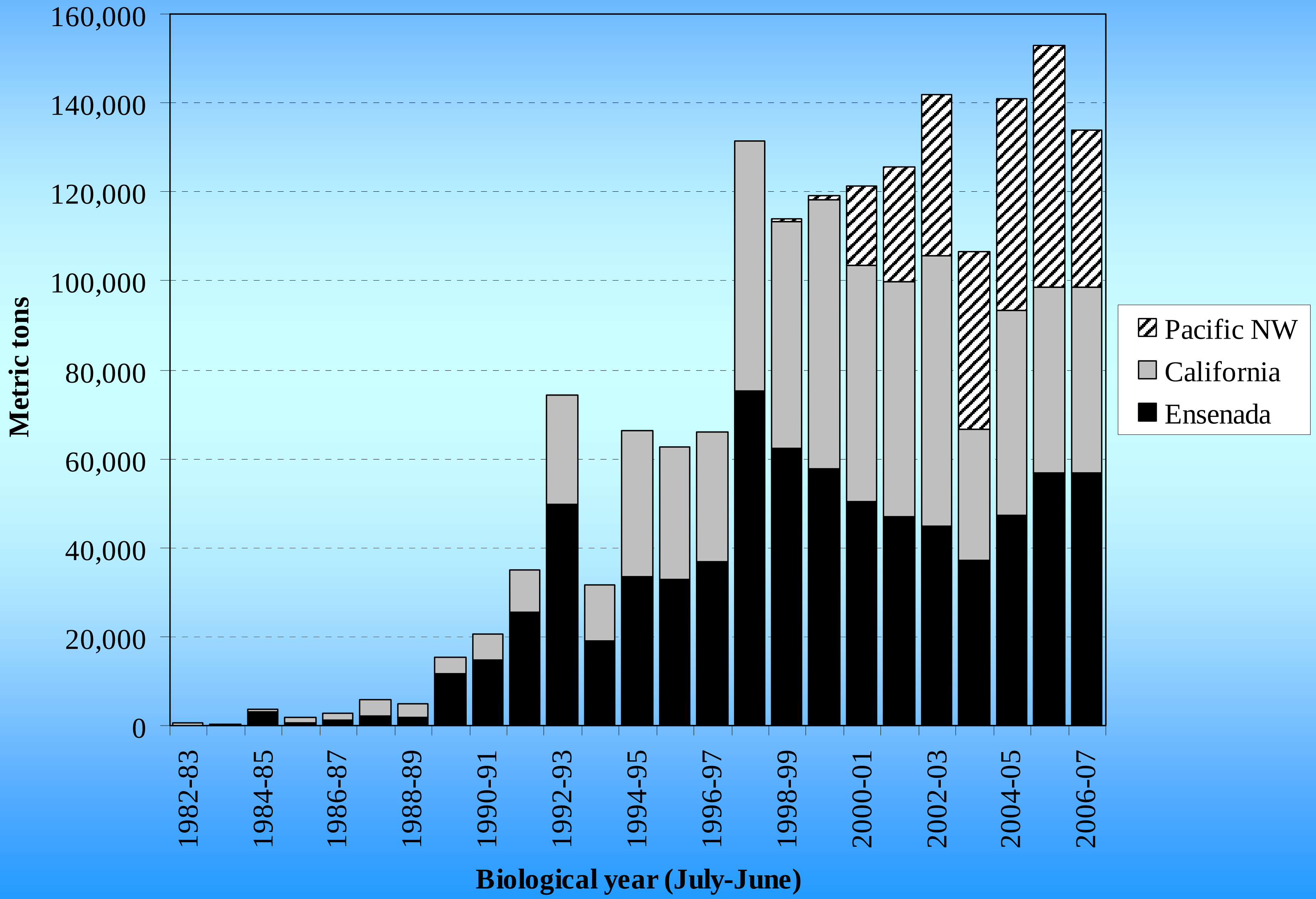
Christa Hrabok

Jake Schweigert

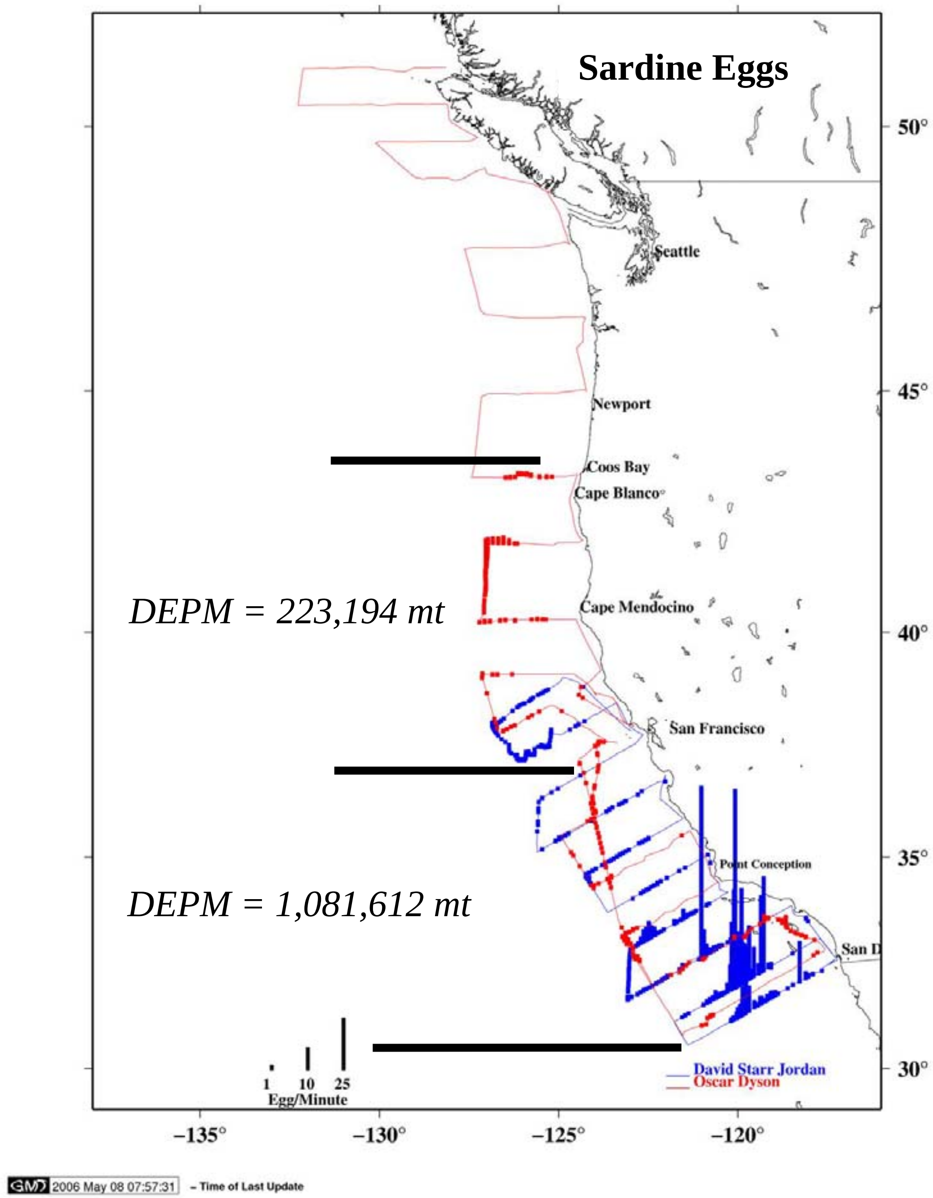
# *2006 Stock Assessment Update*
# *- Changes from 2005 -*

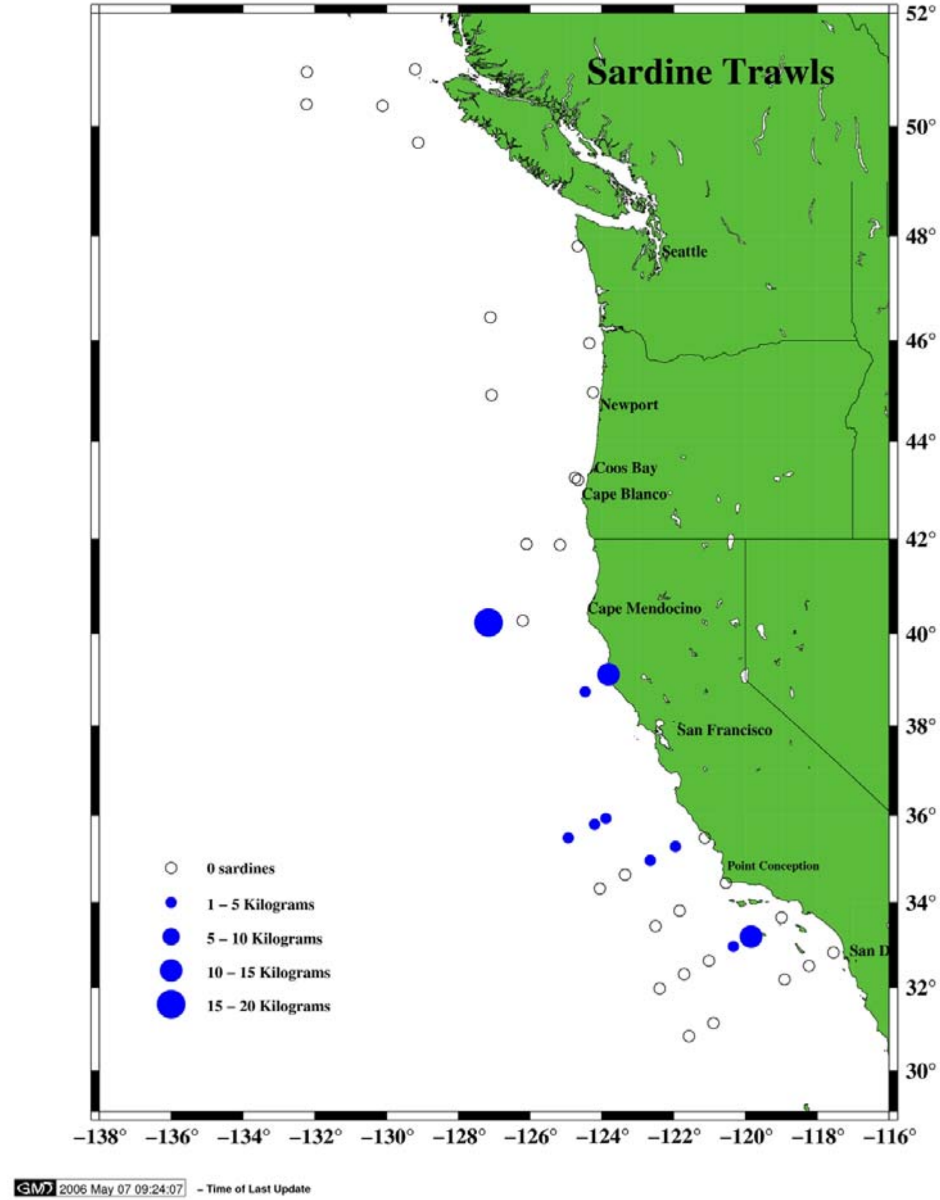
- **Three Fisheries:**
  - **Ensenada, California, and Pacific Northwest**
    - ***New landings and port samples from CA & NW for 2005-06;***
    - ***New Ensenada landings for 2005.***
- **Two Indices of Abundance (Central & Southern CA):**
  - **Annual egg production surveys (DEPM estimates of SSB)**
    - ***New estimate from April 2006 survey.***
  - **Aerial spotter survey (pre-adults; no new data in 2006)**
- **Environmental Data:**
  - **SST at Scripps Pier (La Jolla)**
    - ***Three-year running average through June 2006.***

# *Landings by Fishery*

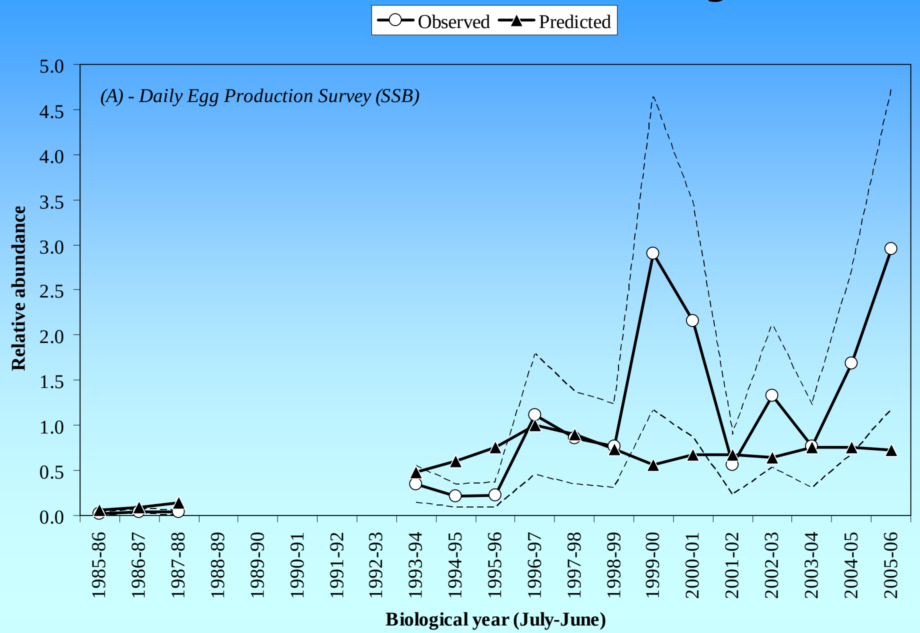


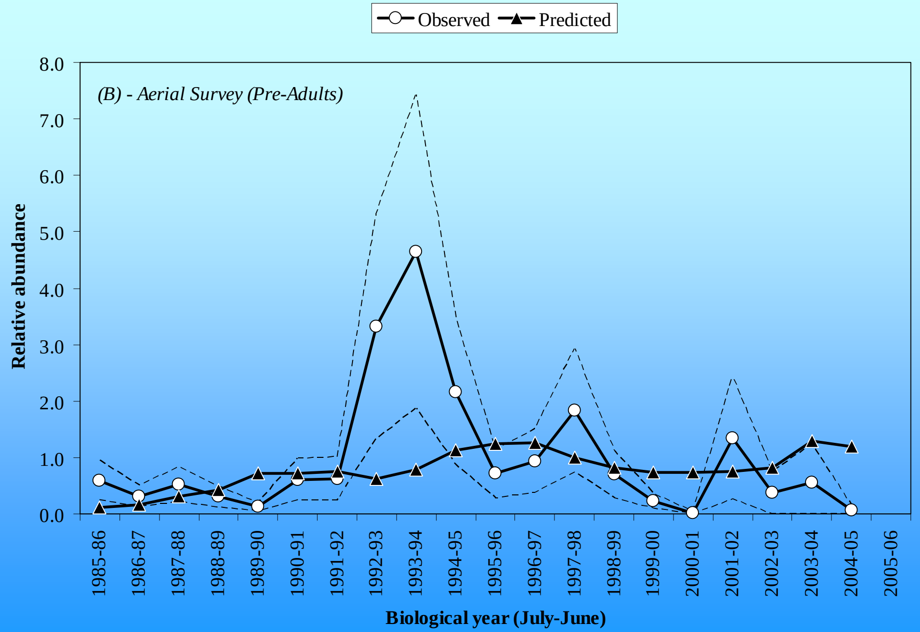
# Sardine Survey – Apr-May, 2006



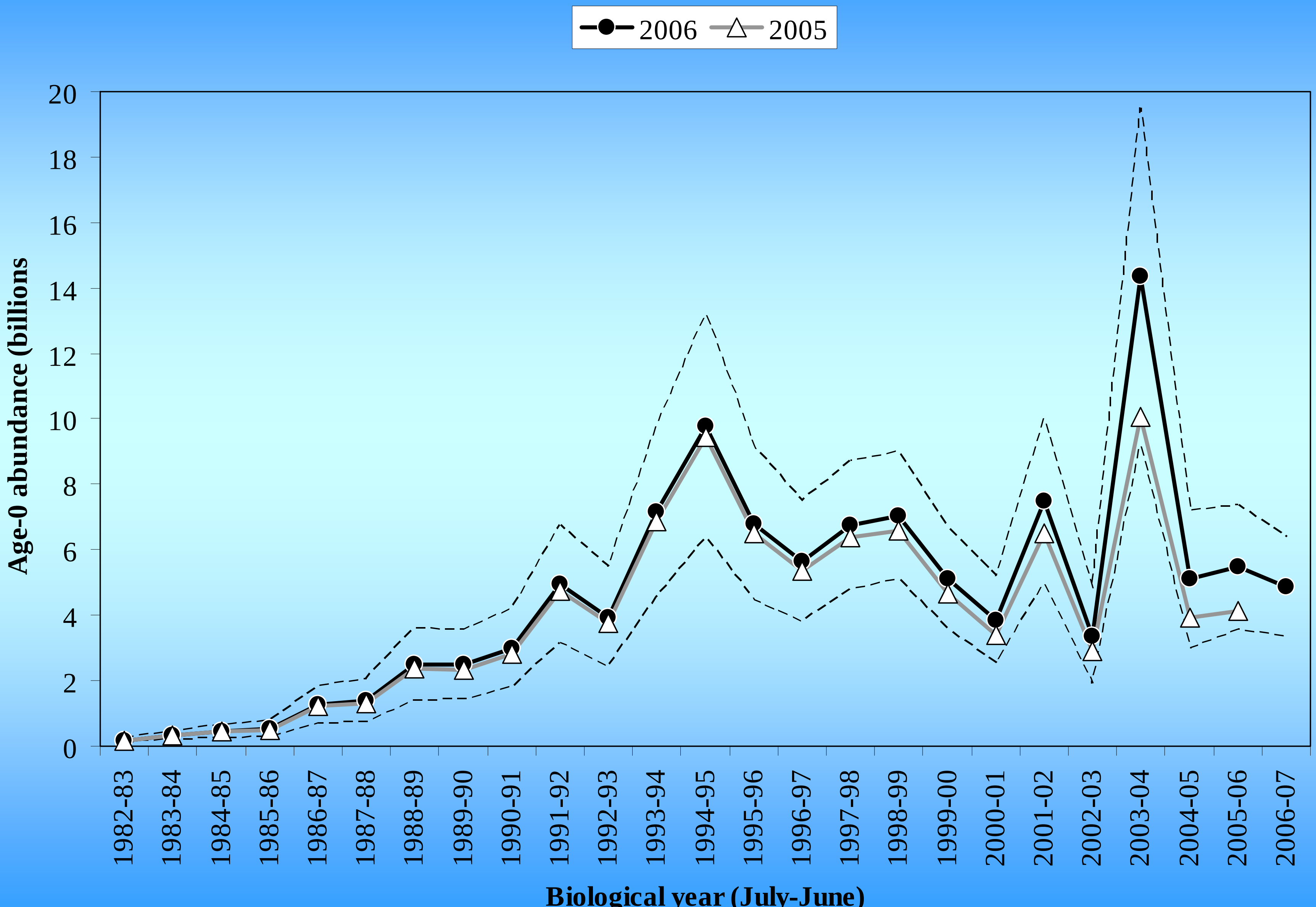



# Model Fits to Survey Data

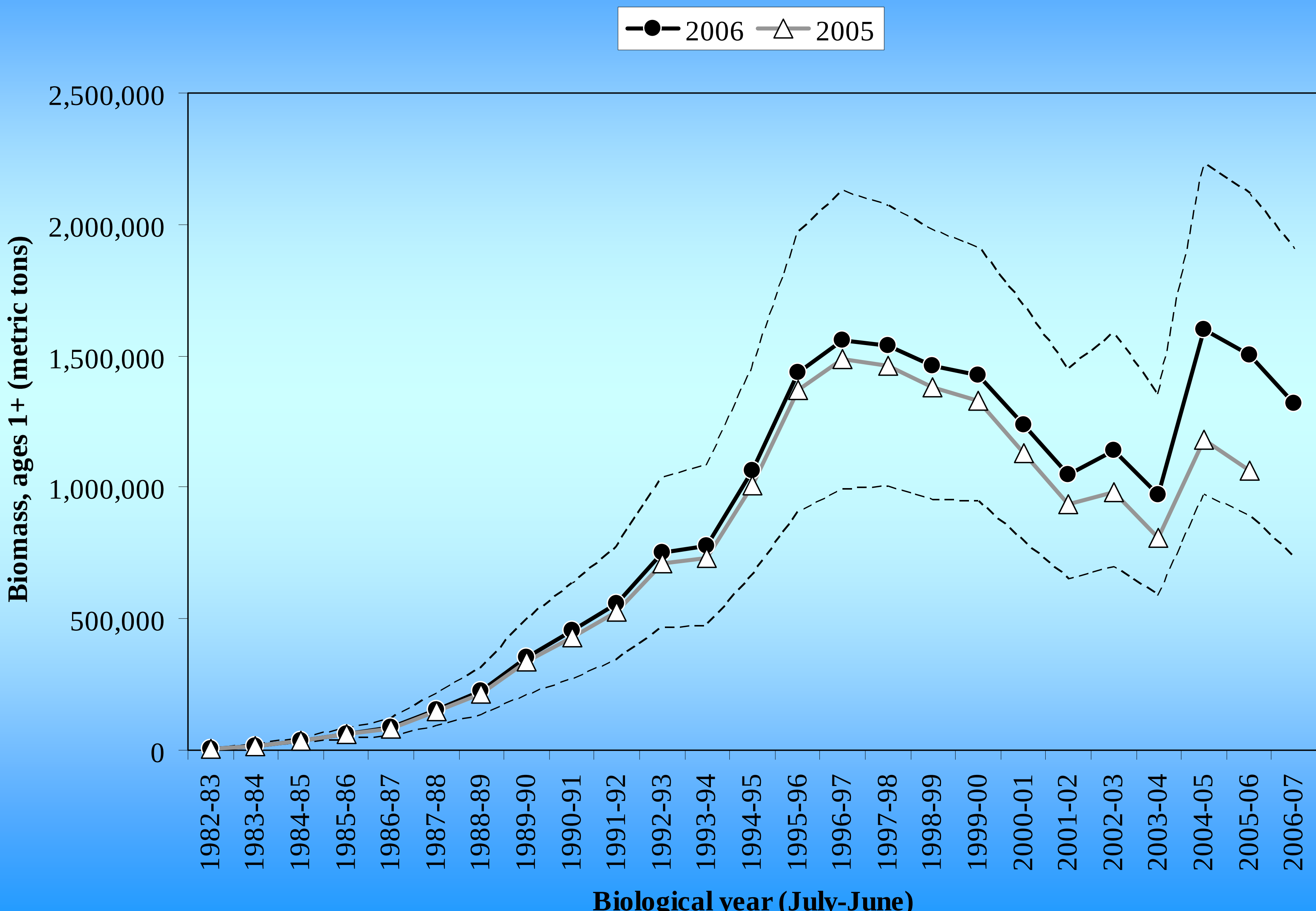


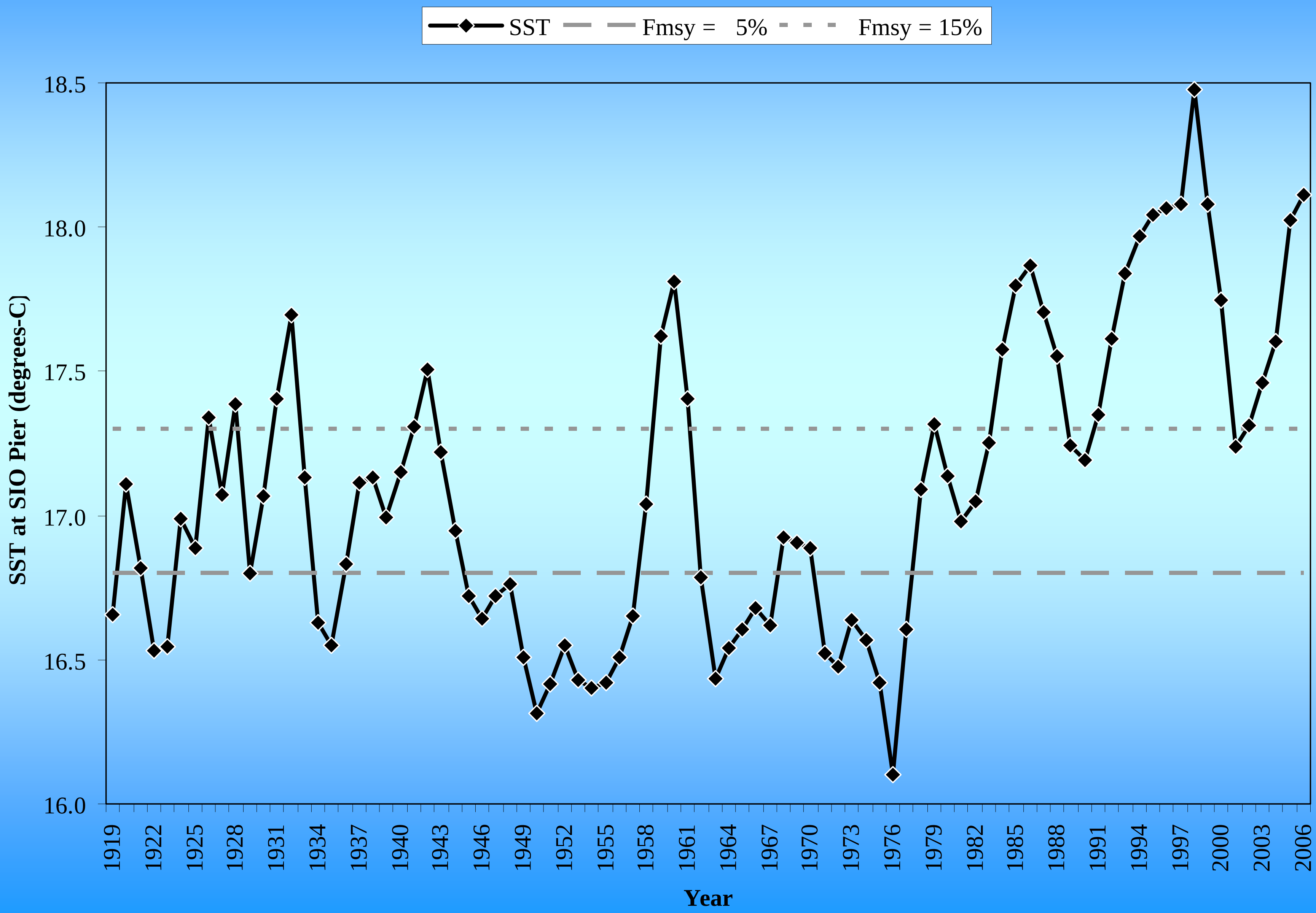
# *Recruitment*



# *Stock Biomass (age 1+)*



# Sea Surface Temperature at SIO Pier



# *U.S. Harvest Guideline Recommended for 2007*

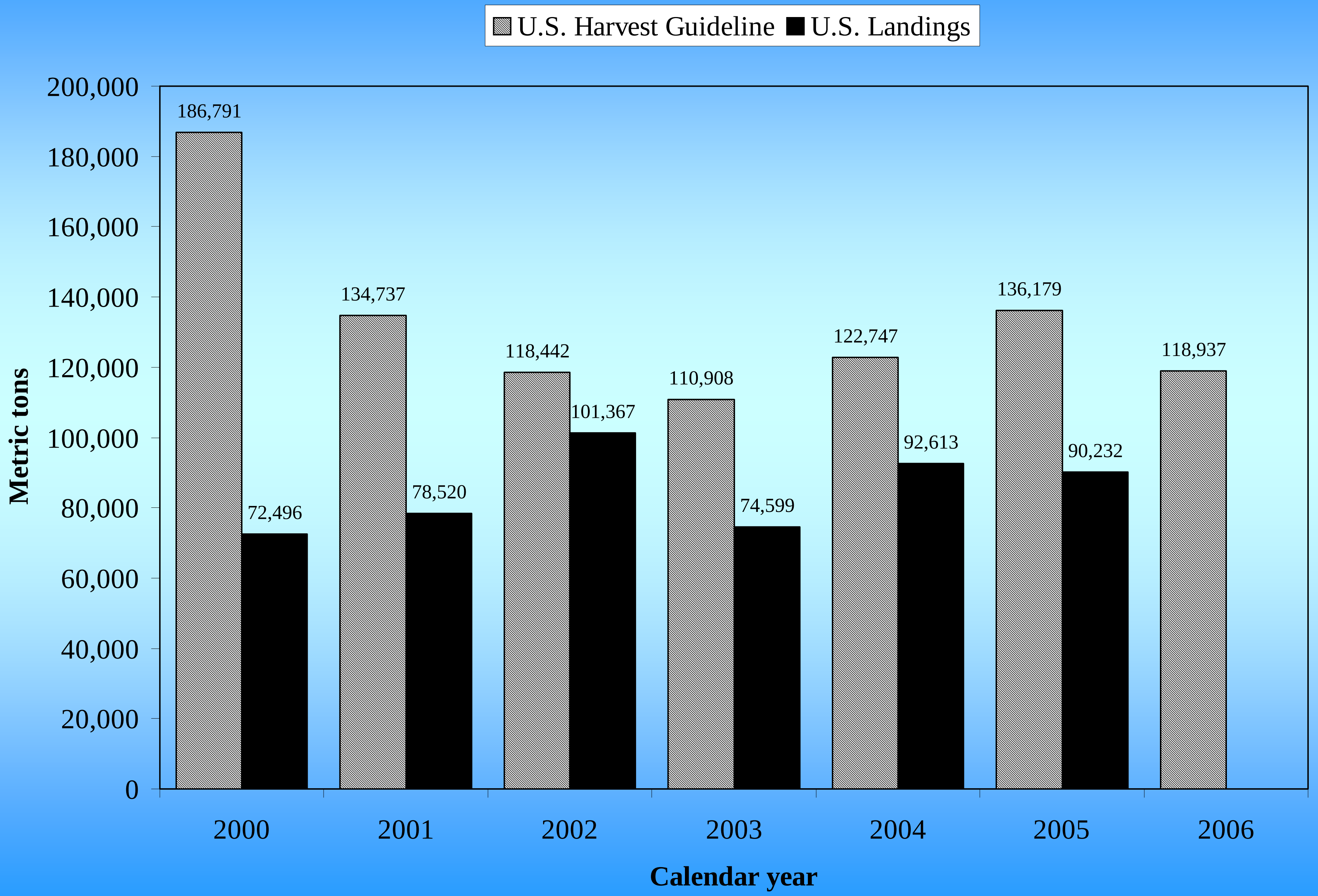
$HG_{2007}$ = (Biomass$_{\text{July 2006}}$ - Cutoff) • Fraction • Distribution

$HG_{2007}$ = (1,319,072 - 150,000) • 0.15 • 0.87

**$HG_{2007}$ = 152,564 mt**

- 28% higher than 2006 HG
- 51,197 mt higher than peak U.S. harvest (2002)

# U.S. Harvest Guidelines and Landings



# *Assessment Plans for 2007*

- ***MEXUS-Pacifico Sardine Stock Assessment Workshop:***
  – NMFS & INP collaboration
  – March 5-9, 2007 in Mazatlan or La Paz

- ***Pacific sardine STAR Panel, Sep 19-21, 2007 (SWFSC):***
  - testing new sardine model in SS2;
  - extend historical catch, length/age comps back to 1919;
  - test sensitivity to stock structure hypotheses;
  - fully utilize data collected from coast-wide and NW surveys;
  - develop indices from historical surveys (CalCOFI ichthyoplankton & CDFG pelagic ‘sea surveys’);
  - re-incorporate environmental covariate in S-R model.

Agenda Item F.1.b
NMFS Report
November 2006

# ASSESSMENT OF THE PACIFIC SARDINE (*Sardinops sagax caerulea*) POPULATION FOR U.S. MANAGEMENT IN 2007

by

Kevin T. Hill[1], Nancy C. H. Lo[1], Beverly J. Macewicz[1], and Roberto Felix-Uraga[2]

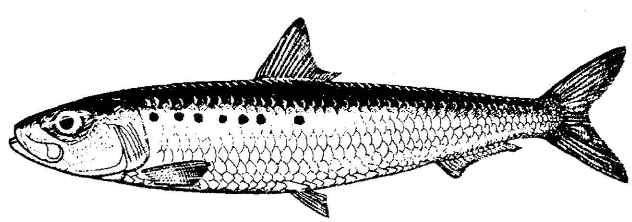
[1] NOAA Fisheries
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla, California 92037
U.S.A.

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

Submitted to

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

24 October 2006



*THIS PAGE IS INTENTIONALLY BLANK*

**TABLE OF CONTENTS**

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ADMB | automatic differentiation model builder (a programming language) |
| ASAP | age structured assessment program |
| BC | British Columbia, Canada |
| CA | State of 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 |
| CDFO | Canada Department of Fisheries and Oceans |
| CICIMAR-IPN | Centro Interdisciplinario de Ciencias Marinas - Instituto Politécnico Nacional |
| CONAPESCA | Comisión Nacional de Acuacultura y Pesca |
| CPS | Coastal Pelagic Species |
| CPSMT | Coastal Pelagic Species Management Team |
| CPSAS | Coastal Pelagic Species Advisory Subpanel |
| CV | coefficient of variation |
| 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 | State of Oregon |
| PFMC | Pacific Fishery Management Council |
| SAFE | stock assessment and fishery evaluation |
| SEMARNAP | Secretaria del Medio Ambiente, Recursos Naturales y Pesca |
| 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 | State of Washington |

## ACKNOWLEDGMENTS

This annual stock assessment depends in large part on the diligent efforts of many colleagues and the timely receipt of their data products. Landings data from the Ensenada fishery were kindly provided by Celia Eva-Cotero of INP-CRIP, Ensenada, Mexico. Port samples for the Ensenada, Mexico, fishery were collected by Walterio Garcia-Franco and Alfredo Cota (INP-CRIP in Ensenada) and were aged by Roberto Felix-Uraga and Casimiro Quiñonez of CICIMAR-IPN, La Paz. Tim Baumgartner (CICESE) transmitted updated landings information from the Ensenada fishery as compiled by Jesús Garcia Esquivel (SEMARNAP-Ensenada). Ed Pederson (IATTC-Ensenada) provided additional information about tuna net pen operations in northern Baja California. Port samples and age data for the California fishery were provided by CDFG Marine Region personnel in Los Alamitos, Santa Barbara and Monterey, with special thanks to Leeanne Laughlin, Valerie Taylor, Kelly O'Reilly, Travis Tanaka, Dianna Porzio, Kim Penttila, Brianna Brady, Alia Al-Humaidhi, and Sonia Torres for long dockside and laboratory hours. Thanks also go to the dedicated staff that collected and processed biological samples from the fisheries off Oregon, Washington, and British Columbia, including Jill Smith, Keith Matteson, and Sheryl Manley of ODFW, and Carol Henry of WDFW. Sandra Rosenfield and Jennifer Topping (WDFW) aged all of the Oregon and Washington otoliths. Monthly landings for the British Columbia fishery were provided by Christa Hrabok of DFO-Canada. Ron Dotson, Amy Hays, and Sue Manion (NMFS, La Jolla) provided aerial spotter logbook data. Numerous staff from SIO and NMFS assisted in the ongoing collection and identification of CalCOFI ichthyoplankton samples. We thank Melissa Carter (SIO) for providing Scripps Pier sea surface temperature data. We are grateful to Christopher Legault and Alan Seaver (NMFS, Woods Hole) for providing and maintaining the ASAP model.

## EXECUTIVE SUMMARY

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 U.S. fishery. 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 report was initially prepared in draft form for the STAR panel's consideration, and was updated for the 2005 and 2006 management cycles (Conser et al. 2004; Hill et al. 2005, 2006). Many of the STAR panel review recommendations as well as considerable new data were incorporated into the stock assessment updates. The assessment is once again updated here for 2007 management; as such, it will be reviewed by the Pacific Fishery Management Council (PFMC) CPSMT, CPSAS, and SSC-CPS subcommittee in October 2006 (Portland, OR), and by the PFMC at it's November meeting in San Diego.

This assessment was conducted using 'ASAP', a forward simulation, likelihood-based, age-structured model developed in AD Model Builder. New information has been incorporated into the update, including: (1) Ensenada landings through December 2005; (2) an additional year of landings and sample data from the California and Pacific Northwest fisheries; and (3) DEPM-based estimates of SSB (San Diego to San Francisco portion) based on the coast-wide survey conducted in April 2006. Model structure is described in Hill et al. (2005), and has not been altered in this assessment update.

Results from the final base model indicate a general decline in stock productivity (recruits per spawning biomass) which began in the mid-1990s. Recruit (age-0) abundance increased rapidly from low levels in 1982-83, peaking at 9.79 billion fish in 1994-95. Recruitment has subsequently declined, with the exception of a strong 2003 year class (YC) estimated at 14.37 billion fish. There was a large proportion of 2003 YC in the catch, as well as relatively high abundance in fishery-independent trawl surveys off California and the Pacific northwest. Stock biomass (ages 1+) peaked at 1.56 million metric tons (mmt) in 1996-97, declining to 0.97 mmt in 2003-04. Stock biomass was estimated to be 1.32 mmt as of July 2006.

The primary motivation for conducting this annual assessment 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. coast-wide harvest guidelines (HG) for sardine for the fishing year beginning on January 1$^{st}$ of each year. Based on the sardine biomass estimate from this assessment (1,319,072 mt) and current environmental conditions, the PFMC control rule suggests a 2007 HG of 152,564 mt for the U.S. fisheries. This HG recommendation is 28% higher than the HG adopted for calendar year 2006, and 51,197 mt higher than the largest recent harvest by the U.S. fisheries.

# 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 20$^{th}$ 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.

Recently-used Pacific sardine stock assessment models were designed for the data-rich environment and subsequently, had been modified in order to function in the new data-limited environment (Hill et al. 1999). The primary thrust of this report is go back to basics by utilizing stock assessment methods 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 California. 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 coastal Baja California to southern 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., 2004; 2005). 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 fisheries off Canada, the U.S., and northern Baja California 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, as well as habitat far offshore from California. During a cooperative U.S.-U.S.S.R. research cruise for jack mackerel in 1991, several tons of sardine were collected 300 nm west of the Southern California Bight (Macewicz and Abramenkoff 1993). Abandonment and re-colonization 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 relatively low biomass levels, sardine appear to be fully mature at age one, whereas at very high biomass levels only some of the two-year-olds are mature (MacCall 1979).

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$^{o}$C to 15$^{o}$C and larvae are most abundant at 13$^{o}$C to 16$^{o}$C. Temperature requirements are apparently flexible, however, because eggs are most common at 22$^{o}$C to 25$^{o}$ C in the Gulf of California and at 17$^{o}$C to 21$^{o}$C off Central and 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.

Sardine are oviparous multiple-batch spawners with annual fecundity that is indeterminate and highly age- or size-dependent (Macewicz et al. 1996). Butler et al. (1993) estimated that two-year-old sardine spawn on average six times per year whereas the oldest sardine spawn up to 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 hatching at 15$^{o}$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 consumed 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. 2005, 2006) 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 for reduction, canning, and frozen bait. Total annual harvest of Pacific sardine by the Mexican fishery is not regulated by quotas, but there is a minimum legal size limit of 165 mm. To date, no international management agreements between the U.S. and Mexico have been developed.

**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 1982). 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 1982). 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. 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 to 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 '**Harvest Guideline for 2007'** below). A thorough description of PFMC management actions for sardine, including harvest guidelines, may be found in the most recent CPS SAFE document (PFMC 2006). U.S. harvest guidelines and resultant landings since calendar year 2000 are displayed in Figure 1.

## ASSESSMENT DATA

**Biological Parameters**

Stock Structure

For purposes of this assessment, we assume a single Pacific sardine stock that extends from northern Baja California, Mexico to British Columbia, Canada and extends well offshore, perhaps 300 nm or more (Macewicz and Abramenkoff 1993; Hill et al. 1999). More specifically, all U.S. 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 and 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 near future, alternative stock structure scenarios will be explored, including one that separates the catches in Ensenada and San Pedro into the respective 'cold' and 'temperate' stocks proposed by Felix-Uraga et al. (2004, 2005) and takes into account subpopulation differences in growth and natural mortality.

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 sardine:

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

where $L_A$ is the length-at-age $A$, $L_\infty$ ('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: $L_\infty = 244$ 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. The correspondence between "Coded Age" and "True Age" is also provided in the table.

Natural Mortality

Adult natural mortality rates have 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

Fishery data for assessing Pacific sardine include commercial landings and port sample (biological) data for three regional fisheries: California (San Pedro and Monterey), northern Baja California (Ensenada), and the Pacific northwest (Oregon, Washington, and British Columbia). Biological data includes individual weight (g), standard length (mm), sex, maturity, and otoliths for age determination. CDFG currently collects 12 random port samples (25 fish per sample) per month to determine age composition and weights-at-age for the directed fishery. Mexican port samples, collected by INP-Ensenada 1989-2002, were aged and made available for this assessment by coauthor Felix-Uraga. ODFW and WDFW have collected port samples since 1999. A listing of sample sizes relative to fishery landings, 1982-83 to present, is provided in Table 2.

Following recommendations of the CPS STAR Panel (PFMC 2004), all fishery inputs were compiled based on a 'biological year' as opposed to a calendar year time step, with the biological year being based on the birthdates used to assigned age. Therefore, data were aggregated from July 1 ($year_x$) through June 30 ($year_{x+1}$). In the input and output files, the sardine fisheries (or 'Fleets') are assigned numbers as follows:

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

Landings

The ASAP model includes commercial landings in California, northern Baja California and the Pacific Northwest from 1982-83 through 2006-07. Landings were aggregated by biological year and are presented in Table 2 and Figure 2.

California commercial landings were obtained from a variety of sources based on dealer landing receipts (CDFG), which in some cases augmented with special sampling for mixed load portions. During California's incidental sardine fishery (1982-83 through 1990-91), many processors reported sardine as mixed with jack or Pacific mackerel, but in some cases sardine were not accurately reported on landing receipts. For these years, sardine landings data were augmented with shore-side 'bucket' sampling of mixed loads to estimate portions of each species. CDFG reports these data in monthly 'Wetfish Tables', which are still distributed by the Department. These tables are considered more accurate than PacFIN or other landing receipt-based statistics for California CPS, so were used for this assessment. Projected landings for the final time step (2006-07) were based on 2005-06 landings.

Ensenada (northern Baja California) landings from July 1982 through December 1999 were compiled using monthly landings from the 'Boletín Anual' series published by the Instituto Nacional de la Pesca's (INP) Ensenada office (e.g. see Garcia and Sánchez, 2003). Monthly catch data from January 2000 through June 2005 were provided by Dr. Tim Baumgartner (CICESE-Ensenada, Pers. Comm.), who obtained the data electronically from Sr. Jesús Garcia Esquivel (Department of Fisheries Promotion and Statistics, SEMARNAP-Ensenada). These new catch data for 2000 to mid-2005 incorporate estimates of sardine delivered directly to tuna rearing pens off northern Baja California, and are overall 37% higher than statistics used in the previous assessment. Ensenada landings for calendar year 2005 were reported to be 56,684 mt (Cota-V. et al. 2006). Projected landings for 2005-06 were based on the 2004-05 value.

For the Pacific Northwest fishery, we included sardine landed in Oregon, Washington, and British Columbia. Monthly landing statistics were provided by ODFW (McCrae 2001-2004, McCrae and Smith 2005), WDFW (WDFW 2001, 2002 and 2005; Robinson 2003, Culver and Henry 2004), and CDFO (Christa Hrabok, pers. comm.). The Pacific Northwest fishery has progressed more slowly in the summer of 2006. Based on landings-to-date the 2006-07 projection is assumed to be about two-thirds of the 2005-06 landings.

Catch-at-age

Descriptions of sardine otolith ageing techniques can be found in Walford and Mosher (1943) and Yaremko (1996). 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. Sample sizes by fishery and biological year are provided in Table 2. In summary, port sample data for the three fisheries were available for the following seasons: California, 1982-82 to 2005-06; Ensenada, 1988-89 to 2002-03; and Pacific northwest, 1998-99 to 2005-06.

Catch-at-age matrices were developed for each fishery using port sample and landings data aggregated by month. Estimates of catch-at-age were weighted to take into account variation in sample size relative to total landings. Sample percent-by-weight for each age class was calculated by dividing the total weight of fish-at-age by the total weight of fish sampled in each month. Landed weight of fish in each age class was estimated as the product of metric tons landed and the percent-by-weight in the fishery sample. Numbers-at-age in the monthly landings were then calculated by dividing the landed weight-at-age by the average individual weight-at-age for the month. For months with landings but no fishery sample taken, data were substituted by summing sample information (i.e., fish numbers, weights, and sample weights) from the two adjacent (previous and following) months. Finally, numbers-at-age were summed across months to provide the catch-at-age (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. Catch-at-age data compiled for ASAP input are provided in Tables 3-5, and proportions-at-age are displayed in Figures 3-5. Based on estimates from preliminary model runs, effective sample sizes for the California and Ensenada fisheries were set to $\lambda$=50. Effective sample size for the Pacific Northwest fishery data was estimated to be lower, and was set to $\lambda$=12 for the final base run. In years with landings but no samples, effective sample size was set to zero.

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 6.

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 number-at-age estimates into stock biomass (Ages 1+) for management, biological samples from fishery-independent sources that span the geographical range of the stock were used to calculate population weights-at-age (Table 7) outside of the ASAP model. Data included survey samples from summer 1998 and spring 2004.

