Agenda Item D.1.a
Supplemental Attachment 1
November 2005

-- DRAFT FOR PFMC REVIEW --

ASSESSMENT OF THE PACIFIC SARDINE (*Sardinops sagax caerulea*) POPULATION FOR U.S. MANAGEMENT IN 2006

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
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Portland, Oregon 97220-1384
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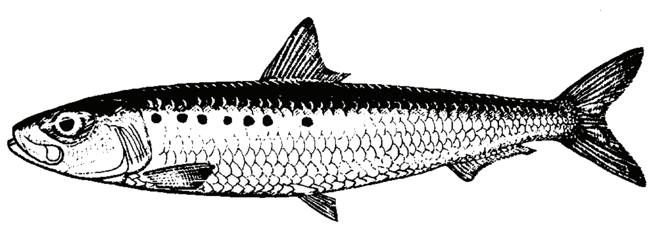

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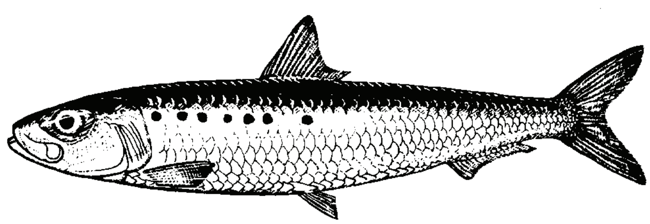

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LIST OF ACRONYMS AND ABBREVIATIONS

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

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. The last assessment and quota-setting process was completed in November 2004, setting a 2005 calendar year quota of 136,179 mt. In June 2004, the PFMC, in conjunction with NOAA Fisheries, organized a Stock Assessment Review (STAR) Panel in La Jolla, California, to provide peer review of the methods used for assessment of Pacific sardine and Pacific mackerel. The following report was initially prepared in draft form for the STAR panel's consideration, and was updated for the 2005 management cycle (Conser et al. 2004). Many of the STAR panel review recommendations as well as considerable new data were incorporated into that stock assessment update. The assessment is updated herein for 2006 management.

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) new landings data from the Ensenada fishery for the period January 2000 through June 2005; (2) an additional year of landings and port sample data from the California and Pacific Northwest fisheries; (3) a new DEPM-based estimate of SSB based on the April 2005 survey off California; (4) addition of enhanced aerial spotter survey data from the Southern California Bight, which have been used to recalculate this time series of relative abundance through 2004-05.

The primary motivation for conducting this assessment annually is to provide the scientific basis for the Pacific Fishery Management Council's (PFMC) sardine management process. This process -- centered on an environmentally-based control rule -- establishes U.S. coast-wide harvest guidelines (HG) for sardine for the fishing year beginning on January 1st of each year. Based on the sardine biomass estimate from this assessment (1,061,391 mt) and current environmental conditions, the PFMC control rule suggests a 2006 HG for U.S. fisheries of 118,937 mt. This HG recommendation is 13% lower than the HG adopted for calendar year 2005, but 22,049 mt higher than the largest recent harvest by the U.S.

INTRODUCTION

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

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

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

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

BACKGROUND

Scientific Name, Distribution, Stock Structure, Management Units

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

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

Pacific sardine have at times been the most abundant fish species in the California Current. When the population is large it is abundant from the tip of Baja California (23^o N latitude) to southeastern Alaska (57^o N latitude), and throughout the Gulf of 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 Baja California), and a Gulf of California subpopulation were distinguished on the basis of serological techniques (Vrooman 1964) and, more recently, a study of temperature-at capture (Felix-Uraga et al., 2004; Felix-Uraga et al., *In Press*). A recent electrophoretic study (Hedgecock et al. 1989) showed, however, no genetic variation among sardine from central and southern California, the Pacific coast of Baja California, or the Gulf of California. A fourth, far northern subpopulation, has also been postulated (Radovich 1982). Although the ranges of the northern and southern subpopulations overlap, the stocks may move north and south at similar times and not overlap significantly. The northern stock is exploited by U.S. fisheries and is included in the Coast Pelagic Species Fishery Management Plan (CPS-FMP; PFMC 1998).

Pacific sardine probably migrated extensively during historical periods when abundance was high, moving north as far as British Columbia in the summer and returning to southern California and northern Baja California in the fall. Tagging studies (Clark and Janssen 1945) indicate that the older and larger fish moved farther north. Migratory patterns were probably complex, and the timing and extent of movement were affected by oceanographic conditions (Hart 1973) and stock biomass. During the 1950s to 1970s, a period of reduced stock size and unfavorably cold sea surface temperatures apparently caused the stock to abandon the northern portion of its range. At present, the combination of increased stock size and warmer sea surface temperatures have resulted in the stock reoccupying areas off northern California, Oregon, Washington, and British Columbia, 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 low biomass levels, sardine appear to be fully mature at age one, whereas at high biomass levels only some of the two-year-olds are mature (MacCall 1979).

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

Pacific sardine spawn in loosely aggregated schools in the upper 50 meters of the water column. Spawning occurs year-round in the southern stock and peaks April through August between San Francisco and Magdalena Bay, and January through April in the Gulf of California (Allen et al. 1990). Off California, sardine eggs are most abundant at sea surface temperatures of 13°C to 15°C and larvae are most abundant at 13°C to 16°C. Temperature requirements are apparently flexible, however, because eggs are most common at 22°C to 25° C in the Gulf of California and at 17°C to 21°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 (Hart 1973).

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°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. 1999; Conser et al.

2004) 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 2006'** below**)**. A thorough description of PFMC management actions for sardine, including harvest guidelines, may be found in the most recent CPS SAFE document (PFMC 2005). U.S. harvest guidelines and resultant landings 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 'cold' and 'temperate' stocks proposed by Felix-Uraga et al. (2004) and takes into account likely 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:

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

where L_A is the length-at-age A, L_∞ ('L infinity') is the theoretical maximum size (length) of the fish, K is the growth coefficient, and t_o ('t zero') is the theoretical age at which the fish would have been zero length. The best estimate of von Bertalanffy parameters for Pacific sardine was: L_∞ = 244 mm, K = 0.319, and t_o = -2.503 (corrected R^2 = 0.561; n = 86,606).

Maximum Age and Size

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

Maturity Schedule

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

Natural Mortality

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

Fishery Data

Overview

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 since 1989, 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 ($year_{x+1}$). ASAP model inputs and outputs (Appendices III & IV) label each biological year with the first year of the increment (e.g., 2004-05 is labeled '2004'). 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 2005-06. 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 2005-06 were based on real data for July-September 2005, substituting monthly data from 2004-05 (i.e. October-June) for corresponding months in 2005-06.

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 2000-2005 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. 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.). Projected landings for 2005-06 were based on real data for July-September 2005, substituting monthly data from 2004-05 (i.e. October-June) for corresponding months in 2005-06.

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.

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 λ=50. Effective sample size for the Pacific Northwest fishery data was estimated to be lower, and was set to λ=12 for the final base run. In years with landings but no samples, effective sample size was set to zero.

Historical catch-at-age data (1932-65) have been examined for possible use in the modeling. Problems with consistency of the ageing during significant parts of the historical period coupled with the lack of indices of abundance for the period, made these data difficult to use in conjunction with data from the contemporary period (1982 to present). While the historical data were not used formally in the modeling, the historical VPA biomass estimates derived from them were used qualitatively for establishing the scale for virgin SSB estimates in the ASAP modeling of the contemporary period.

Fishery weight at age

Mean weights-at-age were calculated for each fishery and biological year by dividing total sampled weight of fish-at-age by the total number of fish-at-age. The current version of ASAP is only configured to accommodate one weight-at-age matrix, so a pooled weight-at-age was calculated by taking a weighted weight-at-age for the three fisheries, using respective landings in each year as a basis for the weighting. Pooled fishery weights-at-age applied in ASAP are provided in Table 6 and Figure 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 stock numbers at age estimates into stock biomass (Ages 1+) estimates for management, biological samples from fishery-independent sources that span the geographical range of the stock were used to calculate population weights-at-age (Table 7). Data included survey samples from summer 1998 and spring 2004.

Fishery-Independent Data

<u>Overview</u>
In the input and output files, the fisheries-independent indices of abundance are assigned numbers are follows:

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

<u>Daily Egg Production Method (DEPM) Spawning Biomass Index (Index 1)</u>
Daily egg production method (DEPM) biomass estimates were available 1985-2004 with several years missing from the series (Table 8, Figure 7). Lo et al. (1996) and Lo and Macewicz (2004) provide the methodology employed and the sampling constraints. Note in particular that adult samples were not taken on a regular basis and consequently, it was necessary to assume that the adult reproductive parameters were constant for most years in the series. The index was taken to represent sardine SSB. CVs for DEPM estimates are also presented in Table 8. The 2004-05 DEPM estimate, based on eggs and adults collected during the April 2005 survey, was 619,320 mt of SSB (Table 8). The modeled selectivity pattern was set using the proportion maturity at age (Table 9, Figure 9). Within ASAP, a CV of 0.30 was applied to all DEPM observations.

<u>Aerial Spotter Survey (Index 2)</u>
Pilots employed by the fishing fleet to locate Pacific sardine (and other pelagic fish) schools report data for each flight on standardized logbooks and provide them under contract to NOAA Fisheries. Spotter indices for sardine have been calculated as year effects estimated using delta log-normal linear models (Lo et al. 1992). The current spotter index covers the period 1985 through 2004, 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, as well as a southward shift in effort to offshore areas off of Baja California. To remedy this problem, NOAA Fisheries contracted 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 Generalized Linear Model (GLM; Table 8).

CVs of GLM estimates were high from 2000-01 onward compared to the earlier part of the time series, partially due to reduced sample sizes in recent years (Table 8, Figure 8). To account for this uncertainty, we applied higher CVs to observed values within ASAP (increasing from 0.3 to 0.7 in the final year; Figure 8), 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).

ASSESSMENT MODEL

ASAP MODEL

Overview

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

The general estimation approach used in the ASAP is that of a flexible forward-simulation that allows for the efficient and reliable estimation of a large number of parameters. The population dynamics and statistical underpinnings of ASAP are well established and date back to Fournier and Archibald (1982), 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 (1998; Appendix I).