## 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 pre-adults (ages 0-2) |

Daily Egg Production Method (DEPM) Spawning Biomass Index (Index 1)
Daily egg production method (DEPM) spawning biomass estimates were available for 1986-1988 and 1994-2006 (Table 8, Figure 7). Methods employed for the DEPM-SSB point estimates are published in Wolf and Smith (1986), Wolf et al. (1987), Wolf (1988a,b), Lo et al. (1996 & 2005), and Lo and Macewicz (2006). Adult samples were not taken on a consistent basis and, consequently, it was necessary to use averaged values for adult reproductive parameters (egg production, daily specific fecundity, etc.) in some years.

A coast-wide sardine survey (Baja California, Mexico to British Columbia, Canada) was conducted April 1-May 8, 2006 (Figure 8). Three U.S. vessels were deployed to sample the area from California to British Columbia, including the FRVs *David Starr Jordan* and *Oscar Dyson,* and the SIO's *New Horizon* which covered the standard CalCOFI stations. The Mexican research vessels *El Puma* and *BIP XI* were used off outer Baja California -- results from this portion of the coast-wide survey are not yet available for an assessment. The original survey design for U.S.-Canada portion included both the *Oscar Dyson* and *David Starr Jordan* in ichthyoplankton and adult sampling (trawl and acoustic), with the *Dyson* sampling from British Columbia to San Francisco and the *David Starr Jordan* from San Diego to San Francisco. Due to trawl equipment failures on the *David Starr Jordan*, the *Oscar Dyson*'s survey tracks were revised to enable trawl sampling off California. Thus, the final survey was not synchronized (egg v. adult samples) as originally planned and had lower spatial resolution.

The *David Starr Jordan* took CalVET and CUFES samples during the entire cruise from April 6-28, and bongo tows in the area north of CalCOFI line 76.7. The *Oscar Dyson* collected trawl, CalVET, and bongo samples in the area from Vancouver Island to north of San Francisco from April 12-May 8 and trawl and CUFES samples during the entire cruise. The *New Horizon* took CalVET and Bongo samples at regular CalCOFI stations from San Diego to north of Point Conception during April 1-17.

The total DEPM-based spawning biomass during April-May 2006 was estimated to be 1,304,806 mt (CV = 0.47) within a 885,523 $km^2$ spawning area from San Diego to British Columbia. This estimate was based on a daily egg production estimate of $0.75/0.05m^2$ (CV = 0.23) and a daily specific fecundity of 10.18 (number of eggs/population weight (g)/day) for the entire survey area. Sardine eggs and adults were not found north of Coos Bay, Oregon. The standard DEPM sampling region off California (San Diego to San Francisco) had a spawning area of 336,774 $km^2$. For this region, egg production was estimated to be $1.37/0.05m^2$ (CV = 0.26), daily specific fecundity was 8.47 (number of eggs/population weight (g)/day), and the resulting spawning biomass was 1,081,612 mt (CV=0.47). Thus, the portion spawning biomass from San Francisco to British Columbia was approximately 223,194mt.

In ASAP, the DEPM index was taken to represent sardine SSB in April (month 10) of each biological year. CVs for DEPM estimates are also presented in Table 8. The 2005-06 DEPM estimate, based on eggs and adults collected from the standard survey area (San Diego to San Francisco) during the April 2006, was 1,081,612 mt of SSB (Table 8). The selectivity pattern for this survey was fixed, based on maturity-at-age proportions (Table 9, Figure 9). Within ASAP, a CV of 0.30 was applied to all DEPM observations.

Aerial Spotter Survey (Index 2)

Pilots employed by the fishing fleet to locate pelagic fish schools, including sardine, report data for each flight on standardized logbooks and provide them to NOAA Fisheries for a fee per flying hour ($1-$5). Spotter indices for sardine were calculated as year effects estimated using delta log-normal linear models (LLM; Lo et al. 1992). The spotter index covers the period 1985 through 2005, with a July-June time step Table 8, Figure 7). After the year 2000, there was rapid decline in both the number of active pilots and total logbooks returned (Tables 10 and 11), as well as a southward shift in effort to offshore areas off of Baja California (Figure 10). To remedy this problem, NOAA Fisheries started to contract professional spotter pilots to survey the Southern California Bight region in 2004 and 2005. Newly available data from this enhanced survey were incorporated into the index, and a new time series was calculated using a delta Generalized Linear Model (GLM). CVs of delta GLM estimates from 2000-01 onward were higher than the earlier portion of the time series partially due to reduced sample size (Table 8, Figures 11 & 12). To account for this uncertainty, we applied higher CVs to observed values within the ASAP model (increasing from 0.3 to 0.7 in the final year; Figure 12), in effect lowering the influence of the 2000-01 to 2004-05 spotter data in the overall likelihood. We applied a CV of 0.30 to all observations prior to 2000-01. The aerial survey index was taken to represent the inshore, younger sardine (primarily ages 0-2; Table 9, Figure 9).

The old time series based on logbook data had an informal design. Pilots flew year-round at night and in the day, and in areas and seasons frequented by the fishery. The pilot's searching behavior, like most fishermen, might be characterized as "adaptive", that is, searches for target species may be concentrated in areas where schools were previously sighted. No doubt exists that a formal fishery-independent survey design would be more precise and less biased than the present indices. However, by altering the design one loses the old aerial surveys most valuable property, i.e., a time series that extends back 38 years. Regardless of its merit, a new index will have little value in stock assessment until it extends over at least 5-10 years. Clearly, the time series that ended in 2000 needed to be extended, but was also valuable to develop a new, more precise index with less potential bias.

The new data collected in 2004 and 2005 were based on a line-transect design with regular occupation of fixed grid lines spaced at regular intervals with random starting points, while the simulated old survey employed a adaptive design to simulate fishing conditions where, having found one school the fishermen will search the vicinity to find others. After searching, the pilot returns to the transect line and continues along the line. In this way, we gathered information appropriate to both old and new survey designs. The month, area, and daylight of new surveys are close to those standardized conditions used in the spotter index model developed by Lo et al (1992): experienced pilots, under contract, flew along the predetermined track lines in March and April from San Diego to San Francisco, at a maximum of 100 nm offshore (Figure 13). In reality, pilots were unable to all assigned surveys in March and April due to weather conditions and their flying schedules. In addition, they only fly in the day time and not in the night alone. As a result, flights in 2004 took place throughout the entire year.

Two analyses were conducted. The first, based on Delta GLM, included new datasets together with the historical aerial survey data, and the second was stand-alone estimates from the strip transect method. For the strip transect method, we grouped flights by month into individual surveys and density of sardine was computed for each survey. In 2004, a total of 5 surveys by month (3, 4, 5, 7, and 9) were accomplished from March-November, including two single-pilot flights in September and November. In 2005, we had two 3-pilot complete surveys, three 2-pilot surveys and one 1-pilot survey during March and April. A set of these two estimates for 5-10 years datasets can be used to calibrate these two estimates and to link the data from the past to the future. The goal of contracted pilots is for the future to use strip transect method on data collect from the predetermine track lines, area and time of the year. In the following sections, we will describe the first analysis: delta linear models: delta lognormal linear model and delta GLM.

*Delta Linear Models*

The relative abundance of pelagic species (e.g. anchovy or sardine) can be expressed as the product of density and a measure of area:

$$I = DA$$

where $I$ is the index of relative abundance for a given year (tons), $D$ is density of sardine (tons per block) and $A$ is the area (blocks) covered by fish spotters. In the original data analysis of the relative abundance of anchovy (Lo et al. 1992), it was reasonable to assume that fish spotters flew over an area that was at least as large as the area occupied by the anchovy stock in each year. This is not so for the entire sardine population but may apply to young sardines (<=2 year old). In the current analysis for sardine, units for the index *(I)* are tons of young sardine, sighted by fish spotters.

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

$$D = dP$$

where $d$ is a standardized measure of sardine density (tons per block) for positive flights (flights during which young sardine were seen) and P is a standardized measure of the proportion of blocks covered by positive flights (referred to as 'proportion positive') (Table 10). We used the product in order to avoid problems that arise from including a large number of zeros, therefore the distribution of D is Delta distribution.

*Delta Lognormal Linear Model*

In the original lognormal linear model, we assumed that data tons/block (y) or proportion positive (p) follows a lognormal distribution and varies with some covariates, i.e. log(y) or log(p+1) was a function of many covariates: year, region, season, pilot, night/day flights plus some interaction terms: log(y) or log(p+1) =x'B. The final estimates of standardized $d$ and $P$ were obtained by taking anti log of the linear equations (x'B) plus correction terms. The relative abundance for each year is:

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

*Delta GLM model*

To continue including spotter pilot data for the stock assessment from the new datasets, we decided to switch from Delta lognormal linear model to a more flexible model, like GLM using S+, to allow us to incorporate other possible distribution of tonnages/block (y) of sardine sighted by the pilots for the positive flights and the proportion of positive flights (p) with appropriate link functions for the expected values (d and P) respectively. As stated in Lo et al. (1992), "…Although we used lognormal linear models for components of the delta distribution, other linear or nonlinear models based on other statistical distributions could be used instead."

For the delta GLM, we chose family of Poisson and used log as the link function for the tons/block of positive flights (d), e.g. log (the expected tonnage/block) = x'B and family of Binomial and the link function of the logistic, for the proportion of positive flight (P), e.g. log(P/(1-P)) = x'B. The estimate of density of sardine is $\hat{D} = \hat{d}\hat{P}$ with variance:

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

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

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

where *A* is total number of blocks within the tradition area covered by spotter pilots prior to 2004.

The time series of the relative abundance of sardines from spotter data set are given in Figure 14 based on the original delta-lognormal distribution and the delta-GLM.

The Delta distribution (Aitchison and Brown 1957; Pennington 1983) was used because of low proportion of positive flights in most years. As the current survey designs continue for long period of time, the Delta distribution may not be needed. The current procedure includes the standardization of region to region 2, which was originally designed for anchovy. For sardine, it may be more proper to use region 3. The current flights all take place in the day time.

*Comparisons between Delta lognormal linear model and Delta GLM*

Data from 1985-2004 (calendar year) were analyzed using both models. Two time series have similar shape except that the time series from lognormal linear model fluctuated a little less than that from Delta GLM even though the peak from the former is higher than the latter (Figure 14). The CVs from LLM (Bradu and Munklak 1970) are higher than those from GLM because the variances of the estimates from LLM included those of bias-correlation terms for the parameter estimates of lognormal distribution and the delta-methods for variance of estimates were used in GLM (Chambers and Hastie 1992).

# ASSESSMENT MODEL

## ASAP Model Description

<u>Overview</u>

The Age-structured Assessment Program (ASAP) model (Legault and Restrepo 1999; see Appendix I) is based on the AD Model Builder (ADMB) software environment, a high-level programming language that utilizes C++ libraries for nonlinear optimization (Otter Research 2001). 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 readily.

The general estimation approach used in the ASAP is that of a flexible forward-simulation that allows for the efficient and reliable estimation of a large number of parameters. The population dynamics and statistical principles of ASAP are well established and date back to Fournier and Archibald (1982), and Deriso et al. (1985). 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 (1999; see 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 Baronov's catch equation and user-provided mean weights at age and natural mortality.
- The method of maximum likelihood serves as the foundation of the overall numerical estimation. Sources of data are compartmentalized into various likelihood components,

depending on the level of structure of the overall, fully-integrated population model. Generally, the ASAP model includes nine likelihood components and a few penalties, given a baseline population model (see Table 12).

- The tuning indices are assumed to represent changes in the population over time for specific age ranges and can be measured in numbers or weight.
- Given the large number of parameters, it is possible to fit both the catch-at-age and the abundance indices relatively well, but often at the expense of producing somewhat unrealistic trends in other stock parameters of interest (e.g., recruitment, selectivity, and catchability). Constraints and penalty functions can be employed to the constrain estimation to more feasible regions of parameter space.
- Because the number of parameters can be large and highly nonlinear, it is often difficult to estimate all parameters simultaneously in one run of the model. In practice, the minimization usually proceeds in phases, where groups of parameters are estimated simultaneously, while the remaining parameters are maintained at their initially assigned ('starting') values. Once the objective function is minimized for a particular phase, more parameters are evaluated in a step-wise fashion. Estimation within additional phases continues until all parameters are estimated. For this assessment, parameters were estimated in the following order: Phase (1): Selectivity in 1$^{st}$ Year, Fmult in 1$^{st}$ Year, Catchability in 1$^{st}$ Year, Stock-Recruitment Relationship, and Steepness; Phase (2): Fmult Deviations, Recruitment Deviations; Phase (3): Selectivity Deviations.
- While ASAP has the ability to estimate population numbers at age in the first year, attempts to do so with sardine resulted in unrealistically high numbers in the initial population which carried through the entire time series. For this reason, we fixed numbers-at-age for the initial population to a biomass equivalent of 5,000 mt. Specifically, numbers-at-age (1,000s) for ages 0 to 5+ were set to the following starting values, respectively: 25,000, 15,000, 9,000, 5,400, 3,240, and 1,944.

Assessment Program with Last Revision Date

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

Likelihood Components and Model Parameters

Likelihood components in the final ASAP base model ('Base-D5') are listed in Table 12. Parameterization summaries for the baseline ASAP model are provided in Table 13.

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 (Conser et al. 2004; Hill et al. 2005). The assessment model '06_Base-A1' constructed for this update is parameterized as described by Hill et al. (2005) – only the fishery and survey data have been updated for the final two time steps (2005-06 and 2006-07).

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 12. A total of 140 parameters were estimated (Table 13). Model run times were usually only a few minutes and 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. Standard deviations were reasonable for most of the key model parameters including the derived parameters such as SSB (Table 13).

### Catch

Model fit to catch data for each fishery is displayed in Figure 15. The observed and predicted time series essentially overlay each other, indicating precise fit to this data source.

### Catch-at-age

Effective sample sizes for the California and Ensenada fisheries were set to $\lambda=50$. Effective sample size for the Pacific Northwest fishery data was set to $\lambda=12$ (Figure 16). Model residuals for catch-at-age data are displayed in Figure 17. Residuals for the three fisheries were random, with no obvious trends over age or time.

### Indices of Abundance

Model fits to DEPM and Aerial Spotter series are displayed in Figure 18. Comparisons of observed data for the two indices may be found in Figure 19. Note the inverse relation between the two indices for the year-year comparison (Figure 19A), and relative lack of correlation when DEPM is lagged by two years (Figure 19B) to account for differences in selectivity.

### Selectivity Estimates

Estimated selectivities ($S_{age}$) for the three respective fisheries are displayed in Figure 20.

Selectivity for the California fishery was estimated for two periods: 1982-1990 (biological years) when the population was smaller, quotas were lower, and a large portion of sardine was captured mixed with schools of jack and Pacific mackerel; and 1991-2006, when the population was larger, quotas were higher, and pure schools of sardine were targeted. Selectivity patterns for the California and Ensenada fisheries were dome-shaped (Figure 20), with 2 year old fish 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 areas) as opposed to gear- or market-related causes. Estimated selectivity for the Pacific Northwest fishery is asymptotic (Figure 20), with the oldest two ages being more or less fully selected. Again, this likely reflects the coast-wide distribution of sardine population.

**Fishing Mortality Rate**

Fishing mortality estimates for the three respective fisheries are displayed in Figure 21. Combined fishing mortality-at-age is displayed in Figure 22 and Table 14.

**Spawning Stock Biomass**

Population SSB from ASAP is provided in Table 15. Population SSB was estimated to be 1.16 mmt as of July 2006. This is well within the range of DEPM-based SSBs estimated from the April 2006 survey: 1.08 mmt from San Diego to San Francisco; 1.30 mmt from San Diego to British Columbia.

**Recruitment**

Recruitment estimates (age-0 abundance) are presented in Tables 13 and 15 and displayed in Figure 23. The recruitment trend is similar to that of Hill et al. (2005), with peaks in 1994-95 (9.79 billion) and 2003-04 (14.37 billion).

**Stock-recruitment Relationship**

Recruitment CVs were set at 0.5 for most years in ASAP. Recruits are poorly estimated in the final years of any age-structured model. To obtain more reasonable estimates of recruitment and biomass in the last several years, we increased weights on spawner-recruit predictions in ASAP by applying gradually smaller CVs (0.4, 0.3, 0.2, 0.1, 0.05) from 2002 to 2006. A similar *S-R* constraint has been applied in previous sardine assessments (Deriso et al. 1996, Hill et al. 1999, Conser et al. 2003, Hill et al. 2005). The relationship between SSB and recruitment is displayed in Figure 24. Beverton-Holt model parameters were estimated as follows: $\alpha$ = 6.1599e+06; $\beta$ = 221,233; Virgin = 1.465e+06; and Steepness ($h$) = 0.66 (Table 13).

Relative spawning success, calculated as anomalies from average *ln(R/SSB)*, is displayed in Figure 25. Spawning success was highest during the onset of the recovery, with a trend toward negative anomalies in more recent years. Positive anomalies in 1993-94 and 2002-03 are attributed to peak year classes in 1994 and 2003.

The strong year class estimated for 2003 was driven, in part, by large portions of this year class in the California fishery samples collected 2003-04 through 2005-06 (Table 3, Figure 3), as well as relatively large proportions of this year class in the Pacific Northwest fishery in 2004-05 and 2005-06 (Table 5, Figure 5). Trawl surveys conducted off California in 2004 and 2005 and the Pacific Northwest from 2003 to 2005 provide fishery-independent evidence for a strong 2003 year class. Length composition data from these surveys are displayed in Figure 26. Off the Pacific Northwest the 2003 year class first appeared in March 2004 as the length mode ranging 100-130 mm SL. This mode progressively appeared in subsequent surveys in July 2004 and March 2005 (Figure 26, top panel). Off California, the presumed 2003 year class appeared as the 140-180 mm SL mode in April 2005. Age determinations for the survey samples are pending.

**Biomass of Stock for PFMC Management (Ages 1+)**

Stock biomass (ages 1+) estimates are presented in Table 15 and displayed in Figure 27. Stock biomass increased from low levels in the early 1980s to a peak of 1.56 mmt in 1996-97. The stock has subsequently declined to lower levels and was estimated to be approximately 1.32 million mt as of July 1, 2006. Stock biomass from the current assessment is similar in trend but slightly higher in magnitude compared to Hill et al. (2005) (Figure 27). This increase is attributed to the 2006 DEPM estimate, which is the highest in the time series (Figure 18A).

**Model Diagnostic Examinations and Uncertainty**

The specifications of the 2006 base model were identical to those of the 2005 assessment – only new fishery and survey data were added in 2006: Ensenada landings (2005); landings and catch-at-age data for California and Pacific Northwest (2005-06); and a DEPM-based SSB estimate from the April 2006 survey. The 2006 base model estimates of biomass and recruitment are considerably higher compared to the 2005 final model. For example, this year's estimate of stock biomass (age 1+) in July 2005 was 42% greater than the final model from 2005, and the 2006 estimate of the 2003 recruitment was 43% higher. During a meeting with the SSC's CPS Subcommittee (17 October, 2006), the following sensitivity tests were completed to more fully understand differences between the 2005 and 2006 assessments:

1. Starting with the 2005 model configuration, the impact of each new data source on assessment outcome was examined: a) adding the landings data; b) adding the 2005-06 catch-at-age data (California and the Pacific Northwest); c) adding the core-area DEPM index for 2006. These tests were performed using the 2005 $\sigma_R$ settings, and shifting $\sigma_R$ for the terminal year-classes (2006 base configuration) and hence imposing less constraint on the size of the 2003 year-class.
2. Examine the relative influence of the two contradictory indices by ignoring the DEPM and Aerial Spotter series in turn.
3. Reduce the emphasis factor placed on the $F_{mult}$ penalty from 1 to 0.1.
4. Conduct a sensitivity run in which the DEPM index for 2006 is set to the estimate for the entire survey area rather than just for the core sampling area.

Results from the sensitivity runs are summarized in Table 16 and Figure 28. Shifting and increasing $\sigma_R$ for the recent year-classes and including the 2006 DEPM estimate resulted in higher estimates of 2003 recruitment and 2006-07 stock biomass (age 1+). Conversely, adding in the 2005-06 catches-at-age resulted in the opposite effect. Excluding the aerial spotter index led to more optimistic results while excluding the DEPM index resulted in much lower recruitment and biomass (Table 16, Figure 28). Survey-based DEPM estimates should provide results that are, in theory, close to absolute estimates of abundance, which suggests that the sensitivity test based on ignoring the DEPM data is less plausible than that in which the spotter index is ignored. The results were fairly insensitive to down-weighting the $F_{mult}$ penalty, and this component will be down-weighted in future assessments. Using the 2006 coast-wide survey DEPM estimate (20% greater than the 'core area' estimate) in the time series only increased model age 1+ biomass by 3.7%.

**Assessment Plans for the Pacific Sardine STAR Panel in 2007**

A full assessment of Pacific sardine is scheduled for STAR Panel review during 19-21 September, 2007. During the assessment update review of 17 October, 2006, the SSC's CPS Subcommittee recommended the following items be examined as part of the 2007 assessment:

1. The selectivity pattern for the aerial spotter index is pre-specified based on the selectivity pattern of the California fishery, adding the assumption that schools of age-zero fish would be visible to the pilots. However, the two California selectivity patterns are not identical, and the selectivity pattern for the spotter planes may have changed in response to changes in the distribution of the resource and fishery targets;
2. The reliability of DEPM estimates depends on representative sampling of eggs and adult reproductive parameters to adequately characterize the spawning season. Analyses should be conducted to assess whether the ability to use the DEPM estimates as indices of abundance (or as estimates of absolute abundance) is compromised due to, for example, spatial-temporal variability in spawning activity. The impact of changes in the spatial distribution of the population on whether DEPM estimates from the core region provide an index that is linearly related to spawning biomass should be examined;
3. The historical CALCOFI data should be examined to explore seasonal patterns in spawning and decadal scale variability in egg production;
4. The available survey data should be assessed to determine whether they support time-varying weight- and maturity-at-age;
5. The possibility of including sea surface temperature as a covariate when fitting the stock-recruitment relationship should be explored;
6. Given the contradictory nature of the two indices of relative abundance, there needs to be a clear rationale for the inclusion of each index in the assessment. Specifically, inclusion and weighting of indices of abundance should be based on consideration of experimental design.
7. The CVs assigned to abundance indices appear to be too small because too few of the 95% confidence intervals are intersected by the population trajectory;
8. The acoustic data collected during the 2006 survey should be analyzed with a view towards the development of an alternative index of abundance.

In addition to items requested above, the sardine STAT plans to explore the following areas for consideration at the 2007 STAR:

1. develop an assessment model using Stock Synthesis 2 (SS2), and compare results to the ASAP update;

2. transition from an annual to a semester or quarterly time step to resolve issues related to seasonal movement and selectivity;
3. extend time series to include previous era; incorporate historical catch, length/age compositions to as early as 1919;
4. explore sensitivity to stock structure hypotheses; expand/contract geographic extent of data;
5. more fully utilize data collected from coast-wide and NW surveys;
6. develop indices of abundance from historical surveys, e.g. CalCOFI ichthyoplankton & CDFG pelagic 'sea surveys';
7. explore re-incorporating environmental covariate in S-R model (also recommended by SSC-CPS Subcommittee).

## HARVEST GUIDELINE FOR 2007

The Pacific sardine harvest guideline recommended for the U.S. fishery in calendar year 2007 is 152,564 mt. Statistics used to determine this harvest guideline are discussed below and presented in Table 17. To calculate the proposed harvest guideline for 2007, 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:

$HG_{2007}$ = ($BIOMASS_{2006}$ - CUTOFF) • FRACTION • DISTRIBUTION;

where $HG_{2007}$ is the total USA (California, Oregon, and Washington) harvest guideline in 2007, $BIOMASS_{2006}$ is the estimated July 1, 2006 stock biomass (ages 1+) from the current assessment (1,319,072 mt), 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 DISTRIBUTION (87%) is the percentage of $BIOMASS_{2006}$ assumed in U.S. 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 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 (1982-2006; Table 8, Figure 29), the appropriate $F_{msy}$ exploitation fraction has consistently been 15%; and this remains the case under current oceanic conditions ($T_{2006}$ = 18.11 °C). The 2007 USA harvest guideline (152,564 mt) is 28% higher than the 2006 harvest guideline (118,937 mt), and 51,197 mt greater than the largest recent harvest by the U.S. fisheries (101,367 mt in 2002; Table 18).

For a broader perspective on coast-wide sardine harvest relative to MSY, we applied the U.S. harvest control rule to the current stock biomass time series, ignoring the 87% pro-ration for assumed U.S. distribution. Theoretical coast-wide HGs and recent harvests are displayed in Figure 30. Based on our current estimate of stock biomass, and ignoring various assumptions regarding stock distribution, the current coast-wide sardine harvest can be viewed as being at or below MSY in recent years.

## LITERATURE CITED

Ahlstrom, E. H. 1960. Synopsis on the biology of the Pacific sardine (*Sardinops caerulea*). Proc. World Sci. Meet. Biol. Sardines and Related Species, FAO, Rome, 2: 415-451

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

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

Barnes, J. T., L. D. Jacobson, A. D. MacCall, and P. Wolf. 1992. Recent population trends and abundance estimates of the Pacific sardine (*Sardinops sagax*). CalCOFI Rep. 33: 60-75.

Baumgartner, T., A. Soutar, and V. Ferriera-Bartrina. 1992. Reconstruction of the history of pacific sardine and northern anchovy populations over the past two millenia from sediments of the Santa Barbara Basin, California. CalCOFI Rep. 33: 24-40.

Bentley, P. J., R. L. Emmett, N. C. H. Lo and G. Moser. 1996. Egg production of Pacific sardine (*Sardinops sagax*) off Oregon in 1994. CalCOFI Rep. 37:193-200.

Bowen, B. W., and W.S. Grant. 1997. Phylogeography of the sardines (*Sardinops* spp.): Assessing biogeographic models and population histories in temperate upwelling zones. Evolution 51, 1601-1610.

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

Butler, J. L. 1987. Comparisons of the larval and juvenile growth and larval mortality rates of Pacific sardine and northern anchovy and implications for species interactions. Ph. D. Thesis, Univ. Calif., San Diego, 240 pp.

Butler, J.L., P.E. Smith, and N.C.H. Lo. 1993. The effect of natural variability of life-history parameters on anchovy and sardine population growth. CalCOFI Rep. 34: 104-111.

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

Chapman W.M. 1936. The pilchard fishery of the state of Washington in 1936 with notes on the food of the silver and chinook salmon off the Washington coast. Dept. of Fisheries, State of Washington, Biological Rept. 36. 30p.

Clark, F. N. 1939. Can the supply of sardines be maintained in California waters? Calif. Fish and Game 25: 172-176.

Clark, F. N., and J. F. Janssen. Jr. 1945. Movements and abundance of the sardine as measured by tag returns. Calif. Div. Fish Game Fish. Bull. 61: 7-42.

Clark, F. N., and J. C. Marr. 1955. Population dynamics of the Pacific sardine. CalCOFI Prog. Rep. 1 July 1953-31 March 1955: 11-48.

Conser, R. J., K. T. Hill, P. R. Crone, N. C. H. Lo, and D. Bergen. 2003. Stock assessment of Pacific sardine with management recommendations for 2004: Executive Summary. Pacific Fishery Management Council, November 2003. 15 p.

Conser, R., K. Hill, P. Crone, N. Lo, and R. Felix-Uraga. 2004. Assessment of the Pacific sardine stock for U.S. management in 2005: Pacific Fishery Management Council, November 2004. 135 p.

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

Culver, M. and C. Henry. 2004. Summary Report of the 2004 Experimental Purse Seine Fishery for Pacific Sardine (*Sardinops sagax*). Washington Department of Fish and Wildlife, Montesano, WA. 12 p. http://wdfw.wa.gov/fish/commercial/sardine/04sardine_summary.pdf

Cushing, D. H. 1971. The dependence of recruitment of parent stock on different groups of fishes. J. Cons. Int. Explor. Mer. 33: 340-362.

Deriso, R., T. J. Quinn and P. R. Neal. 1985. Catch-age analysis with auxiliary information. Can. J. Fish. Aquat. Sci. 42:4.

Deriso, R. B., J. T. Barnes, L. D. Jacobson, and P. J. Arenas. 1996. Catch-at-age analysis for Pacific sardine (*Sardinops sagax*), 1983-1995. CalCOFI Rep. 37:175-187.

Eschmeyer, W. N., E. S. Herald, and H. Hammann. 1983. A Field Guide to Pacific Coast Fishes of North America. Houghton Mifflin Company, Boston, MA. 336 p.

Félix-Uraga, R., V. M. Gómez-Muñoz, C. Quiñónez-Velázquez, F. Neri Melo-Barrera, and W. García-Franco. 2004. On the existence of Pacific sardine groups off the west coast of Baja California and Southern California. CalCOFI Rep. 45: 146-151.

Felix-Uraga, R., V. M. Gómez-Muñoz, C. Quiñónez-Velázquez, F. Neri Melo-Barrera, K. T. Hill and W. García-Franco. 2005. Pacific sardine stock discrimination off the west coast of Baja California and southern California using otolith morphometry. CalCOFI Rep. 46: 113-121.

Fournier, D. A. and C. P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 39: 1195-1207.

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

Hargreaves, N.B., D.M. Ware, and G.A. McFarlane. 1994. Return of the Pacific sardine (*Sardinops sagax*) to the British Columbia coast in 1992. Can. J. Fish. Aquat. Sci. 51: 460-463.

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

Hedgecock, D., E. S. Hutchinson, G. Li, F. L. Sly, and K. Nelson. 1989. Genetic and morphometric variation in the Pacific sardine, *Sardinops sagax caerulea*: comparisons and contrasts with historical data and with variability in the northern anchovy, *Engraulis mordax*. Fish. Bull. 87: 653-671.

Hill, K. T. 1999. Determining age composition of coastal pelagic species in northern California, Oregon, and Washington coastal waters. Pacific States Marine Fisheries Commission. Gladstone, Oregon. Project #1-IJ-9 Final Report. 47 p.

Hill, K.T., L.D. Jacobson, N.C.H. Lo, M. Yaremko, and M. Dege. 1999. Stock assessment of Pacific sardine for 1998 with management recommendations for 1999. Calif. Dept. Fish. Game. Marine Region Admin. Rep. 99-4. 92 pp.

Hill, K. T. and P. R. Crone. 2004. Stock assessment of Pacific mackerel (*Scomber japonicus*) in 2004. Pacific Fishery Management Council. Portland, Oregon.

Hill, K. T., N. C. H. Lo, B. J. Macewicz, and R. Felix-Uraga. 2005. Assessment of the Pacific sardine (Sardinops sagax caerulea) population for U.S. management in 2006. Pacific Fishery Management Council, Agenda Item D.1.a, Supplemental Attachment 1. 141 p.

Hill, K. T., N. C. H. Lo, B. J. Macewicz, and R. Felix-Uraga. 2006. Assessment of the Pacific sardine (*Sardinops sagax caerulea*) population for U.S. management in 2006. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-386. 75 p.

Jacobson, L. J. and A. D. MacCall. 1995. Stock-recruitment models for Pacific sardine (*Sardinops sagax*). Can. J. Fish. Aquat. Sci. 52:566-577.

Lasker R. 1970. Utilization of zooplankton energy by a Pacific sardine population in the California Current, p. 265-284. *In*: J.H. Steele (ed.). Marine Food Chains. Oliver and Boyd Ltd., Edinburgh.

Leet, W. S., C. M. Dewees, R. Klingbeil, and E. J. Larson (Eds.). 2001. California's Living Marine Resources: A Status Report. Calif. Dep. Fish and Game. ANR Publication #SG01-11.

Legault, C. M., and V. R. Restrepo. 1999. A flexible forward age-structured assessment program. ICCAT Coll. Vol. Sci. Pap. 49(2): 246-253.

Lluch-Belda, D., D.B. Lluch-Cota, S. Hernandez-Vazquea, C.A. Salina-Zavala. 1991. Sardine and anchovy spawning as related to temperature and upwelling in the California Current system. CalCOFI Rep. 32: 105-111.

Lo, N. C. H., L. D. Jacobson and J. L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49:2515-2526. http://lajolla.noaa.gov/om/library/publications/CR/1992/9264.pdf

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

Lo, N. C. H., B. J. Macewicz, and D. A. Griffith. 2005. Spawning biomass of Pacific sardine (*Sardinops sagax*) from 1994-2004 off California. CalCOFI Rep. 46: 93-112.

Lo, N. C. H. and B. J. Macewicz. 2006. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2005. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-387. 29 p.

MacCall, A. D. 1979. Population estimates for the waning years of the Pacific sardine fishery. CalCOFI Rep. 20: 72-82.

MacCall, A. D. 1990. Dynamic Geography of Marine Fish Populations. University of Washington Press. 153 p.

Macewicz, B. J. and D. N. Abramenkoff. 1993. Collection of jack mackerel, *Trachurus symmetricus*, off southern California during 1991 cooperative U.S.-U.S.S.R. cruise. Southwest Fisheries Science Center, National Marine Fisheries Service, Admin. Rep. LJ-93-07. 13 p.

Macewicz B. J, J. J. Castro-Gonzalez, C. E. Cotero Altamirano, and J. R. Hunter. 1996. Adult reproductive parameters of Pacific Sardine (*Sardinops sagax*) during 1994 CalCOFI Rep 37:140-151.

Mangel, M., and P. E. Smith. 1990. Presence-absence sampling for fisheries management. Can. J. Fisheries Aquat. Sci. 47(10):1875-1887.

McCrae, J. 2001. Oregon's Sardine Fishery, 2000. Newport, OR: Oregon Department of Fish and Wildlife. 12pp. http://www.dfw.state.or.us/MRP/publications/sardine_1.pdf

McCrae, J. 2002. Oregon's Sardine Fishery, 2001. Newport, OR: Oregon Department of Fish and Wildlife. 15pp. http://www.dfw.state.or.us/MRP/publications/sardine_2.pdf

McCrae, J. 2003. Oregon's Sardine Fishery, 2002. Newport, OR: Oregon Department of Fish and Wildlife. 13pp. http://www.dfw.state.or.us/MRP/publications/sardine_3.pdf

McCrae, J. 2004. Oregon's Sardine Fishery, 2003. Newport, OR: Oregon Department of Fish and Wildlife. 12pp. http://www.dfw.state.or.us/MRP/publications/sardine_4.pdf

McCrae, J. and J. Smith. 2005. Oregon's Sardine Fishery, 2004. Newport, OR: Oregon Department of Fish and Wildlife. 14pp. http://www.dfw.state.or.us/MRP/publications/sardine_5.pdf

Murphy, G. I. 1966. Population biology of the Pacific sardine (*Sardinops caerulea*). Proc. Calif. Acad. Sci. Vol. 34 (1): 1-84.

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

Parrish, R. H., R. Serra, and W. S. Grant. 1989. The monotypic sardines, *Sardina* and *Sardinops*: their taxonomy, distribution, stock structure and zoogeography. Can. J. Fish. Aquat. Sci. 46: 2019-2036.

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

PFMC 1998. Amendment 8 (to the northern anchovy fishery management plan) incorporating a name change to: the coastal pelagic species fishery management plan. Pacific Fishery Management Council, Portland, OR.

PFMC 2004. Pacific sardine STAR panel meeting report. Pacific Fishery Management Council Briefing Book, Agendum I.2.b, September 2004. 12 p.

PFMC 2006. Status of the Pacific Coast Coastal Pelagic Species Fishery and Recommended Acceptable Biological Catches. Stock Assessment and Fishery Evaluation – 2006. Pacific Fishery Management Council, Portland, OR. http://www.pcouncil.org/cps/cpssafe/0606safe.html

Phillips, J. B. 1948. Growth of the sardine, *Sardinops caerulea*, 1941-42 through 1946-47. Calif. Div. Fish Game Fish Bull. 71: 33 p.

Radovich, J. 1982. The collapse of the California sardine fishery: what have we learned? CalCOFI Rep. 23: 56-78.

Robinson, M. 2003. Summary Report of the 2003 Trial Purse Seine Fishery for Pacific Sardine (*Sardinops sagax*). Washington Department of Fish and Wildlife, Montesano, WA. http://wdfw.wa.gov/fish/commercial/sardine/03sardine_summary.pdf

Smith, P. E. 1978. Biological effects of ocean variability: time inferred from fish scales in anaerobic sediments off California. CalCOFI Rep. 13: 63-70.

Soutar, A. and J. D. Isaacs. 1969. History of fish populations inferred from fish scales in anaerobic sediments off California. CalCOFI Rep. 13: 63-70.

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

Vrooman, A. M. 1964. Serologically differentiated subpopulations of the Pacific sardine, *Sardinops caerulea*. J. Fish. Res. Bd. Canada, 21: 691-701.

Walford, L. A. and K. H. Mosher. 1943. Studies on the Pacific pilchard or sardine (*Sardinops caerulea*). U.S. Dep. of Interior, Fish and Wildlife Service, Special Sci. Rep. No. 20. 33 p.

WDFW. 2001. Summary Report of the 2001 Trial Purse Seine Fishery for Pacific Sardine (*Sardinops sagax*). Washington Department of Fish and Wildlife, Montesano, WA. http://wdfw.wa.gov/fish/commercial/sardine/01sardine_summary.pdf.

WDFW. 2002. Summary Report of the 2002 Trial Purse Seine Fishery for Pacific Sardine (*Sardinops sagax*). Washington Department of Fish and Wildlife, Montesano, WA. http://wdfw.wa.gov/fish/commercial/sardine/02sardine_summary.pdf

WDFW. 2005. 2005 Washington Experimental Sardine Fishery Summary. http://wdfw.wa.gov/fish/commercial/sardine/sardine_creel05.htm

Wolf, P. and P. E. Smith. 1986. The relative magnitude of the 1985 Pacific sardine spawning biomass off southern California. CalCOFI Rep. 27: 25-31.

Wolf. P., P. E. Smith, and C. L. Scannell. 1987. The relative magnitude of the 1986 Pacific sardine spawning biomass off California. CalCOFI Rep. 28: 21-26.

Wolf, P. 1988a. Status of the spawning biomass of Pacific sardine, 1987-1988. Calif. Dep. Fish Game, Mar. Res. Div., Rep. to the Legislature, 9 p.

Wolf, P. 1988b. Status of the spawning biomass of Pacific sardine, 1988-1989. Calif. Dep. Fish Game, Mar. Res. Div., Rep. to the Legislature, 8 p.

Yaremko, M. L. 1996. Age determination in Pacific sardine, *Sardinops sagax*. NOAA Tech. Mem. NOAA-TM-NMFS-SWFSC-223. 33 p.