- Model estimation begins in the first year of available data with an estimate of the population abundance-at-age.
- The spawning stock for that year is calculated and the associated recruitment for the next year is determined via the stock-recruitment relationship (in this case, based on a Beverton-Holt model). Recruitment variability is accommodated by accounting for divergence from the estimated central tendency (expected value).
- Each cohort estimated in the initial population abundance at age is then reduced by the total mortality rate and subsequently, projected into the next year/age combination. This process of estimating recruitment and projecting the population ‘forward’ continues until the final year of data is reached.
- Total mortality rates (Z) used to decrease cohort abundances over time represent the sum of natural mortality (M) and the fishing mortalities (F) from all fisheries.
- The Fs for each fishery are assumed to be ‘separable’ into age (commonly referred to as selectivity) and year (commonly referred to as F-multipliers). The product of selectivity-at-age and the year specific F-multiplier equals the F for each fishery/year/age combination.
- The added structure of time-varying selectivity and/or catchability can be incorporated

via the estimation of random walks.

- Predicted catch in weight and catch-at-age are estimated using 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 (Table 10).
- The tuning indices are assumed to represent changes in the population over time for specific age ranges and can be measured in numbers or weight.
- Given the large number of parameters, it is possible to fit both the catch-at-age and the abundance indices relatively well, but often at the expense of producing somewhat unrealistic trends in other stock parameters of interest (e.g., recruitment, selectivity, and catchability). Constraints and penalty functions can be employed to the constrain estimation to more feasible regions of parameter space.
- Because the number of parameters can be large and highly nonlinear, it is often difficult to estimate all parameters simultaneously in one run of the model. In practice, the minimization usually proceeds in phases, where groups of parameters are estimated simultaneously, while the remaining parameters are maintained at their initially assigned ('starting') values. Once the objective function is minimized for a particular phase, more parameters are evaluated in a step-wise fashion. Estimation within additional phases continues until all parameters are estimated.

Assessment Program with Last Revision Date

ASAP version 1.3.2 (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). A listing of the ADMB code (template file) is provided in Appendix II.

Likelihood Components and Model Parameters

Likelihood components in the final ASAP base model ('Base-D5') are listed in Table 10. Parameterization summaries for the baseline ASAP model are provided in Table 11. See also Appendix IV for a complete 'report' file listing (i.e., output file, including input data, fixed and estimated parameter values, etc.).

Convergence Criteria

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

MODEL RESULTS

Overview

An ASAP model was developed initially by mimicking (to the extent possible) the structure employed in the last CANSAR-TAM stock assessment (Conser et al 2003). However, as noted above, recent assessments have not used the fisheries data from the northern area (OR+WA+BC) – instead fish were moved from the modeled southern area at fixed transfer rates. In this implementation of ASAP, fisheries data from the northern area were fully incorporated and no assumptions were made regarding sardine migration rates. The initial model configuration was then modified following recommendations of the June 2004 STAR Panel and further examination of model diagnostics. This process resulted in the baseline model 'Base-D5' described herein.

In the ASAP baseline model, most parameters were freely estimated without strong constraints or penalties. The likelihood components at the optimal solution are provided in Table 10. A total of 136 parameters were estimated (Table 11). Model run times were usually only a few minutes and generally converged without problem, and with a positive-definite Hessian matrix. Limited exploration of the response surface via adjustments to the starting values did not uncover additional local minima. Standard deviations were reasonable for most of the key model parameters including the derived parameters such as SSB (Table 11).

Catch

Model fit to catch data for each fishery is displayed in Figure 11. The observed and predicted time series essentially overlay each other, indicating a precise fit to this data source.

Catch-at-age

Model residuals for catch-at-age data are displayed in Figure 13. Residuals for the three fisheries were random, with no obvious trends over age or time.

Indices of Abundance

Model fit to DEPM data is displayed in Figure 14A. Model fit to Aerial Spotter data is displayed in Figure 14B. Comparisons of observed data for the two indices may be found in Figures 10A&B. Note the inverse relation between the two indices for the year-year comparison (Figure 10A), and relative lack of correlation when DEPM is lagged by two years (Figure 10B) to account for differences in selectivity.

Selectivity Estimates

Estimated selectivity (S_{age}) for the three respective fisheries is displayed in Figure 15. 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 1991-2005, when the population was larger, quotas were higher, and pure schools of sardine were targeted. Estimated selectivity patterns for the California and Ensenada fisheries were dome-shaped (Figure 15), 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 grounds) as opposed to gear- or market-related causes. Estimated selectivity for the Pacific Northwest fishery is asymptotic

(Figure 15), with the oldest two ages being more or less fully selected. Again, this likely reflects the coast-wide distribution of sardine population.

Fishing Mortality Rate

Fishing mortality estimates for the three respective fisheries are displayed in Figure 16. Combined fishing mortality-at-age is displayed in Figure 17 and Table 12.

Spawning Stock Biomass

Population SSB from the final model is provided in Tables 11 and 13.

Recruitment

Recruitment estimates (age-0 abundance) are presented in Tables 11 and 13 and displayed in Figure 18. The recruitment trend is generally similarly similar to that of Conser et al. (2004), with peaks in 1994-95 (9.46 billion) and 2003-04 (10.04 billion). The trend increases more rapidly and to a slightly higher peak in 1994-95. This change is attributed to the greater magnitude of change in the Aerial Spotter GLM index (selectivity for pre-adults), which was entirely recalculated for the current assessment.

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 recent 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 2001 to 2005. A similar *S-R* constraint has been applied in previous sardine assessments (Deriso et al. 1996, Hill et al. 1999, Conser et al. 2003). The relationship between SSB and recruitment is displayed in Figure 19. Steepness for the Beverton-Holt model was estimated to be 0.67 (Table 11).

Relative spawning success, calculated as anomalies from average *ln(R/SSB)*, is displayed in Figure 20. 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 recruitment estimated for 2003 was driven, in part, by large portions of this year class in the California fishery samples in 2003-04 and 2004-05 (Table 3, Figure 3), as well as relatively large proportions of this year class in the Pacific Northwest fishery in 2004-05 (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 21. 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 21, 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 (age 1+) estimates are presented in Table 13 and displayed in Figure 22. Stock biomass increased from low levels in the early 1980s to a peak of 1.49 million mt in 1996-

97. The stock has subsequently declined to lower levels and was estimated to be approximately 1.06 million mt as of July 1, 2005. The biomass trend from the current assessment peaks several years earlier, and at a slightly higher level than presented in Conser et al. (2004) (Figure 22). This difference is attributed to the change in estimated recruitments (Figure 18), driven in part by the new Aerial Survey GLM time series.

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

Areas of Uncertainty
The principal areas of uncertainty are:

1. A coast-wide population survey has not been conducted since 1994. A synoptic survey is being planned for April 2006, hopefully including participation by Mexico and Canada;
2. Evidence exists for a shift in maturity schedule, but recent survey samples indicate high year to year variability. Weights-at-age in the California and Ensenada fishery data display high inter-annual variability, and there is a need to improve the weight-at-age vector applied to population numbers for modeling and management purposes. Adult samples collected during the April 2006 synoptic survey should address both areas of uncertainty;
3. Stock structure and migration rates are not well understood and require further research efforts.

HARVEST GUIDELINE FOR 2006

The harvest guideline recommended for the USA (California, Oregon, and Washington) Pacific sardine fishery for calendar year 2005 is 118,937 mt. Statistics used to determine this harvest guideline are discussed below and presented in Table 14. To calculate the proposed harvest guideline for 2006, 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:

$$HG_{2006} = (BIOMASS_{2005} - CUTOFF) \bullet FRACTION \bullet DISTRIBUTION$$

where HG_{2006} is the total USA (California, Oregon, and Washington) harvest guideline recommended for 2006, $BIOMASS_{2005}$ is the estimated July 1,2005 stock biomass (ages 1+) from the current assessment (1,061,391 mt; see above), CUTOFF is the lowest level of estimated biomass at which harvest is allowed (150,000 mt), FRACTION is an environment-based percentage of biomass above the CUTOFF that can be harvested by the fisheries (see below), and DISTRIBUTION (87%) is the percentage of $BIOMASS_{2005}$ 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 (1982-2005; Table 8, Figure 23), the appropriate F_{msy} exploitation fraction has consistently been 15%; and this remains the case under current oceanic conditions (T_{2005} = 18.03 °C). The 2006 USA harvest guideline (118,937 mt) is 13% lower than the 2005 harvest guideline (136,179 mt), but 22,049 mt higher than the highest recent harvest by the U.S. fisheries (96,896 mt in 2002; Table 15). Recent fishery practices and market conditions indicate the lower HG may not be constraining with regard to USA fishery landings in 2006 (PFMC 2005).

However, recent recruitment levels are not well-estimated, resulting in a high degree of uncertainty with respect to recent recruitment. If the actual recruitment in recent years is less than that estimated in the model and/or should the general sea-surface temperature decline continue, it is likely that harvest guidelines in the out years will constrain USA fishery practices and removals. Further when viewed on a stock-wide basis and considering the landings of Mexico and Canada as well as the USA (Table 15; Figure 24), adherence to an implied ‘stock-wide harvest guideline’ may constrain fisheries even without recruitment and sea-surface temperature declines.

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

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

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

	-------- 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	45,851	4,034	88	47,379	0	0	47,746	1,738	36

Table 3. Pacific sardine catch-at-age (thousands of fish) and landings (metric tons), 1982-2005 seasons (July-June), for the California fishery (Fishery 1). Landings for 2005 (i.e. 2005-06) were projected.

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	27,554	734,286	88,954	12,512	2,853	893	45,851.2
2005-06	---	---	---	---	---	---	*39,998.7*

Table 4. Pacific sardine catch-at-age (thousands of fish) and landings (metric tons), 1982-2005 seasons (July-June), for the segment of the Mexican fishery that lands its product in Ensenada, Baja California, Mexico (Fishery 2). Ensenada landings for 2005-06 were based on incomplete data and projected.

Biological	------------------- Catch-at-age (thousands)	---------------------					Landings
Year	0	1	2	3	4	5+	(mt)
1982-83	---	---	---	---	---	---	149.5
1983-84	---	---	---	---	---	---	124.1
1984-85	---	---	---	---	---	---	3,174.2
1985-86	---	---	---	---	---	---	647.3
1986-87	---	---	---	---	---	---	1,118.4
1987-88	---	---	---	---	---	---	2,076.8
1988-89	---	---	---	---	---	---	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	---	---	---	---	---	---	44,937.9
2003-04	---	---	---	---	---	---	37,040.3
2004-05	---	---	---	---	---	---	47,379.4
2005-06	---	---	---	---	---	---	*47,379.4*

Table 5. Pacific sardine catch-at-age (thousands of fish) and landings (metric tons), 1982-2005 seasons (July-June), for the fisheries off Oregon and Washington, USA and British Columbia, Canada (Fishery 3). Landings for 2005 (i.e. 2005-06) were projected.