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 sample sizes (number of fish) for production of fishery catch-at-age.

| | ------- CALIFORNIA ------- | | | ------- ENSENADA ------- | | | -- PACIFIC NORTHWEST -- | | |
|---|---|---|---|---|---|---|---|---|---|
| Biological Year | Landings (mt) | # Fish Sampled | Fish per 1,000 mt | Landings (mt) | # Fish Sampled | Fish per 1,000 mt | Landings (mt) | # Fish Sampled | 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 | 4,305 | 77 | 75,179 | 485 | 6 | 28 | 0 | 0 |
| 1998-99 | 51,005 | 4,463 | 88 | 62,333 | 537 | 9 | 563 | 31 | 55 |
| 1999-00 | 60,360 | 2,672 | 44 | 57,743 | 553 | 10 | 1,155 | 178 | 154 |
| 2000-01 | 52,916 | 3,196 | 60 | 50,457 | 512 | 10 | 17,923 | 2,006 | 112 |
| 2001-02 | 52,981 | 4,283 | 81 | 46,948 | 362 | 8 | 25,683 | 2,581 | 100 |
| 2002-03 | 60,714 | 3,216 | 53 | 44,938 | 55 | 1 | 36,123 | 2,834 | 78 |
| 2003-04 | 29,650 | 3,572 | 120 | 37,040 | 0 | 0 | 39,860 | 2,488 | 62 |
| 2004-05 | 45,858 | 4,057 | 88 | 47,379 | 0 | 0 | 47,747 | 1,870 | 39 |
| 2005-06 | 41,812 | 4,823 | 115 | 56,684 | 0 | 0 | 54,356 | 1,151 | 21 |

Table 3. Pacific sardine catch-at-age (thousands of fish) and landings (metric tons) for the California fishery (Fishery 1), 1982-83 to 2006-07 seasons (July-June). Landings were projected for 2006-07.

| Biological | -------------- Catch-at-age (thousands) --------------- | | | | | | Landings |
|---|---|---|---|---|---|---|---|
| Year | 0 | 1 | 2 | 3 | 4 | 5+ | (mt) |
| 1982-83 | 0 | 880 | 1,261 | 261 | 56 | 8 | 337.2 |
| 1983-84 | 398 | 740 | 1,135 | 78 | 3 | 0 | 248.2 |
| 1984-85 | 17 | 804 | 1,611 | 282 | 0 | 0 | 397.0 |
| 1985-86 | 19 | 2,273 | 4,907 | 715 | 40 | 0 | 1,191.1 |
| 1986-87 | 185 | 1,167 | 5,924 | 2,305 | 175 | 26 | 1,548.2 |
| 1987-88 | 38 | 14,431 | 9,912 | 3,757 | 676 | 58 | 3,810.3 |
| 1988-89 | 356 | 4,999 | 11,193 | 2,602 | 786 | 109 | 2,919.0 |
| 1989-90 | 188 | 15,741 | 9,135 | 1,533 | 91 | 0 | 3,658.8 |
| 1990-91 | 1,350 | 9,506 | 14,557 | 10,456 | 5,050 | 2,919 | 5,855.6 |
| 1991-92 | 7,452 | 21,252 | 28,460 | 12,301 | 5,303 | 5,714 | 9,574.2 |
| 1992-93 | 33,463 | 147,999 | 98,106 | 22,749 | 5,997 | 3,354 | 24,319.9 |
| 1993-94 | 26,760 | 41,603 | 50,290 | 30,094 | 5,058 | 2,043 | 12,431.2 |
| 1994-95 | 206,712 | 236,588 | 64,598 | 29,723 | 4,091 | 868 | 32,902.4 |
| 1995-96 | 84,888 | 240,038 | 132,467 | 12,176 | 1,793 | 122 | 29,819.7 |
| 1996-97 | 89,636 | 96,347 | 136,744 | 57,311 | 7,157 | 2,119 | 29,026.8 |
| 1997-98 | 49,163 | 325,948 | 218,952 | 97,980 | 31,395 | 5,755 | 56,172.3 |
| 1998-99 | 219,059 | 601,996 | 183,576 | 25,483 | 14,214 | 1,990 | 51,005.2 |
| 1999-00 | 209,576 | 729,802 | 252,953 | 13,953 | 5,931 | 1,325 | 60,360.5 |
| 2000-01 | 173,501 | 260,540 | 283,685 | 157,218 | 12,562 | 1,851 | 52,915.6 |
| 2001-02 | 525,651 | 184,094 | 148,101 | 105,555 | 20,576 | 6,988 | 52,980.7 |
| 2002-03 | 126,574 | 568,045 | 156,788 | 31,379 | 10,102 | 2,505 | 60,713.6 |
| 2003-04 | 403,850 | 79,132 | 93,183 | 20,685 | 8,140 | 4,558 | 29,649.7 |
| 2004-05 | 28,510 | 733,750 | 88,935 | 12,513 | 2,853 | 893 | 45,858.4 |
| 2005-06 | 322,969 | 345,966 | 244,257 | 14,913 | 2,013 | 2,214 | 41,811.6 |
| 2006-07 | 0 | 0 | 0 | 0 | 0 | 0 | *41,811.6* |

Table 4. Pacific sardine catch-at-age (thousands of fish) and landings (metric tons) for the segment of the Mexican fishery that lands its product in Ensenada, Baja California (Fishery 2), 1982-83 to 2006-07 seasons (July-June). Landings were projected for 2006-07.

| Biological | ------------------- Catch-at-age (thousands) --------------------- | | | | | | Landings |
|---|---|---|---|---|---|---|---|
| Year | 0 | 1 | 2 | 3 | 4 | 5+ | (mt) |
| 1982-83 | 0 | 0 | 0 | 0 | 0 | 0 | 149.5 |
| 1983-84 | 0 | 0 | 0 | 0 | 0 | 0 | 124.1 |
| 1984-85 | 0 | 0 | 0 | 0 | 0 | 0 | 3,174.2 |
| 1985-86 | 0 | 0 | 0 | 0 | 0 | 0 | 647.3 |
| 1986-87 | 0 | 0 | 0 | 0 | 0 | 0 | 1,118.4 |
| 1987-88 | 0 | 0 | 0 | 0 | 0 | 0 | 2,076.8 |
| 1988-89 | 0 | 0 | 0 | 0 | 0 | 0 | 1,875.7 |
| 1989-90 | 30,029 | 35,488 | 15,431 | 4,272 | 1,887 | 66 | 11,663.2 |
| 1990-91 | 26,364 | 41,035 | 34,641 | 8,016 | 1,643 | 1,440 | 14,746.3 |
| 1991-92 | 20,559 | 68,135 | 50,263 | 41,932 | 18,599 | 8,898 | 25,447.3 |
| 1992-93 | 236,304 | 512,739 | 53,762 | 395 | 263 | 0 | 49,889.8 |
| 1993-94 | 103,939 | 69,104 | 120,215 | 8,697 | 0 | 0 | 19,108.4 |
| 1994-95 | 262,031 | 174,392 | 55,347 | 42,693 | 5,253 | 0 | 33,392.7 |
| 1995-96 | 191,289 | 144,459 | 85,039 | 17,658 | 5,799 | 0 | 32,834.8 |
| 1996-97 | 39,883 | 112,217 | 132,568 | 46,846 | 23,194 | 2,034 | 36,897.2 |
| 1997-98 | 44,799 | 157,950 | 266,468 | 184,200 | 79,962 | 23,397 | 75,179.4 |
| 1998-99 | 267,923 | 285,025 | 154,083 | 102,702 | 64,506 | 13,703 | 62,333.2 |
| 1999-00 | 393,256 | 288,886 | 164,243 | 81,932 | 31,978 | 13,576 | 57,743.0 |
| 2000-01 | 143,737 | 290,687 | 88,381 | 33,814 | 8,185 | 1,593 | 50,456.8 |
| 2001-02 | 221,428 | 236,772 | 145,254 | 14,659 | 1,715 | 0 | 46,948.1 |
| 2002-03 | 0 | 0 | 0 | 0 | 0 | 0 | 44,937.9 |
| 2003-04 | 0 | 0 | 0 | 0 | 0 | 0 | 37,040.3 |
| 2004-05 | 0 | 0 | 0 | 0 | 0 | 0 | 47,379.4 |
| 2005-06 | 0 | 0 | 0 | 0 | 0 | 0 | 56,684.0 |
| 2006-07 | 0 | 0 | 0 | 0 | 0 | 0 | *56,684.0* |

Table 5. Pacific sardine catch-at-age (thousands of fish) and landings (metric tons) for the fisheries off Oregon, Washington, and British Columbia, Canada (Fishery 3), 1982-83 to 2006-07 seasons (July-June). Landings for 2006-07 were projected to be two-thirds of the 2005-06 value.

| Biological | -------------- Catch-at-age (thousands) --------------- | | | | | | Landings |
|---|---|---|---|---|---|---|---|
| Year | 0 | 1 | 2 | 3 | 4 | 5+ | (mt) |
| 1982-83 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 1983-84 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 1984-85 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 1985-86 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 1986-87 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 1987-88 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 1988-89 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 1989-90 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 1990-91 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 1991-92 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 1992-93 | 0 | 0 | 0 | 0 | 0 | 0 | 4.1 |
| 1993-94 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 1994-95 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 1995-96 | 0 | 0 | 0 | 0 | 0 | 0 | 22.7 |
| 1996-97 | 0 | 0 | 0 | 0 | 0 | 0 | 43.5 |
| 1997-98 | 0 | 0 | 0 | 0 | 0 | 0 | 28.0 |
| 1998-99 | 0 | 0 | 0 | 0 | 0 | 0 | 562.8 |
| 1999-00 | 0 | 0 | 3,791 | 1,937 | 1,040 | 2,262 | 1,154.6 |
| 2000-01 | 0 | 1,814 | 45,205 | 48,656 | 19,198 | 13,823 | 17,923.0 |
| 2001-02 | 178 | 3,499 | 21,320 | 70,724 | 44,439 | 26,569 | 25,682.9 |
| 2002-03 | 0 | 1,726 | 6,647 | 28,202 | 73,487 | 87,564 | 36,123.0 |
| 2003-04 | 0 | 4,538 | 38,538 | 37,039 | 25,874 | 129,242 | 39,860.2 |
| 2004-05 | 0 | 141,327 | 58,285 | 45,783 | 26,510 | 93,795 | 47,747.1 |
| 2005-06 | 0 | 8,925 | 230,672 | 69,493 | 33,543 | 116,754 | 54,356.1 |
| 2006-07 | 0 | 0 | 0 | 0 | 0 | 0 | *35,331.0* |

Table 6. Pacific sardine fishery weight-at-age (kg) for the 1982-83 to 2006-07 seasons (July-June). Values are weighted averages based on landings of the three respective fisheries.

| Biological | --------- Fishery Weight-at-age (kg) ----------- | | | | | |
|---|---|---|---|---|---|---|
| Year | 0 | 1 | 2 | 3 | 4 | 5+ |
| 1982-83 | 0.069 | 0.118 | 0.128 | 0.155 | 0.184 | 0.187 |
| 1983-84 | 0.069 | 0.087 | 0.138 | 0.154 | 0.167 | 0.187 |
| 1984-85 | 0.083 | 0.108 | 0.135 | 0.148 | 0.164 | 0.160 |
| 1985-86 | 0.074 | 0.117 | 0.148 | 0.170 | 0.185 | 0.186 |
| 1986-87 | 0.054 | 0.111 | 0.150 | 0.164 | 0.184 | 0.172 |
| 1987-88 | 0.087 | 0.107 | 0.142 | 0.169 | 0.183 | 0.187 |
| 1988-89 | 0.069 | 0.101 | 0.148 | 0.169 | 0.185 | 0.195 |
| 1989-90 | 0.109 | 0.130 | 0.153 | 0.161 | 0.170 | 0.165 |
| 1990-91 | 0.082 | 0.122 | 0.143 | 0.152 | 0.155 | 0.159 |
| 1991-92 | 0.059 | 0.097 | 0.132 | 0.146 | 0.157 | 0.169 |
| 1992-93 | 0.054 | 0.062 | 0.095 | 0.123 | 0.161 | 0.146 |
| 1993-94 | 0.047 | 0.070 | 0.079 | 0.082 | 0.131 | 0.146 |
| 1994-95 | 0.050 | 0.062 | 0.087 | 0.095 | 0.102 | 0.115 |
| 1995-96 | 0.057 | 0.069 | 0.079 | 0.096 | 0.111 | 0.116 |
| 1996-97 | 0.063 | 0.077 | 0.107 | 0.114 | 0.121 | 0.122 |
| 1997-98 | 0.049 | 0.073 | 0.094 | 0.114 | 0.118 | 0.118 |
| 1998-99 | 0.042 | 0.056 | 0.078 | 0.103 | 0.104 | 0.115 |
| 1999-00 | 0.051 | 0.056 | 0.063 | 0.065 | 0.071 | 0.093 |
| 2000-01 | 0.057 | 0.078 | 0.089 | 0.096 | 0.106 | 0.126 |
| 2001-02 | 0.042 | 0.070 | 0.101 | 0.114 | 0.132 | 0.145 |
| 2002-03 | 0.054 | 0.084 | 0.100 | 0.113 | 0.128 | 0.145 |
| 2003-04 | 0.046 | 0.088 | 0.101 | 0.113 | 0.136 | 0.150 |
| 2004-05 | 0.048 | 0.065 | 0.089 | 0.114 | 0.130 | 0.155 |
| 2005-06 | 0.046 | 0.067 | 0.080 | 0.088 | 0.110 | 0.150 |
| 2006-07 | 0.046 | 0.067 | 0.080 | 0.088 | 0.110 | 0.150 |

Table 7. Pacific sardine population weight-at-age (kg) used to calculate the total stock biomass (Ages 1+) for management, and population SSB as presented in Table 15.

| Biological | --- Population Weight-at-age (kg) --- | | | | |
|---|---|---|---|---|---|
| Year | 1 | 2 | 3 | 4 | 5+ |
| 1982-83 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1983-84 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1984-85 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1985-86 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1986-87 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1987-88 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1988-89 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1989-90 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1990-91 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1991-92 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1992-93 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1993-94 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1994-95 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1995-96 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1996-97 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1997-98 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1998-99 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 1999-00 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 2000-01 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 2001-02 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 2002-03 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 2003-04 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 2004-05 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 2005-06 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |
| 2006-07 | 0.103 | 0.147 | 0.168 | 0.172 | 0.179 |

Table 8. Pacific sardine time series of survey indices of relative abundance and sea-surface temperature, 1982-2006. The SST is a moving average of monthly SST observations for the three-year period prior to July 1st of the given year.

| Biological | DEPM (SSB) | | Aerial Spotter (pre-adult) | | SST at SIO Pier |
|---|---|---|---|---|---|
| Year | Estimate (mt) | CV | Estimate (mt) | CV | (°C) |
| 1982-83 | --- | | --- | --- | 17.05 |
| 1983-84 | --- | | --- | --- | 17.25 |
| 1984-85 | --- | | --- | --- | 17.58 |
| 1985-86 | 7,659 | --- | 19,301 | 0.34 | 17.80 |
| 1986-87 | 15,704 | --- | 10,177 | 0.32 | 17.87 |
| 1987-88 | 13,526 | --- | 16,807 | 0.22 | 17.71 |
| 1988-89 | --- | | 9,880 | 0.27 | 17.55 |
| 1989-90 | --- | | 3,999 | 0.23 | 17.24 |
| 1990-91 | --- | | 19,781 | 0.15 | 17.19 |
| 1991-92 | --- | | 20,384 | 0.14 | 17.35 |
| 1992-93 | --- | | 107,743 | 0.14 | 17.61 |
| 1993-94 | 127,102 | 0.32 | 150,630 | 0.10 | 17.84 |
| 1994-95 | 79,997 | 0.60 | 70,240 | 0.12 | 17.97 |
| 1995-96 | 83,176 | 0.48 | 23,079 | 0.12 | 18.04 |
| 1996-97 | 409,579 | 0.31 | 30,414 | 0.18 | 18.07 |
| 1997-98 | 313,986 | 0.41 | 59,407 | 0.15 | 18.08 |
| 1998-99 | 282,248 | 0.42 | 22,651 | 0.15 | 18.47 |
| 1999-00 | 1,063,837 | 0.67 | 7,454 | 0.17 | 18.08 |
| 2000-01 | 790,925 | 0.45 | 739 | 0.44 | 17.75 |
| 2001-02 | 206,333 | 0.35 | 43,543 | 0.38 | 17.24 |
| 2002-03 | 485,121 | 0.36 | 12,082 | 0.42 | 17.31 |
| 2003-04 | 281,639 | 0.30 | 17,959 | 0.75 | 17.46 |
| 2004-05 | 619,320 | 0.54 | 2,005 | 1.03 | 17.60 |
| 2005-06 | 1,081,612 | 0.47 | --- | --- | 18.03 |
| 2006-07 | --- | | --- | --- | 18.11 |

Table 9. Selectivities applied to survey data in the ASAP model.

| | Age | | | | | |
|---|---|---|---|---|---|---|
| **Survey** | 0 | 1 | 2 | 3 | 4 | 5+ |
| DEPM | | | | | | |
| 1982-2006 | 0.30 | 0.53 | 0.91 | 0.97 | 0.99 | 1.00 |
| Aerial Spotter | | | | | | |
| 1982-2005 | 1.00 | 1.00 | 0.59 | 0.18 | 0.03 | 0.00 |

Table 10. Total number of flights by year, flights with sightings by year, and proportion of positive flights by year, for calendar years 1985 to 2005. A = Flights, B = Flights with Sightings, C = Proportion of Positive Flights.

| Year | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 783 | 692 | 591 | 595 | 599 | 849 | 541 | 432 | 586 | 609 | 692 | 513 | 553 | 514 | 429 | 340 | 31 | 107 | 13 | 44 | 22 |
| B | 115 | 123 | 206 | 239 | 165 | 261 | 294 | 228 | 306 | 339 | 312 | 166 | 187 | 174 | 151 | 72 | 9 | 21 | 3 | 39 | 20 |
| C | 0.17 | 0.22 | 0.31 | 0.31 | 0.22 | 0.36 | 0.54 | 0.43 | 0.5 | 0.6 | 0.55 | 0.45 | 0.41 | 0.45 | 0.45 | 0.3 | 0.35 | 0.23 | 0.23 | 0.85 | 0.92 |

Table 11. Number of positive flights, day versus night, for calendar years 1985 to 2005.

| Year | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Day | 20 | 64 | 64 | 85 | 107 | 62 | 140 | 136 | 152 | 203 | 125 | 141 | 54 | 105 | 86 | 96 | 1 | 54 | 9 | 21 | 3 |
| Night | 0 | 51 | 59 | 121 | 132 | 103 | 121 | 158 | 76 | 103 | 214 | 171 | 112 | 82 | 88 | 55 | 2 | 18 | 0 | 0 | 0 |
| Unkwn | 0 | 3 | 4 | 1 | 3 | 4 | 8 | 6 | 6 | 4 | 4 | 4 | 0 | 3 | 3 | 4 | 3 | 0 | 0 | 0 | 0 |

Table 12. Likelihood components for the baseline model in which 140 parameters were estimated. See text for definitions of fleet (fishery) numbers and index numbers.

| **Component** | **RSS** | **nobs** | **Lambda** | **Likelihood** | **% of Total** |
|---|---|---|---|---|---|
| Catch_Fleet_1 | 0.0020 | 25 | 100 | 0.1995 | |
| Catch_Fleet_2 | 0.0054 | 25 | 100 | 0.5390 | |
| Catch_Fleet_3 | 0.1224 | 25 | 100 | 12.2400 | |
| **Catch_Fleet_Total** | **0.1298** | 75 | 100 | **12.9784** | **2%** |
| Discard_Fleet_1 | 0.0000 | 25 | 0 | 0.0000 | |
| Discard_Fleet_2 | 0.0000 | 25 | 0 | 0.0000 | |
| Discard_Fleet_3 | 0.0000 | 25 | 0 | 0.0000 | |
| Discard_Fleet_Total | 0.0000 | 75 | 0 | 0.0000 | |
| **CAA_proportions** | --- | 450 | --- | **215.2380** | **39%** |
| Discard_proportions | --- | 450 | --- | 0.0000 | |
| Index_Fit_1 | 13.2986 | 16 | 1 | 67.3526 | |
| Index_Fit_2 | 37.7115 | 20 | 1 | 132.6520 | |
| **Index_Fit_Total** | **51.0101** | 36 | 2 | **200.0050** | **37%** |
| Selectivity_devs_fleet_1 | 15.5946 | 1 | 0 | 0.0000 | |
| Selectivity_devs_fleet_2 | 0.0000 | 1 | 0 | 0.0000 | |
| Selectivity_devs_fleet_3 | 0.0000 | 1 | 0 | 0.0000 | |
| **Selectivity_devs_Total** | **15.5946** | 3 | 0 | **0.0000** | **0%** |
| Catchability_devs_index_1 | 0.0000 | 16 | 10 | 0.0000 | |
| Catchability_devs_index_2 | 0.0000 | 20 | 10 | 0.0000 | |
| **Catchability_devs_Total** | **0.0000** | 36 | 20 | **0.0000** | **0%** |
| Fmult_fleet_1 | 6.6400 | 24 | 1 | 6.6400 | |
| Fmult_fleet_2 | 15.3860 | 24 | 1 | 15.3860 | |
| Fmult_fleet_3 | 53.9198 | 24 | 1 | 53.9198 | |
| **Fmult_fleet_Total** | **75.9458** | 72 | 3 | **75.9458** | **14%** |
| N_year_1 | 0.0000 | 5 | 0 | 0.0000 | |
| **Stock-Recruit_Fit** | **15.3656** | 25 | 1 | **27.5839** | **5%** |
| **Recruit_devs** | **15.3656** | 25 | 1 | **15.3656** | **3%** |
| SRR_steepness | 0.0001 | 1 | 0 | 0.0000 | |
| SRR_virgin_stock | 0.1580 | 1 | 0 | 0.0000 | |
| Curvature_over_age | 19.7258 | 12 | 0 | 0.0000 | |
| Curvature_over_time | 31.1892 | 414 | 0 | 0.0000 | |
| F_penalty | 2.1666 | 150 | 0.001 | 0.0022 | |
| Mean_Sel_year1_pen | 0.0000 | 18 | 1000 | 0.0000 | |
| Max_Sel_penalty | 2.3543 | 1 | 100 | 0.0000 | |
| Fmult_Max_penalty | 0.0000 | -- | 100 | 0.0000 | |
| **TOTAL** | **229.0055** | **1849** | | **547.1189** | **100%** |

Table 13. ASAP parameter estimates and standard deviations for the baseline model. The first 140 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 | Biol. Year | Fishery | Param # | Parameter | Estimate | Std. Dev. |
|---|---|---|---|---|---|---|
| 1 | 1982 | 1 | 1 | log_sel_year1 | -5.301E+00 | 1.426E+02 |
| 2 | 1982 | 1 | 2 | log_sel_year1 | -1.781E+00 | 1.426E+02 |
| 3 | 1982 | 1 | 3 | log_sel_year1 | -3.682E-01 | 1.426E+02 |
| 4 | 1982 | 1 | 4 | log_sel_year1 | -7.867E-01 | 1.426E+02 |
| 5 | 1982 | 1 | 5 | log_sel_year1 | -1.551E+00 | 1.426E+02 |
| 6 | 1982 | 1 | 6 | log_sel_year1 | -2.154E+00 | 1.426E+02 |
| 1 | 1982 | 2 | 7 | log_sel_year1 | -2.644E+00 | 2.444E+02 |
| 2 | 1982 | 2 | 8 | log_sel_year1 | -1.846E+00 | 2.444E+02 |
| 3 | 1982 | 2 | 9 | log_sel_year1 | -1.710E+00 | 2.444E+02 |
| 4 | 1982 | 2 | 10 | log_sel_year1 | -2.078E+00 | 2.444E+02 |
| 5 | 1982 | 2 | 11 | log_sel_year1 | -2.429E+00 | 2.444E+02 |
| 6 | 1982 | 2 | 12 | log_sel_year1 | -4.031E+00 | 2.444E+02 |
| 1 | 1982 | 3 | 13 | log_sel_year1 | -6.000E+00 | 2.008E-02 |
| 2 | 1982 | 3 | 14 | log_sel_year1 | -2.032E+00 | 1.482E+00 |
| 3 | 1982 | 3 | 15 | log_sel_year1 | -9.006E-02 | 1.437E+00 |
| 4 | 1982 | 3 | 16 | log_sel_year1 | 4.889E-01 | 1.442E+00 |
| 5 | 1982 | 3 | 17 | log_sel_year1 | 8.563E-01 | 1.454E+00 |
| 6 | 1982 | 3 | 18 | log_sel_year1 | 5.431E-01 | 1.454E+00 |
| 1 | 1982 | 1 | 19 | log_sel_devs_vector | 3.619E+00 | 7.829E-01 |
| 2 | 1982 | 1 | 20 | log_sel_devs_vector | 1.250E+00 | 7.278E-01 |
| 3 | 1982 | 1 | 21 | log_sel_devs_vector | -1.527E-01 | 7.235E-01 |
| 4 | 1982 | 1 | 22 | log_sel_devs_vector | -1.528E-01 | 7.392E-01 |
| 5 | 1982 | 1 | 23 | log_sel_devs_vector | -3.406E-01 | 8.236E-01 |
| 6 | 1982 | 1 | 24 | log_sel_devs_vector | -8.764E-01 | 9.683E-01 |
| 1 | 1982 | 2 | 25 | log_sel_devs_vector | 0.000E+00 | 5.810E+03 |
| 2 | 1982 | 2 | 26 | log_sel_devs_vector | 0.000E+00 | 5.810E+03 |
| 3 | 1982 | 2 | 27 | log_sel_devs_vector | 0.000E+00 | 5.810E+03 |
| 4 | 1982 | 2 | 28 | log_sel_devs_vector | 0.000E+00 | 5.810E+03 |
| 5 | 1982 | 2 | 29 | log_sel_devs_vector | 0.000E+00 | 5.810E+03 |
| 6 | 1982 | 2 | 30 | log_sel_devs_vector | 0.000E+00 | 5.810E+03 |
| 1 | 1982 | 3 | 31 | log_sel_devs_vector | 0.000E+00 | 5.810E+03 |
| 2 | 1982 | 3 | 32 | log_sel_devs_vector | 0.000E+00 | 5.810E+03 |
| 3 | 1982 | 3 | 33 | log_sel_devs_vector | 0.000E+00 | 5.810E+03 |
| 4 | 1982 | 3 | 34 | log_sel_devs_vector | 0.000E+00 | 5.810E+03 |
| 5 | 1982 | 3 | 35 | log_sel_devs_vector | 0.000E+00 | 5.810E+03 |
| 6 | 1982 | 3 | 36 | log_sel_devs_vector | 0.000E+00 | 5.810E+03 |
| --- | 1982 | 1 | 37 | log_Fmult_year1 | -1.376E+00 | 1.426E+02 |
| --- | 1982 | 2 | 38 | log_Fmult_year1 | -2.108E+00 | 2.444E+02 |
| --- | 1982 | 3 | 39 | log_Fmult_year1 | -1.500E+01 | 9.710E-03 |
| --- | 1983 | 1 | 40 | log_Fmult_devs | -9.874E-01 | 1.433E-01 |
| --- | 1984 | 1 | 41 | log_Fmult_devs | -7.882E-01 | 1.314E-01 |
| --- | 1985 | 1 | 42 | log_Fmult_devs | 3.626E-01 | 1.312E-01 |

cont'd next page…

Table 13 (cont'd). ASAP parameter estimates and standard deviations for the baseline model.

| Coded Age | Biol. Year | Fishery | Param # | Parameter | Estimate | Std. Dev. |
|---|---|---|---|---|---|---|
| --- | 1986 | 1 | 43 | log_Fmult_devs | -1.151E-01 | 1.309E-01 |
| --- | 1987 | 1 | 44 | log_Fmult_devs | 5.253E-01 | 1.352E-01 |
| --- | 1988 | 1 | 45 | log_Fmult_devs | -8.129E-01 | 1.255E-01 |
| --- | 1989 | 1 | 46 | log_Fmult_devs | -1.897E-01 | 1.271E-01 |
| --- | 1990 | 1 | 47 | log_Fmult_devs | 1.803E-01 | 1.180E-01 |
| --- | 1991 | 1 | 48 | log_Fmult_devs | 5.150E-08 | 7.071E-01 |
| --- | 1992 | 1 | 49 | log_Fmult_devs | 1.039E+00 | 1.091E-01 |
| --- | 1993 | 1 | 50 | log_Fmult_devs | -7.139E-01 | 1.097E-01 |
| --- | 1994 | 1 | 51 | log_Fmult_devs | 6.319E-01 | 1.107E-01 |
| --- | 1995 | 1 | 52 | log_Fmult_devs | -3.576E-01 | 1.074E-01 |
| --- | 1996 | 1 | 53 | log_Fmult_devs | -1.974E-01 | 1.053E-01 |
| --- | 1997 | 1 | 54 | log_Fmult_devs | 8.613E-01 | 1.072E-01 |
| --- | 1998 | 1 | 55 | log_Fmult_devs | 2.006E-01 | 1.074E-01 |
| --- | 1999 | 1 | 56 | log_Fmult_devs | 3.434E-01 | 1.109E-01 |
| --- | 2000 | 1 | 57 | log_Fmult_devs | -2.504E-01 | 1.059E-01 |
| --- | 2001 | 1 | 58 | log_Fmult_devs | 8.888E-02 | 1.078E-01 |
| --- | 2002 | 1 | 59 | log_Fmult_devs | -4.093E-02 | 1.194E-01 |
| --- | 2003 | 1 | 60 | log_Fmult_devs | -8.180E-01 | 1.191E-01 |
| --- | 2004 | 1 | 61 | log_Fmult_devs | 2.013E-01 | 1.242E-01 |
| --- | 2005 | 1 | 62 | log_Fmult_devs | 6.727E-02 | 1.148E-01 |
| --- | 2006 | 1 | 63 | log_Fmult_devs | 2.296E-01 | 1.134E-01 |
| --- | 1983 | 2 | 64 | log_Fmult_devs | -1.024E+00 | 1.292E-01 |
| --- | 1984 | 2 | 65 | log_Fmult_devs | 2.327E+00 | 1.195E-01 |
| --- | 1985 | 2 | 66 | log_Fmult_devs | -1.969E+00 | 1.115E-01 |
| --- | 1986 | 2 | 67 | log_Fmult_devs | 1.682E-01 | 1.161E-01 |
| --- | 1987 | 2 | 68 | log_Fmult_devs | 6.449E-02 | 1.195E-01 |
| --- | 1988 | 2 | 69 | log_Fmult_devs | -4.435E-01 | 1.085E-01 |
| --- | 1989 | 2 | 70 | log_Fmult_devs | 1.265E+00 | 1.119E-01 |
| --- | 1990 | 2 | 71 | log_Fmult_devs | 1.473E-01 | 1.067E-01 |
| --- | 1991 | 2 | 72 | log_Fmult_devs | 4.978E-01 | 1.077E-01 |
| --- | 1992 | 2 | 73 | log_Fmult_devs | 7.833E-01 | 1.070E-01 |
| --- | 1993 | 2 | 74 | log_Fmult_devs | -1.013E+00 | 1.075E-01 |
| --- | 1994 | 2 | 75 | log_Fmult_devs | 2.359E-01 | 1.087E-01 |
| --- | 1995 | 2 | 76 | log_Fmult_devs | -2.528E-01 | 1.053E-01 |
| --- | 1996 | 2 | 77 | log_Fmult_devs | -6.571E-02 | 1.044E-01 |
| --- | 1997 | 2 | 78 | log_Fmult_devs | 8.811E-01 | 1.060E-01 |
| --- | 1998 | 2 | 79 | log_Fmult_devs | 9.348E-02 | 1.053E-01 |
| --- | 1999 | 2 | 80 | log_Fmult_devs | 1.385E-01 | 1.084E-01 |
| --- | 2000 | 2 | 81 | log_Fmult_devs | -2.529E-01 | 1.046E-01 |
| --- | 2001 | 2 | 82 | log_Fmult_devs | -2.223E-02 | 1.062E-01 |
| --- | 2002 | 2 | 83 | log_Fmult_devs | -1.496E-01 | 1.152E-01 |
| --- | 2003 | 2 | 84 | log_Fmult_devs | -3.803E-01 | 1.199E-01 |
| --- | 2004 | 2 | 85 | log_Fmult_devs | 1.247E-01 | 1.178E-01 |
| --- | 2005 | 2 | 86 | log_Fmult_devs | 2.747E-01 | 1.123E-01 |

cont'd next page…

Table 13 (cont'd).  ASAP parameter estimates and standard deviations for the baseline model.

| Coded Age | Biol. Year | Fishery | Param # | Parameter | Estimate | Std. Dev. |
|---|---|---|---|---|---|---|
| --- | 2006 | 2 | 87 | log_Fmult_devs | 2.372E-01 | 1.127E-01 |
| --- | 1983 | 3 | 88 | log_Fmult_devs | -9.389E-02 | 6.856E-01 |
| --- | 1984 | 3 | 89 | log_Fmult_devs | -9.370E-02 | 6.856E-01 |
| --- | 1985 | 3 | 90 | log_Fmult_devs | -9.261E-02 | 6.852E-01 |
| --- | 1986 | 3 | 91 | log_Fmult_devs | -8.736E-02 | 6.833E-01 |
| --- | 1987 | 3 | 92 | log_Fmult_devs | -7.315E-02 | 6.778E-01 |
| --- | 1988 | 3 | 93 | log_Fmult_devs | -4.447E-02 | 6.667E-01 |
| --- | 1989 | 3 | 94 | log_Fmult_devs | 2.727E-02 | 6.419E-01 |
| --- | 1990 | 3 | 95 | log_Fmult_devs | 1.947E-01 | 5.955E-01 |
| --- | 1991 | 3 | 96 | log_Fmult_devs | 6.631E-01 | 5.007E-01 |
| --- | 1992 | 3 | 97 | log_Fmult_devs | 3.027E+00 | 3.073E-01 |
| --- | 1993 | 3 | 98 | log_Fmult_devs | -2.909E+00 | 2.801E-01 |
| --- | 1994 | 3 | 99 | log_Fmult_devs | 7.466E-02 | 3.358E-01 |
| --- | 1995 | 3 | 100 | log_Fmult_devs | 4.238E+00 | 2.491E-01 |
| --- | 1996 | 3 | 101 | log_Fmult_devs | 2.590E-01 | 1.178E-01 |
| --- | 1997 | 3 | 102 | log_Fmult_devs | -4.759E-01 | 1.147E-01 |
| --- | 1998 | 3 | 103 | log_Fmult_devs | 3.097E+00 | 1.126E-01 |
| --- | 1999 | 3 | 104 | log_Fmult_devs | 1.148E+00 | 1.175E-01 |
| --- | 2000 | 3 | 105 | log_Fmult_devs | 2.459E+00 | 1.056E-01 |
| --- | 2001 | 3 | 106 | log_Fmult_devs | 3.478E-01 | 1.049E-01 |
| --- | 2002 | 3 | 107 | log_Fmult_devs | 4.764E-01 | 1.081E-01 |
| --- | 2003 | 3 | 108 | log_Fmult_devs | 1.182E-01 | 1.159E-01 |
| --- | 2004 | 3 | 109 | log_Fmult_devs | 2.005E-01 | 1.239E-01 |
| --- | 2005 | 3 | 110 | log_Fmult_devs | 1.366E-02 | 1.499E-01 |
| --- | 2006 | 3 | 111 | log_Fmult_devs | -4.019E-01 | 1.530E-01 |
| 1 | 1982 | --- | 112 | log_recruit_devs | -3.415E+00 | 1.766E-01 |
| 1 | 1983 | --- | 113 | log_recruit_devs | 4.976E-01 | 2.129E-01 |
| 1 | 1984 | --- | 114 | log_recruit_devs | 1.622E-01 | 2.035E-01 |
| 1 | 1985 | --- | 115 | log_recruit_devs | -4.973E-01 | 1.996E-01 |
| 1 | 1986 | --- | 116 | log_recruit_devs | -1.077E-02 | 1.733E-01 |
| 1 | 1987 | --- | 117 | log_recruit_devs | -2.311E-01 | 1.602E-01 |
| 1 | 1988 | --- | 118 | log_recruit_devs | 7.926E-03 | 1.326E-01 |
| 1 | 1989 | --- | 119 | log_recruit_devs | -2.206E-01 | 1.235E-01 |
| 1 | 1990 | --- | 120 | log_recruit_devs | -2.457E-01 | 1.239E-01 |
| 1 | 1991 | --- | 121 | log_recruit_devs | 1.959E-01 | 1.097E-01 |
| 1 | 1992 | --- | 122 | log_recruit_devs | -7.404E-02 | 1.286E-01 |
| 1 | 1993 | --- | 123 | log_recruit_devs | 5.363E-01 | 1.106E-01 |
| 1 | 1994 | --- | 124 | log_recruit_devs | 8.343E-01 | 1.036E-01 |
| 1 | 1995 | --- | 125 | log_recruit_devs | 4.006E-01 | 1.160E-01 |
| 1 | 1996 | --- | 126 | log_recruit_devs | 1.621E-01 | 1.263E-01 |
| 1 | 1997 | --- | 127 | log_recruit_devs | 2.852E-01 | 1.252E-01 |
| 1 | 1998 | --- | 128 | log_recruit_devs | 3.397E-01 | 1.193E-01 |
| 1 | 1999 | --- | 129 | log_recruit_devs | 5.421E-02 | 1.229E-01 |
| 1 | 2000 | --- | 130 | log_recruit_devs | -1.677E-01 | 1.336E-01 |

cont'd next page…

Table 13 (cont'd). ASAP parameter estimates and standard deviations for the baseline model.

| Coded Age | Biol. Year | Fishery | Param # | Parameter | Estimate | Std. Dev. |
|---|---|---|---|---|---|---|
| 1 | 2001 | --- | 131 | log_recruit_devs | 4.529E-01 | 1.262E-01 |
| 1 | 2002 | --- | 132 | log_recruit_devs | -3.448E-01 | 1.749E-01 |
| 1 | 2003 | --- | 133 | log_recruit_devs | 1.112E+00 | 1.329E-01 |
| 1 | 2004 | --- | 134 | log_recruit_devs | 4.905E-02 | 1.550E-01 |
| 1 | 2005 | --- | 135 | log_recruit_devs | 1.156E-01 | 9.654E-02 |
| 1 | 2006 | --- | 136 | log_recruit_devs | 1.961E-03 | 5.033E-02 |
| --- | 1982 | --- | 137 | log_q_year1 | -1.346E+01 | 2.040E-01 |
| --- | 1982 | --- | 138 | log_q_year1 | -1.334E+01 | 1.736E-01 |
| --- | --- | --- | 139 | log_SRR_virgin | 1.420E+01 | 1.448E-01 |
| --- | --- | --- | 140 | SRR_steepness | 6.559E-01 | 4.164E-02 |
| --- | 1982 | --- | 141 | SSB | 7.393E+03 | 6.801E+02 |
| --- | 1983 | --- | 142 | SSB | 1.524E+04 | 2.112E+03 |
| --- | 1984 | --- | 143 | SSB | 3.559E+04 | 5.769E+03 |
| --- | 1985 | --- | 144 | SSB | 5.774E+04 | 1.031E+04 |
| --- | 1986 | --- | 145 | SSB | 8.807E+04 | 1.651E+04 |
| --- | 1987 | --- | 146 | SSB | 1.486E+05 | 2.918E+04 |
| --- | 1988 | --- | 147 | SSB | 2.231E+05 | 4.527E+04 |
| --- | 1989 | --- | 148 | SSB | 3.665E+05 | 7.409E+04 |
| --- | 1990 | --- | 149 | SSB | 4.317E+05 | 8.615E+04 |
| --- | 1991 | --- | 150 | SSB | 4.899E+05 | 9.468E+04 |
| --- | 1992 | --- | 151 | SSB | 4.674E+05 | 8.952E+04 |
| --- | 1993 | --- | 152 | SSB | 4.918E+05 | 9.691E+04 |
| --- | 1994 | --- | 153 | SSB | 6.293E+05 | 1.171E+05 |
| --- | 1995 | --- | 154 | SSB | 7.786E+05 | 1.437E+05 |
| --- | 1996 | --- | 155 | SSB | 1.024E+06 | 1.858E+05 |
| --- | 1997 | --- | 156 | SSB | 9.769E+05 | 1.705E+05 |
| --- | 1998 | --- | 157 | SSB | 8.040E+05 | 1.411E+05 |
| --- | 1999 | --- | 158 | SSB | 6.286E+05 | 1.064E+05 |
| --- | 2000 | --- | 159 | SSB | 7.524E+05 | 1.360E+05 |
| --- | 2001 | --- | 160 | SSB | 7.514E+05 | 1.430E+05 |
| --- | 2002 | --- | 161 | SSB | 7.298E+05 | 1.425E+05 |
| --- | 2003 | --- | 162 | SSB | 8.237E+05 | 1.613E+05 |
| --- | 2004 | --- | 163 | SSB | 8.365E+05 | 1.643E+05 |
| --- | 2005 | --- | 164 | SSB | 8.335E+05 | 1.703E+05 |
| --- | 2006 | --- | 165 | SSB | 7.312E+05 | 1.634E+05 |
| 1 | 1982 | --- | 166 | recruits | 1.759E+05 | 3.286E+04 |
| 1 | 1983 | --- | 167 | recruits | 3.277E+05 | 6.536E+04 |
| 1 | 1984 | --- | 168 | recruits | 4.668E+05 | 1.024E+05 |
| 1 | 1985 | --- | 169 | recruits | 5.191E+05 | 1.231E+05 |
| 1 | 1986 | --- | 170 | recruits | 1.261E+06 | 2.886E+05 |
| 1 | 1987 | --- | 171 | recruits | 1.392E+06 | 3.235E+05 |
| 1 | 1988 | --- | 172 | recruits | 2.495E+06 | 5.542E+05 |
| 1 | 1989 | --- | 173 | recruits | 2.481E+06 | 5.310E+05 |
| 1 | 1990 | --- | 174 | recruits | 3.004E+06 | 6.006E+05 |

cont'd next page…

Table 13 (cont'd).  ASAP parameter estimates and standard deviations for the baseline model.

| Coded Age | Biol. Year | Fishery | Param # | Parameter | Estimate | Std. Dev. |
|---|---|---|---|---|---|---|
| 1 | 1991 | --- | 175 | recruits | 4.954E+06 | 9.053E+05 |
| 1 | 1992 | --- | 176 | recruits | 3.941E+06 | 7.644E+05 |
| 1 | 1993 | --- | 177 | recruits | 7.148E+06 | 1.314E+06 |
| 1 | 1994 | --- | 178 | recruits | 9.785E+06 | 1.711E+06 |
| 1 | 1995 | --- | 179 | recruits | 6.803E+06 | 1.170E+06 |
| 1 | 1996 | --- | 180 | recruits | 5.641E+06 | 9.205E+05 |
| 1 | 1997 | --- | 181 | recruits | 6.737E+06 | 9.810E+05 |
| 1 | 1998 | --- | 182 | recruits | 7.054E+06 | 9.766E+05 |
| 1 | 1999 | --- | 183 | recruits | 5.100E+06 | 7.763E+05 |
| 1 | 2000 | --- | 184 | recruits | 3.853E+06 | 6.682E+05 |
| 1 | 2001 | --- | 185 | recruits | 7.487E+06 | 1.257E+06 |
| 1 | 2002 | --- | 186 | recruits | 3.371E+06 | 7.291E+05 |
| 1 | 2003 | --- | 187 | recruits | 1.437E+07 | 2.578E+06 |
| 1 | 2004 | --- | 188 | recruits | 5.100E+06 | 1.057E+06 |
| 1 | 2005 | --- | 189 | recruits | 5.468E+06 | 9.519E+05 |
| 1 | 2006 | --- | 190 | recruits | 4.877E+06 | 7.563E+05 |
| 6 | 1982 | --- | 191 | plus_group | 1.944E+03 | 0.000E+00 |
| 6 | 1983 | --- | 192 | plus_group | 3.299E+03 | 3.712E+01 |
| 6 | 1984 | --- | 193 | plus_group | 4.266E+03 | 5.359E+01 |
| 6 | 1985 | --- | 194 | plus_group | 4.844E+03 | 8.269E+01 |
| 6 | 1986 | --- | 195 | plus_group | 5.629E+03 | 1.254E+02 |
| 6 | 1987 | --- | 196 | plus_group | 2.329E+04 | 4.267E+03 |
| 6 | 1988 | --- | 197 | plus_group | 5.187E+04 | 1.059E+04 |
| 6 | 1989 | --- | 198 | plus_group | 8.793E+04 | 1.888E+04 |
| 6 | 1990 | --- | 199 | plus_group | 1.189E+05 | 2.626E+04 |
| 6 | 1991 | --- | 200 | plus_group | 2.280E+05 | 5.289E+04 |
| 6 | 1992 | --- | 201 | plus_group | 3.125E+05 | 7.413E+04 |
| 6 | 1993 | --- | 202 | plus_group | 4.697E+05 | 1.179E+05 |
| 6 | 1994 | --- | 203 | plus_group | 5.588E+05 | 1.422E+05 |
| 6 | 1995 | --- | 204 | plus_group | 6.432E+05 | 1.638E+05 |
| 6 | 1996 | --- | 205 | plus_group | 8.682E+05 | 2.168E+05 |
| 6 | 1997 | --- | 206 | plus_group | 9.462E+05 | 2.302E+05 |
| 6 | 1998 | --- | 207 | plus_group | 1.292E+06 | 3.098E+05 |
| 6 | 1999 | --- | 208 | plus_group | 1.709E+06 | 4.118E+05 |
| 6 | 2000 | --- | 209 | plus_group | 1.636E+06 | 4.034E+05 |
| 6 | 2001 | --- | 210 | plus_group | 1.383E+06 | 3.608E+05 |
| 6 | 2002 | --- | 211 | plus_group | 1.217E+06 | 3.373E+05 |
| 6 | 2003 | --- | 212 | plus_group | 1.072E+06 | 3.240E+05 |
| 6 | 2004 | --- | 213 | plus_group | 8.892E+05 | 2.920E+05 |
| 6 | 2005 | --- | 214 | plus_group | 7.097E+05 | 2.543E+05 |
| 6 | 2006 | --- | 215 | plus_group | 8.084E+05 | 2.973E+05 |

Table 14. Pacific sardine instantaneous rates of fishing mortality at age ($yr^{-1}$) for biological years 1982-83 to 2006-07 (July-June).

| Biological | ----- Instantaneous Fishing Mortality Rate at Age ($yr^{-1}$) ----- | | | | | |
|---|---|---|---|---|---|---|
| Year | 0 | 1 | 2 | 3 | 4 | 5+ |
| 1982-83 | 0.010 | 0.062 | 0.197 | 0.130 | 0.064 | 0.031 |
| 1983-84 | 0.004 | 0.023 | 0.073 | 0.048 | 0.024 | 0.012 |
| 1984-85 | 0.032 | 0.078 | 0.111 | 0.075 | 0.049 | 0.013 |
| 1985-86 | 0.005 | 0.020 | 0.054 | 0.036 | 0.019 | 0.008 |
| 1986-87 | 0.006 | 0.021 | 0.051 | 0.034 | 0.018 | 0.008 |
| 1987-88 | 0.006 | 0.028 | 0.078 | 0.052 | 0.027 | 0.012 |
| 1988-89 | 0.004 | 0.015 | 0.038 | 0.025 | 0.013 | 0.006 |
| 1989-90 | 0.013 | 0.034 | 0.056 | 0.038 | 0.023 | 0.007 |
| 1990-91 | 0.015 | 0.040 | 0.066 | 0.045 | 0.027 | 0.008 |
| 1991-92 | 0.032 | 0.078 | 0.086 | 0.059 | 0.036 | 0.008 |
| 1992-93 | 0.075 | 0.186 | 0.204 | 0.139 | 0.083 | 0.019 |
| 1993-94 | 0.030 | 0.076 | 0.083 | 0.056 | 0.032 | 0.008 |
| 1994-95 | 0.044 | 0.117 | 0.125 | 0.084 | 0.046 | 0.011 |
| 1995-96 | 0.033 | 0.086 | 0.092 | 0.062 | 0.035 | 0.008 |
| 1996-97 | 0.029 | 0.075 | 0.081 | 0.055 | 0.031 | 0.007 |
| 1997-98 | 0.070 | 0.180 | 0.195 | 0.132 | 0.075 | 0.018 |
| 1998-99 | 0.080 | 0.208 | 0.225 | 0.153 | 0.087 | 0.021 |
| 1999-00 | 0.100 | 0.266 | 0.287 | 0.196 | 0.110 | 0.029 |
| 2000-01 | 0.078 | 0.210 | 0.245 | 0.191 | 0.141 | 0.063 |
| 2001-02 | 0.080 | 0.220 | 0.263 | 0.213 | 0.167 | 0.082 |
| 2002-03 | 0.073 | 0.205 | 0.263 | 0.235 | 0.210 | 0.117 |
| 2003-04 | 0.041 | 0.115 | 0.174 | 0.183 | 0.195 | 0.121 |
| 2004-05 | 0.048 | 0.136 | 0.207 | 0.220 | 0.236 | 0.148 |
| 2005-06 | 0.058 | 0.159 | 0.234 | 0.240 | 0.251 | 0.152 |
| 2006-07 | 0.073 | 0.195 | 0.253 | 0.225 | 0.205 | 0.111 |

Table 15. Pacific sardine population numbers at age (millions), spawning stock biomass (SSB, mt), and age 1+ biomass (mt) at the beginning of each biological year, 1982-83 to 2006-07 (July-June). ‘Model SSB’ is based on maturity-at-age (Table 1) and fishery weights-at-age (Table 6) and is used in ASAP to estimate stock-recruitment. ‘Population SSB’ and ‘Age 1+ biomass’ were calculated using assumed population weights-at-age (Table 7). Total landings by biological year are also provided. Recruitment is shown as population numbers at age-0. Age 1+ biomass as of July 2006 (bold) serves as the basis for setting a harvest guideline for the U.S. fishery in calendar year 2007 (calculated in Table 17).