Biological	-------------------	Catch-at-age (thousands)			-------------------		Landings
Year	0	1	2	3	4	5+	(mt)
1982-83	---	---	---	---	---	---	0.0
1983-84	---	---	---	---	---	---	0.0
1984-85	---	---	---	---	---	---	0.0
1985-86	---	---	---	---	---	---	0.0
1986-87	---	---	---	---	---	---	0.0
1987-88	---	---	---	---	---	---	0.0
1988-89	---	---	---	---	---	---	0.0
1989-90	---	---	---	---	---	---	0.0
1990-91	---	---	---	---	---	---	0.0
1991-92	---	---	---	---	---	---	0.0
1992-93	---	---	---	---	---	---	4.1
1993-94	---	---	---	---	---	---	0.0
1994-95	---	---	---	---	---	---	0.0
1995-96	---	---	---	---	---	---	22.7
1996-97	---	---	---	---	---	---	43.5
1997-98	---	---	---	---	---	---	28.0
1998-99	---	---	---	---	---	---	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	141,867	47,637	46,185	27,292	96,306	47,746.3
2005-06	---	---	---	---	---	---	*48,384.0*

Table 6. Pacific sardine fishery weight-at-age (kg), 1982-2005 seasons (July-June). Values are weighted estimates 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	0.066	0.097	0.116	0.130	0.156
2005-06	0.048	0.066	0.097	0.116	0.130	0.156

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

Biological Year	------- Population Weight-at-age (kg) -------- 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

Table 8. Pacific sardine time series of survey indices of relative abundance and sea-surface temperature, 1982-2005. The SST is a moving average of monthly SST observations for the three-year period prior to July 1st of the given year.

Biological Year	DEPM (SSB) Estimate (mt)	CV	Aerial Spotter (pre-adult) Estimate (mt)	CV	SST at SIO Pier (°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	---	---	---	---	18.03

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

	Age					
Survey	0	1	2	3	4	5+
DEPM						
1982-2005	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. Likelihood components for the baseline model in which 136 parameters were estimated. See text for definitions of fleet (fishery) numbers and index numbers.

Component	**RSS**	**nobs**	**Lambda**	**Likelihood**	**% of Total**
Catch_Fleet_1	0.0021	24	100	0.2086	
Catch_Fleet_2	0.0055	24	100	0.5504	
Catch_Fleet_3	0.1217	24	100	12.1723	
Catch_Fleet_Total	**0.1293**	72	100	**12.9314**	**2%**
Discard_Fleet_1	0.0000	24	0	0.0000	
Discard_Fleet_2	0.0000	24	0	0.0000	
Discard_Fleet_3	0.0000	24	0	0.0000	
Discard_Fleet_Total	0.0000	72	0	0.0000	
CAA_proportions	na	432	na	**208.2440**	**39%**
Discard_proportions	na	432	na	0.0000	
Index_Fit_1	12.3232	15	1	62.3062	
Index_Fit_2	35.2134	20	1	127.3310	
Index_Fit_Total	**47.5366**	35	2	**189.6370**	**36%**
Selectivity_devs_fleet_1	15.0597	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	**15.0597**	3	0	**0.0000**	**0%**
Catchability_devs_index_1	0.0000	15	10	0.0000	
Catchability_devs_index_2	0.0000	20	10	0.0000	
Catchability_devs_Total	**0.0000**	35	20	**0.0000**	**0%**
Fmult_fleet_1	6.5107	23	1	6.5107	
Fmult_fleet_2	15.2223	23	1	15.2223	
Fmult_fleet_3	53.8653	23	1	53.8653	
Fmult_fleet_Total	**75.5983**	69	3	**75.5983**	**14%**
N_year_1	0.0000	5	0	0.0000	
Stock-Recruit_Fit	**14.5603**	24	1	**30.1618**	**6%**
Recruit_devs	**14.5603**	24	1	**14.5603**	**3%**
SRR_steepness	0.0014	1	0	0.0000	
SRR_virgin_stock	0.0601	1	0	0.0000	
Curvature_over_age	20.6278	12	0	0.0000	
Curvature_over_time	30.1193	396	0	0.0000	
F_penalty	1.9479	144	0.001	0.0019	
Mean_Sel_year1_pen	0.0000	18	1000	0.0000	
Max_Sel_penalty	2.5512	1	100	0.0000	
Fmult_Max_penalty	0.0000	?	100	0.0000	
TOTAL	**222.7521**	**1776**		**531.1347**	**100%**

Table 11. ASAP parameter estimates and standard deviations for the baseline model. The first 136 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	-5.29E+00	1.43E+02
2	1982	1	2	log_sel_year1	-1.78E+00	1.43E+02
3	1982	1	3	log_sel_year1	-3.75E-01	1.43E+02
4	1982	1	4	log_sel_year1	-7.96E-01	1.43E+02
5	1982	1	5	log_sel_year1	-1.57E+00	1.43E+02
6	1982	1	6	log_sel_year1	-2.17E+00	1.43E+02
1	1982	2	7	log_sel_year1	-2.64E+00	2.45E+02
2	1982	2	8	log_sel_year1	-1.84E+00	2.45E+02
3	1982	2	9	log_sel_year1	-1.70E+00	2.45E+02
4	1982	2	10	log_sel_year1	-2.07E+00	2.45E+02
5	1982	2	11	log_sel_year1	-2.43E+00	2.45E+02
6	1982	2	12	log_sel_year1	-4.05E+00	2.45E+02
1	1982	3	13	log_sel_year1	-6.00E+00	2.25E-02
2	1982	3	14	log_sel_year1	-1.95E+00	1.51E+00
3	1982	3	15	log_sel_year1	-1.70E-01	1.47E+00
4	1982	3	16	log_sel_year1	4.49E-01	1.47E+00
5	1982	3	17	log_sel_year1	9.37E-01	1.48E+00
6	1982	3	18	log_sel_year1	4.07E-01	1.48E+00
1	1982	1	19	log_sel_devs_vector	3.56E+00	7.83E-01
2	1982	1	20	log_sel_devs_vector	1.23E+00	7.28E-01
3	1982	1	21	log_sel_devs_vector	-8.86E-02	7.24E-01
4	1982	1	22	log_sel_devs_vector	-1.31E-01	7.39E-01
5	1982	1	23	log_sel_devs_vector	-2.78E-01	8.24E-01
6	1982	1	24	log_sel_devs_vector	-8.81E-01	9.70E-01
1	1982	2	25	log_sel_devs_vector	0.00E+00	5.81E+03
2	1982	2	26	log_sel_devs_vector	0.00E+00	5.81E+03
3	1982	2	27	log_sel_devs_vector	0.00E+00	5.81E+03
4	1982	2	28	log_sel_devs_vector	0.00E+00	5.81E+03
5	1982	2	29	log_sel_devs_vector	0.00E+00	5.81E+03
6	1982	2	30	log_sel_devs_vector	0.00E+00	5.81E+03
1	1982	3	31	log_sel_devs_vector	0.00E+00	5.81E+03
2	1982	3	32	log_sel_devs_vector	0.00E+00	5.81E+03
3	1982	3	33	log_sel_devs_vector	0.00E+00	5.81E+03
4	1982	3	34	log_sel_devs_vector	0.00E+00	5.81E+03
5	1982	3	35	log_sel_devs_vector	0.00E+00	5.81E+03
6	1982	3	36	log_sel_devs_vector	0.00E+00	5.81E+03
---	1982	1	37	log_Fmult_year1	-1.37E+00	1.43E+02
---	1982	2	38	log_Fmult_year1	-2.09E+00	2.45E+02
---	1982	3	39	log_Fmult_year1	-1.50E+01	1.09E-02
---	1983	1	40	log_Fmult_devs	-9.69E-01	1.42E-01
---	1984	1	41	log_Fmult_devs	-7.77E-01	1.31E-01
---	1985	1	42	log_Fmult_devs	3.57E-01	1.31E-01

Table 11 (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	-1.15E-01	1.31E-01
---	1987	1	44	log_Fmult_devs	5.31E-01	1.35E-01
---	1988	1	45	log_Fmult_devs	-8.06E-01	1.26E-01
---	1989	1	46	log_Fmult_devs	-1.83E-01	1.27E-01
---	1990	1	47	log_Fmult_devs	1.87E-01	1.18E-01
---	1991	1	48	log_Fmult_devs	5.29E-08	7.07E-01
---	1992	1	49	log_Fmult_devs	1.04E+00	1.09E-01
---	1993	1	50	log_Fmult_devs	-7.18E-01	1.10E-01
---	1994	1	51	log_Fmult_devs	6.33E-01	1.11E-01
---	1995	1	52	log_Fmult_devs	-3.68E-01	1.08E-01
---	1996	1	53	log_Fmult_devs	-2.09E-01	1.05E-01
---	1997	1	54	log_Fmult_devs	8.73E-01	1.08E-01
---	1998	1	55	log_Fmult_devs	2.18E-01	1.08E-01
---	1999	1	56	log_Fmult_devs	3.66E-01	1.11E-01
---	2000	1	57	log_Fmult_devs	-2.31E-01	1.06E-01
---	2001	1	58	log_Fmult_devs	1.22E-01	1.08E-01
---	2002	1	59	log_Fmult_devs	-1.24E-03	1.21E-01
---	2003	1	60	log_Fmult_devs	-7.51E-01	1.18E-01
---	2004	1	61	log_Fmult_devs	2.78E-01	1.22E-01
---	2005	1	62	log_Fmult_devs	-7.84E-02	1.11E-01
---	1983	2	63	log_Fmult_devs	-1.02E+00	1.30E-01
---	1984	2	64	log_Fmult_devs	2.33E+00	1.20E-01
---	1985	2	65	log_Fmult_devs	-1.97E+00	1.11E-01
---	1986	2	66	log_Fmult_devs	1.72E-01	1.16E-01
---	1987	2	67	log_Fmult_devs	7.21E-02	1.19E-01
---	1988	2	68	log_Fmult_devs	-4.38E-01	1.09E-01
---	1989	2	69	log_Fmult_devs	1.27E+00	1.12E-01
---	1990	2	70	log_Fmult_devs	1.54E-01	1.07E-01
---	1991	2	71	log_Fmult_devs	5.00E-01	1.08E-01
---	1992	2	72	log_Fmult_devs	7.82E-01	1.07E-01
---	1993	2	73	log_Fmult_devs	-1.02E+00	1.08E-01
---	1994	2	74	log_Fmult_devs	2.29E-01	1.09E-01
---	1995	2	75	log_Fmult_devs	-2.55E-01	1.05E-01
---	1996	2	76	log_Fmult_devs	-6.45E-02	1.04E-01
---	1997	2	77	log_Fmult_devs	8.88E-01	1.06E-01
---	1998	2	78	log_Fmult_devs	1.06E-01	1.05E-01
---	1999	2	79	log_Fmult_devs	1.59E-01	1.09E-01
---	2000	2	80	log_Fmult_devs	-2.27E-01	1.05E-01
---	2001	2	81	log_Fmult_devs	8.23E-03	1.07E-01
---	2002	2	82	log_Fmult_devs	-1.17E-01	1.16E-01
---	2003	2	83	log_Fmult_devs	-3.00E-01	1.18E-01
---	2004	2	84	log_Fmult_devs	1.77E-01	1.16E-01
---	2005	2	85	log_Fmult_devs	2.69E-02	1.10E-01
---	1983	3	86	log_Fmult_devs	-8.37E-02	6.87E-01