| Biological | --- Population Numbers-at-age (millions) --- | | | | | | Model | Population | Age 1+ | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 0 | 1 | 2 | 3 | 4 | 5+ | SSB | SSB | Biomass | Landings |
| 1982-83 | 176 | 15 | 9 | 5 | 3 | 2 | 7,393 | 5,543 | 4,680 | 487 |
| 1983-84 | 328 | 117 | 9 | 5 | 3 | 3 | 15,236 | 12,826 | 15,395 | 372 |
| 1984-85 | 467 | 219 | 77 | 6 | 3 | 4 | 35,590 | 29,056 | 36,085 | 3,571 |
| 1985-86 | 519 | 303 | 136 | 46 | 4 | 5 | 57,736 | 48,793 | 60,367 | 1,838 |
| 1986-87 | 1,261 | 346 | 199 | 86 | 30 | 6 | 88,068 | 78,108 | 85,518 | 2,667 |
| 1987-88 | 1,392 | 841 | 227 | 127 | 56 | 23 | 148,640 | 124,428 | 155,124 | 5,887 |
| 1988-89 | 2,495 | 927 | 548 | 141 | 81 | 52 | 223,080 | 194,543 | 222,866 | 4,795 |
| 1989-90 | 2,481 | 1,666 | 612 | 354 | 92 | 88 | 366,450 | 286,496 | 352,707 | 15,322 |
| 1990-91 | 3,004 | 1,641 | 1,080 | 388 | 228 | 119 | 431,690 | 387,036 | 453,436 | 20,602 |
| 1991-92 | 4,954 | 1,984 | 1,058 | 678 | 249 | 228 | 489,870 | 492,340 | 557,239 | 35,022 |
| 1992-93 | 3,941 | 3,217 | 1,230 | 650 | 428 | 312 | 467,370 | 613,992 | 751,102 | 74,214 |
| 1993-94 | 7,148 | 2,452 | 1,791 | 673 | 380 | 470 | 491,760 | 702,226 | 777,950 | 31,540 |
| 1994-95 | 9,785 | 4,651 | 1,523 | 1,105 | 426 | 559 | 629,310 | 907,218 | 1,062,119 | 66,295 |
| 1995-96 | 6,803 | 6,276 | 2,774 | 901 | 681 | 643 | 778,570 | 1,158,675 | 1,437,764 | 62,677 |
| 1996-97 | 5,641 | 4,413 | 3,861 | 1,695 | 567 | 868 | 1,024,000 | 1,341,011 | 1,559,516 | 65,968 |
| 1997-98 | 6,737 | 3,673 | 2,744 | 2,386 | 1,075 | 946 | 976,910 | 1,375,343 | 1,536,719 | 131,380 |
| 1998-99 | 7,054 | 4,212 | 2,056 | 1,514 | 1,401 | 1,292 | 803,950 | 1,291,477 | 1,462,943 | 113,901 |
| 1999-00 | 5,100 | 4,366 | 2,293 | 1,101 | 871 | 1,709 | 628,580 | 1,229,013 | 1,427,391 | 119,258 |
| 2000-01 | 3,853 | 3,092 | 2,242 | 1,153 | 607 | 1,636 | 752,430 | 1,090,755 | 1,238,913 | 121,295 |
| 2001-02 | 7,487 | 2,389 | 1,680 | 1,177 | 639 | 1,383 | 751,430 | 977,236 | 1,048,074 | 125,612 |
| 2002-03 | 3,371 | 4,631 | 1,285 | 866 | 637 | 1,217 | 729,770 | 925,604 | 1,139,043 | 141,774 |
| 2003-04 | 14,370 | 2,100 | 2,528 | 662 | 459 | 1,072 | 823,690 | 972,553 | 969,557 | 106,550 |
| 2004-05 | 5,100 | 9,245 | 1,255 | 1,424 | 370 | 889 | 836,480 | 1,177,696 | 1,599,603 | 140,985 |
| 2005-06 | 5,468 | 3,258 | 5,412 | 684 | 766 | 710 | 833,470 | 1,323,892 | 1,503,871 | 152,852 |
| 2006-07 | 4,877 | 3,459 | 1,862 | 2,870 | 361 | 808 | 731,210 | 1,160,075 | **1,319,072** | 133,827 |

Table 16. Estimates of 2003 recruitment, the age 1+ biomass in 2005-06 and 2006-07, and the 2006 and 2007 harvest guidelines for a) the 2005 final model, b) the 2006 base model, and c) the sensitivity tests based on modifying the assumptions regarding the data inputs and assumptions of the assessment model.

| **Assessment Run:** | 2003 Recruitment (Billions) | 2006-07 Age 1+ biomass (mt) | 2007 HG (mt) | 2005-06 Age 1+ biomass (mt) | 2006 HG (mt) |
|---|---|---|---|---|---|
| 2005 final model | 10.04 | - | - | 1,061,391 | 118,937 |
| 2005 $\sigma_R$ values | | | | | |
| + Landings | 10.14 | 886,888 | 96,164 | 1,068,636 | 119,882 |
| + catch-at-age | 8.30 | 743,976 | 77,514 | 895,365 | 97,270 |
| + DEPM | 12.01 | 1,198,244 | 136,796 | 1,377,556 | 160,196 |
| 2006 $\sigma_R$ values | | | | | |
| + Landings | 13.24 | 1,010,210 | 112,257 | 1,236,957 | 141,848 |
| + catch-at-age | 9.70 | 817,036 | 87,048 | 970,195 | 107,036 |
| + DEPM (base model) | 14.37 | 1,319,072 | 152,564 | 1,503,871 | 176,680 |
| Ignore DEPM | 5.60 | 246,595 | 12,606 | 361,455 | 27,595 |
| Ignore Aerial Spotter | 17.12 | 1,625,193 | 192,513 | 1,844,860 | 221,179 |
| $F_{mult}$ pen = 0.1 | 14.82 | 1,361,620 | 158,116 | 1,550,159 | 182,721 |
| DEPM – coast-wide SSB | 14.87 | 1,368,373 | 158,998 | 1,556,995 | 183,613 |

Table 17. Proposed harvest guideline for Pacific sardine for the 2007 management year. See 'Harvest Guideline' section for methods used to derive harvest guideline.

| Stock biomass (age 1+, mt) | Cutoff (mt) | Fraction | Distribution | Harvest guideline (mt) |
|---|---|---|---|---|
| 1,319,072 | 150,000 | 15% | 87% | **152,564** |

Table 18. Coast-wide harvest (mt) of Pacific sardine for calendar years 1983 through 2005.

| Calendar | México | United States | | | | Canada | Total |
|---|---|---|---|---|---|---|---|
| Year | Ensenada | So. Cal. | No. Cal. | Oregon | Wash. | B.C. | Landings |
| 1983 | 274 | 352 | 0 | 0 | 0 | 0 | 626 |
| 1984 | 0 | 171 | 64 | 0 | 0 | 0 | 235 |
| 1985 | 3,722 | 559 | 34 | 0 | 0 | 0 | 4,315 |
| 1986 | 243 | 1,051 | 113 | 0 | 0 | 0 | 1,407 |
| 1987 | 2,432 | 2,056 | 39 | 0 | 0 | 0 | 4,526 |
| 1988 | 2,035 | 3,775 | 10 | 0 | 0 | 0 | 5,820 |
| 1989 | 6,224 | 3,443 | 238 | 0 | 0 | 0 | 9,905 |
| 1990 | 11,375 | 2,508 | 307 | 0 | 0 | 0 | 14,190 |
| 1991 | 31,392 | 6,774 | 976 | 0 | 0 | 0 | 39,142 |
| 1992 | 34,568 | 16,061 | 3,128 | 4 | 0 | 0 | 53,761 |
| 1993 | 32,045 | 15,488 | 705 | 0 | 0 | 0 | 48,237 |
| 1994 | 20,877 | 10,346 | 2,359 | 0 | 0 | 0 | 33,582 |
| 1995 | 35,396 | 36,561 | 4,928 | 0 | 0 | 23 | 76,908 |
| 1996 | 39,065 | 25,171 | 8,885 | 0 | 0 | 0 | 73,121 |
| 1997 | 68,439 | 32,837 | 13,361 | 0 | 0 | 71 | 114,707 |
| 1998 | 47,812 | 31,975 | 9,081 | 1 | 0 | 488 | 89,357 |
| 1999 | 58,569 | 42,863 | 13,884 | 775 | 0 | 24 | 116,116 |
| 2000 | 67,845 | 46,835 | 11,367 | 9,529 | 4,765 | 1,722 | 142,063 |
| 2001 | 46,071 | 47,662 | 7,241 | 12,780 | 10,837 | 1,266 | 125,857 |
| 2002 | 46,845 | 49,366 | 14,078 | 22,711 | 15,212 | 739 | 148,951 |
| 2003 | 41,342 | 30,289 | 7,448 | 25,258 | 11,604 | 977 | 116,918 |
| 2004 | 41,897 | 32,393 | 15,308 | 36,112 | 8,799 | 4,438 | 138,948 |
| 2005 | 56,684 | 30,253 | 7,940 | 45,110 | 6,929 | 3,232 | 150,147 |

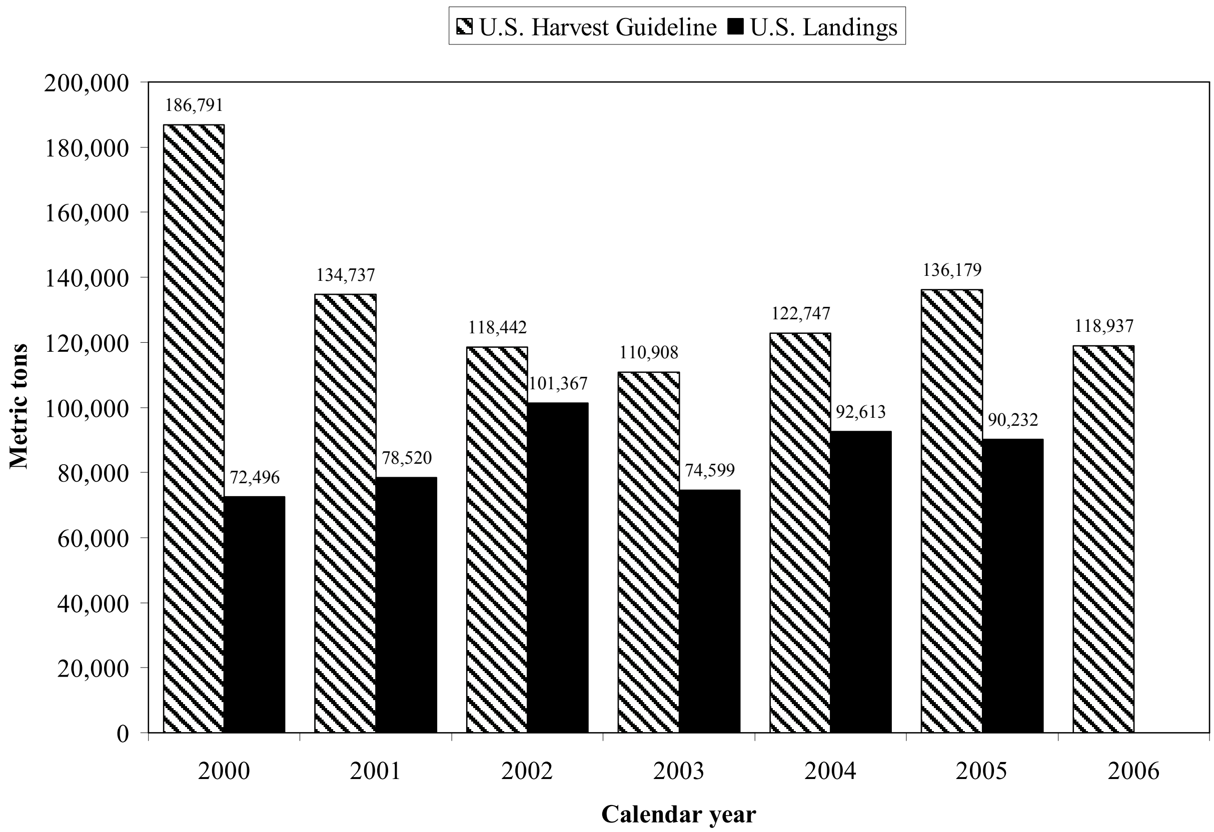



Figure 1. U.S. Pacific sardine harvest guidelines and resultant landings (mt) since the onset of PFMC management in calendar year 2000.

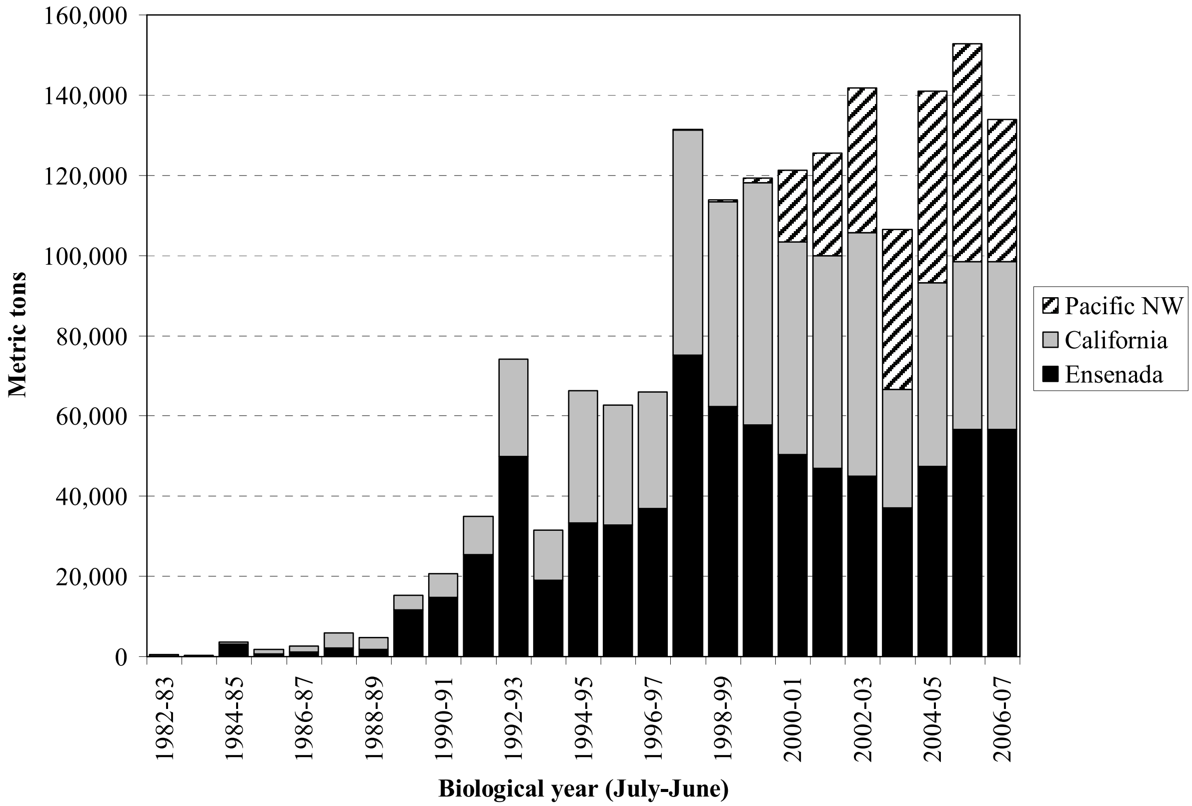



Figure 2. Pacific sardine landings (mt) by fishery for biological years 1982-83 to 2006-07 (July-June). Landings were projected for 2006-07.

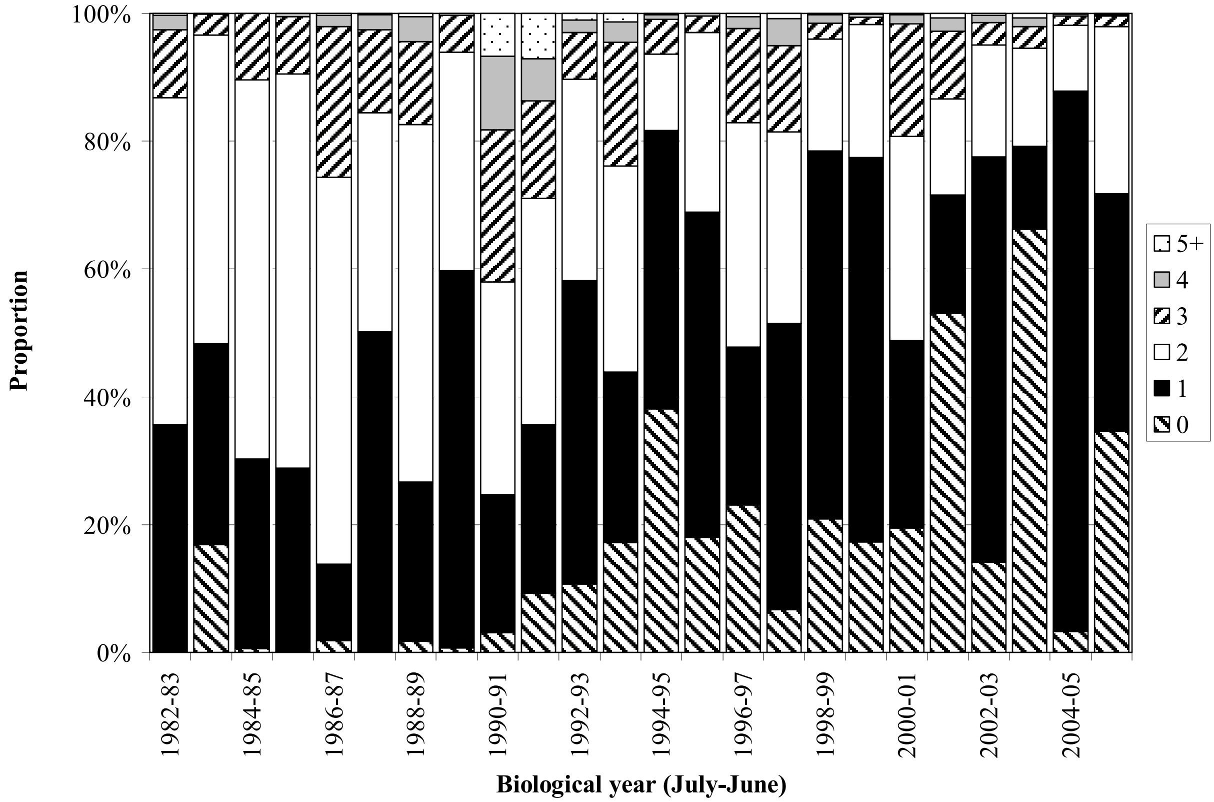



Figure 3. Catch-at-age proportions for the Pacific sardine fishery in California (San Pedro and Monterey) for biological years 1982-83 to 2005-06 (July-June).

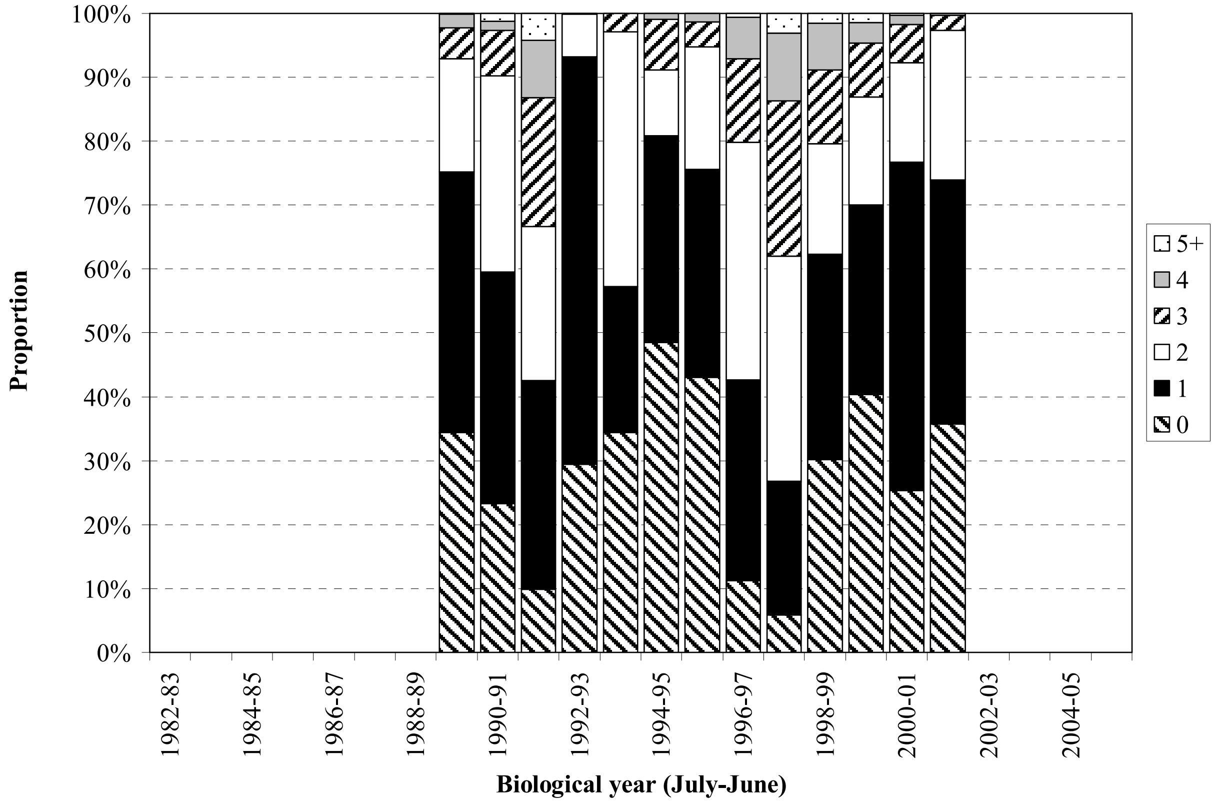



Figure 4. Catch-at-age proportions for the Pacific sardine fishery in Ensenada (Baja California, Mexico) for biological years 1989-90 to 2001-02 (July-June).

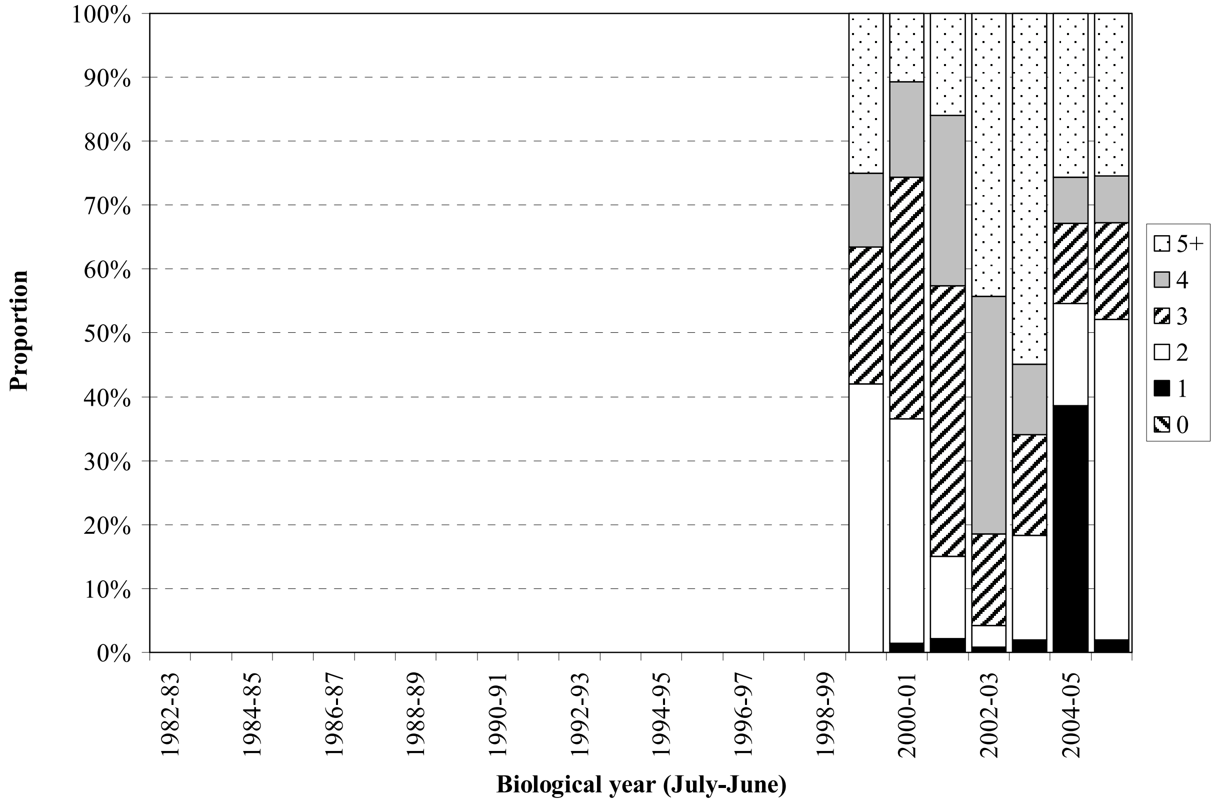



Figure 5. Catch-at-age proportions for the Pacific sardine fishery in the Pacific Northwest for biological years 1999-00 to 2005-06 (July-June).

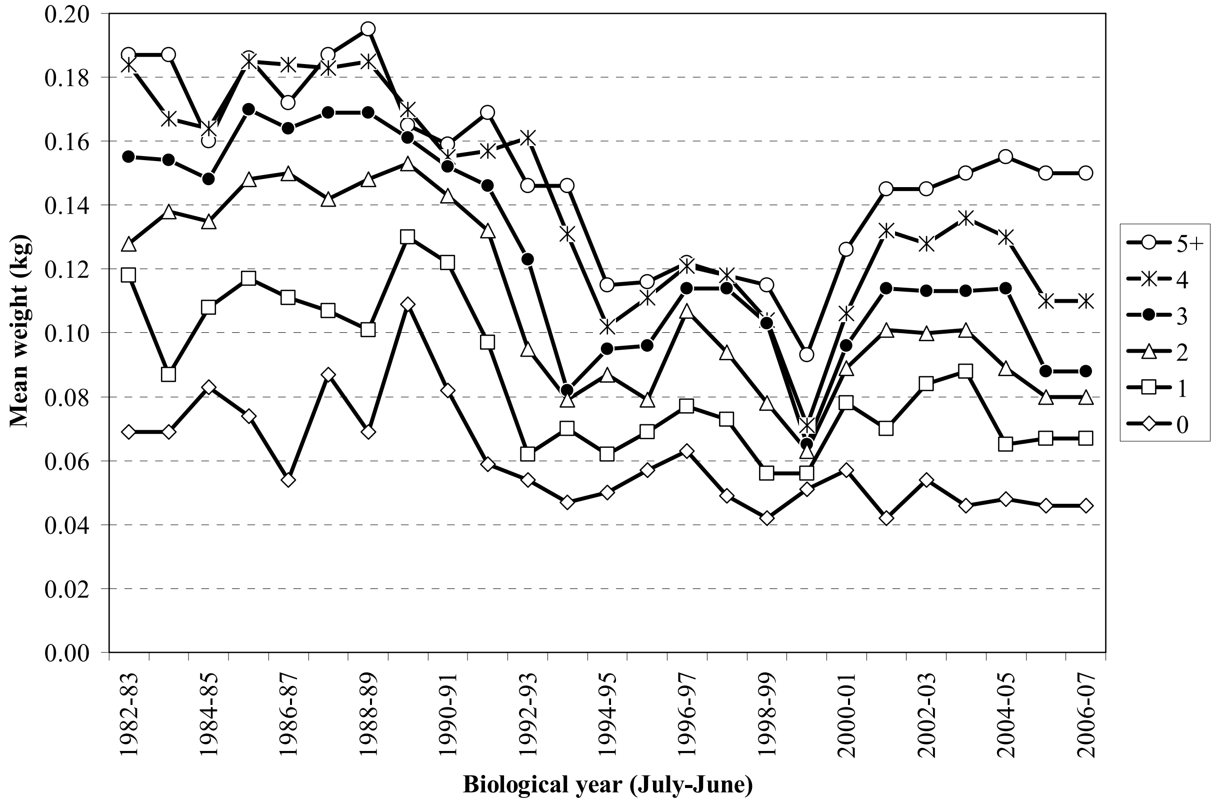



Figure 6. Pooled fishery weight-at-age (kg) for Pacific sardine as applied in the ASAP base model. Whole body weights were averaged across the three fisheries using respective landings to weight the data.

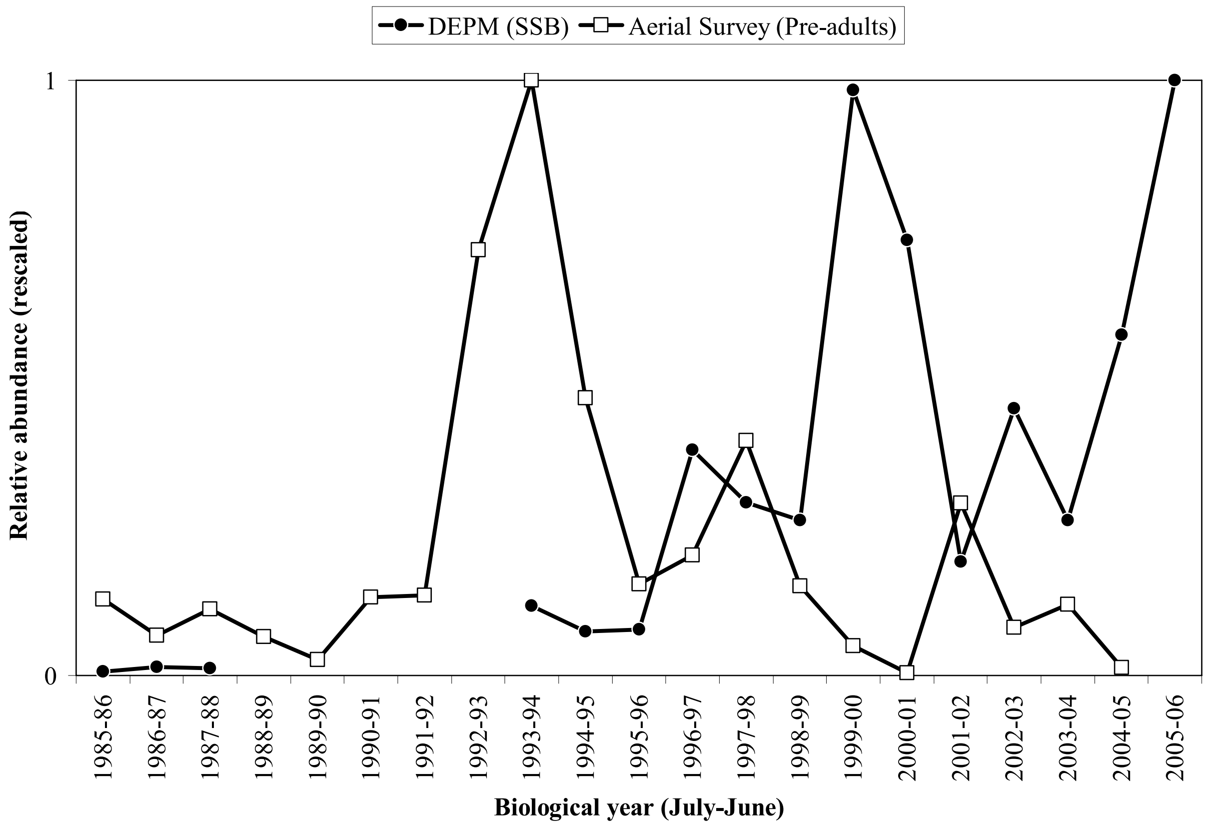



Figure 7. Rescaled indices of relative abundance for Pacific sardine applied in ASAP.

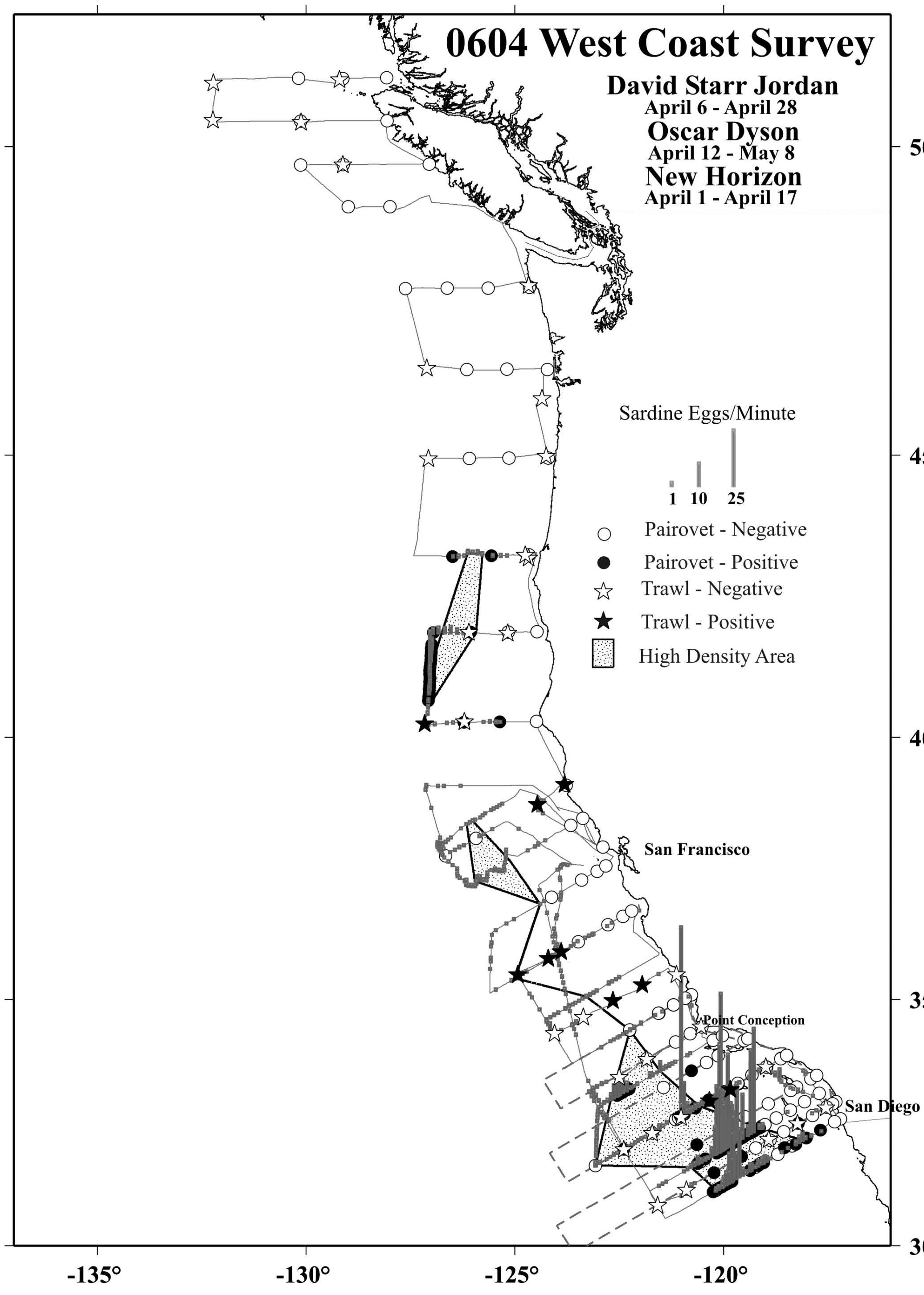



Figure 8. Track lines occupied by three research vessels from April 1 to May 8, 2006, for the coast-wide sardine survey. Shaded area was the high density area for sardine eggs.

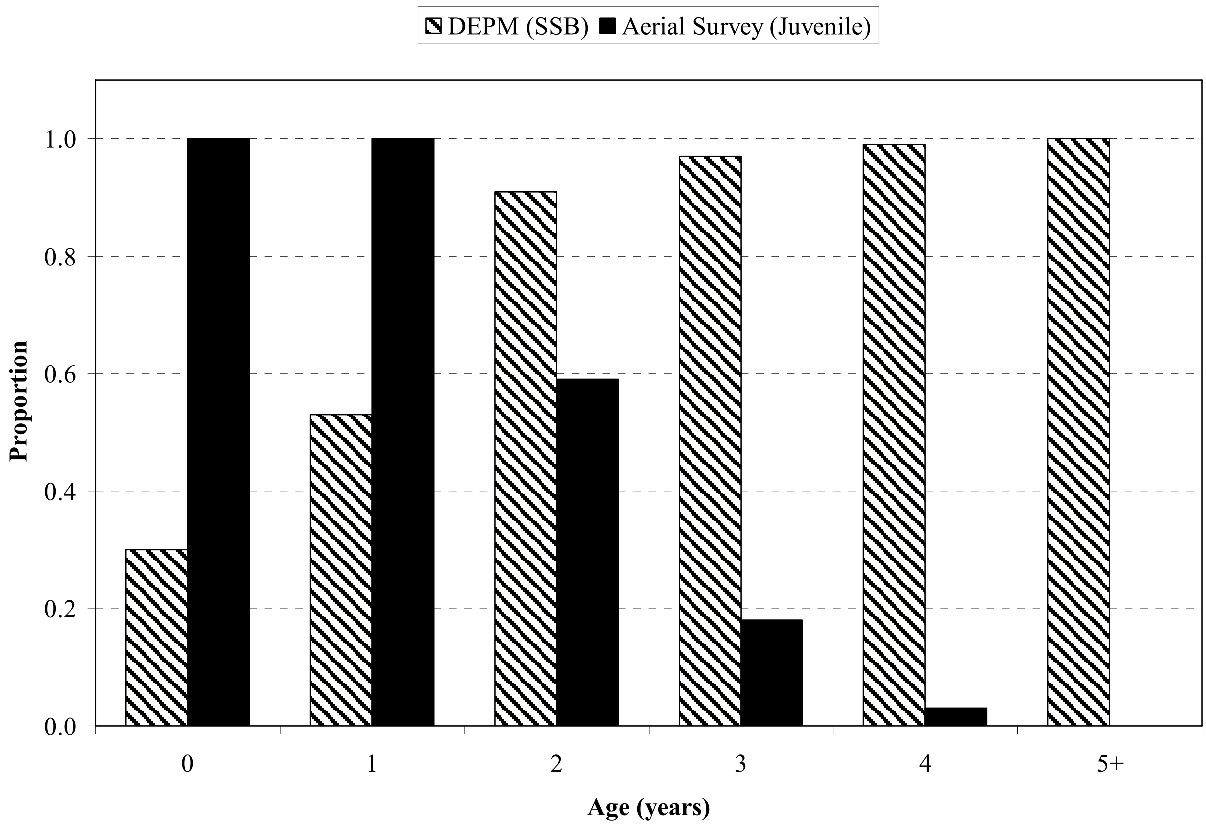



Figure 9. Selectivity patterns applied to Pacific sardine survey data in ASAP.

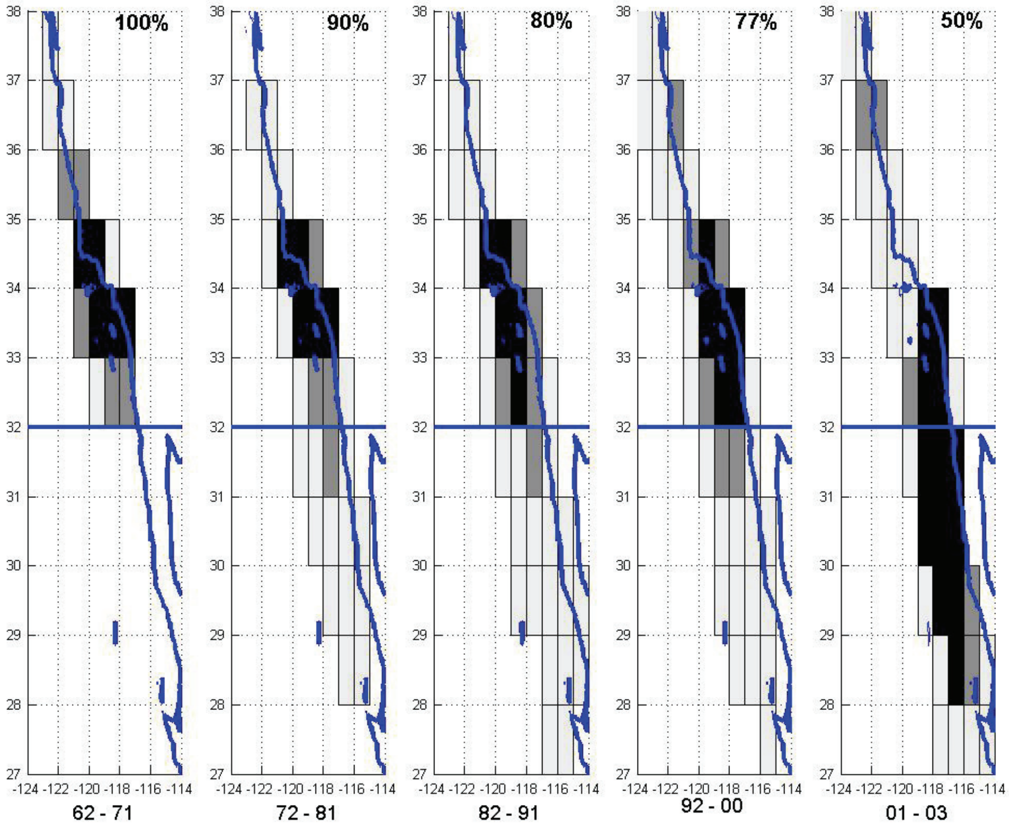



Figure 10. Distribution and southward shift of aerial spotter effort, Monterey Bay (California) to Cedros Island (Baja California), 1962 to 2003.

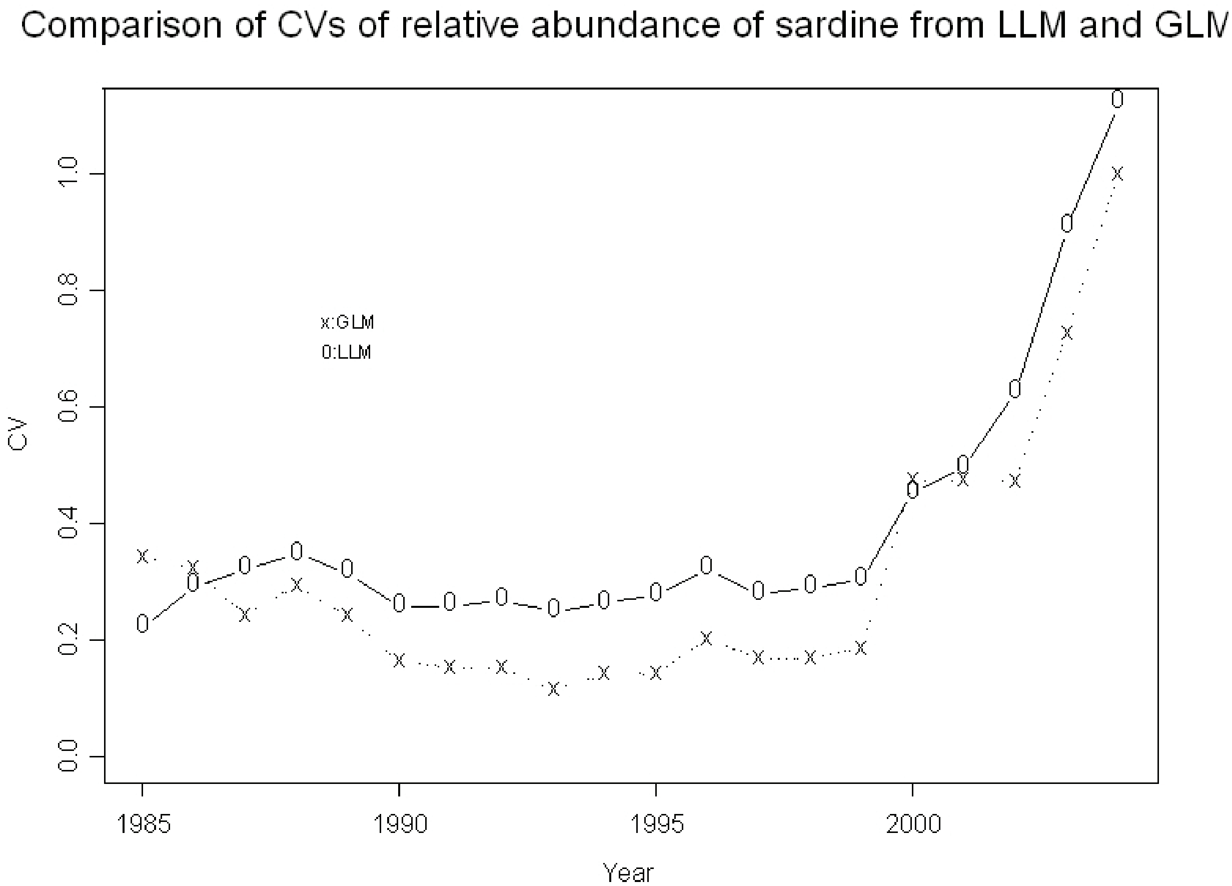



Figure 11. Coefficient of variation (CV) of the estimates of the relative abundance of young sardine based on GLM (x) and LLM (0).

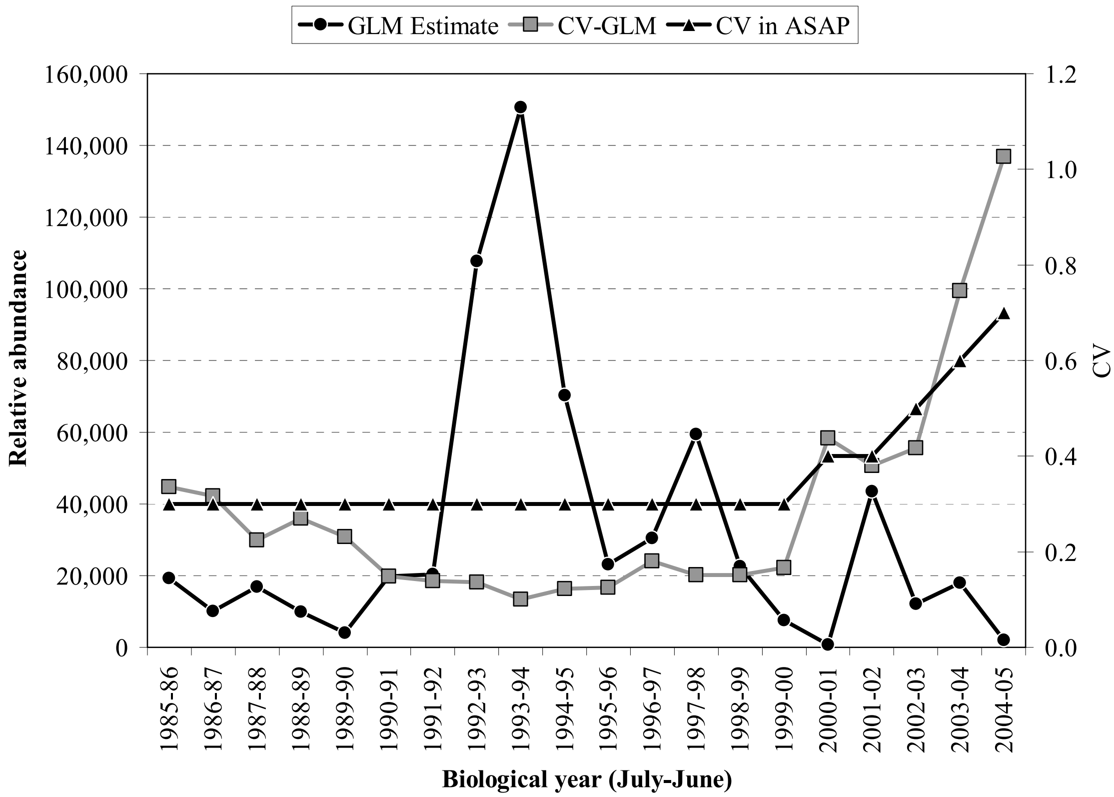



Figure 12. Aerial spotter survey index of relative abundance and coefficients of variation (CVs) from the GLM. CVs applied in the ASAP model are also displayed.