Table 11 (cont'd). ASAP parameter estimates and standard deviations for the baseline model.

Coded Age	Biol. Year	Fishery	Param #	Parameter	Estimate	Std. Dev.
---	1984	3	87	log_Fmult_devs	-8.35E-02	6.87E-01
---	1985	3	88	log_Fmult_devs	-8.25E-02	6.86E-01
---	1986	3	89	log_Fmult_devs	-7.77E-02	6.85E-01
---	1987	3	90	log_Fmult_devs	-6.38E-02	6.79E-01
---	1988	3	91	log_Fmult_devs	-3.48E-02	6.68E-01
---	1989	3	92	log_Fmult_devs	3.60E-02	6.43E-01
---	1990	3	93	log_Fmult_devs	2.02E-01	5.96E-01
---	1991	3	94	log_Fmult_devs	6.72E-01	5.01E-01
---	1992	3	95	log_Fmult_devs	3.02E+00	3.09E-01
---	1993	3	96	log_Fmult_devs	-2.89E+00	2.81E-01
---	1994	3	97	log_Fmult_devs	7.36E-02	3.37E-01
---	1995	3	98	log_Fmult_devs	4.22E+00	2.50E-01
---	1996	3	99	log_Fmult_devs	2.71E-01	1.21E-01
---	1997	3	100	log_Fmult_devs	-4.92E-01	1.18E-01
---	1998	3	101	log_Fmult_devs	3.10E+00	1.15E-01
---	1999	3	102	log_Fmult_devs	1.19E+00	1.21E-01
---	2000	3	103	log_Fmult_devs	2.49E+00	1.07E-01
---	2001	3	104	log_Fmult_devs	3.67E-01	1.06E-01
---	2002	3	105	log_Fmult_devs	5.06E-01	1.11E-01
---	2003	3	106	log_Fmult_devs	1.76E-01	1.20E-01
---	2004	3	107	log_Fmult_devs	2.26E-01	1.29E-01
---	2005	3	108	log_Fmult_devs	-1.47E-01	1.54E-01
1	1982	---	109	log_recruit_devs	-3.30E+00	1.75E-01
1	1983	---	110	log_recruit_devs	4.21E-01	2.16E-01
1	1984	---	111	log_recruit_devs	9.76E-02	2.05E-01
1	1985	---	112	log_recruit_devs	-5.51E-01	1.99E-01
1	1986	---	113	log_recruit_devs	-5.41E-02	1.72E-01
1	1987	---	114	log_recruit_devs	-2.65E-01	1.58E-01
1	1988	---	115	log_recruit_devs	4.99E-03	1.30E-01
1	1989	---	116	log_recruit_devs	-2.17E-01	1.22E-01
1	1990	---	117	log_recruit_devs	-2.15E-01	1.24E-01
1	1991	---	118	log_recruit_devs	2.55E-01	1.10E-01
1	1992	---	119	log_recruit_devs	-8.82E-03	1.29E-01
1	1993	---	120	log_recruit_devs	6.02E-01	1.11E-01
1	1994	---	121	log_recruit_devs	9.09E-01	1.05E-01
1	1995	---	122	log_recruit_devs	4.74E-01	1.17E-01
1	1996	---	123	log_recruit_devs	2.37E-01	1.27E-01
1	1997	---	124	log_recruit_devs	3.61E-01	1.25E-01
1	1998	---	125	log_recruit_devs	4.00E-01	1.20E-01
1	1999	---	126	log_recruit_devs	8.95E-02	1.23E-01
1	2000	---	127	log_recruit_devs	-1.67E-01	1.34E-01
1	2001	---	128	log_recruit_devs	4.43E-01	1.26E-01
1	2002	---	129	log_recruit_devs	-3.57E-01	1.68E-01
1	2003	---	130	log_recruit_devs	8.95E-01	1.36E-01

Table 11 (cont'd). ASAP parameter estimates and standard deviations for the baseline model.