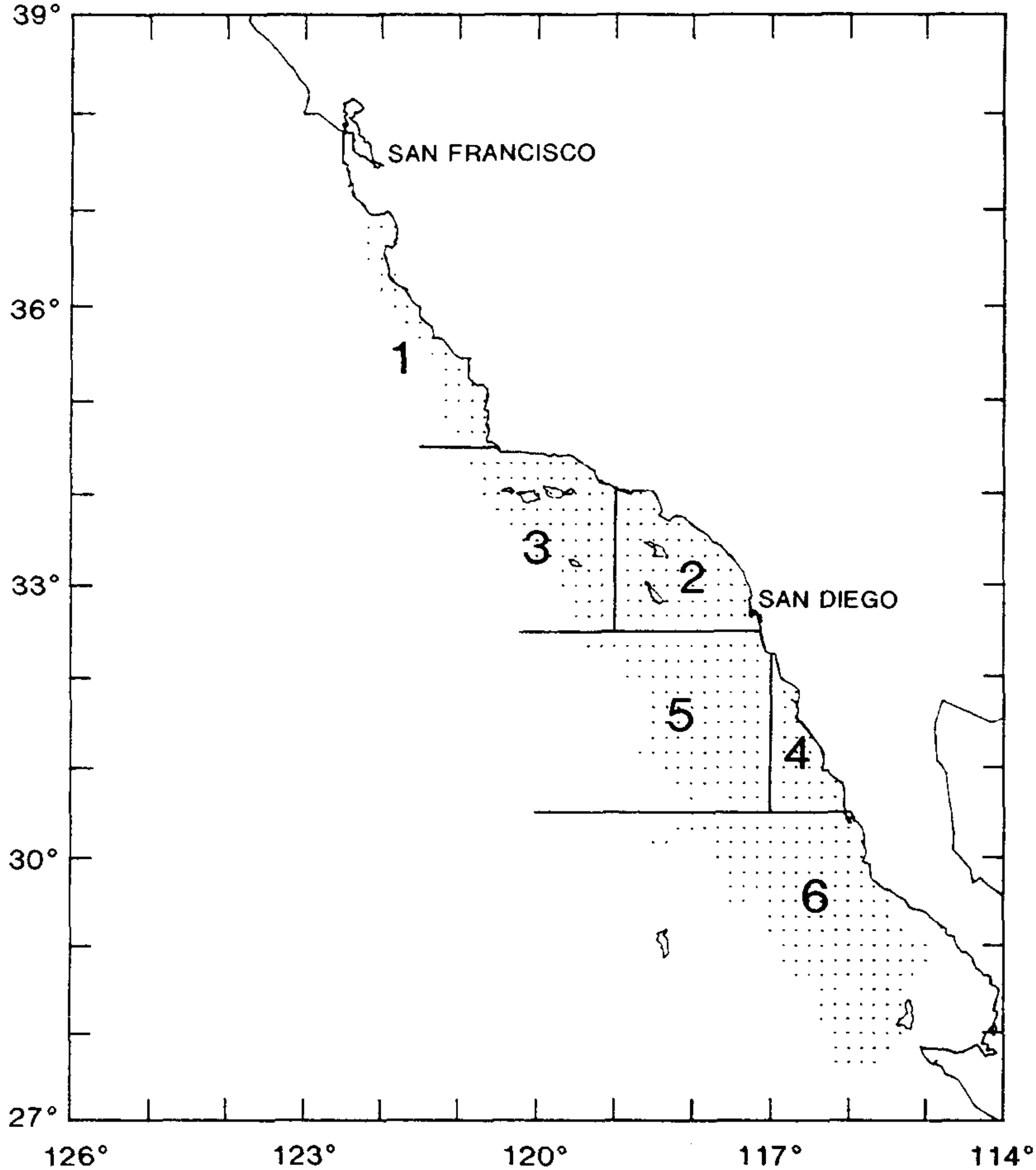



Figure 13. Study area, regions, and blocks covered by fish spotters in 1989. Regions are outlined and denoted by numbers. Blocks are denoted by dots (reproduced from Lo et al. 1992)

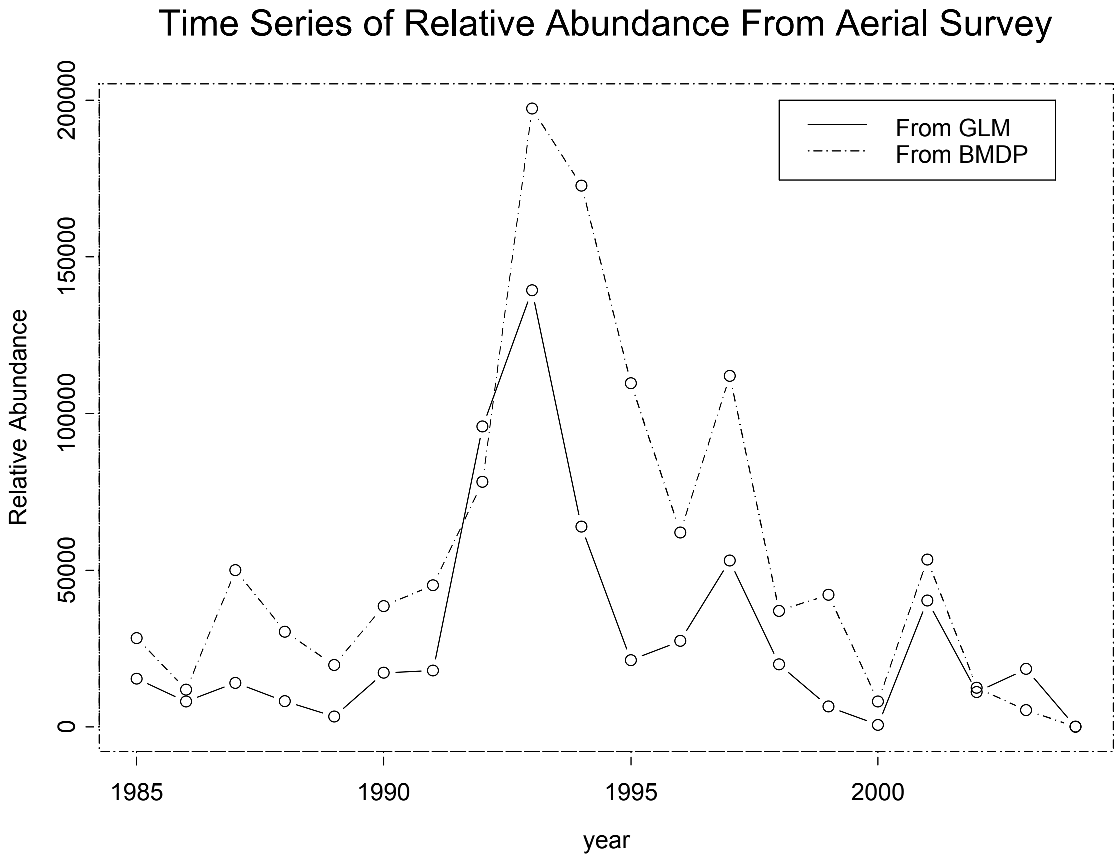



Figure 14. Time series of relative abundance of young sardine from 1985-86 to 2004-05 (July-June).

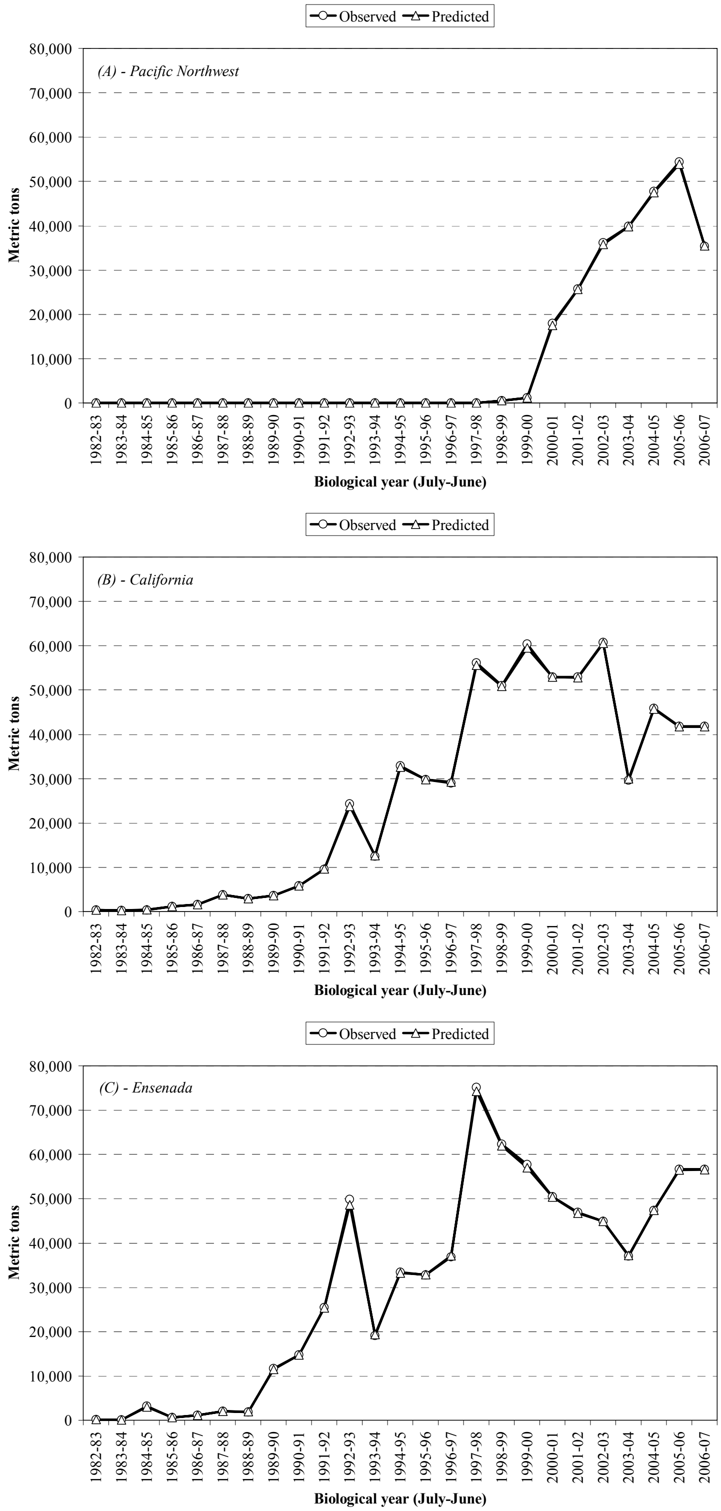



Figure 15. Observed and predicted estimates of total catch (mt) from the ASAP model (1982-83 to 2006-07): (A) Pacific northwest, (B) California, and (C) Ensenada.

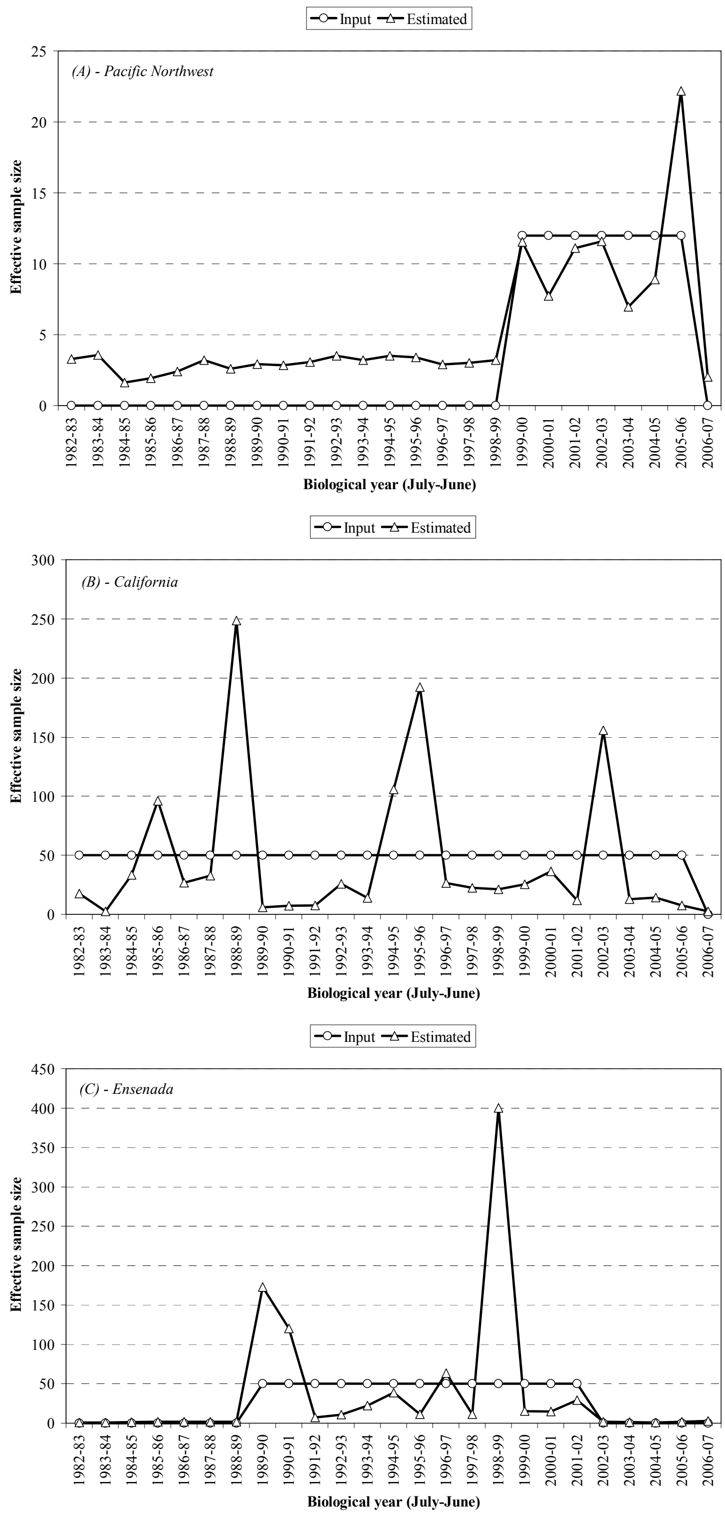



Figure 16. Effective sample sizes estimated for catch-at-age data from the (A) Pacific northwest, (B) California, and (C) Ensenada fisheries.

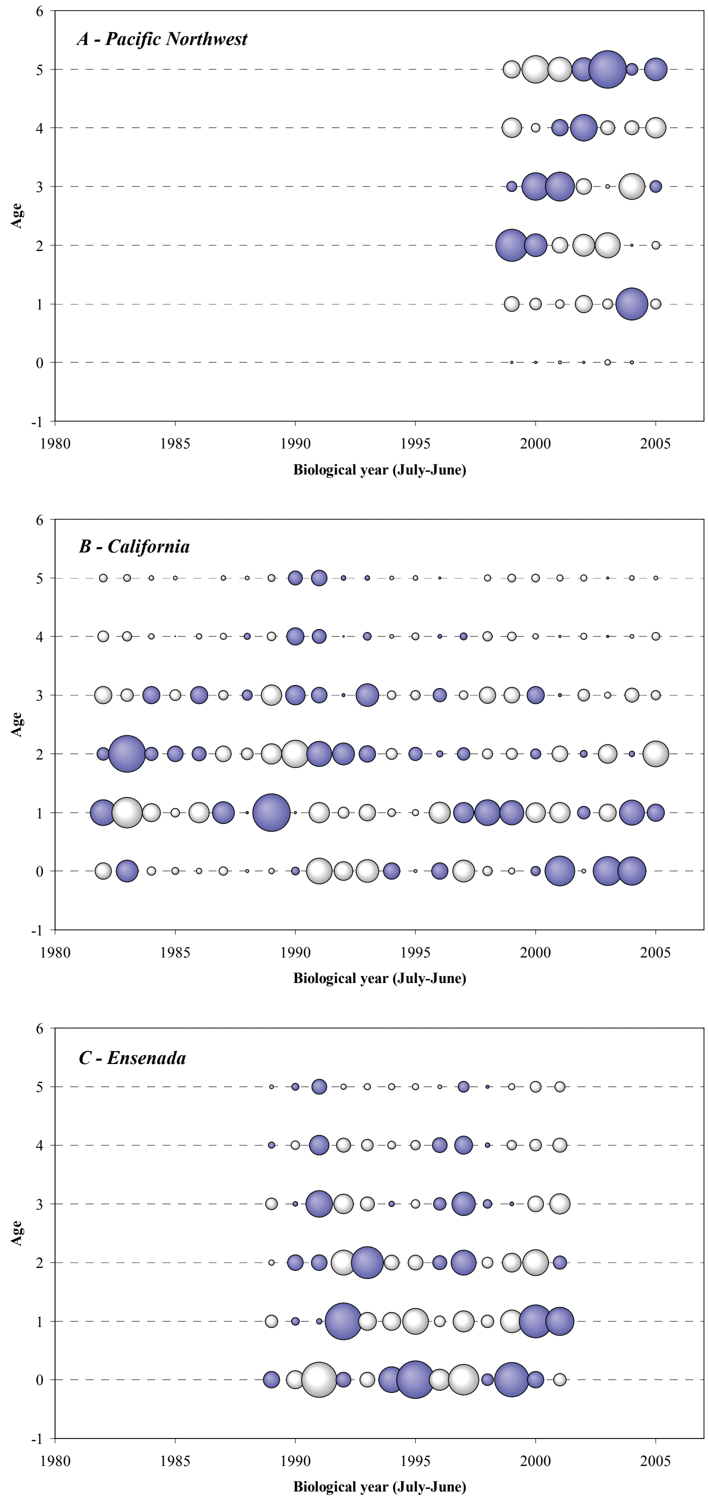
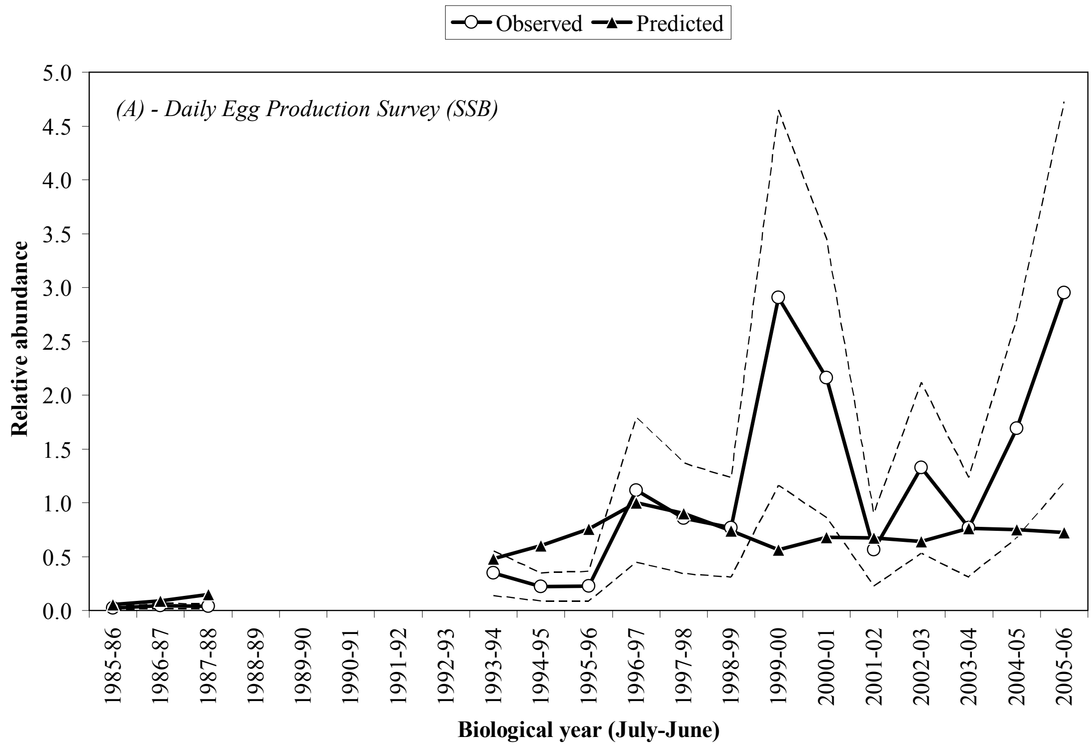



Figure 17. Standardized residuals from ASAP model fit to catch-at-age data for the three sardine fisheries. Dark bubbles are positive residuals, light bubbles are negative.



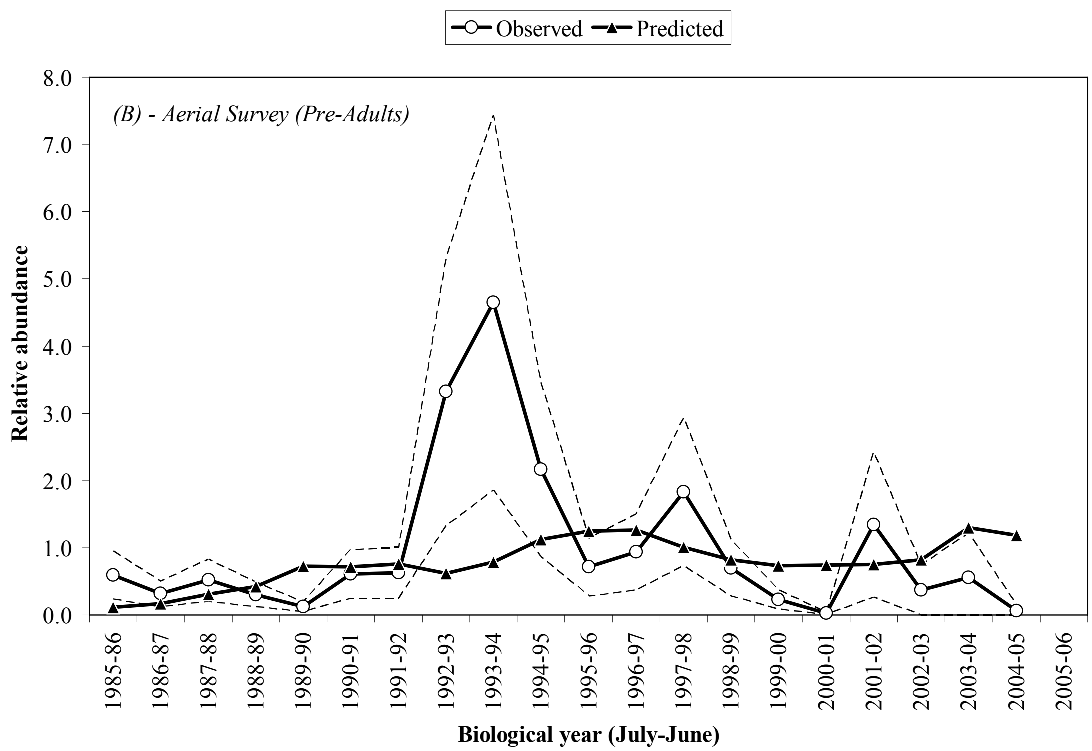
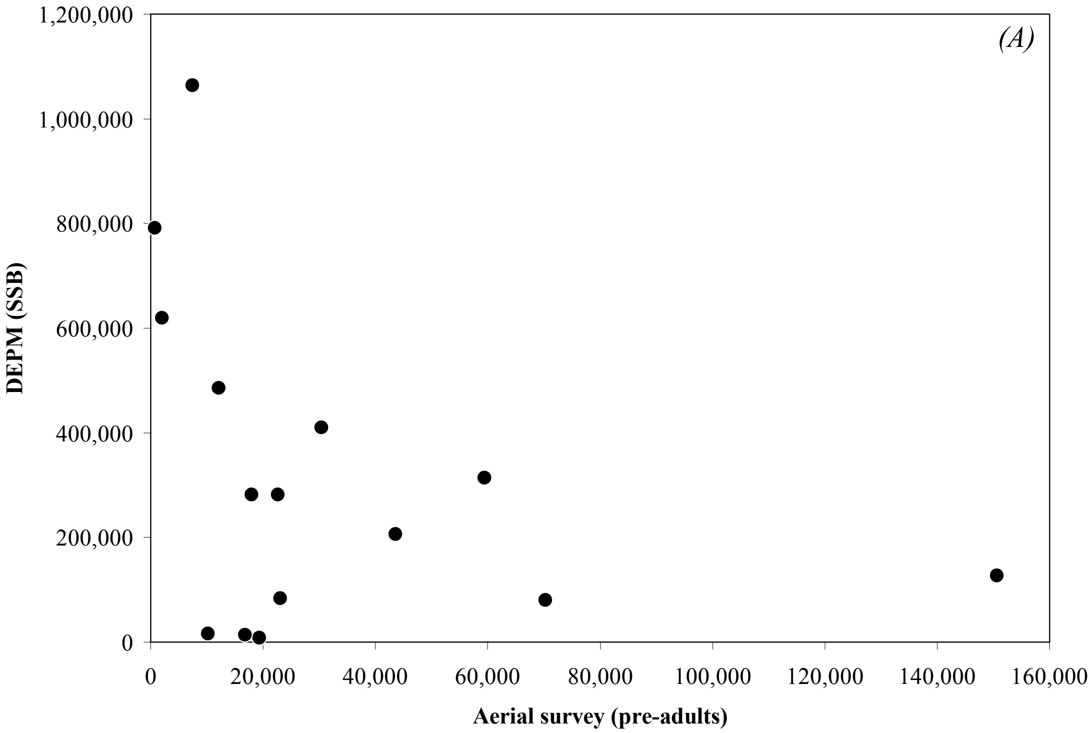




Figure 18. ASAP model fits to survey data: (A) Index of relative abundance of sardine spawning stock biomass (mt) based on daily egg production method (DEPM) estimates from ichthyoplankton survey data, 1985-86 to 1987-88, and 1993-94 to 2006-06; (B) Index of relative abundance of sardine pre-adult biomass (primarily age 0-2 fish) based on aerial spotter plane survey, 1985-86 to 2004-05.



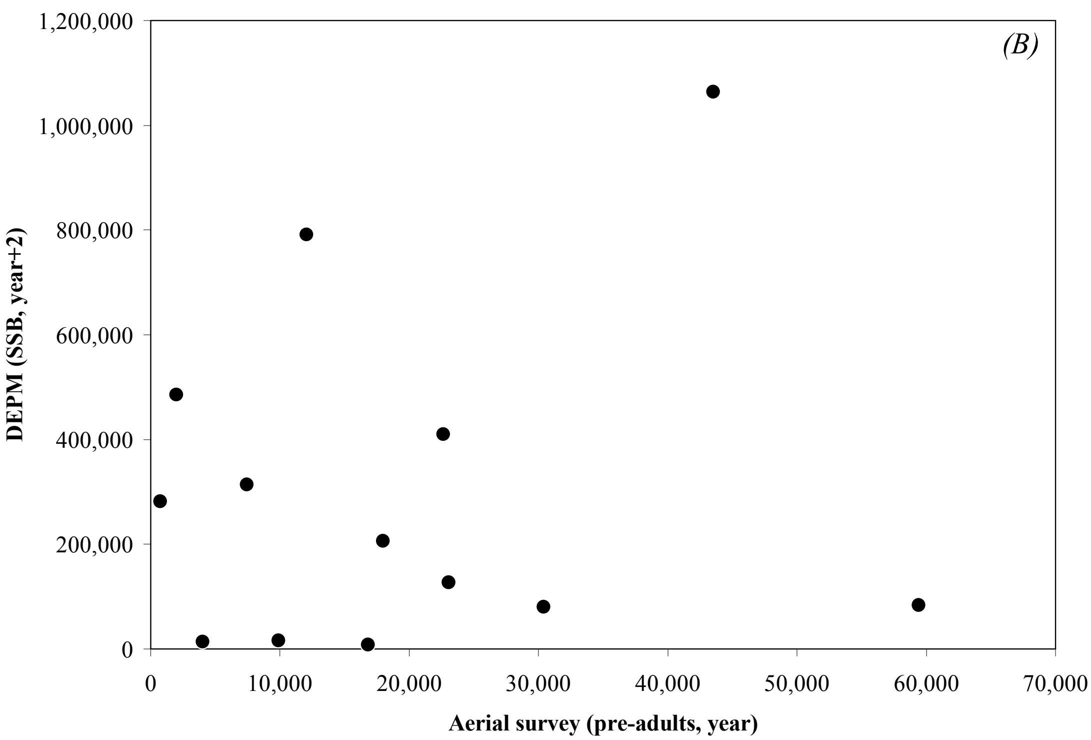




Figure 19. Comparisons of observed values for the DEPM survey (index of spawning stock biomass) and Aerial Spotter survey (index of young sardine): (A) year by year comparisons, and (B) surveys lagged two years, i.e. the aerial spotter index values were plotted against the DEPM index two years later.

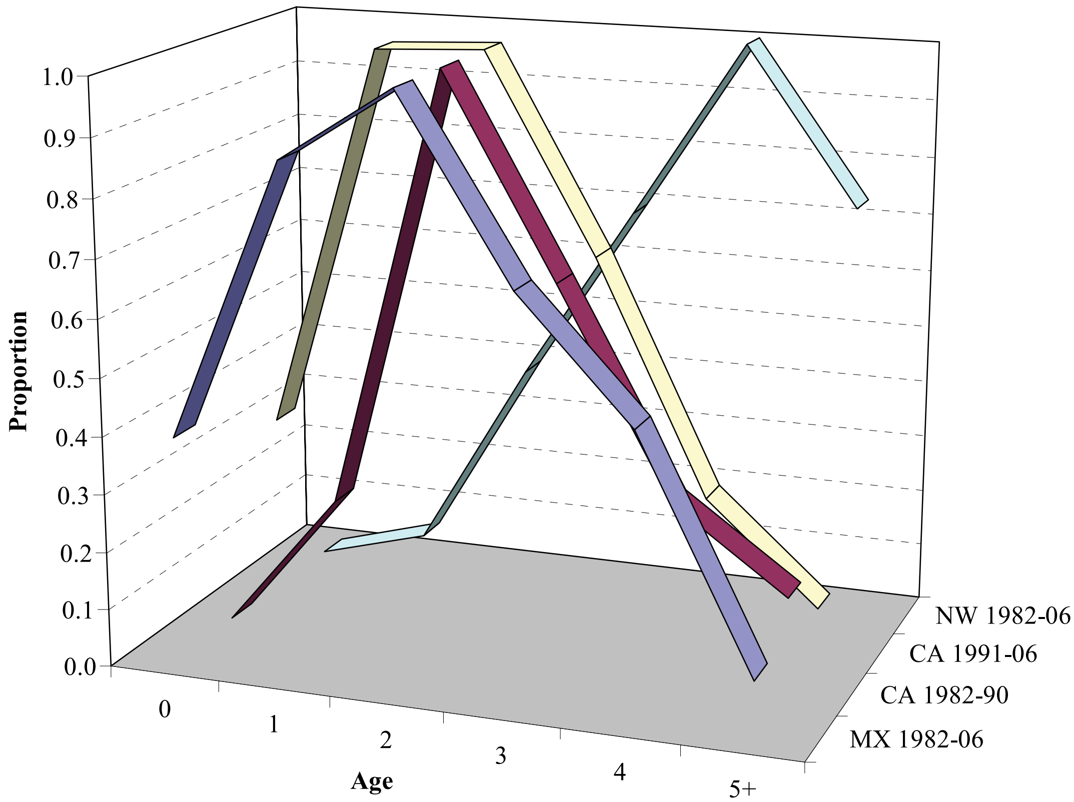



Figure 20. Fishery selectivities estimated in the ASAP baseline model. Selectivities for the California fishery were estimated in two time blocks: 1982-83 to 1990-91 (incidental fishery) and 1991-92 to 2006-07 (directed fishery).

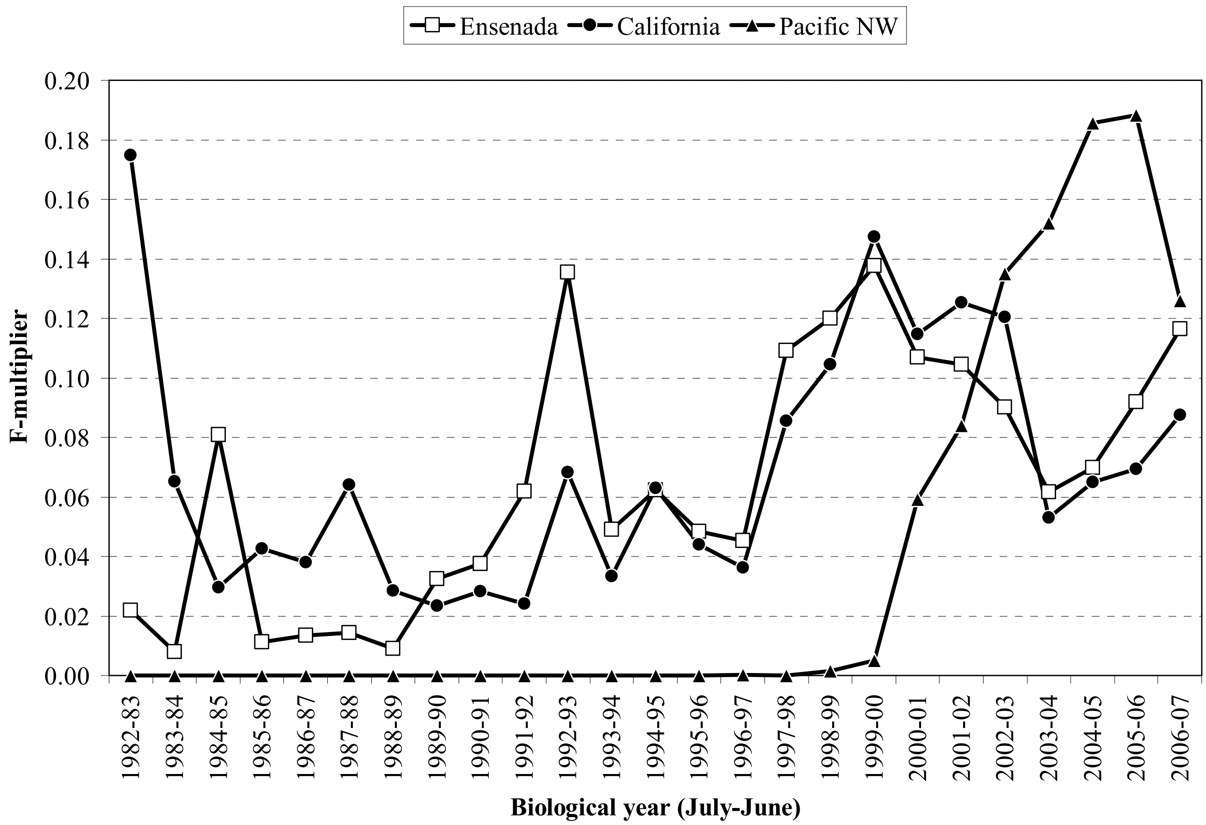



Figure 21. ASAP baseline model estimates of instantaneous rate of fishing mortality ($yr^{-1}$) for fully-selected age(s) in the three modeled fisheries.

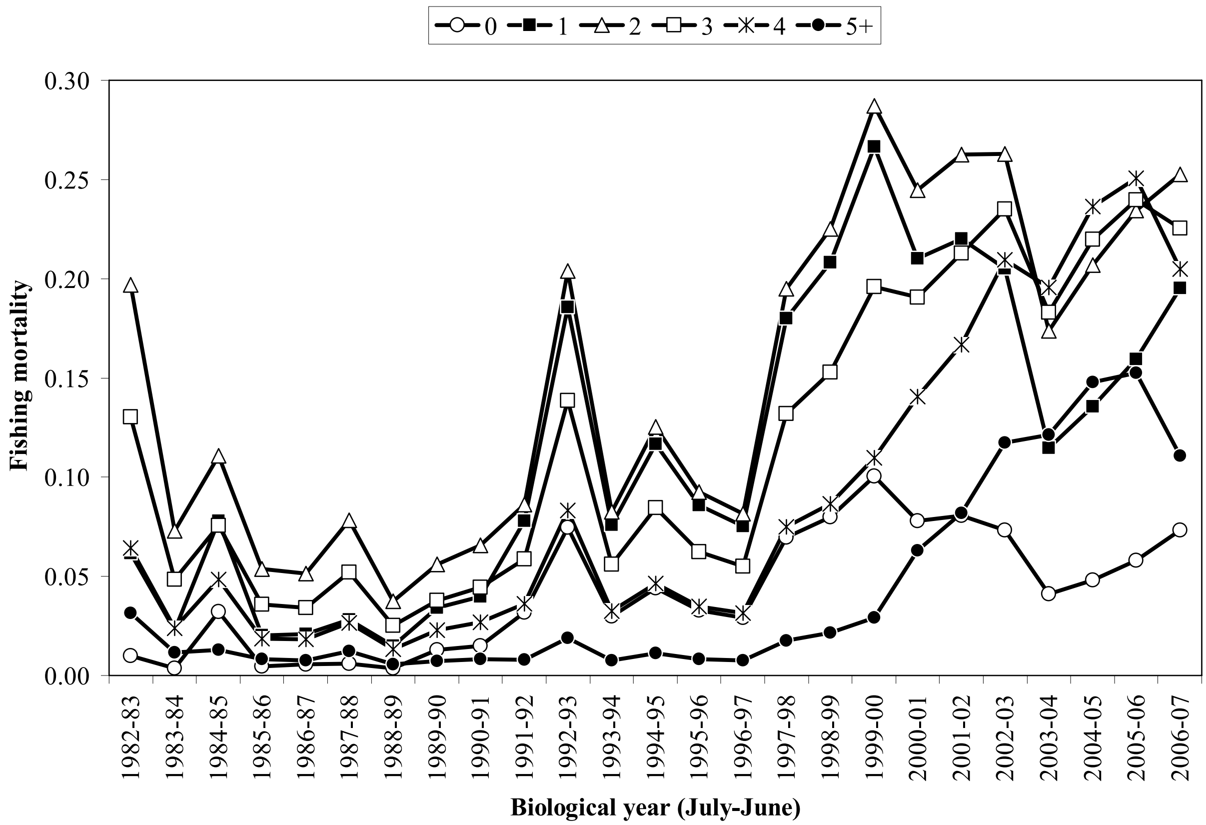



Figure 22. Estimated instantaneous rates of fishing mortality ($yr^{-1}$) by age and year for the combined fisheries in the ASAP baseline model.

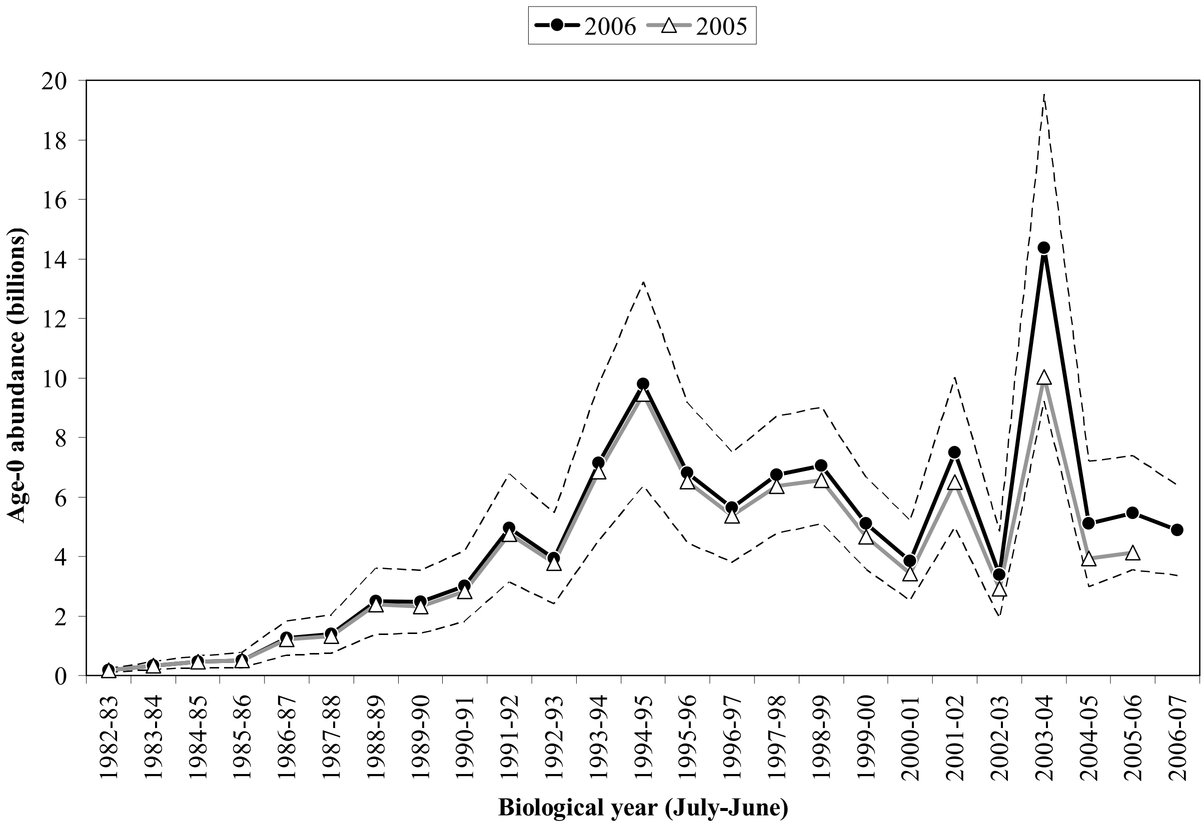



Figure 23. Pacific sardine recruitment estimates (age 0 abundance in billions) from the ASAP baseline model (solid circles) along with a 2-standard deviation uncertainty envelope (dashed lines). Corresponding estimates from Hill et al. (2005) are shown for comparison (triangles).

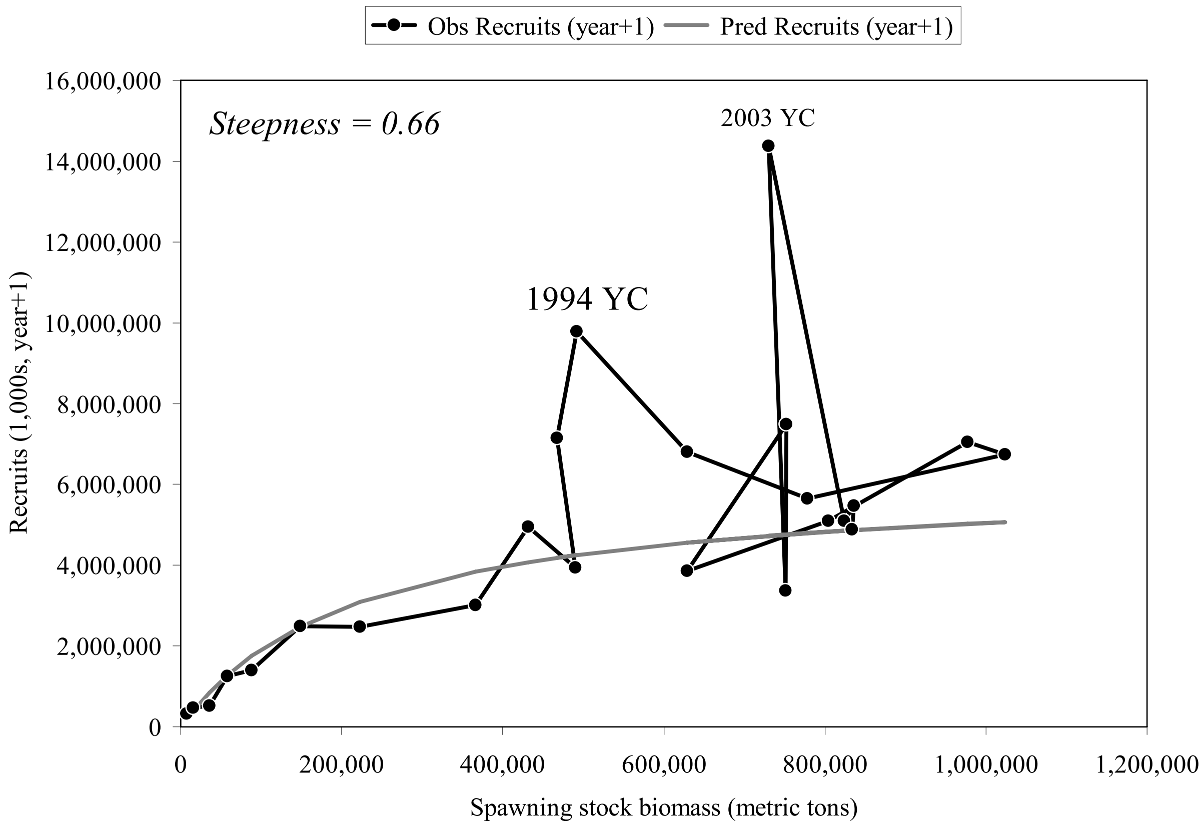



Figure 24. Sardine spawning stock biomass and recruitment estimates from the baseline model. Estimated recruitments from the Beverton-Holt stock-recruitment relationship are also shown. Year labels indicate the biological year associated with the spawning stock biomass.

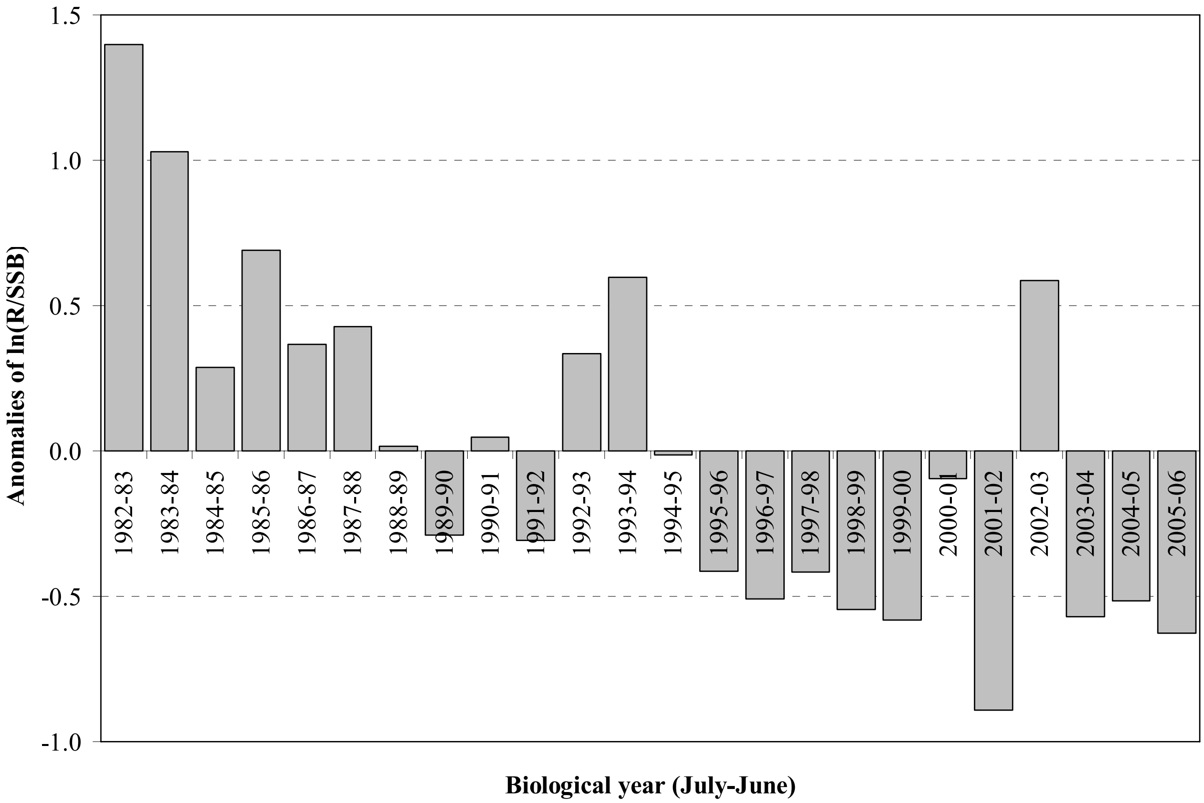
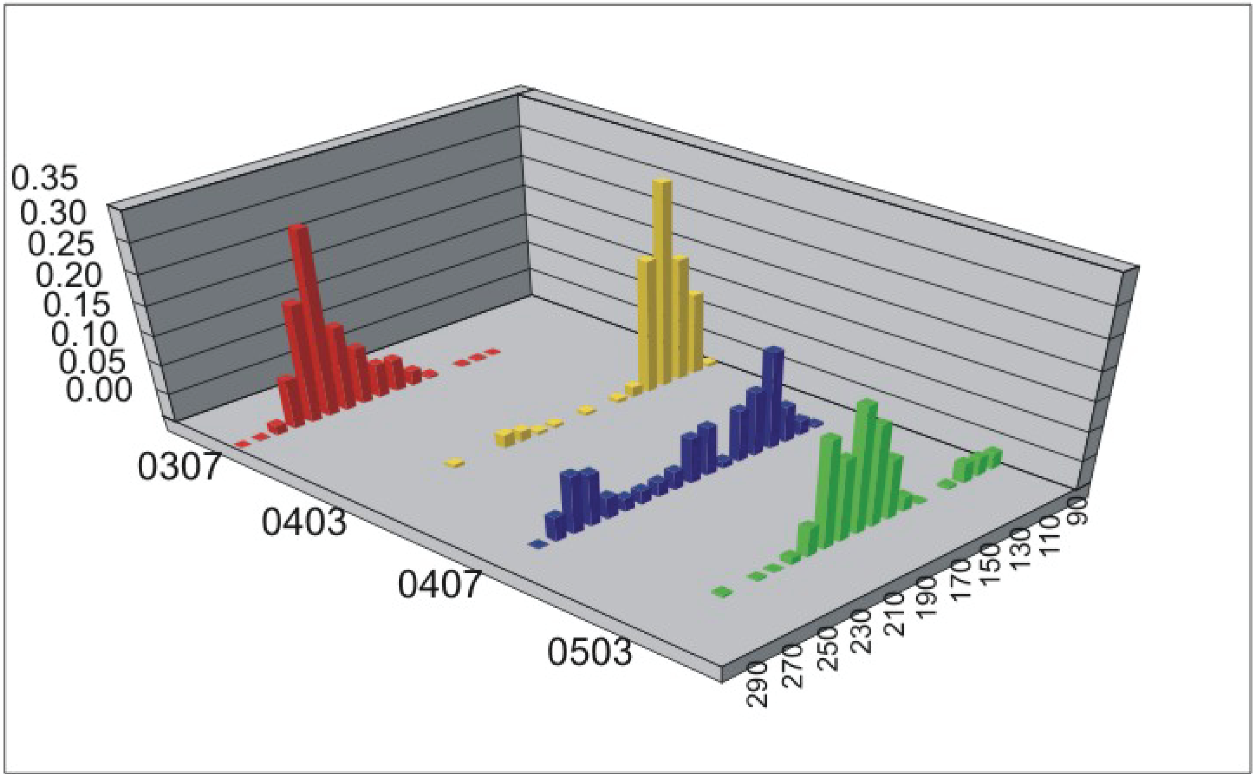



Figure 25. Relative reproductive success of Pacific sardine, 1982-83 to 2005-06.



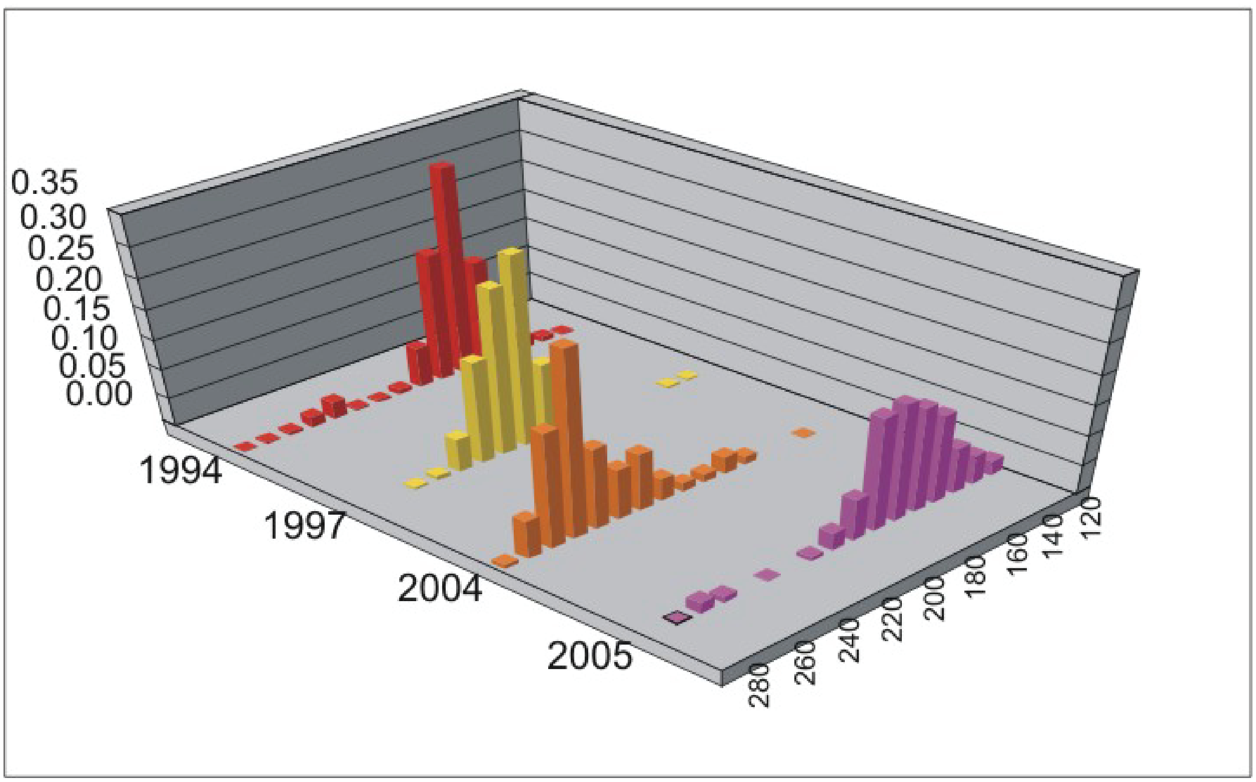




Figure 26. Length compositions of Pacific sardine collected during fishery-independent surveys, with evidence for a relatively strong 2003 year class in both areas: (top) Pacific northwest surveys in July 2003, March 2004, July 2004, and March 2005; (bottom) April surveys conducted in California offshore waters in 1994, 1997, 2004, and 2005.

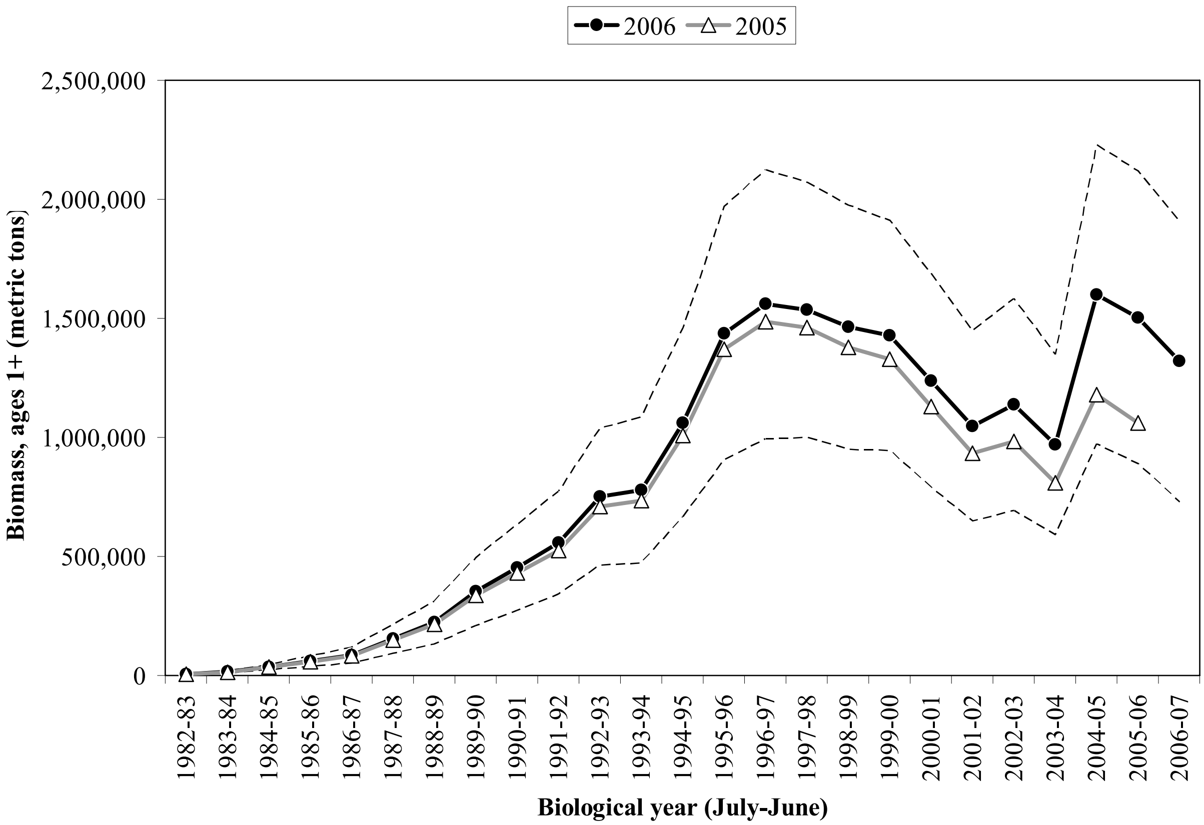



Figure 27. Pacific sardine stock biomass (ages 1+) estimates from the ASAP baseline model (solid circles) along with a 2-standard deviation uncertainty envelope (dashed lines). Corresponding estimates from Hill et al. (2005) are shown for comparison (triangles).

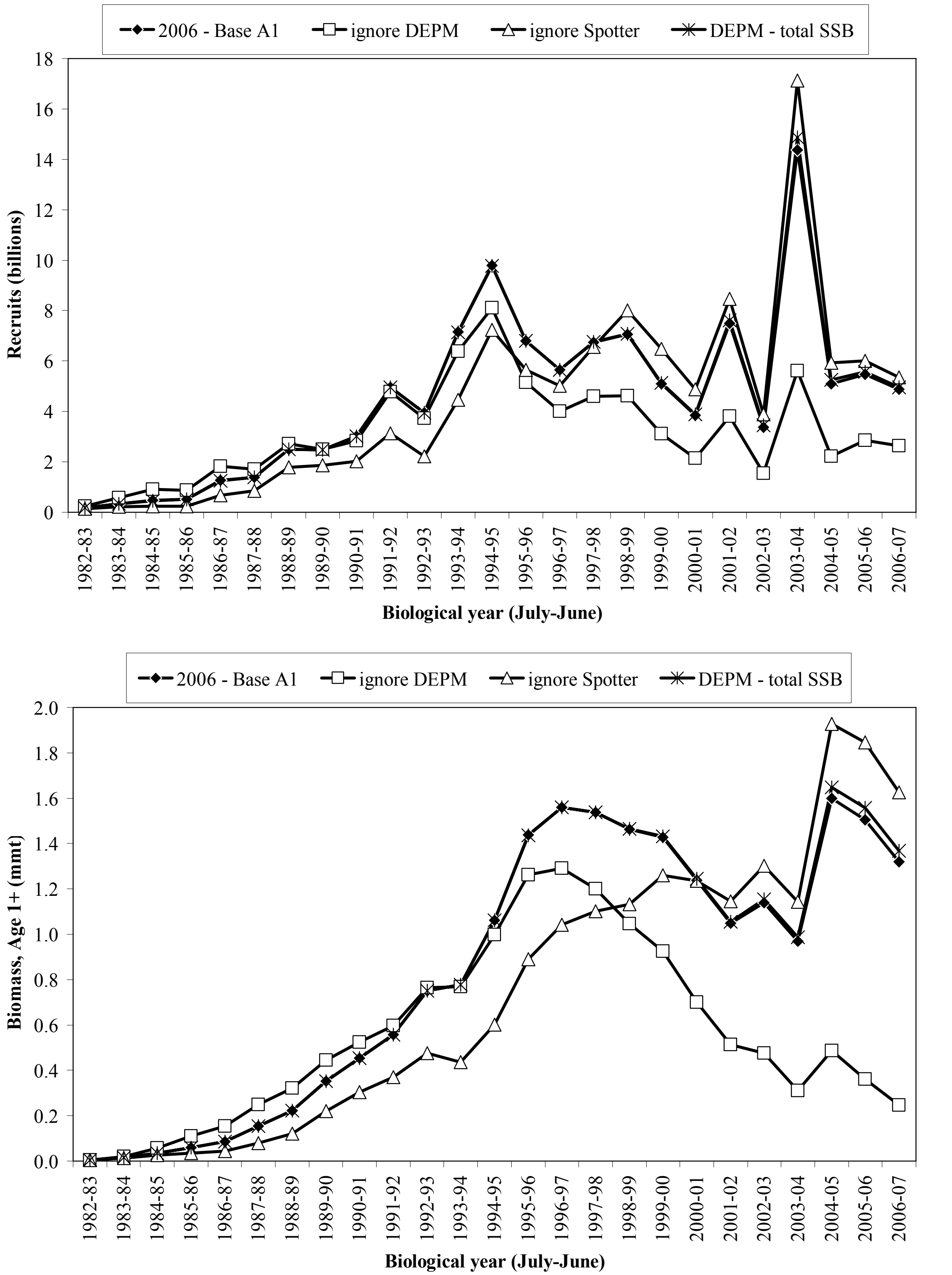



Figure 28. Sensitivity of recruitment and stock biomass estimates to the DEPM and Aerial Spotter indices.

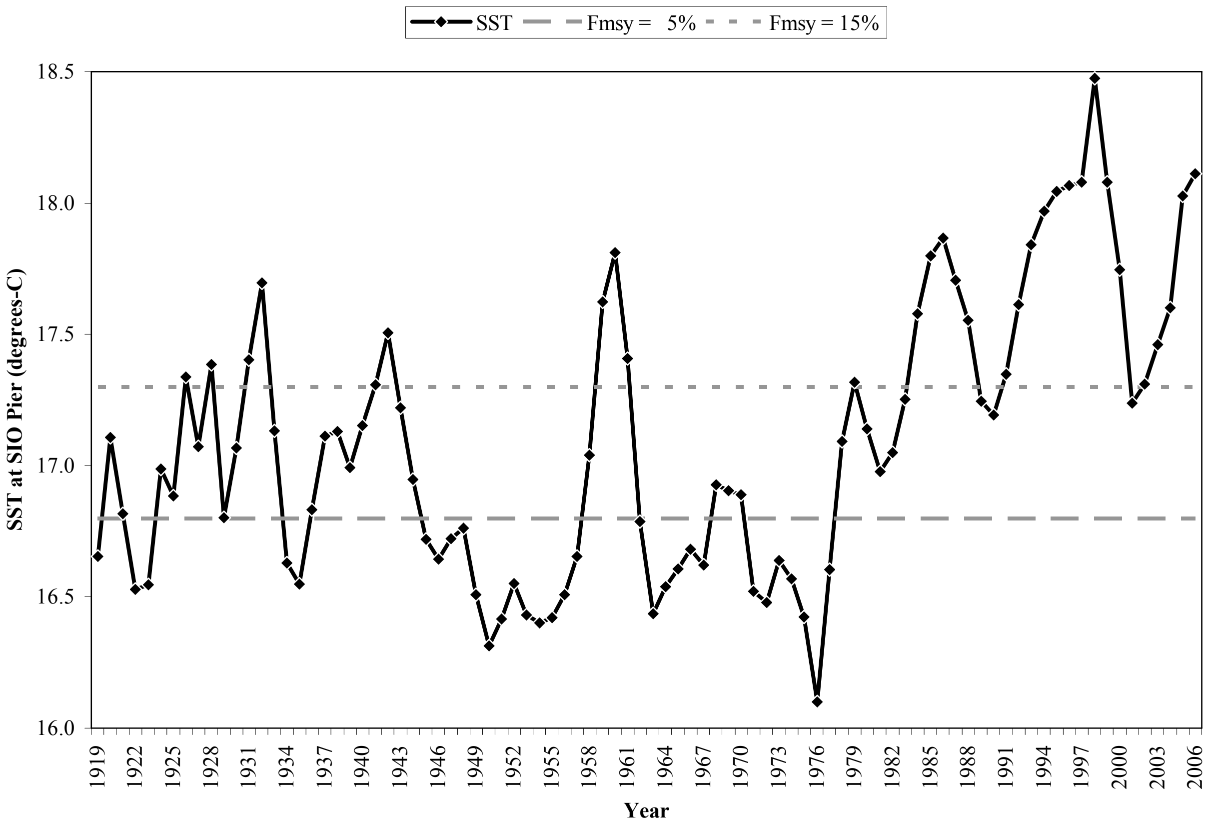



Figure 29. Three-season (July-June) running average of sea surface temperature (SST) data collected daily at Scripps Institution of Oceanography pier since 1916. For any given year, SST is the running average temperature during the three preceding years, e.g. the 2006 estimate is the average from July 1, 2003 through June 30, 2006. The 2006 value used for management in 2007 is 18.11 °C, so a 15% exploitation fraction ($F_{msy}$) should be applied in the harvest control rule.

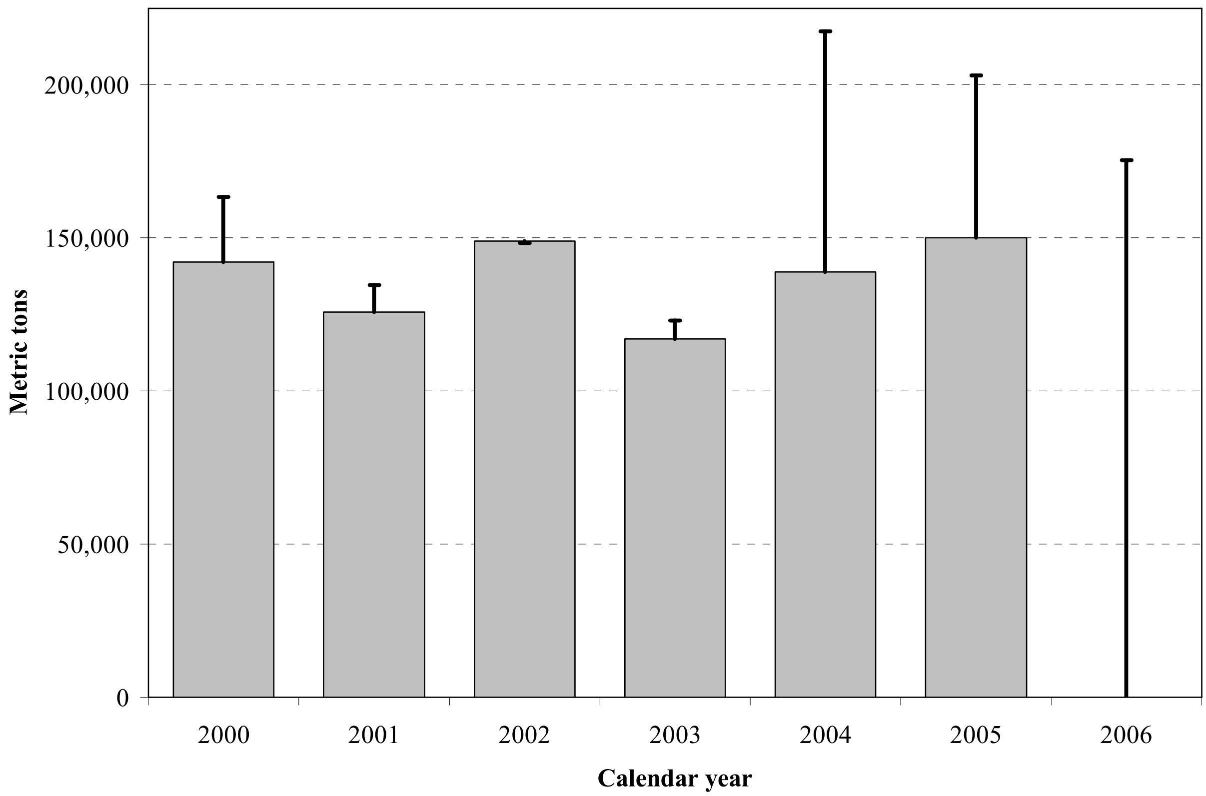



Figure 30. Coast-wide harvest (gray bars) of Pacific sardine relative to retrospective (theoretical) harvest guidelines (black lines) based on the biomass time series from the current assessment. Total HGs are based on the formula presented in 'HARVEST GUIDELINE FOR 2007' but are not prorated for assumed U.S. Distribution and therefore represent the sustainable harvest for the west coast of North America.

# APPENDICES I-IV

SCRS/1998/058 Col.Vol.Sci.Pap. ICCAT, 49 (2) : 246-253 (1999)

# A FLEXIBLE FORWARD AGE-STRUCTURED ASSESSMENT PROGRAM

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


## SUMMARY

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

## RÉSUMÉ

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

## RESUMEN

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


[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.

## 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

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

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

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

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

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

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

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

$$N_{a,y} = N_{a-1,y-1} e^{-Z_{a-1,y-1}} \quad for\ a < A$$

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

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

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

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

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

*Time-varying parameters*

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

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

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

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

as do the fleet specific fishing mortality rate multipliers

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

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

Parameter estimation

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

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

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

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

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

and indices of abundance (lognormally distributed)

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

where variables with a hat are estimated by the model and variables without a hat are input as observations. The second term in the catch proportion summation causes the likelihood to equal zero for a perfect fit. The sigmas in equation 18 are input by the user and can optionally be set to all equal 1.0 for equal weighting of all index points. The weights ($\lambda$) 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 $\lambda$ equal to the inverse of the assumed variance for each component

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

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

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

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

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

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

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

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

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

and over time

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

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

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

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

Additional Features

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

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

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

**Discussion**

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

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

**Acknowledgments**

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

**References**

Deriso, R.B., T.J. Quinn II and P.R. Neal. 1985. Catch-age analysis with auxiliary information. Can. J. Fish. Aquat. Sci. 42:815-824.

Fournier, D. and C.P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 39:1195-1207.

Greiwank, A. and G.F. Corliss (eds). 1991. Automatic differentiation of algorithms: theory, implementation and application. Proceedings of the SIAM Workshop on the Automatic Differentiation of Algorithms, held Jan. 6-8, Breckenridge, CO. Soc. Indust. and Applied Mathematics, Philadelphia.

ICCAT. 1997. Report for biennial period 1996-1997. Part I (1996), Vol. 2. Int. Comm. Cons. Atl. Tunas. 204 pp.

Ianelli, J.N. and D.A. Fournier. 1998. Alternative age-structured analyses of the NRC simulated stock assessment data. NOAA Tech. Memo. NMFS-F/SPO-30. pp. 81-96.

McAllister, M.K. and J.N. Ianelli. 1997. Bayesian stock assessment using catch-age data and the sampling-importance resampling algorithm. Can. J. Fish. Aquat. Sci. 54:284-300.

Methot, R. 1998. Application of stock synthesis to NRC test data sets. NOAA Tech. Memo. NMFS-F/SPO-30. pp. 59-80.

Porch, C.E. and S.C. Turner. In Press. Catch-at-age analyses of west Atlantic bluefin tuna incorporating data from 1960 to 1994 (preliminary results). Int. Comm. Cons. Atl. Tunas, Coll. Vol. Sci. Pap. (Working Document SCRS/96/119).

Powers, J.E. and V.R. Restrepo. 1992. Additional options for age-sequenced analysis. Int. Comm. Cons. Atl. Tunas, Coll. Vol. Sci. Pap. 39:346-354.

Restrepo, V.R. and C.M. Legault. In Press. A stochastic implementation of an age-structured production model. Int. Comm. Cons. Atl. Tunas, Coll. Vol. Sci. Pap. (Working Document SCRS/97/59).

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

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

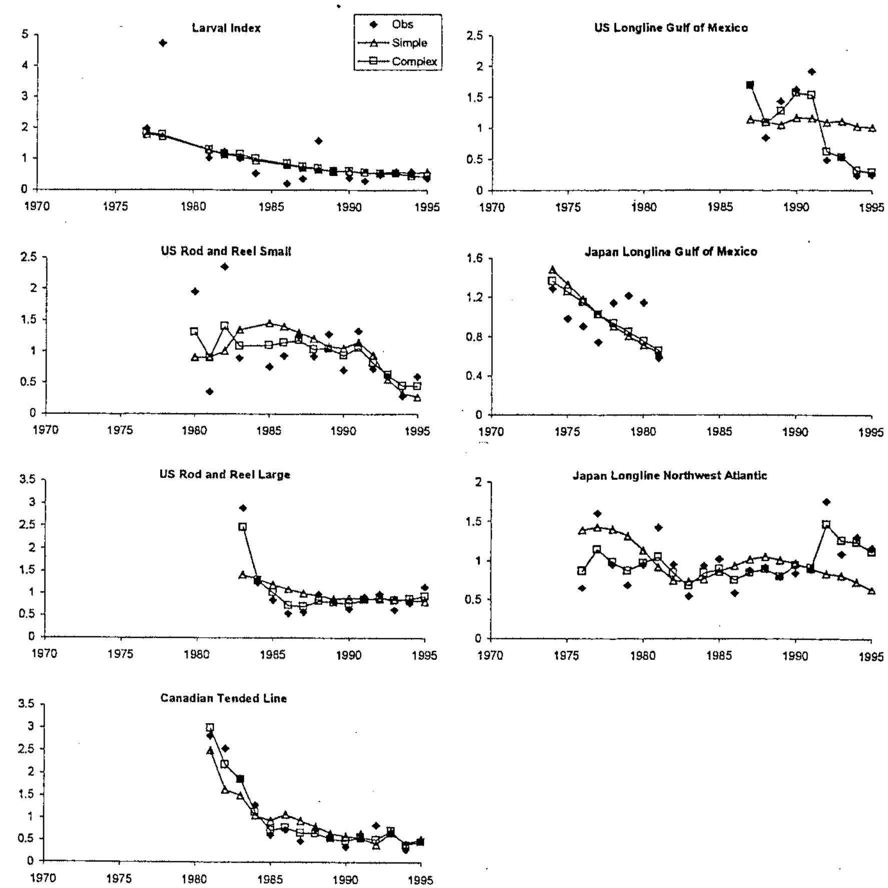



Figure 1. Observed and predicted indices for the simple and complex ASAP analyses.



(Legault and Restrepo 1999)

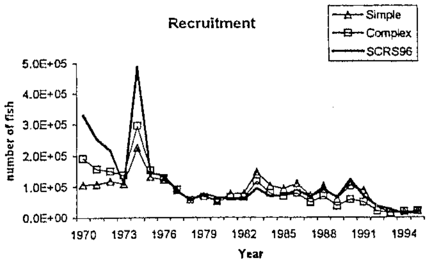



Figure 2. Estimated recruitment from two ASAP analyses and the SCRS 1996 assessment.

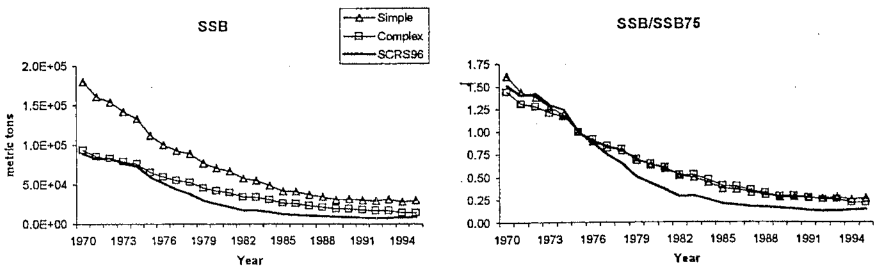



Figure 3. Spawning stock biomass (SSB) from two ASAP analyses and SCRS 1996.

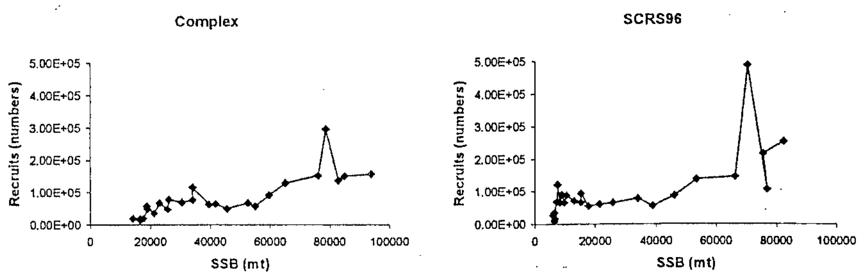



Figure 4. Complex ASAP analysis and SCRS 1996 stock-recruitment relationships.

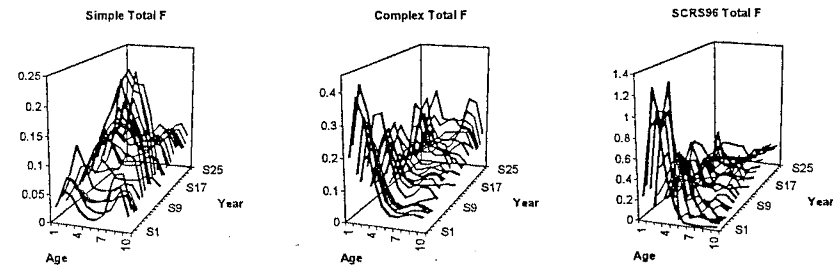



Figure 5. Estimated fishing mortality rates by age and year for two ASAP analyses and SCRS 1996.

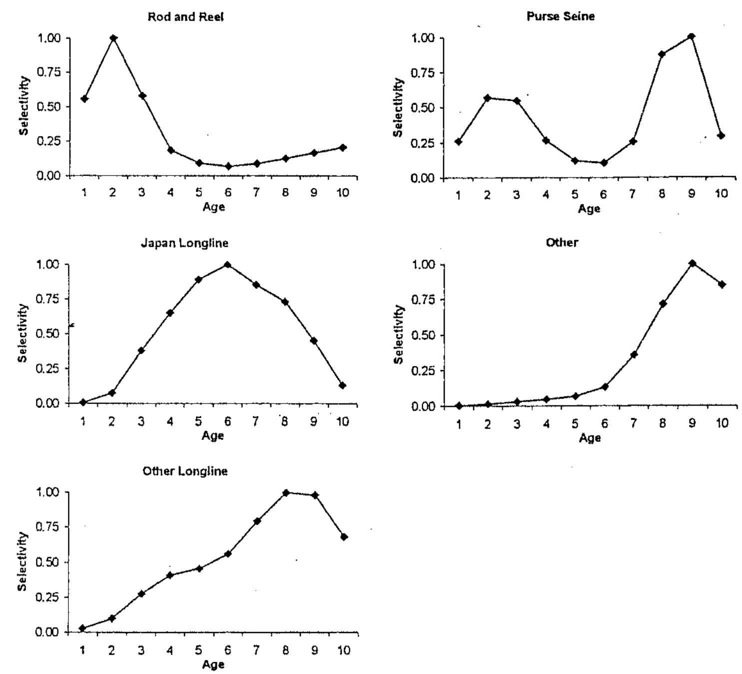



Figure 6a. Selectivity at age for the simple ASAP analysis, constant over all years for each fleet.

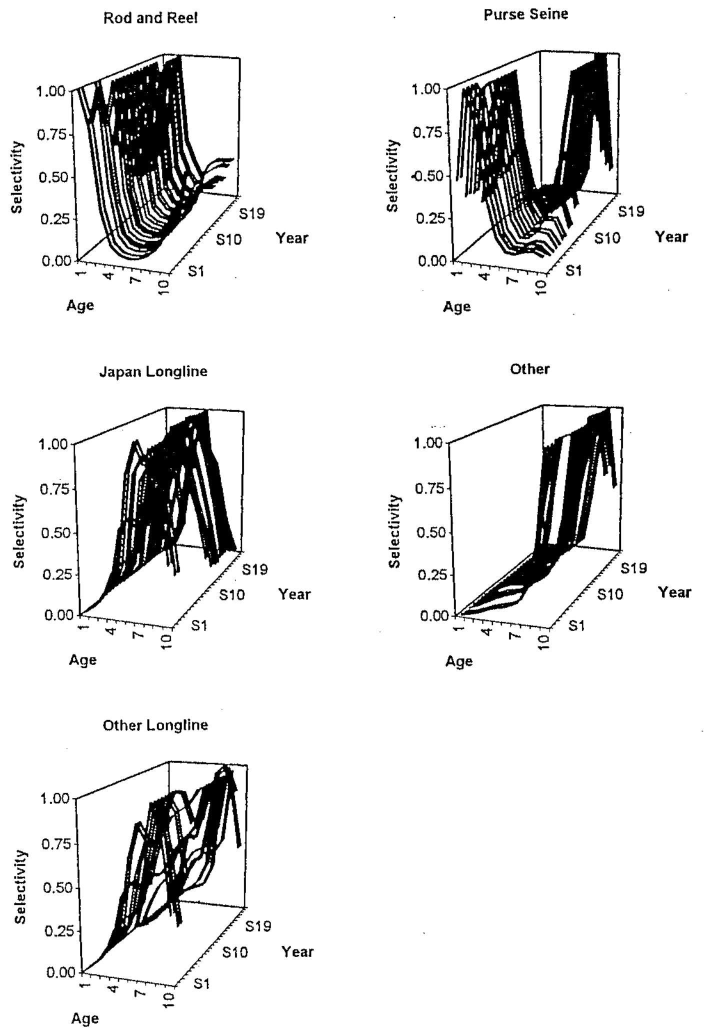



Figure 6b. Selectivity at age for the complex ASAP analysis.

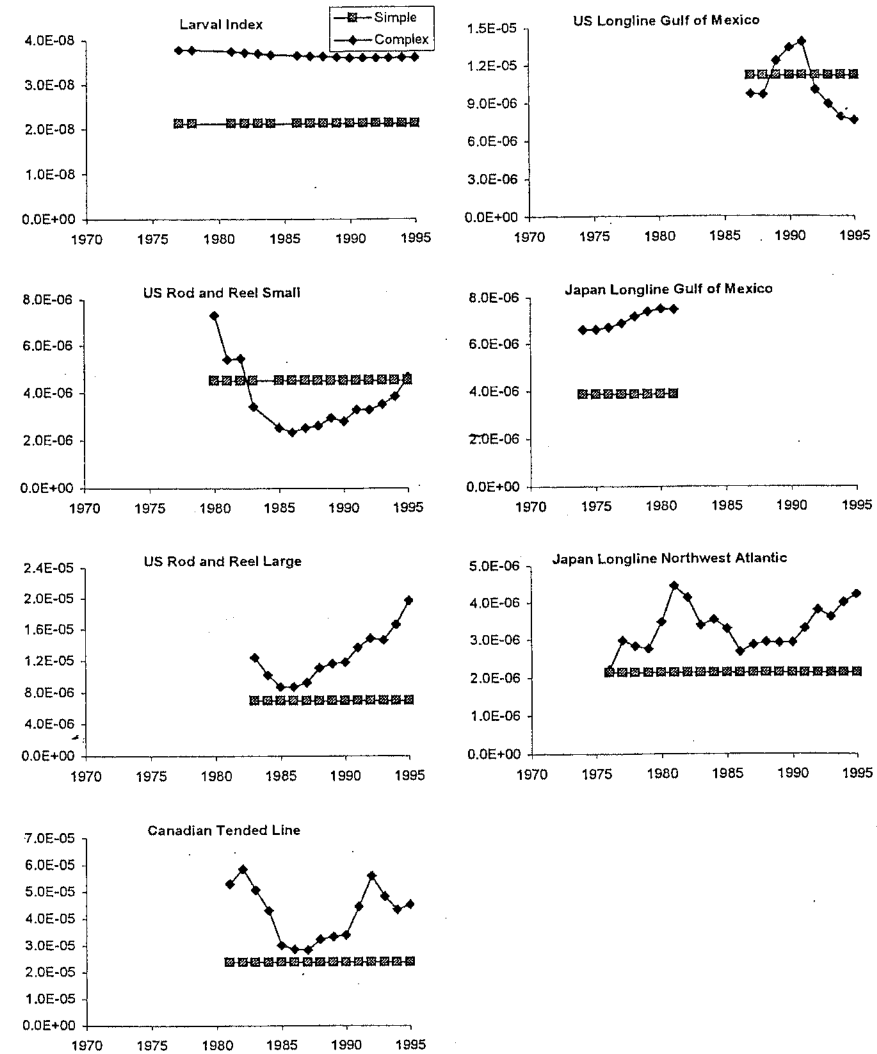



Figure 7. Catchability for each tuning index from the two ASAP analyses.

# 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 (.DAT) FILE

```
# 06_Base-A1: DEPM SD->SF
# Number of Years
   25
# First Year
   1982
# 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
   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   0.148   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   0.187
   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   0.146   0.157   0.169
   0.054   0.062   0.095   0.123   0.161   0.146
   0.047   0.070   0.079   0.082   0.131   0.146
   0.050   0.062   0.087   0.095   0.102   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   0.103   0.104   0.115
   0.051   0.056   0.063   0.065   0.071   0.093
   0.057   0.078   0.089   0.096   0.106   0.126
   0.042   0.070   0.101   0.114   0.132   0.145
   0.054   0.084   0.100   0.113   0.128   0.145
   0.046   0.088   0.101   0.113   0.136   0.150
   0.048   0.065   0.089   0.114   0.130   0.155
   0.046   0.067   0.080   0.088   0.110   0.150
   0.046   0.067   0.080   0.088   0.110   0.150
# 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
   1991
   1982
   1982
# 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
  403849.8  79132.48  93183.01  20685.07  8140.487  4557.628  29649.72
  28509.74  733750.1  88935.02  12513.04  2853.135   893.092  45858.38
  322969.2  345966.2  244256.7  14913.27  2013.493  2213.583  41811.61
         0         0         0         0         0         0  41811.61
# 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
  393256.3  288886.2  164242.6  81931.72  31977.57  13575.79  57742.96
  143736.6  290686.7  88381.13  33814.01  8185.344  1592.863   50456.8
  221427.8  236771.8  145253.8   14659.2  1715.397         0  46948.12
         0         0         0         0         0         0  44937.89
         0         0         0         0         0         0  37040.34
         0         0         0         0         0         0  47379.38
         0         0         0         0         0         0     56684
         0         0         0         0         0         0     56684
```

```
# 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  4538.045  38537.97  37039.26  25874.24  129241.6  39860.19
        0  141326.7  58284.51   45783.2  26509.66  93795.09  47747.13
        0  8924.823  230671.9   69492.9  33542.63  116754.1  54356.12
        0         0         0         0         0         0     35331
# Fleet 1 Discards at Age - Last Column is Total Weight
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
# 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
         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
         0          0          0          0          0          0          0
         0          0          0          0          0          0          0
# Fleet 1 Proportion Released at Age
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
# 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
         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
         0         0         0         0         0         0
         0         0         0         0         0         0
# Number of Indices
   2
#$DEPM
#$Aerial
# 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
    1982      -999       0.3       0.3      0.53      0.91      0.97      0.99         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      7659       0.3       0.3      0.53      0.91      0.97      0.99         1
    1986     15704       0.3       0.3      0.53      0.91      0.97      0.99         1
    1987     13526       0.3       0.3      0.53      0.91      0.97      0.99         1
    1988      -999       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    127102       0.3       0.3      0.53      0.91      0.97      0.99         1
    1994     79997       0.3       0.3      0.53      0.91      0.97      0.99         1
    1995     83176       0.3       0.3      0.53      0.91      0.97      0.99         1
    1996    409579       0.3       0.3      0.53      0.91      0.97      0.99         1
    1997    313986       0.3       0.3      0.53      0.91      0.97      0.99         1
    1998    282248       0.3       0.3      0.53      0.91      0.97      0.99         1
    1999   1063837       0.3       0.3      0.53      0.91      0.97      0.99         1
    2000    790925       0.3       0.3      0.53      0.91      0.97      0.99         1
    2001    206333       0.3       0.3      0.53      0.91      0.97      0.99         1
    2002    485121       0.3       0.3      0.53      0.91      0.97      0.99         1
    2003    281639       0.3       0.3      0.53      0.91      0.97      0.99         1
    2004    619320       0.3       0.3      0.53      0.91      0.97      0.99         1
    2005   1081612       0.3       0.3      0.53      0.91      0.97      0.99         1
    2006      -999       0.3       0.3      0.53      0.91      0.97      0.99         1
# INDEX - 2
    1982      -999       0.3         1         1      0.59      0.18      0.03         0
    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     19301       0.3         1         1      0.59      0.18      0.03         0
    1986     10177       0.3         1         1      0.59      0.18      0.03         0
    1987     16807       0.3         1         1      0.59      0.18      0.03         0
    1988      9880       0.3         1         1      0.59      0.18      0.03         0
    1989      3999       0.3         1         1      0.59      0.18      0.03         0
    1990     19781       0.3         1         1      0.59      0.18      0.03         0
    1991     20384       0.3         1         1      0.59      0.18      0.03         0
    1992    107743       0.3         1         1      0.59      0.18      0.03         0
    1993    150630       0.3         1         1      0.59      0.18      0.03         0
    1994     70240       0.3         1         1      0.59      0.18      0.03         0
    1995     23079       0.3         1         1      0.59      0.18      0.03         0
    1996     30414       0.3         1         1      0.59      0.18      0.03         0
    1997     59407       0.3         1         1      0.59      0.18      0.03         0
    1998     22651       0.3         1         1      0.59      0.18      0.03         0
    1999      7454       0.3         1         1      0.59      0.18      0.03         0
    2000       739       0.4         1         1      0.59      0.18      0.03         0
    2001     43543       0.4         1         1      0.59      0.18      0.03         0
    2002     12082       0.5         1         1      0.59      0.18      0.03         0
    2003     17959       0.6         1         1      0.59      0.18      0.03         0
    2004      2005       0.7         1         1      0.59      0.18      0.03         0
    2005      -999       0.3         1         1      0.59      0.18      0.03         0
    2006      -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
   0.5
   0.5
   0.4
   0.3
   0.2
   0.1
   0.05
#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        12
        50        50        12
        50        50        12
        50         0        12
        50         0        12
        50         0        12
        50         0        12
         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
         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   0   0
# Lambda for Selectivity Curvature at Age
  0
# Lambda for Selectivity Curvature Over Time
  0
# Lambda for Deviations from Initial Steepness
  0
# Lambda for Deviation from Initial log of Virgin Stock Size
  0
# NAA for Year 1
 25000  15000  9000  5400  3240  1944
# Log of F mult in 1st year by Fleet
  -2   -2   -5
# log of Catchability in 1st year by index
  0   0
# Initial log of Virgin Stock Size
  13.8
# Initial Steepness
  0.65
# 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
  2008
# Year Projected Recruits, What Projected, Target, non- directed F mult
      2007         2         2         2        -1
      2008         2         2         2        -1
# Test Value
  -23456
#####
# ---- FINIS ----
```

# APPENDIX IV

# ASAP REPORT (.REP) FILE

```
obj_fun        = 547.119
Component          RSS      nobs  Lambda  Likelihood
  Catch_Fleet_1        0.0019949   25   100   0.19949
  Catch_Fleet_2        0.00538988   25   100   0.538988
  Catch_Fleet_3        0.1224   25   100   12.24
Catch_Fleet_Total     0.129784   75   100   12.9784
  Discard_Fleet_1        0   25   0   0
  Discard_Fleet_2        0   25   0   0
  Discard_Fleet_3        0   25   0   0
Discard_Fleet_Total     0   75   0   0
CAA_proportions      N/A            450    see_below      215.238
Discard_proportions      N/A            450    see_below      0
  Index_Fit_1         13.2986   16   1   67.3526
  Index_Fit_2         37.7115   20   1   132.652
Index_Fit_Total     51.0101   36   2   200.005
  Selectivity_devs_fleet_1   15.5946  1   0  0
  Selectivity_devs_fleet_2   0  1   0  0
  Selectivity_devs_fleet_3   0  1   0  0
Selectivity_devs_Total   15.5946  3   0  0
  Catchability_devs_index_1  0  16  10  0
  Catchability_devs_index_2  0  20  10  0
Catchability_devs_Total  0  36  20  0
  Fmult_fleet_1     6.63998   24   1  6.63998
  Fmult_fleet_2     15.386   24   1  15.386
  Fmult_fleet_3     53.9198   24   1  53.9198
Fmult_fleet_Total   75.9458   72   3  75.9458
N_year_1            0   5   0   0
Stock-Recruit_Fit   15.3656  25   1   27.5839
Recruit_devs        15.3656   25   1   15.3656
SRR_steepness       8.0509e-05      1 0   0
SRR_virgin_stock    0.158039      1 0  0
Curvature_over_age  19.7258   12   0   0
Curvature_over_time 31.1892   414   0   0
F_penalty           2.16659    150     0.001     0.00216659
Mean_Sel_year1_pen  0   18      1000  0
Max_Sel_penalty     2.35433        1       100 0
Fmult_Max_penalty   0        ?      100 0

 Input and Estimated effective sample sizes for fleet 1
1982  50  17.5705
1983  50  2.81014
1984  50  33.3228
1985  50  96.1609
1986  50  26.8492
1987  50  32.8747
1988  50  248.685
1989  50  6.07636
1990  50  7.27095
1991  50  7.50472
1992  50  25.7758
1993  50  13.9515
1994  50  105.714
1995  50  192.16
1996  50  26.6725
1997  50  22.442
1998  50  21.328
1999  50  25.5639
2000  50  36.5195
2001  50  12.0709
2002  50  155.665
2003  50  12.8571
2004  50  14.3696
2005  50  7.55778
2006  0  2.73223
 Total  1200  1154.51
```

Input and Estimated effective sample sizes for fleet 2

| | | |
|---|---|---|
| 1982 | 0 | 0.812828 |
| 1983 | 0 | 1.21763 |
| 1984 | 0 | 1.73586 |
| 1985 | 0 | 2.10088 |
| 1986 | 0 | 2.00304 |
| 1987 | 0 | 1.92893 |
| 1988 | 0 | 2.18141 |
| 1989 | 50 | 173.131 |
| 1990 | 50 | 120.44 |
| 1991 | 50 | 7.62285 |
| 1992 | 50 | 11.1869 |
| 1993 | 50 | 22.1698 |
| 1994 | 50 | 38.9446 |
| 1995 | 50 | 11.3838 |
| 1996 | 50 | 63.6676 |
| 1997 | 50 | 11.4871 |
| 1998 | 50 | 400.314 |
| 1999 | 50 | 15.6407 |
| 2000 | 50 | 15.1235 |
| 2001 | 50 | 29.1268 |
| 2002 | 0 | 1.93462 |
| 2003 | 0 | 1.71357 |
| 2004 | 0 | 1.20123 |
| 2005 | 0 | 2.07514 |
| 2006 | 0 | 3.04096 |
| Total | 650 | 942.185 |

Input and Estimated effective sample sizes for fleet 3

| | | |
|---|---|---|
| 1982 | 0 | 3.27447 |
| 1983 | 0 | 3.56327 |
| 1984 | 0 | 1.64022 |
| 1985 | 0 | 1.92209 |
| 1986 | 0 | 2.40621 |
| 1987 | 0 | 3.21002 |
| 1988 | 0 | 2.58937 |
| 1989 | 0 | 2.93267 |
| 1990 | 0 | 2.83782 |
| 1991 | 0 | 3.07521 |
| 1992 | 0 | 3.49846 |
| 1993 | 0 | 3.21733 |
| 1994 | 0 | 3.49585 |
| 1995 | 0 | 3.39616 |
| 1996 | 0 | 2.88787 |
| 1997 | 0 | 2.99734 |
| 1998 | 0 | 3.1921 |
| 1999 | 12 | 11.5402 |
| 2000 | 12 | 7.72572 |
| 2001 | 12 | 11.1171 |
| 2002 | 12 | 11.5726 |
| 2003 | 12 | 6.95198 |
| 2004 | 12 | 8.88631 |
| 2005 | 12 | 22.1731 |
| 2006 | 0 | 2.01382 |
| Total | 84 | 132.117 |

Input and Estimated effective Discard sample sizes for fleet 1

| | | |
|---|---|---|
| 1982 | 0 | 1e+15 |
| 1983 | 0 | 1e+15 |
| 1984 | 0 | 1e+15 |
| 1985 | 0 | 1e+15 |
| 1986 | 0 | 1e+15 |
| 1987 | 0 | 1e+15 |
| 1988 | 0 | 1e+15 |
| 1989 | 0 | 1e+15 |
| 1990 | 0 | 1e+15 |
| 1991 | 0 | 1e+15 |
| 1992 | 0 | 1e+15 |
| 1993 | 0 | 1e+15 |
| 1994 | 0 | 1e+15 |
| 1995 | 0 | 1e+15 |
| 1996 | 0 | 1e+15 |

```
1997  0  1e+15
1998  0  1e+15
1999  0  1e+15
2000  0  1e+15
2001  0  1e+15
2002  0  1e+15
2003  0  1e+15
2004  0  1e+15
2005  0  1e+15
2006  0  1e+15
 Total  0  2.5e+16
 Input and Estimated effective Discard sample sizes for fleet 2
1982  0  1e+15
1983  0  1e+15
1984  0  1e+15
1985  0  1e+15
1986  0  1e+15
1987  0  1e+15
1988  0  1e+15
1989  0  1e+15
1990  0  1e+15
1991  0  1e+15
1992  0  1e+15
1993  0  1e+15
1994  0  1e+15
1995  0  1e+15
1996  0  1e+15
1997  0  1e+15
1998  0  1e+15
1999  0  1e+15
2000  0  1e+15
2001  0  1e+15
2002  0  1e+15
2003  0  1e+15
2004  0  1e+15
2005  0  1e+15
2006  0  1e+15
 Total  0  2.5e+16
 Input and Estimated effective Discard sample sizes for fleet 3
1982  0  1e+15
1983  0  1e+15
1984  0  1e+15
1985  0  1e+15
1986  0  1e+15
1987  0  1e+15
1988  0  1e+15
1989  0  1e+15
1990  0  1e+15
1991  0  1e+15
1992  0  1e+15
1993  0  1e+15
1994  0  1e+15
1995  0  1e+15
1996  0  1e+15
1997  0  1e+15
1998  0  1e+15
1999  0  1e+15
2000  0  1e+15
2001  0  1e+15
2002  0  1e+15
2003  0  1e+15
2004  0  1e+15
2005  0  1e+15
2006  0  1e+15
 Total  0  2.5e+16

Observed and predicted total fleet catch by year
 fleet 1 total catches
1982  337.2  333.468
1983  248.21  248.267
1984  396.98  401.733
```

```
1985  1191.13  1186.12
1986  1548.2  1559.41
1987  3810.27  3763.03
1988  2918.96  2937.76
1989  3658.77  3668.28
1990  5855.6  5835.7
1991  9574.24  9657.82
1992  24319.9  23778.6
1993  12431.2  12617.9
1994  32902.4  32602.8
1995  29819.7  29832.3
1996  29026.8  29267.8
1997  56172.3  55621.9
1998  51005.2  50803.5
1999  60360.5  59480.2
2000  52915.6  52961.7
2001  52980.7  52788.2
2002  60713.6  60512
2003  29649.7  29974.2
2004  45858.4  45709.1
2005  41811.6  41763.1
2006  41811.6  41713.2
 fleet 2 total catches
1982  149.5  147.868
1983  124.1  128.406
1984  3174.2  3041.86
1985  647.3  661.585
1986  1118.4  1117.89
1987  2076.8  2067.43
1988  1875.7  1908.06
1989  11663.2  11513.8
1990  14746.3  14755.4
1991  25447.3  25398.6
1992  49889.8  48601.5
1993  19108.4  19388.3
1994  33392.7  33265.9
1995  32834.8  32854.1
1996  36897.2  37135.9
1997  75179.4  74225.1
1998  62333.2  61994.4
1999  57743  57051.2
2000  50456.8  50429.6
2001  46948.1  46789.9
2002  44937.9  44945.3
2003  37040.3  37242.5
2004  47379.4  47348.9
2005  56684  56449.8
2006  56684  56545.7
 fleet 3 total catches
1982  0  0.0011299
1983  0  0.00138505
1984  0  0.00329934
1985  0  0.00728589
1986  0  0.0120295
1987  0  0.0171515
1988  0  0.0273334
1989  0  0.0422132
1990  0  0.0721152
1991  0  0.173433
1992  4.08  3.71129
1993  0  0.19791
1994  0  0.239992
1995  22.68  21.7146
1996  43.54  43.2061
1997  28.03  29.1227
1998  562.84  551.918
1999  1154.59  1169.58
2000  17923  17503.5
2001  25682.9  25622.7
2002  36123  35761.1
2003  39860.2  39804.6
```

```
2004  47747.1  47466.2
2005  54356.1  53951.2
2006  35331  35475.7
Observed and predicted total fleet Discards by year
 fleet 1 total Discards
1982  0  0
1983  0  0
1984  0  0
1985  0  0
1986  0  0
1987  0  0
1988  0  0
1989  0  0
1990  0  0
1991  0  0
1992  0  0
1993  0  0
1994  0  0
1995  0  0
1996  0  0
1997  0  0
1998  0  0
1999  0  0
2000  0  0
2001  0  0
2002  0  0
2003  0  0
2004  0  0
2005  0  0
2006  0  0
 fleet 2 total Discards
1982  0  0
1983  0  0
1984  0  0
1985  0  0
1986  0  0
1987  0  0
1988  0  0
1989  0  0
1990  0  0
1991  0  0
1992  0  0
1993  0  0
1994  0  0
1995  0  0
1996  0  0
1997  0  0
1998  0  0
1999  0  0
2000  0  0
2001  0  0
2002  0  0
2003  0  0
2004  0  0
2005  0  0
2006  0  0
 fleet 3 total Discards
1982  0  0
1983  0  0
1984  0  0
1985  0  0
1986  0  0
1987  0  0
1988  0  0
1989  0  0
1990  0  0
1991  0  0
1992  0  0
1993  0  0
1994  0  0
1995  0  0
```

```
1996  0  0
1997  0  0
1998  0  0
1999  0  0
2000  0  0
2001  0  0
2002  0  0
2003  0  0
2004  0  0
2005  0  0
2006  0  0

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"
1985  0.0861777  0.0209057  0.0577915
1986  0.0861777  0.0428649  0.0882363
1987  0.0861777  0.0369199  0.148081
1993  0.0861777  0.346932  0.48313
1994  0.0861777  0.218356  0.603974
1995  0.0861777  0.227033  0.756976
1996  0.0861777  1.11797  1.00019
1997  0.0861777  0.857042  0.902386
1998  0.0861777  0.770411  0.741247
1999  0.0861777  2.9038  0.563132
2000  0.0861777  2.15887  0.677965
2001  0.0861777  0.563197  0.671848
2002  0.0861777  1.32416  0.641003
2003  0.0861777  0.768749  0.760935
2004  0.0861777  1.69047  0.7516
2005  0.0861777  2.95232  0.724871
index number 2
units = 1
month = -1
starting and ending ages for selectivity = 1  6
selectivity choice = -1
" year, sigma2, obs index, pred index"
1985  0.0861777  0.595457  0.115016
1986  0.0861777  0.313972  0.167534
1987  0.0861777  0.518515  0.30878
1988  0.0861777  0.304809  0.421379
1989  0.0861777  0.123374  0.727223
1990  0.0861777  0.610266  0.720113
1991  0.0861777  0.628869  0.760289
1992  0.0861777  3.32399  0.621566
1993  0.0861777  4.6471  0.78324
1994  0.0861777  2.16698  1.12571
1995  0.0861777  0.712013  1.25021
1996  0.0861777  0.938306  1.26366
1997  0.0861777  1.83277  1.00539
1998  0.0861777  0.698808  0.819443
1999  0.0861777  0.229964  0.736223
2000  0.14842  0.022799  0.740299
2001  0.14842  1.34335  0.754905
2002  0.223144  0.372743  0.818937
2003  0.307485  0.554055  1.30033
2004  0.398776  0.0618565  1.18673

Selectivity by age and year for each fleet rescaled so max=1.0
 fleet 1 selectivity at age
 0.0072091 0.24344 1 0.657983 0.306401 0.167719
 0.0072091 0.24344 1 0.657983 0.306401 0.167719
 0.0072091 0.24344 1 0.657983 0.306401 0.167719
 0.0072091 0.24344 1 0.657983 0.306401 0.167719
 0.0072091 0.24344 1 0.657983 0.306401 0.167719
 0.0072091 0.24344 1 0.657983 0.306401 0.167719
 0.0072091 0.24344 1 0.657983 0.306401 0.167719
```

```
0.0072091 0.24344 1 0.657983 0.306401 0.167719
0.0072091 0.24344 1 0.657983 0.306401 0.167719
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
0.313406 0.990269 1 0.657902 0.253928 0.0813379
fleet 2 selectivity at age
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
0.39268 0.872428 1 0.691863 0.487295 0.0981551
fleet 3 selectivity at age
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
0.00105293 0.0556705 0.388168 0.692564 1 0.731143
```

```
Fmult by year for each fleet
1982   0.174819 0.0219865 7.20208e-07
1983   0.0651269 0.00789853 6.55667e-07
1984   0.0296097 0.0809585 5.97024e-07
1985   0.0425487 0.0113043 5.44215e-07
1986   0.0379237 0.0133753 4.98688e-07
1987   0.0641279 0.0142662 4.63511e-07
1988   0.0284462 0.00915621 4.43349e-07
1989   0.0235316 0.0324476 4.55607e-07
1990   0.0281811 0.0375969 5.53561e-07
1991   0.02419 0.0618492 1.07439e-06
1992   0.0683481 0.135366 2.21694e-05
1993   0.0334711 0.0491582 1.20926e-06
1994   0.0629626 0.0622387 1.303e-06
1995   0.0440354 0.0483377 9.02452e-05
1996   0.0361485 0.0452635 0.000116923
1997   0.085539 0.109245 7.26477e-05
1998   0.104541 0.11995 0.00160739
1999   0.147376 0.137773 0.00506412
2000   0.114737 0.106987 0.0592321
2001   0.125401 0.104635 0.0838698
2002   0.120372 0.0900977 0.135047
2003   0.0531199 0.0615953 0.151987
2004   0.0649629 0.0697721 0.18573
2005   0.0694832 0.0918336 0.188285
2006   0.0874143 0.116421 0.125969

Directed F by age and year for each fleet
 fleet 1 directed F at age
 0.00126028 0.0425579 0.174819 0.115028 0.0535646 0.0293203
 0.000469506 0.0158545 0.0651269 0.0428524 0.0199549 0.010923
 0.000213459 0.00720818 0.0296097 0.0194827 0.00907243 0.0049661
 0.000306738 0.0103581 0.0425487 0.0279963 0.013037 0.00713621
 0.000273395 0.00923214 0.0379237 0.0249531 0.0116198 0.00636051
 0.000462304 0.0156113 0.0641279 0.0421951 0.0196489 0.0107555
 0.000205072 0.00692495 0.0284462 0.0187171 0.00871595 0.00477096
 0.000169642 0.00572854 0.0235316 0.0154834 0.00721011 0.00394669
 0.00020316 0.00686041 0.0281811 0.0185427 0.0086347 0.00472649
 0.0075813 0.0239546 0.02419 0.0159146 0.00614252 0.00196756
 0.0214207 0.067683 0.0683481 0.0449663 0.0173555 0.00555929
 0.0104901 0.0331454 0.0334711 0.0220207 0.00849926 0.00272247
 0.0197329 0.0623499 0.0629626 0.0414232 0.015988 0.00512125
 0.013801 0.0436069 0.0440354 0.028971 0.0111818 0.00358175
 0.0113292 0.0357967 0.0361485 0.0237822 0.00917912 0.00294024
 0.0268085 0.0847066 0.085539 0.0562763 0.0217208 0.00695757
 0.0327639 0.103524 0.104541 0.0687779 0.026546 0.00850317
 0.0461887 0.145942 0.147376 0.0969592 0.037423 0.0119873
 0.0359591 0.11362 0.114737 0.0754854 0.0291348 0.00933243
 0.0393014 0.124181 0.125401 0.0825015 0.0318428 0.0101999
 0.0377254 0.119201 0.120372 0.0791931 0.0305659 0.00979082
 0.0166481 0.052603 0.0531199 0.0349477 0.0134886 0.00432067
 0.0203598 0.0643307 0.0649629 0.0427392 0.0164959 0.00528395
 0.0217765 0.068807 0.0694832 0.0457131 0.0176437 0.00565162
 0.0273962 0.0865636 0.0874143 0.05751 0.0221969 0.0071101
 fleet 2 directed F at age
 0.00863366 0.0191816 0.0219865 0.0152116 0.0107139 0.00215809
 0.0031016 0.0068909 0.00789853 0.0054647 0.00384892 0.000775281
 0.0317908 0.0706305 0.0809585 0.0560122 0.0394507 0.00794649
 0.00443896 0.00986216 0.0113043 0.007821 0.00550852 0.00110957
 0.0052522 0.011669 0.0133753 0.00925385 0.00651771 0.00131285
 0.00560206 0.0124462 0.0142662 0.00987025 0.00695186 0.0014003
 0.00359546 0.00798813 0.00915621 0.00633484 0.00446178 0.000898728
 0.0127415 0.0283082 0.0324476 0.0224493 0.0158115 0.00318489
 0.0147636 0.0328006 0.0375969 0.0260119 0.0183208 0.00369033
 0.024287 0.053959 0.0618492 0.0427912 0.0301388 0.00607081
 0.0531556 0.118097 0.135366 0.0936548 0.0659633 0.0132869
 0.0193035 0.042887 0.0491582 0.0340107 0.0239546 0.00482513
 0.0244399 0.0542988 0.0622387 0.0430606 0.0303286 0.00610904
 0.0189813 0.0421712 0.0483377 0.033443 0.0235547 0.00474459
 0.0177741 0.0394892 0.0452635 0.0313162 0.0220567 0.00444285
 0.0428985 0.0953087 0.109245 0.0755828 0.0532348 0.010723
```

```
 0.0471022 0.104648 0.11995 0.0829892 0.0584513 0.0117737
 0.0541009 0.120197 0.137773 0.0953202 0.0671363 0.0135231
 0.0420116 0.0933383 0.106987 0.0740202 0.0521342 0.0105013
 0.0410882 0.0912867 0.104635 0.0723932 0.0509882 0.0102705
 0.0353796 0.0786038 0.0900977 0.0623352 0.0439042 0.00884355
 0.0241873 0.0537375 0.0615953 0.0426155 0.0300151 0.00604589
 0.0273981 0.0608711 0.0697721 0.0482727 0.0339996 0.00684848
 0.0360612 0.0801182 0.0918336 0.0635362 0.0447501 0.00901393
 0.0457161 0.101569 0.116421 0.0805471 0.0567313 0.0114273
 fleet 3 directed F at age
 7.58327e-10 4.00944e-08 2.79562e-07 4.9879e-07 7.20208e-07 5.26575e-07
 6.9037e-10 3.65013e-08 2.54509e-07 4.54091e-07 6.55667e-07 4.79386e-07
 6.28623e-10 3.32366e-08 2.31746e-07 4.13477e-07 5.97024e-07 4.36509e-07
 5.73019e-10 3.02967e-08 2.11247e-07 3.76903e-07 5.44215e-07 3.97898e-07
 5.25082e-10 2.77622e-08 1.93575e-07 3.45373e-07 4.98688e-07 3.64612e-07
 4.88044e-10 2.58039e-08 1.7992e-07 3.21011e-07 4.63511e-07 3.38893e-07
 4.66814e-10 2.46814e-08 1.72094e-07 3.07047e-07 4.43349e-07 3.24151e-07
 4.79721e-10 2.53639e-08 1.76852e-07 3.15537e-07 4.55607e-07 3.33113e-07
 5.8286e-10 3.08171e-08 2.14875e-07 3.83377e-07 5.53561e-07 4.04732e-07
 1.13125e-09 5.98117e-08 4.17043e-07 7.44081e-07 1.07439e-06 7.8553e-07
 2.33428e-08 1.23418e-06 8.60545e-06 1.53537e-05 2.21694e-05 1.6209e-05
 1.27326e-09 6.73199e-08 4.69395e-07 8.37487e-07 1.20926e-06 8.84138e-07
 1.37196e-09 7.25387e-08 5.05783e-07 9.02411e-07 1.303e-06 9.52679e-07
 9.50216e-08 5.024e-06 3.50303e-05 6.25005e-05 9.02452e-05 6.59821e-05
 1.23111e-07 6.50915e-06 4.53857e-05 8.09764e-05 0.000116923 8.54871e-05
 7.64927e-08 4.04433e-06 2.81995e-05 5.03131e-05 7.26477e-05 5.31158e-05
 1.69246e-06 8.94842e-05 0.000623937 0.00111322 0.00160739 0.00117523
 5.33215e-06 0.000281922 0.00196573 0.00350723 0.00506412 0.00370259
 6.23671e-05 0.00329748 0.022992 0.041022 0.0592321 0.0433071
 8.83088e-05 0.00466907 0.0325556 0.0580852 0.0838698 0.0613208
 0.000142195 0.00751813 0.0524209 0.0935286 0.135047 0.0987385
 0.000160031 0.00846117 0.0589964 0.10526 0.151987 0.111124
 0.00019556 0.0103397 0.0720943 0.12863 0.18573 0.135795
 0.00019825 0.0104819 0.0730862 0.130399 0.188285 0.137663
 0.000132636 0.00701277 0.0488972 0.0872417 0.125969 0.0921014
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
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 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 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
 0 0 0 0 0 0
```

```
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 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 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
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 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
 0.00989395 0.0617395 0.196805 0.13024 0.0642792 0.031479
 0.0035711 0.0227454 0.0730257 0.0483176 0.0238045 0.0116988
 0.0320043 0.0778387 0.110568 0.0754952 0.0485237 0.012913
 0.0047457 0.0202202 0.0538532 0.0358177 0.018546 0.00824618
 0.0055256 0.0209011 0.0512991 0.0342073 0.018138 0.00767372
 0.00606436 0.0280576 0.0783943 0.0520656 0.0266012 0.0121561
 0.00380053 0.0149131 0.0376026 0.0250523 0.0131782 0.00567002
 0.0129112 0.0340367 0.0559794 0.037933 0.0230221 0.00713192
 0.0149667 0.039661 0.0657782 0.0445549 0.0269561 0.00841722
 0.0318683 0.0779137 0.0860396 0.0587066 0.0362824 0.00803916
 0.0745764 0.185781 0.203723 0.138637 0.083341 0.0188624
 0.0297935 0.0760325 0.0826298 0.0560323 0.032455 0.00754848
 0.0441728 0.116649 0.125202 0.0844848 0.0463179 0.0112312
 0.0327823 0.0857831 0.0924082 0.0624765 0.0348268 0.00839232
 0.0291034 0.0752924 0.0814574 0.0551793 0.0313528 0.00746858
 0.069707 0.180019 0.194813 0.131909 0.0750282 0.0177337
 0.0798678 0.208262 0.225116 0.15288 0.0866047 0.0214521
 0.100295 0.266421 0.287115 0.195787 0.109623 0.029213
 0.0780331 0.210256 0.244715 0.190528 0.140501 0.0631408
 0.0804779 0.220136 0.262592 0.21298 0.166701 0.0817911
 0.0732472 0.205323 0.262891 0.235057 0.209517 0.117373
 0.0409954 0.114802 0.173712 0.182824 0.19549 0.12149
 0.0479535 0.135542 0.206829 0.219641 0.236225 0.147927
 0.058036 0.159407 0.234403 0.239649 0.250679 0.152329
 0.0732449 0.195145 0.252732 0.225299 0.204897 0.110639

Population Numbers at the Start of the Year
```

```
 175909 15000 9000 5400 3240 1944
 327650 116755 9452.8 4955.11 3177.7 3299.35
 466770 218847 76502.9 5890.17 3164.84 4265.87
 519130 303030 135712 45913.5 3661.2 4843.78
 1.2612e+06 346336 199061 86201 29693.9 5629.3
 1.39199e+06 840752 227354 126762 55839.1 23291.2
 2.49516e+06 927440 547980 140909 80660.4 51871.5
 2.48055e+06 1.66621e+06 612479 353766 92117.1 87934.3
 3.00429e+06 1.64143e+06 1.07952e+06 388206 228310 118868
 4.9539e+06 1.98392e+06 1.0575e+06 677557 248882 227982
 3.94064e+06 3.21654e+06 1.23018e+06 650423 428284 312484
 7.14775e+06 2.45167e+06 1.79055e+06 672629 379550 469681
 9.78495e+06 4.65063e+06 1.52308e+06 1.10506e+06 426308 558764
 6.80306e+06 6.27562e+06 2.77418e+06 900805 680730 643196
 5.64093e+06 4.41316e+06 3.86086e+06 1.69545e+06 567257 868233
 6.73745e+06 3.67277e+06 2.74367e+06 2.38555e+06 1.07548e+06 946170
 7.05428e+06 4.21215e+06 2.05634e+06 1.51359e+06 1.40147e+06 1.29189e+06
 5.09969e+06 4.36565e+06 2.29266e+06 1.10055e+06 870755 1.7091e+06
 3.85269e+06 3.09221e+06 2.24195e+06 1.15327e+06 606545 1.63574e+06
 7.48696e+06 2.38868e+06 1.67972e+06 1.1766e+06 638949 1.38267e+06
 3.37096e+06 4.6306e+06 1.2848e+06 865921 637405 1.21658e+06
 1.43697e+07 2.10003e+06 2.52783e+06 662134 458856 1.07168e+06
 5.09979e+06 9.24543e+06 1.25502e+06 1.42426e+06 369682 889153
 5.4682e+06 3.25843e+06 5.41183e+06 684080 766447 709729
 4.87735e+06 3.45877e+06 1.86235e+06 2.86964e+06 360837 808374
q by index
 index 1 q over time
1985  1.43169e-06
1986  1.43169e-06
1987  1.43169e-06
1993  1.43169e-06
1994  1.43169e-06
1995  1.43169e-06
1996  1.43169e-06
1997  1.43169e-06
1998  1.43169e-06
1999  1.43169e-06
2000  1.43169e-06
2001  1.43169e-06
2002  1.43169e-06
2003  1.43169e-06
2004  1.43169e-06
2005  1.43169e-06
 index 2 q over time
1985  1.61491e-06
1986  1.61491e-06
1987  1.61491e-06
1988  1.61491e-06
1989  1.61491e-06
1990  1.61491e-06
1991  1.61491e-06
1992  1.61491e-06
1993  1.61491e-06
1994  1.61491e-06
1995  1.61491e-06
1996  1.61491e-06
1997  1.61491e-06
1998  1.61491e-06
1999  1.61491e-06
2000  1.61491e-06
2001  1.61491e-06
2002  1.61491e-06
2003  1.61491e-06
2004  1.61491e-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 =  0.0714593 0.200877 0.465516 0.189411 0.0545472 0.018189
Year 2 Obs  =  0.169036 0.314323 0.482457 0.0330455 0.00113799 0
Year 2 Pred =  0.0532061 0.63454 0.20618 0.0719299 0.0217261 0.0124175
```

```
Year 3 Obs  =  0.00623416 0.296401 0.593645 0.10372 0 0
Year 3 Pred =  0.0249648 0.38697 0.54739 0.0281809 0.00713939 0.00535535
Year 4 Obs  =  0.00241776 0.285805 0.616905 0.0899026 0.00496916 0
Year 4 Pred =  0.0155072 0.303476 0.549655 0.123383 0.00461845 0.00336072
Year 5 Obs  =  0.0189627 0.119253 0.605573 0.235668 0.0178412 0.00270213
Year 5 Pred =  0.0257107 0.236716 0.551065 0.158264 0.0255773 0.00266716
Year 6 Obs  =  0.00130323 0.499856 0.343311 0.130117 0.0233988 0.00201374
Year 6 Pred =  0.018758 0.37869 0.410978 0.152615 0.0316772 0.00728132
Year 7 Obs  =  0.0177527 0.249386 0.558377 0.129822 0.0392278 0.00543565
Year 7 Pred =  0.0198293 0.247604 0.594657 0.101201 0.0271257 0.00958209
Year 8 Obs  =  0.00703147 0.589819 0.342294 0.0574598 0.00339551 0
Year 8 Pred =  0.0138317 0.310673 0.464366 0.177962 0.0217287 0.0114381
Year 9 Obs  =  0.0308006 0.216845 0.332065 0.238511 0.115201 0.0665783
Year 9 Pred =  0.0119487 0.217937 0.581705 0.138998 0.0383788 0.0110324
Year 10 Obs  =  0.0925943 0.264054 0.353626 0.152843 0.0658885 0.0709947
Year 10 Pred =  0.308709 0.38241 0.205073 0.0875397 0.0125404 0.00372822
Year 11 Obs  =  0.107367 0.47486 0.314778 0.0729923 0.0192408 0.0107617
Year 11 Pred =  0.20678 0.506935 0.194208 0.0695745 0.0181353 0.00436672
Year 12 Obs  =  0.171705 0.266947 0.322688 0.193097 0.0324528 0.0131112
Year 12 Pred =  0.322974 0.342625 0.251927 0.0630302 0.0138782 0.00556521
Year 13 Obs  =  0.380979 0.436043 0.119058 0.0547803 0.00753916 0.00160051
Year 13 Pred =  0.311138 0.451928 0.148878 0.0724025 0.0109721 0.00468223
Year 14 Obs  =  0.180045 0.509112 0.280958 0.0258238 0.00380215 0.000259252
Year 14 Pred =  0.182148 0.518074 0.230566 0.0499386 0.0147532 0.00452039
Year 15 Obs  =  0.230241 0.247479 0.351243 0.147211 0.018383 0.00544268
Year 15 Pred =  0.158819 0.384299 0.338546 0.0990016 0.0129265 0.00640832
Year 16 Obs  =  0.067421 0.446998 0.300266 0.134368 0.0430546 0.00789294
Year 16 Pred =  0.210353 0.344528 0.258173 0.151954 0.027139 0.00785348
Year 17 Obs  =  0.209362 0.575347 0.175449 0.0243546 0.0135849 0.00190237
Year 17 Pred =  0.232813 0.414323 0.202717 0.101419 0.0373591 0.0113685
Year 18 Obs  =  0.172698 0.601383 0.208442 0.0114978 0.00488724 0.00109176
Year 18 Pred =  0.18217 0.457132 0.240209 0.0790217 0.0250944 0.0163731
Year 19 Obs  =  0.195086 0.292953 0.318977 0.176777 0.0141252 0.00208159
Year 19 Pred =  0.16831 0.401918 0.289759 0.100476 0.0208638 0.0186735
Year 20 Obs  =  0.530444 0.185772 0.149451 0.106517 0.0207639 0.0070519
Year 20 Pred =  0.33 0.312214 0.21754 0.102501 0.0219372 0.015807
Year 21 Obs  =  0.141362 0.634408 0.175105 0.0350454 0.0112822 0.00279752
Year 21 Pred =  0.144094 0.588924 0.160811 0.0721964 0.020748 0.0132258
Year 22 Obs  =  0.662539 0.129821 0.152872 0.0339351 0.0133549 0.00747706
Year 22 Pred =  0.474394 0.211741 0.250576 0.0430039 0.0114368 0.0088483
Year 23 Obs  =  0.032866 0.845866 0.102524 0.014425 0.00328909 0.00102956
Year 23 Pred =  0.127033 0.698986 0.0927734 0.0688691 0.00684837 0.00549048
Year 24 Obs  =  0.34641 0.371076 0.261985 0.0159957 0.00215963 0.00237424
Year 24 Pred =  0.164202 0.295144 0.478566 0.0397051 0.0170857 0.00529728
Year 25 Obs  =  0 0 0 0 0 0
Year 25 Pred =  0.182013 0.385799 0.204425 0.209792 0.0102754 0.0076959
 fleet 2
Year 1 Obs  =  0 0 0 0 0 0
Year 1 Pred =  0.724252 0.133949 0.0866179 0.0370581 0.0161416 0.00198067
Year 2 Obs  =  0 0 0 0 0 0
Year 2 Pred =  0.527337 0.413776 0.037516 0.0137621 0.00628715 0.00132231
Year 3 Obs  =  0 0 0 0 0 0
Year 3 Pred =  0.407363 0.41544 0.16398 0.00887676 0.0034014 0.000938887
Year 4 Obs  =  0 0 0 0 0 0
Year 4 Pred =  0.322278 0.414955 0.209715 0.0494993 0.00280245 0.000750418
Year 5 Obs  =  0 0 0 0 0 0
Year 5 Pred =  0.465501 0.281977 0.183169 0.0553139 0.0135209 0.000518833
Year 6 Obs  =  0 0 0 0 0 0
Year 6 Pred =  0.34002 0.451628 0.136766 0.0534025 0.0167652 0.00141808
Year 7 Obs  =  0 0 0 0 0 0
Year 7 Pred =  0.397496 0.326559 0.218843 0.0391613 0.0158763 0.00206375
Year 8 Obs  =  0.344479 0.407095 0.177018 0.0490113 0.0216422 0.000754415
Year 8 Pred =  0.294356 0.434992 0.181426 0.0731094 0.0135013 0.00261533
Year 9 Obs  =  0.23302 0.362699 0.30618 0.0708474 0.0145262 0.0127277
Year 9 Pred =  0.292223 0.350674 0.261178 0.0656219 0.0274049 0.00289891
Year 10 Obs  =  0.0986565 0.326966 0.241201 0.201222 0.0892526 0.0427021
Year 10 Pred =  0.368589 0.321046 0.19542 0.0877253 0.0229326 0.00428729
Year 11 Obs  =  0.294107 0.638161 0.0669132 0.000492181 0.000327089 0
Year 11 Pred =  0.255724 0.440818 0.191689 0.072217 0.0343508 0.00520122
Year 12 Obs  =  0.344222 0.228855 0.398122 0.0288015 0 0
Year 12 Pred =  0.382455 0.285284 0.238098 0.0626453 0.0251708 0.0063472
```

```
Year 13 Obs  =  0.485498 0.323118 0.102549 0.0791029 0.00973217 0
Year 13 Pred =  0.374948 0.382942 0.143192 0.0732318 0.0202515 0.00543451
Year 14 Obs  =  0.430594 0.325179 0.191424 0.039749 0.0130531 0
Year 14 Pred =  0.227881 0.455743 0.230222 0.0524381 0.0282696 0.00544687
Year 15 Obs  =  0.111799 0.314561 0.371607 0.131316 0.0650148 0.00570222
Year 15 Pred =  0.196484 0.334303 0.334282 0.102801 0.0244938 0.00763587
Year 16 Obs  =  0.0591969 0.208714 0.352109 0.243401 0.105662 0.0309165
Year 16 Pred =  0.251821 0.29001 0.246673 0.15268 0.0497608 0.0090551
Year 17 Obs  =  0.301735 0.320996 0.173528 0.115662 0.0726467 0.015432
Year 17 Pred =  0.277413 0.34714 0.192788 0.10143 0.0681815 0.013047
Year 18 Obs  =  0.403808 0.296637 0.168649 0.08413 0.0328356 0.01394
Year 18 Pred =  0.223291 0.393984 0.23499 0.0812954 0.0471107 0.0193291
Year 19 Obs  =  0.253774 0.513221 0.156041 0.0597002 0.0144516 0.00281227
Year 19 Pred =  0.206148 0.346141 0.283253 0.103291 0.0391393 0.0220285
Year 20 Obs  =  0.357241 0.381996 0.234345 0.0236504 0.00276754 0
Year 20 Pred =  0.384611 0.255862 0.202356 0.100268 0.0391597 0.0177437
Year 21 Obs  =  0 0 0 0 0 0
Year 21 Pred =  0.182017 0.523083 0.162125 0.0765435 0.0401414 0.0160907
Year 22 Obs  =  0 0 0 0 0 0
Year 22 Pred =  0.535796 0.168155 0.225874 0.0407657 0.0197841 0.00962515
Year 23 Obs  =  0 0 0 0 0 0
Year 23 Pred =  0.165807 0.641508 0.0966452 0.0754467 0.0136907 0.00690219
Year 24 Obs  =  0 0 0 0 0 0
Year 24 Pred =  0.200667 0.253616 0.466776 0.040726 0.0319801 0.00623504
Year 25 Obs  =  0 0 0 0 0 0
Year 25 Pred =  0.223144 0.332575 0.200026 0.215873 0.0192945 0.00908722
 fleet 3
Year 1 Obs  =  0 0 0 0 0 0
Year 1 Pred =  0.0150442 0.066215 0.260464 0.287371 0.256611 0.114294
Year 2 Obs  =  0 0 0 0 0 0
Year 2 Pred =  0.0179196 0.334611 0.184551 0.174584 0.163509 0.124826
Year 3 Obs  =  0 0 0 0 0 0
Year 3 Pred =  0.00957203 0.23231 0.557795 0.0778677 0.0611686 0.0612867
Year 4 Obs  =  0 0 0 0 0 0
Year 4 Pred =  0.00509409 0.156089 0.479874 0.29209 0.0339018 0.0329511
Year 5 Obs  =  0 0 0 0 0 0
Year 5 Pred =  0.00703906 0.101471 0.400964 0.312255 0.156476 0.0217948
Year 6 Obs  =  0 0 0 0 0 0
Year 6 Pred =  0.0050304 0.159007 0.292912 0.294944 0.189825 0.0582812
Year 7 Obs  =  0 0 0 0 0 0
Year 7 Pred =  0.00549386 0.107409 0.437863 0.20206 0.167936 0.0792377
Year 8 Obs  =  0 0 0 0 0 0
Year 8 Pred =  0.00359841 0.126548 0.321069 0.33365 0.126317 0.0888167
Year 9 Obs  =  0 0 0 0 0 0
Year 9 Pred =  0.00292306 0.0834763 0.3782 0.245049 0.209798 0.0805543
Year 10 Obs  =  0 0 0 0 0 0
Year 10 Pred =  0.00374167 0.077558 0.28718 0.332452 0.178166 0.120903
Year 11 Obs  =  0 0 0 0 0 0
Year 11 Pred =  0.00240807 0.0987857 0.26131 0.253874 0.247562 0.136061
Year 12 Obs  =  0 0 0 0 0 0
Year 12 Pred =  0.0037524 0.0666105 0.338178 0.229456 0.189005 0.172998
Year 13 Obs  =  0 0 0 0 0 0
Year 13 Pred =  0.00425343 0.10338 0.23515 0.310133 0.175822 0.171261
Year 14 Obs  =  0 0 0 0 0 0
Year 14 Pred =  0.00226197 0.107655 0.330816 0.194315 0.214757 0.150195
Year 15 Obs  =  0 0 0 0 0 0
Year 15 Pred =  0.00145674 0.0589834 0.358779 0.284531 0.138982 0.157268
Year 16 Obs  =  0 0 0 0 0 0
Year 16 Pred =  0.00154397 0.0423152 0.218942 0.34947 0.233498 0.154231
Year 17 Obs  =  0 0 0 0 0 0
Year 17 Pred =  0.00170465 0.0507633 0.171494 0.232679 0.320644 0.222715
Year 18 Obs  =  0 0 0.419829 0.214478 0.115201 0.250492
Year 18 Pred =  0.00136388 0.057269 0.207785 0.185375 0.220228 0.327979
Year 19 Obs  =  0 0.0140967 0.351258 0.378068 0.149171 0.107407
Year 19 Pred =  0.00115065 0.0459783 0.228875 0.215231 0.167196 0.341569
Year 20 Obs  =  0.00106905 0.0209877 0.127875 0.424182 0.266532 0.159355
Year 20 Pred =  0.00252268 0.0399376 0.19214 0.245518 0.196575 0.323307
Year 21 Obs  =  0 0.00873497 0.0336332 0.142704 0.37185 0.443078
Year 21 Pred =  0.00129922 0.0888544 0.167527 0.203968 0.219287 0.319065
Year 22 Obs  =  0 0.0192919 0.16383 0.157459 0.109995 0.549424
Year 22 Pred =  0.00567974 0.0424205 0.346623 0.161326 0.160507 0.283444
```

```
Year 23 Obs  =  0 0.386456 0.159378 0.125194 0.0724903 0.256482
Year 23 Pred =  0.00190057 0.174992 0.160369 0.32285 0.120103 0.219784
Year 24 Obs  =  0 0.0194277 0.502131 0.151273 0.0730162 0.254152
Year 24 Pred =  0.00153405 0.0461399 0.516575 0.116229 0.187108 0.132414
Year 25 Obs  =  0 0 0 0 0 0
Year 25 Pred =  0.00141504 0.0501891 0.183624 0.511048 0.0936408 0.160083

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
Year 24 Obs  =  0 0 0 0 0 0
Year 24 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 25 Obs  =  0 0 0 0 0 0
Year 25 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
Year 24 Obs  =  0 0 0 0 0 0
Year 24 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 25 Obs  =  0 0 0 0 0 0
Year 25 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
Year 24 Obs  =  0 0 0 0 0 0
Year 24 Pred =  1e-15 1e-15 1e-15 1e-15 1e-15 1e-15
Year 25 Obs  =  0 0 0 0 0 0
Year 25 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     0.714087     16.7359
  Fmax     9.99999     66.1683
  F30%SPR  0.839562     18.5612
  F40%SPR  0.531468     13.9209
  Fmsy     0.424127     12.1976    SSmsy    283774     MSY   90034.4
  Foy      0.318095     xxxxxx    SSoy    366942     OY   86960.4
  Fcurrent 0.252732     9.41344

Stock-Recruitment Relationship Parameters
 alpha     = 6.15988e+06
 beta      = 221233
 virgin    = 1.46526e+06
 steepness = 0.655858
"Spawning Stock, Obs Recruits(year+1), Pred Recruits(year+1)"
1982  7393.35  327650  199199
1983  15235.5  466770  396877
1984  35589.7  519130  853617
1985  57735.9  1.2612e+06  1.27486e+06
1986  88068.4  1.39199e+06  1.75392e+06
1987  148641  2.49516e+06  2.47546e+06
1988  223085  2.48055e+06  3.09277e+06
1989  366452  3.00429e+06  3.841e+06
1990  431689  4.9539e+06  4.0727e+06
1991  489872  3.94064e+06  4.24347e+06
1992  467372  7.14775e+06  4.18085e+06
1993  491761  9.78495e+06  4.24855e+06
1994  629314  6.80306e+06  4.55765e+06
1995  778567  5.64093e+06  4.79684e+06
1996  1.024e+06  6.73745e+06  5.0655e+06
1997  976914  7.05428e+06  5.02248e+06
1998  803946  5.09969e+06  4.83058e+06
1999  628577  3.85269e+06  4.55626e+06
2000  752435  7.48696e+06  4.76026e+06
2001  751432  3.37096e+06  4.75881e+06
2002  729769  1.43697e+07  4.7269e+06
2003  823690  5.09979e+06  4.8557e+06
2004  836477  5.4682e+06  4.87147e+06
2005  833468  4.87735e+06  4.86779e+06
2006  731211       xxxx   4.72907e+06

average F (ages 4 to 8 unweighted) by year
Projection into Future
Projected NAA
 2 3.03848e+06 1.90745e+06 969578 1.53555e+06 682179
 2 1.34064 2.03674e+06 1.2786e+06 649925 1.48658e+06
Projected Directed FAA
 1.38193e-06 3.68186e-06 4.76837e-06 4.25078e-06 3.86586e-06 2.08745e-06
 1.38193e-06 3.68186e-06 4.76837e-06 4.25078e-06 3.86586e-06 2.08745e-06
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
 2.27798e-06 9.22051 7.49645 3.3969 4.89261 1.17367
 2.27798e-06 4.06828e-06 8.00457 4.47955 2.07081 2.55763
Projected Discards at Age (in numbers)
 0 0 0 0 0 0
 0 0 0 0 0 0
Projected Yield at Age
 1.04787e-07 0.617774 0.599716 0.298927 0.538187 0.176051
 1.04787e-07 2.72575e-07 0.640366 0.3942 0.227789 0.383644
"Year, Total Yield (in weight), Total Discards (in weight), SSB, proj_what, SS/SSmsy"
2007  2.23066  0  599070  2  2.11108
2008  1.646  0  551180  2  1.94232

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
 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 0.148 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 0.187
 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 0.146 0.157 0.169
 0.054 0.062 0.095 0.123 0.161 0.146
 0.047 0.07 0.079 0.082 0.131 0.146
 0.05 0.062 0.087 0.095 0.102 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 0.103 0.104 0.115
 0.051 0.056 0.063 0.065 0.071 0.093
 0.057 0.078 0.089 0.096 0.106 0.126
 0.042 0.07 0.101 0.114 0.132 0.145
 0.054 0.084 0.1 0.113 0.128 0.145
 0.046 0.088 0.101 0.113 0.136 0.15
 0.048 0.065 0.089 0.114 0.13 0.155
 0.046 0.067 0.08 0.088 0.11 0.15
 0.046 0.067 0.08 0.088 0.11 0.15
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 0.14356 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 0.187
 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 0.14162 0.15543 0.169
 0.0162 0.03286 0.08645 0.11931 0.15939 0.146
 0.0141 0.0371 0.07189 0.07954 0.12969 0.146
 0.015 0.03286 0.07917 0.09215 0.10098 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 0.09991 0.10296 0.115
 0.0153 0.02968 0.05733 0.06305 0.07029 0.093
 0.0171 0.04134 0.08099 0.09312 0.10494 0.126
 0.0126 0.0371 0.09191 0.11058 0.13068 0.145
 0.0162 0.04452 0.091 0.10961 0.12672 0.145
 0.0138 0.04664 0.09191 0.10961 0.13464 0.15
 0.0144 0.03445 0.08099 0.11058 0.1287 0.155
 0.0138 0.03551 0.0728 0.08536 0.1089 0.15
 0.0138 0.03551 0.0728 0.08536 0.1089 0.15

SSmsy_ratio = 3.31891
Fmsy_ratio =  0.595888
that's all
```

# TRIBAL COMMENTS ON PACIFIC SARDINE STOCK ASSESSMENT AND HARVEST GUIDELINE FOR 2007

For the 2007 sardine fishing season, the proposed Harvest Guideline for sardine's coastwide will be at a level that will be sufficient for a tribal sardine "test" fishery to occur without any disruption to the non-Indian sardine fleet.

The tribes that are interested in participating in a sardine fishery should:

1) Develop tribal regulations and procedures for 2007,
2) Coordinate their fishing plans with the Northwest Indian Fisheries Commission.

Beyond 2007, the tribes will likely request an allocation of sardine and present their proposals to the PFMC Coastal Pelagic Species Tribal Allocation Committee.

11/15/2006

# SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON PACIFIC SARDINE STOCK ASSESSMENT AND HARVEST GUIDELINE

Dr. Kevin Hill (Southwest Fisheries Science Center) discussed the stock assessment of Pacific sardine with the Scientific and Statistical Committee (SSC). The SSC Coastal Pelagic Species (CPS) subcommittee reviewed the Pacific sardine assessment during a joint meeting with the Coastal Pelagic Species Management Team (CPSMT) and Coastal Pelagic Species Advisory Subpanel (CPSAS) on October 17, 2006, based on the draft terms of reference for CPS assessments (see Agenda Item F.2). The assessment of Pacific sardine is based on the same modelling software (Age-Structured Assessment Program (ASAP)), specifications, and data sources as the 2005 assessment, except that the landings data for Ensenada, the landings and catch-at-age data for California and the Pacific Northwest, and an additional estimate of spawning biomass based on the April 2006 survey were included in the assessment.

The assessment has followed the draft terms of reference for CPS stock assessment updates because the assessment carried forward the previously reviewed structure and the model results are consistent with previous data and results. The SSC therefore supports the continued use of the base model in the development of management advice. The SSC highlights that the two main indices of abundance remain inconsistent. In particular, the SSC is concerned that two indices appear to give contradictory signals, and not having 2006 data for the spotter index may have influenced the results towards the signal from the egg production indices, which was at an all time high in 2006. This issue needs to be addressed for the next assessment.

The assessment update led to an increase in both the estimate of the 2003 recruitment and 2005 age 1+ biomass. The SSC endorses the use of the harvest guideline (152,564mt) estimated using the fishery management plan control rule and the biomass estimate of 1.32 million mt for the management of the Pacific sardine fishery for 2007. This harvest guideline is 28% larger than the 2006 harvest guideline of 118,937 mt.

A Stock Assessment Review Panel is scheduled for September 19-21, 2007, to review the Pacific sardine assessment. Dr. Hill informed the SSC that he planned to move the model software for the assessment from ASAP to Stock Synthesis 2, to explore starting the model prior to 1983, and to examine the implications of alternative assumptions about stock structure. Dr. Hill is also planning to continue to collaborate with Mexican scientists to obtain catch data, catch-at-age data, and indices of larval abundance for Baja California.

PFMC
11/14/06

# COASTAL PELAGIC SPECIES ADVISORY SUBPANEL REPORT ON THE PACIFIC SARDINE STOCK ASSESSMENT AND HARVEST GUIDELINE

The Coastal Pelagic Species Advisory Subpanel (CPSAS) met October 19, 2006 in Portland, Oregon. At the meeting, the CPSAS heard a presentation from Dr. Kevin Hill, reviewing the preliminary results from the Pacific sardine stock assessment utilizing the Age-Structured Assessment Program (ASAP) model. The report included the recommended preliminary harvest guideline (HG) of 152,564 mt for the 2007 fishery, 34,627 mt higher than the 2006 HG. The CPSAS unanimously agrees this stock assessment represents the best available science at this time. The CPSAS supports the recommended preliminary HG, which is based on the harvest formula defined in the Coastal Pelagic Species (CPS) Fishery Management Plan (FMP). The CPSAS also recommends a 45 percent incidental catch rate be allowed for other CPS fisheries in the event that a seasonal allocation be taken before the end of an allocation period or the HG is taken before the end of the year.

The CPSAS is pleased that a synoptic survey of the sardine resource took place in April 2006, although Daily Egg Production Method (DEPM) data used in the assessment included only the standard survey area from San Diego to San Francisco. The CPSAS recommends that coastwide synoptic surveys continue on an annual basis and that data collected during these surveys, including DEPM data collected in the area from San Francisco to British Columbia be included in the assessment model for the 2007 stock assessment. Including the full spawning range will produce more accurate assessments.

The CPSAS appreciates that fisheries data from the Pacific Northwest (PNW) were fully incorporated in this assessment. Additional research is needed to fully evaluate stock structure, differential growth and migration rates of subpopulations, spawning contribution and the relationship of PNW sardine to the spawning biomass as a whole.

The CPSAS recommends the Council encourage the National Marine Fisheries Service to continue to fund comprehensive coastwide annual CPS research, including the survey off the PNW, and encourage similar cooperative surveys in Canada and Mexico.

The CPSAS continues to believe strongly that coordinated international management of CPS fisheries is essential to avoid the potential for coastwide overfishing. Moreover, the CPSAS also agrees that inclusion of complete Mexican catch statistics is vital to the CPS assessment process. The CPSAS encourages the Council and NMFS and the State Department to continue working to achieve timely receipt of research data from Mexico.

PFMC
10/26/06

# COASTAL PELAGIC SPECIES MANAGEMENT TEAM REPORT ON THE PACIFIC SARDINE STOCK ASSESSMENT AND HARVEST GUIDELINE

The Coastal Pelagic Species Management Team (CPSMT) met in a joint session with the Coastal Pelagic Species (CPS) Subcommittee of the Scientific and Statistical Committee to review the current stock assessment update for Pacific sardine. Dr. Kevin Hill presented the draft assessment of the Pacific sardine resource on behalf of the stock assessment team. The CPSMT supports the conclusions from the Pacific sardine stock assessment and further recommends that the Pacific Fishery Management Council (Council) implement the resulting harvest guideline (HG) associated with the harvest control rule stipulated in the CPS Fishery Management Plan (FMP) for the 2007 management season (January 1, 2007 through December 31, 2007). Based on a stock biomass (ages 1+) estimate of 1,319,072 mt, the HG for U.S. fisheries is 152,564 mt. This HG recommendation is roughly 28% greater than the HG adopted by the Council for the 2006 fishing year and is over 50,000 mt greater than the largest recent harvest by U.S. fisheries. Although the 2007 annual HG is unlikely to be exceeded, the possibility exists that a seasonal allocation may become constraining. The CPSMT notes the CPS FMP includes provisions for the Council to establish incidental landing allowances and set-asides for incidental sardine landings should a seasonal allocation be attained.

Stock assessment modeling of Pacific sardine was conducted using a forward-simulation, maximum likelihood-based Age-structured Assessment Program (ASAP). The assessment is an update from 2006 which incorporated new landings data from the Ensenada fishery; landings and sample data from the California and Pacific Northwest fisheries; and daily egg production (DEPM) based estimates of spawning biomass for the San Diego to San Francisco area based on observations from the coast-wide sardine survey conducted in April 2006. Parameterization of the current ASAP baseline model was identical to the previous stock assessment.

Finally, overfishing for Pacific sardine is defined in the CPS FMP as harvest exceeding acceptable biological catch (ABC). Recent U.S. annual landings have been well below ABCs. The ‘cutoff’ value (150,000 mt) in the harvest control rule essentially serves as a proxy for a minimum stock size threshold. The current total stock biomass estimate (1,319,072 mt) is well above this threshold level. It is important to note that over the last several fishing years, the U.S.-based commercial fishery has not realized the recommended HGs. However, uncertainty still exists concerning the magnitude of fisheries in Mexico that harvest Pacific sardine and thus, caution is recommended when evaluating fishery impacts on transboundary Pacific sardine stocks.

PFMC
10/26/06

STOCK ASSESSMENT REVIEW PANEL TERMS OF REFERENCE FOR 2007

Full assessments for Pacific sardine and Pacific mackerel typically occur every third year, necessitating a three-year cycle for the Coastal Pelagic Species (CPS) Stock Assessment Review (STAR) process. If entirely new, structurally changed or significantly revised assessments are developed in a full assessment, a STAR Panel must be convened to review the assessment prior to its use for setting harvest guidelines. Full stock assessment reports are developed and distributed following each STAR Panel review. Updated assessments are conducted during interim years and involve a less formal review process. The next CPS STAR Panel process is due to be completed in 2007.

The last CPS STAR panel convened in June 2004 to review full assessments for both Pacific mackerel and Pacific sardine. For 2007, full assessments for these two species are planned to be reviewed by two separate STAR Panels. These STAR Panels are scheduled for May 1-3, 2007 for Pacific mackerel and September 19-21, 2007 for Pacific sardine. To help guide and coordinate stock assessment authors and reviewers, a draft of the revised *Terms of Reference for a Coastal Pelagic Species Stock Assessment Review Process* (Agenda Item F.2.b, Attachment 1) has been completed by the Scientific and Statistical Committee (SSC) and has been reviewed and approved by the Coastal Pelagic Species Management Team (CPSMT) and the Coastal Pelagic Species Advisory Subpanel (CPSAS).

The Pacific Fishery Management Council (Council) is scheduled to review and approve a public review draft of the CPS Terms of Reference at its November 2006 meeting. Following a public review period, the Council will consider adopting a final draft for use in the 2007 CPS STAR process at the March 2007 Council meeting in Seattle, Washington.

**Council Action:**

**Adopt Terms of Reference for Coastal Pelagic Species STAR Panels for Public Review.**

Reference Materials:

1. Agenda Item F.2.b, Attachment 1: Terms of Reference for a Coastal Pelagic Species Stock Assessment Review Process, Review Draft.
2. Agenda Item F.2.d, CPSMT Report.
3. Agenda Item F.2.d, CPSAS Report.
4. Agenda Item F.2.d, Supplemental SSC Report.

Agenda Order:

a. Agenda Item Overview — Mike Burner
b. SSC Report — Bob Conrad
c. Agency and Tribal Comments
d. Reports and Comments of Advisory Bodies
e. Public Comment
f. **Council Action**: Adopt Terms of Reference for Coastal Pelagic Species STAR Panels for Public Review

PFMC
10/25/06

# TERMS OF REFERENCE FOR A COASTAL PELAGIC SPECIES STOCK ASSESSMENT REVIEW PROCESS

REVIEW DRAFT

**OCTOBER 2006**

## Introduction

The purpose of this document is to help the Council family and others understand the coastal pelagic species (CPS) stock assessment review (STAR) process. Parties involved in the CPS STAR process are the National Marine Fisheries Service (NMFS); state agencies; the Council and its advisors, including the Scientific and Statistical Committee (SSC), Coastal Pelagic Species Management Team (CPSMT), Coastal Pelagic Species Advisory Subpanel (CPSAS), Council staff; and interested persons. The STAR process is a key element in an overall process designed to make timely use of new fishery and survey data, to analyze and understand these data as completely as possible, to provide opportunity for public comment, and to assure the results are as accurate and error-free as possible. The STAR process is designed to assist in balancing these somewhat conflicting goals of timeliness, completeness and openness.

Stock assessments for Pacific sardine and Pacific mackerel are conducted annually to assess the abundance, trends and appropriate harvest levels for these species.[1/] Assessments use statistical population models to simultaneously analyze and integrate a combination of survey, fishery, and biological data. Since 2004, the CPS assessments have undergone an assessment cycle and peer review process. There are two distinct types of assessments which are subject to different review procedures. "Full assessments" involve a re-examination of the underlying assumptions, data, and model parameters used to assess the stock, while "update assessments" maintain the model structure of the previous full assessment and are generally restricted to the addition of new data that have become available since the last assessment.

Full assessments for Pacific sardine and Pacific mackerel typically occur every third year, necessitating a three-year STAR Panel cycle. If entirely new, structurally changed or significantly revised assessments are developed, a STAR Panel must be convened to review the assessment prior its use for setting harvest guidelines. Full stock assessment reports are developed and distributed following each STAR Panel review. Updated assessments are conducted during interim years and involve a less formal review by the CPSMT and the SSC. Details from interim-year assessments are documented in executive summaries.

---

1/ Stock assessments are conducted for species "actively" managed under the Coastal Pelagic Species Fishery Management Plan (FMP). That is, fisheries for Pacific sardine and Pacific mackerel are actively managed via annual harvest guidelines and management specifications, which are based on current stock assessment information. Jack mackerel, Northern anchovy, and market squid are "monitored" species under the FMP. Annual landings of these species are monitored and reported in the annual Stock Assessment and Fishery Evaluation (SAFE) report, but harvest guidelines are not set for them.

## STAR Goals and Objectives

The goals and objectives for the CPS assessment and review process[2/] are to:

1. Ensure that CPS stock assessments provide the kinds and quality of information required by all members of the Council family.
2. Satisfy the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) and other legal requirements.
3. Provide a well-defined, Council-oriented process that helps make CPS stock assessments the "best available" scientific information and facilitates use of the information by the Council. In this context, "well-defined" means with a detailed calendar, explicit responsibilities for all participants, and specified outcomes and reports.
4. Emphasize external, independent review of CPS stock assessment work.
5. Increase understanding and acceptance of CPS stock assessment and review work by all members of the Council family.
6. Identify research needed to improve assessments, reviews and fishery management in the future.
7. Use assessment and review resources effectively and efficiently.

## Responsibilities

### *Shared Responsibilities*

All parties have a stake in assuring adequate technical review of stock assessments. NMFS must determine that the best scientific advice has been used when it approves fishery management recommendations made by the Council. The Council uses advice from the SSC to determine whether the information on which it will base its recommendation is the "best available" scientific advice. Fishery managers and scientists providing technical documents to the Council for use in management need to ensure the work is technically correct.

Program reviews, in-depth external reviews, and peer-reviewed scientific publications are used by federal and state agencies to provide quality assurance for the basic scientific methods used to produce stock assessments. However, the time-frame for this sort of review is not suited to the routine examination of assessments that are, generally, the primary basis for a harvest recommendation. The review of current stock assessments requires a routine, dedicated effort that simultaneously meets the needs of NMFS, the Council, and others. Leadership, in the context of the stock assessment review process for CPS species, means consulting with all interested parties to plan, prepare terms of reference, and develop a calendar of events and a list of deliverables. Coordination means organizing and carrying out review meetings, distributing documents in a timely fashion, and making sure that assessments and reviews are completed according to plan. Leadership and coordination both involve costs, both monetary and time, which have not been calculated, but are likely substantial.

---

2/ In this document, the term "stock assessment" includes activities, analyses, and management recommendations, beginning with data collection, and continuing through to the development of management recommendations by the Coastal Pelagic Species Management Team and information presented to the Council as a basis for management decisions.

The Council and NMFS share primary responsibility for a successful STAR process. The Council will sponsor the process and involve its standing advisory committees, especially the SSC. The chair of the SSC CPS subcommittee will coordinate, oversee and facilitate the process. Together they will consult with all interested parties to plan, prepare terms of reference, and develop a calendar of events and a list of deliverables. NMFS and the Council will share fiscal and logistical responsibilities.

The CPS STAR process is sponsored by the Council, because the Federal Advisory Committee Act (FACA) limits the ability of NMFS to establish advisory committees. FACA specifies a procedure for convening advisory committees that provide consensus recommendations to the federal government. The intent of FACA was to limit the number of advisory committees; ensure that advisory committees fairly represent affected parties; and ensure that advisory committee meetings, discussions, and reports are carried out and prepared in full public view. Under FACA, advisory committees must be chartered by the Department of Commerce through a rather cumbersome process. However, the Magnuson-Stevens Act exempts the Council from FACA per se, but requires public notice and open meetings similar to those under FACA.

### *CPS STAR Coordination*

The SSC CPS subcommittee chair will work with the Council, Council staff, other agencies, groups or interested persons that carry out assessment work to coordinate and organize Stock Assessment Team (STAT) Teams, STAR Panels, and reviews of assessment updates. The objective is to make sure that work is carried out in a timely fashion according to the calendar and terms of reference.

The SSC CPS Subcommittee chair, in consultation with the SSC and the Southwest Fisheries Science Center (SWFSC), will select STAR Panel chairs, and will coordinate the selection of external reviewers. Criteria for reviewer qualifications, nomination, and selection will be established by the SWFSC in consultation with the SSC, and will be based principally on a candidate's knowledge of stock assessments and familiarity with West Coast CPS fisheries. The public is welcome to nominate qualified reviewers. Following any modifications to the stock assessments resulting from STAR Panel reviews and prior to distribution of stock assessment documents and STAR Panel reports, the SSC CPS Subcommittee chair will review the stock assessments and panel reports for consistency with the terms of reference, especially completeness. If inconsistencies are identified, authors will be requested to make appropriate revisions in time to meet the deadline for distributing documents for the CPSMT meeting at which HG recommendations are developed.

Individuals (employed by NMFS, state agencies, or other entities) that conduct assessments or technical work in connection with CPS stock assessments are responsible for ensuring their work is technically sound and complete. The Council's review process is the principal means for review of complete stock assessments, although additional in-depth technical review of methods and data is desirable. Stock assessments conducted by NMFS, state agencies, or other entities must be completed and reviewed in full accordance with the terms of reference, at times specified in the calendar.

### *CPSMT Responsibilities*

The CPSMT is responsible for identifying and evaluating potential management actions based on the best available scientific information. In particular, the CPSMT makes HG recommendations to the Council based on agreed control rules. The CPSMT will use stock assessments, STAR Panel reports, and other information in making their HG recommendations. Preliminary HG recommendations will be developed by the CPSMT according to the management process defined in Council Operating Procedures (COP-9). A representative of the CPSMT will serve as a liaison to each assessment update review meeting or STAR Panel, but will not serve as a member of a STAR Panel. The CPSMT will not seek revision or additional review of the stock assessments after they have been reviewed by the STAR Panel. The CPSMT chair will communicate any unresolved issues to the SSC for consideration. Successful separation of scientific (i.e., STAT Team and STAR Panels) from management (i.e., CPSMT) work depends on stock assessment documents and STAR reviews being completed by the time the CPSMT meets to discuss preliminary HG levels.

### *CPSAS Responsibilities*

The chair of the CPSAS will appoint a representative to participate at an assessment update review meeting or STAR Panel meeting. The CPSAS representative will participate in review discussions as an advisor to the STAR Panel, in the same capacity as the CPSMT advisor.

The CPSAS representative will attend the CPSMT meeting at which preliminary HG recommendations are developed. The CPSAS representative will also attend subsequent CPSMT, Council, and other necessary meetings.

The CPSAS representative will provide appropriate data and advice to the assessment update review meeting, STAR Panel, and CPSMT, and will report to the CPSAS on STAR Panel and other meeting proceedings.

### *SSC Responsibilities*

The SSC will participate in the stock assessment review process and provide the CPSMT and Council with technical advice related to the stock assessments and the review process.

The SSC will assign at least two members from its CPS subcommittee to each assessment update review meeting. The SSC representatives at the review meeting will prepare a meeting summary and present it to the full SSC at its next regular meeting. The SSC will review any additional analytical work required or carried out by the CPSMT after the stock assessments have been reviewed at the update review meeting. In addition, the SSC will review and advise the CPSMT and Council on harvest guideline recommendations.

The SSC will assign at least one member from its CPS Subcommittee to each STAR Panel for reviewing full assessments. This member will chair the STAR Panel and will be expected to attend the assigned STAR Panel meeting, the CPSMT meeting at which HG recommendations are made, and the Council meetings when CPS stock assessment agenda items are discussed. The SSC representative on the STAR Panel will present the STAR Panel report at CPSMT, SSC and Council meetings. The SSC representative will communicate SSC comments or questions to the CPSMT and STAR Panel chair. The SSC will review any additional analytical work on any of the stock assessments required or carried out by the CPSMT after the stock assessments have been reviewed by the STAR Panels. In addition, the SSC will review and advise the CPSMT and Council on harvest guideline recommendations.

The SSC, during their normally scheduled meetings, will serve as arbitrator to resolve disagreements between the STAT Team, STAR Panel, or CPSMT. The STAT Team and the STAR Panel may disagree on technical issues regarding an assessment. In this case, the stock assessment report must include a point-by-point response by the STAT Team to each of the STAR Panel recommendations. Estimates and projections representing all sides of the disagreement need to be presented, reviewed, and commented on by the SSC.

### *Council Staff Responsibilities*

Council staff will prepare meeting notices and distribute stock assessment documents, stock summaries, meeting minutes, and other appropriate documents. Council staff will assist in coordination of the STAR process. Staff will also publish or maintain file copies of reports from each STAR Panel (containing items specified in the STAR Panel's term of reference), the outline for CPS stock assessment documents, comments from external reviewers, SSC, CPSMT, and CPSAS, letters from the public, and any other relevant information. At a minimum, the stock assessments (STAT Team reports, STAR Panel reports, and stock summaries) should be published and distributed in the Council's annual CPS SAFE document.

## Terms of Reference for STAR Panels and Their Meetings

The principal responsibility of the STAR Panel is to carry out the following terms of reference. The STAR Panel's work includes:

1. reviewing draft stock assessment documents and any other pertinent information (e.g.; previous assessments and STAR Panel reports, if available);

2. working with STAT Teams to ensure assessments are reviewed as needed;

3. documenting meeting discussions; and

4. reviewing summaries of stock status (prepared by STAT Teams) for inclusion in the SAFE document.

STAR Panels normally include an SSC chair, at least one "external" member (i.e., outside the Council family and not involved in management or assessment of West Coast CPS, and one additional member. The total number of STAR Panel members should be at least "n+2" where n is the number of stock assessments and "2" counts the chair and external reviewer. In addition to Panel members, STAR meetings will include CPSMT and CPSAS advisory representatives with responsibilities as laid out in their terms of reference. STAR Panels normally meet for one week. The number of assessments reviewed per Panel should not exceed two.

The STAR Panel is responsible for determining if a stock assessment document is sufficiently complete. It is the Panel's responsibility to identify assessments that cannot be reviewed or completed for any reason. The Panel's decision that an assessment is complete should be made by consensus. If a Panel cannot reach agreement, then the nature of the disagreement must be described in its report.

The STAR Panel’s terms of reference concern technical aspects of stock assessment work. The STAR Panel should strive for a risk neutral approach in its reports and deliberations. Confidence intervals of indices and model outputs, as well as other measures of uncertainty that could affect management decisions, should be provided in completed stock assessments and the reports prepared by STAR Panels. The STAR Panel should identify scenarios that are unlikely or have a flawed technical basis.

Recommendations and requests to the STAT Team for additional or revised analyses must be clear, explicit and in writing. A written summary of discussion on significant technical points and lists of all STAR Panel recommendations and requests to the STAT Team are required in the STAR Panel's report. This should be completed (at least in draft form) prior to the end of the meeting. It is the chair and Panel's responsibility to carry out any follow-up review work that is required.

Additional analyses required in the stock assessment should be completed during the STAR Panel meeting. If follow-up work by the STAT Team is required after the review meeting, then it is the Panel's responsibility to track STAT Team progress. In particular, the chair is responsible for communicating with all Panel members (by phone, email, or any convenient means) to determine if the revised stock assessment and documents are complete and ready to be used by managers in the Council family. If stock assessments and reviews are not complete at the end of the STAR Panel meeting, then the work must be completed prior to the CPSMT meeting where the assessments and preliminary HG levels are discussed.

The STAR Panel, STAT Team, and all interested parties are legitimate meeting participants that must be accommodated in discussions. It is the STAR Panel chair's responsibility to manage discussions and public comment so that work can be completed.

STAT Teams and STAR Panels may disagree on technical issues. If the STAR Panel and STAT Team disagree, the STAR Panel must document the areas of disagreement in its report. The STAR Panel may request additional analysis based on alternative approaches. Estimates representing all sides of the disagreement need to be presented in the assessment document, reviewed, and commented on by the SSC. It is expected that the STAT Team will make a good faith effort to complete these analyses.

The SSC representative on the STAR Panel is expected to attend CPSMT and Council meetings where stock assessments and harvest projections are discussed to explain the reviews and provide other technical information and advice.

The chair is responsible for providing Council staff with a camera ready and suitable electronic version of the Panel's report for inclusion in the annual SAFE report.

## Suggested Template for STAR Panel Report

- Minutes of the STAR Panel meeting, including name and affiliation of STAR Panel members.
- List of analyses requested by the STAR Panel.
- Comments on the technical merits and/or deficiencies in the assessment and recommendations for remedies.
- Explanation of areas of disagreement regarding STAR Panel recommendations:

  among STAR Panel members (majority and minority reports), and

  between the STAR Panel and STAT Team.
- Unresolved problems and major uncertainties, (e.g., any special issues that complicate scientific assessment, questions about the best model scenario).
- Prioritized recommendations for future research and data collection.

## Terms of Reference for CPS STAT Teams

The STAT Team will carry out its work according to these terms of reference for full assessments.

Each STAT Team will appoint a representative to coordinate work with the STAR Panel and attend the STAR Panel meeting.

Each STAT Team will appoint a representative who will attend the CPSMT, CPSAS, and Council meetings where preliminary harvest levels are discussed. In addition, a representative of the STAT Team should attend the CPSMT and Council meeting where final HG recommendations are developed, if requested or necessary. At these meetings, the STAT Team member shall be available to answer questions about the STAT Team report.

The STAT Team is responsible for preparing three versions of the stock assessment document, (1) a "draft" for discussion at the stock assessment review meeting; (2) a revised "complete draft" for distribution to the CPSMT, CPSAS, SSC, and Council for discussions about preliminary harvest levels; (3) a "final" version published in the SAFE report. Other than authorized changes, only editorial and other minor changes should be made between the "complete draft" and "final" versions. The STAT Team will distribute "draft" assessment documents to the STAR Panel, Council, and CPSMT and CPSAS representatives at least two weeks prior to the STAR Panel meeting.

The STAT Team is responsible for bringing computerized data and working assessment models to the review meeting in a form that can be analyzed on site. STAT Teams should take the initiative in building and selecting candidate models. If possible, the STAT Team should have several complete models and be prepared to justify model recommendations.

The STAT Team is responsible for producing the complete draft by the end of the STAR Panel meeting. In the event that the complete draft is not completed, the Team is responsible for completing the work as soon as possible and to the satisfaction of the STAR Panel at least one week before the CPSMT meeting.

The STAT Team and the STAR Panel may disagree on technical issues regarding an assessment.A complete stock assessment must include a point-by-point response by the STAT Team to each of the STAR Panel recommendations. Estimates and projections representing all sides of any disagreements need to be presented, reviewed, and commented on by the SSC.

Electronic versions of final assessment documents, parameter files, data files, and key output files must be provided to Council staff.

## Terms of Reference for Stock Assessment Updates

The STAR process is designed to provide a comprehensive, independent review of a stock assessment. In other situations, a less comprehensive review of assessment results is desirable, particularly in situations where a "model" has already been critically examined and the objective is to simply update the "model" by incorporating the most recent data. For CPS, this typically occurs during two years out of every three because that is the default cycle for CPS assessments. In this context, a "model" refers not only to the population dynamics model *per se*, but to the particular data sources that are used as inputs to the model, the statistical framework for fitting the data, and the analytical treatment of model outputs used in providing management advice, including reference points and the harvest guideline (HG). These terms of reference establish a procedure for a limited, but still rigorous review for stock assessments that fall into this latter category. However, it is recognized that what in theory may seem to be a simple update, may in practice result in a situation that is impossible to resolve in an abbreviated process. In these cases, it may not be possible to update the assessment – rather the assessment may need to be revised in the next full assessment review cycle.

*Qualification*

The Scientific and Statistical Committee (SSC) will determine whether a stock assessment qualifies as an update under these terms of reference. To qualify, a stock assessment must carry forward its fundamental structure from a model that was previously reviewed and endorsed by a STAR panel. In practice this means similarity in: (a) the particular sources of data used, (b) the analytical methods used to summarize data prior to input to the model, (c) the software used in programming the assessment, (d) the assumptions and structure of the population dynamics model underlying the stock assessment, (e) the statistical framework for fitting the model to the data and determining goodness of fit, (f) the procedure for weighting of the various data components, and (g) the analytical treatment of model outputs in determining management reference points. A stock assessment update is appropriate in situations where no significant change in these seven factors has occurred, other than extending the time series of elements within particular data components used by the model, e.g., adding information from a recently completed survey and an update of landings. Extending CPUE time series based on fitted models (i.e., GLM models) will require refitting the model and updating all values in the time series. Assessments using updated CPUE time series qualify as updates if the CPUE standardization models follow the criteria for assessment models described above that are applicable to CPUE standardization models. In practice there will always be valid reasons for altering a model, as defined in this broad context, although, in the interests of stability, such changes should be resisted as much as possible. Instead, significant alterations should be addressed in the next subsequent full assessment and review.

*Composition of the Review Panel*

The CPS subcommittee of the SSC will conduct the review of stock assessment updates. A lead reviewer for each updated assessment will be designated by the chair of the CPS subcommittee from among the membership of this subcommittee, and it will be the lead reviewer's responsibility to ensure the review is completed properly and that a written report of the proceedings is produced. In addition, the CPS management team (CPSMT) and the CPS advisory panel (CPSAS) will designate one person each to participate in the review in an advisory capacity.

*Review Format*

Stock assessment updates will be reviewed during a single meeting of the SSC CPS Subcommittee. This meeting may precede or follow a normally scheduled SSC meeting. The review process will be as follows. The STAT team preparing the update will distribute the updated stock assessment to the review panelists at least two weeks prior to the review meeting. In addition, Council staff will provide panelists with a copy of the last stock assessment reviewed under the full STAR process, as well as the previous STAR panel report. Review of stock assessment updates is not expected to require analytical requests or model runs during the meeting, although large or unexpected changes in model results may necessitate some model exploration. The review will focus on two crucial questions: (1) has the assessment complied with the terms of reference for stock assessment updates and (2) are new input data and model results sufficiently consistent with previous data and results that the updated assessment can form the basis of Council decision-making. If either of these criteria is not met, then a full stock assessment will be required in the next year.

*STAT Team Deliverables*

Since there will be limited opportunities for revision during the review meeting, it is the STAT team's responsibility to provide the Panel with a completed update at least two weeks prior to the meeting. To streamline the process, the team can reference whatever material it chooses, including that presented in the previous stock assessment (e.g., a description of methods, data sources, stock structure, etc.). However, it is essential that any new information being incorporated into the assessment be presented in enough detail, so that the review panel can determine whether the update satisfactorily meets the Council's requirement to use the best available scientific information. Of particular importance will be a retrospective analysis showing the performance of the model with and without the updated data streams. Similarly, if any minor changes to the "model" structure are adopted, above and beyond updating specific data streams, a sensitivity analysis to those changes will be required.

In addition to documenting changes in the performance of the model, the STAT Team will be required to present key assessment outputs in tabular form. Specifically, the STAT Team's final update document should include the following:

- Title page and list of preparers
- Executive Summary (see Appendix B)
- Introduction
- Documentation of updated data sources
- Short description of overall model structure
- Base-run results (largely tabular and graphical)

- Uncertainty analysis, including retrospective analysis.

*Review Panel Report*

The stock assessment review panel will issue a report that will include the following items:

- Name and affiliation of panelists
- Comments on the technical merits and/or deficiencies of the update
- Explanation of areas of disagreement among panelists and between the panel and STAT team
- Recommendation regarding the adequacy of the updated assessment for use in management

## Appendix A: Outline for CPS Stock Assessment Documents

This is an outline of items that should be included in stock assessment reports for CPS managed by the Pacific Fishery Management Council. The outline is a working document meant to provide assessment authors with flexible guidelines about how to organize and communicate their work. All items listed in the outline may not be appropriate or available for each assessment. In the interest of clarity and uniformity of presentation, stock assessment authors and reviewers are encouraged (but not required) to use the same organization and section names as in the outline. It is important that time trends of catch, abundance, harvest rates, recruitment and other key quantities be presented in tabular form to facilitate full understanding and followup work.

1. Title page and list of preparers (the names and affiliations of the stock assessment team (STAT) either alphabetically or as first and secondary authors)

2. Executive Summary (this also serves as the STAT summary included in the SAFE)

3. Introduction
   a. Scientific name, distribution, stock structure, management units
   b. Important features of life history that affect management (e.g., migration, sexual dimorphism, bathymetric demography)
   c. Important features of current fishery and relevant history of fishery
   d. Management history (e.g., changes in management measures, harvest guidelines)
   e. Management performance : a table or tables comparing annual biomass, harvest guidelines, and landings for each management subarea and year

4. Assessment
   a. Data
      i. Landings by year and fishery, catch-at-age, weight-at-age, survey and CPUE data, data used to estimate biological parameters (e.g., growth rates, maturity schedules, and natural mortality) with coefficients of variances (CVs) or variances if available. Include complete tables and figures if practical
      ii. Sample size information for length and age composition data by area, year, etc.

   b. History of modeling approaches used for this stock and changes between current and previous assessment models

   c. Model description
      i. Complete description of any new modeling approaches
      ii. Assessment program with last revision date (i.e., date executable program file was compiled)
      iii. List and description of all likelihood components in the model
      iv. Constraints on parameters, selectivity assumptions, natural mortality, assumed level of age reader agreement or assumed ageing error (if applicable), and other assumed parameters
      v. Description of stock-recruitment constraint or components
      vi. Critical assumptions and consequences of assumption failures

vii. Convergence criteria

d. Model selection and evaluation
   i. Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models
   ii. Use hierarchical approach where possible (e.g., asymptotic vs. domed selectivities, constant vs. time varying selectivities)
   iii. Do parameter estimates make sense, are they credible?
   iv. Residual analysis (e.g., residual plots, time series plots of observed and predicted values, or other approach)
   v. Convergence status and convergence criteria for "base-run(s)"
   vi. Randomization run results or other evidence of search for global best estimates

e. Base-run(s) results
   i. Table listing all parameters in the stock assessment model used for base runs, their purpose (e.g., recruitment parameter, selectivity parameter) and whether or not the parameter was actually estimated in the stock assessment model
   ii. Time-series of total and spawning biomass, recruitment and fishing mortality or exploitation rate estimates (table and figures)
   iii. Selectivity estimates (if not included elsewhere)
   iv. Stock-recruitment relationship

f. Uncertainty and sensitivity analyses
   i. The best approach for describing uncertainty and range of probable biomass estimates in CPS assessments may depend on the situation. Possible approaches include:
      A. Sensitivity analyses (tables or figures) that show ending biomass levels or likelihood component values obtained while systematically varying emphasis factors for each type of data in the model
      B. Likelihood profiles for parameters or biomass levels
      C. CVs for biomass estimated by bootstrap, Bayesian, or asymptotic methods
      D. Subjective appraisal of magnitude and sources of uncertainty
      E. Comparison of alternate models
      F. Comparison of alternate assumptions about recent recruitment
   ii. If a range of model runs (e.g., based on CVs or alternate assumptions about model structure or recruitment) is used to depict uncertainty, then it is important that some qualitative or quantitative information about relative probability be included. If no statements about relative probability can be made, then it is important to state that all scenarios (or all scenarios between the bounds depicted by the runs) are equally likely
   iii. If possible, ranges depicting uncertainty should include at least three runs: (a) one judged most probable; (b) at least one that depicts the range of uncertainty in the direction of lower current biomass levels; and (c) one that depicts the range of uncertainty in the direction of higher current biomass levels. The entire range of uncertainty should be carried through to the value for the HG
   iv. Retrospective analysis (retrospective bias in base model or models for each area)

v. Historic analysis (plot of actual estimates from current and previous assessments for each area)
vi Simulation results (if available)

5. Harvest Control Rules

**Pacific Sardine**
The CPS FMP defines the maximum sustainable yield (MSY) control rule for Pacific sardine. This formula is intended to prevent Pacific sardine from being overfished and maintain relatively high and consistent catch levels over a long-term. The harvest formula for sardine is:

HG = (TOTAL STOCK BIOMASS - CUTOFF) • FRACTION • U.S. DISTRIBUTION,

where harvest guideline (HG) is the total U.S. (California, Oregon, and Washington) harvest recommended for the next fishing year, TOTAL STOCK BIOMASS is the estimated stock biomass (ages 1+) from the current assessment, CUTOFF is the lowest level of estimated biomass at which harvest is allowed, FRACTION is an environment-based percentage of biomass above the CUTOFF that can be harvested by the fisheries, and U.S. DISTRIBUTION is the percentage of TOTAL STOCK BIOMASS in U.S. 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 during relatively warm-water ocean conditions, the following formula has been used to determine an appropriate (sustainable) FRACTION value:

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

where T is the running average sea-surface temperature at Scripps Pier, La Jolla, California during the three preceding years. Under the harvest control rule, $F_{MSY}$ is constrained and ranges between 5% and 15% depending on the value of T. Based on the T values observed throughout the period covered by this stock assessment (1983-2002), the appropriate $F_{MSY}$ exploitation fraction has consistently been 15%; and this remains the case under current oceanic conditions ($T_{2002}$ = 17.3 °C). However, it should be noted that the decline in sea-surface temperature observed in recent years (1998-2002) may invoke environmentally-based reductions in the exploitation fraction in the near future and could substantially reduce the harvest guideline.

The harvest guideline recommended for the U.S. (California, Oregon, and Washington) Pacific sardine fishery for 2003 was 110,908 mt.

**Pacific Mackerel**
The CPS FMP defines the MSY control rule for Pacific mackerel as:

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

where HG is the U.S. harvest guideline, CUTOFF (18,200 mt) is the lowest level of estimated biomass at which harvest is allowed, FRACTION (30%) is the fraction of biomass above CUTOFF that can be taken by fisheries, and STOCK DISTRIBUTION (70%) is the average fraction of total BIOMASS in U.S. waters.

CUTOFF and FRACTION values applied in the Council's harvest policy for mackerel are based on simulations published by MacCall et al. in 1985. BIOMASS is the estimated biomass of fish age 1 and older for the whole stock as of July 1. As for Pacific sardine, FRACTION is a proxy for $F_{MSY}$.

Based on this formula and current BIOMASS of 77, 516 mt, the HG for the July 1, 2002 - June 30, 2003 season was 12,456 mt. The recommended harvest guideline was 1,381 mt lower (-10%) than the 2001-2002 HG, but similar to the average yield (14,053 mt) realized by the fishery since the 1992-1993 season.

6. Target Fishing Mortality Rates (if changes are proposed)

7. Management Recommendations

8. Research Needs (prioritized)

9. Acknowledgments (include STAR Panel members and affiliations as well as names and affiliations of persons who contributed data, advice or information but were not part of the assessment team)

10. Literature Cited

11. Complete Parameter Files and Results for Base Runs

## Appendix B: Template for Executive Summary Prepared by STAT Teams

Stock: species/area, including an evaluation of any potential biological basis for regional management

Catches: trends and current levels-include table for last ten years and graph with long term data

Data and assessment: date of last assessment, type of assessment model, data available, new information, and information lacking

Unresolved problems and major uncertainties: any special issues that complicate scientific assessment, questions about the best model scenario, etc.

Stock biomass: trends and current levels relative to virgin or historic levels, description of uncertainty-include table for last 10 years and graph with long term estimates

Recruitment: trends and current levels relative to virgin or historic levels-include table for last 10 years and graph with long term estimates

Exploitation status: exploitation rates (i.e., total catch divided by exploitable biomass) – include a table with the last 10 years of data and a graph showing the trend in fishing mortality relative to the target (y-axis) plotted against the trend in biomass relative to the target (x-axis).

Management performance: catches in comparison to the HG values for the most recent 10 years (when available), actual catch and discard.

Research and data needs: identify information gaps that seriously impede the stock assessment

Rebuilding Projections: principal results from rebuilding analysis if the stock is overfished

Summary Table: as detailed in the attached spreadsheet

# SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON STOCK ASSESSMENT REVIEW PANEL TERMS OF REFERENCE FOR 2007

The Scientific and Statistical Committee (SSC) discussed the draft Coastal Pelagic Species Stock Assessment Review Panel Terms of Reference (TOR) for 2007. The primary difference from the previous version is that the draft TOR specifies a process to accommodate assessment updates. The proposed mechanism for dealing with assessment updates was based on the approach that has been adopted for groundfish updates which provides a desirable degree of consistency between the assessment review processes for species under the two fishery management plans. Also, clarification is given in the draft TOR for the roles of various advisory bodies and participants in organizing and carrying out the reviews. The SSC has identified a few minor edits to correct typographical errors and improve readability, but the potential changes do not affect content. It is desirable to keep the draft document on track for potential adoption at the March 2007 meeting of the Pacific Fishery Management Council so that it may be in place for the 2007 assessments. The SSC recommends that the Pacific Fishery Management Council adopt the document for public review.

PFMC
11/14/06

# COASTAL PELAGIC SPECIES ADVISORY SUBPANEL STATEMENT ON THE STOCK ASSESSMENT REVIEW (STAR) PANEL TERMS OF REFERENCE FOR 2007

The Coastal Pelagic Species Advisory Subpanel (CPSAS) met on October 19, 2006 and reviewed the draft *Terms of Reference for a Coastal Pelagic Species Stock Assessment Review Process* (Agenda Item F.2.b, Attachment 1) and recommends the Pacific Fishery Management Council adopt the document for public review.

PFMC
10/26/06

# COASTAL PELAGIC SPECIES MANAGEMENT TEAM STATEMENT ON STOCK ASSESSMENT REVIEW (STAR) PANEL TERMS OF REFERENCE FOR 2007

The Coastal Pelagic Species Management Team (CPSMT) met October 17-18, 2006 in a joint session with the Coastal Pelagic Species (CPS) Subcommittee of the Scientific and Statistical Committee and reviewed the draft *Terms of Reference for a Coastal Pelagic Species Stock Assessment Review Process* (Agenda Item F.2.b, Attachment 1). The CPSMT recommends the Pacific Fishery Management Council adopt the document for public review.

PFMC
10/26/06