Coded Age	Biol. Year	Fishery	Param #	Parameter	Estimate	Std. Dev.
1	2004	---	131	log_recruit_devs	-4.96E-02	9.61E-02
1	2005	---	132	log_recruit_devs	9.96E-04	5.03E-02
---	1982	---	133	log_q_year1 (DEPM)	-1.33E+01	2.04E-01
---	1982	---	134	log_q_year1 (Aerial)	-1.33E+01	1.69E-01
---	---	---	135	log_SRR_virgin	1.40E+01	1.40E-01
---	---	---	136	SRR_steepness	6.74E-01	4.24E-02
---	1982	---	137	SSB	7.25E+03	6.49E+02
---	1983	---	138	SSB	1.49E+04	2.03E+03
---	1984	---	139	SSB	3.47E+04	5.57E+03
---	1985	---	140	SSB	5.62E+04	9.95E+03
---	1986	---	141	SSB	8.55E+04	1.58E+04
---	1987	---	142	SSB	1.43E+05	2.77E+04
---	1988	---	143	SSB	2.14E+05	4.26E+04
---	1989	---	144	SSB	3.49E+05	6.90E+04
---	1990	---	145	SSB	4.09E+05	7.96E+04
---	1991	---	146	SSB	4.63E+05	8.72E+04
---	1992	---	147	SSB	4.42E+05	8.23E+04
---	1993	---	148	SSB	4.65E+05	8.94E+04
---	1994	---	149	SSB	5.98E+05	1.08E+05
---	1995	---	150	SSB	7.41E+05	1.33E+05
---	1996	---	151	SSB	9.75E+05	1.72E+05
---	1997	---	152	SSB	9.28E+05	1.57E+05
---	1998	---	153	SSB	7.57E+05	1.28E+05
---	1999	---	154	SSB	5.85E+05	9.52E+04
---	2000	---	155	SSB	6.86E+05	1.20E+05
---	2001	---	156	SSB	6.69E+05	1.25E+05
---	2002	---	157	SSB	6.31E+05	1.23E+05
---	2003	---	158	SSB	6.61E+05	1.36E+05
---	2004	---	159	SSB	6.48E+05	1.37E+05
---	2005	---	160	SSB	6.78E+05	1.54E+05
1	1982	---	161	Recruits	1.69E+05	3.13E+04
1	1983	---	162	Recruits	3.21E+05	6.36E+04
1	1984	---	163	Recruits	4.57E+05	9.96E+04
1	1985	---	164	Recruits	5.04E+05	1.18E+05
1	1986	---	165	Recruits	1.22E+06	2.74E+05
1	1987	---	166	Recruits	1.33E+06	3.03E+05
1	1988	---	167	Recruits	2.38E+06	5.17E+05
1	1989	---	168	Recruits	2.33E+06	4.87E+05
1	1990	---	169	Recruits	2.82E+06	5.51E+05
1	1991	---	170	Recruits	4.74E+06	8.45E+05
1	1992	---	171	Recruits	3.77E+06	7.17E+05
1	1993	---	172	Recruits	6.86E+06	1.23E+06
1	1994	---	173	Recruits	9.46E+06	1.61E+06
1	1995	---	174	Recruits	6.51E+06	1.09E+06

Table 11 (cont'd). ASAP parameter estimates and standard deviations for the baseline model.

Coded Age	Biol. Year	Fishery	Param #	Parameter	Estimate	Std. Dev.
1	1996	---	175	Recruits	5.37E+06	8.48E+05
1	1997	---	176	Recruits	6.37E+06	8.91E+05
1	1998	---	177	Recruits	6.57E+06	8.68E+05
1	1999	---	178	Recruits	4.65E+06	6.81E+05
1	2000	---	179	Recruits	3.41E+06	5.76E+05
1	2001	---	180	Recruits	6.50E+06	1.07E+06
1	2002	---	181	Recruits	2.91E+06	6.13E+05
1	2003	---	182	Recruits	1.00E+07	1.89E+06
1	2004	---	183	Recruits	3.94E+06	6.81E+05
1	2005	---	184	Recruits	4.13E+06	6.34E+05
6	1982	---	185	plus_group	1.94E+03	0.00E+00
6	1983	---	186	plus_group	3.30E+03	3.69E+01
6	1984	---	187	plus_group	4.26E+03	5.36E+01
6	1985	---	188	plus_group	4.84E+03	8.32E+01
6	1986	---	189	plus_group	5.61E+03	1.27E+02
6	1987	---	190	plus_group	2.24E+04	4.06E+03
6	1988	---	191	plus_group	5.03E+04	1.02E+04
6	1989	---	192	plus_group	8.55E+04	1.83E+04
6	1990	---	193	plus_group	1.15E+05	2.53E+04
6	1991	---	194	plus_group	2.19E+05	5.03E+04
6	1992	---	195	plus_group	2.98E+05	6.98E+04
6	1993	---	196	plus_group	4.44E+05	1.10E+05
6	1994	---	197	plus_group	5.22E+05	1.31E+05
6	1995	---	198	plus_group	5.95E+05	1.50E+05
6	1996	---	199	plus_group	8.07E+05	1.99E+05
6	1997	---	200	plus_group	8.82E+05	2.12E+05
6	1998	---	201	plus_group	1.21E+06	2.87E+05
6	1999	---	202	plus_group	1.61E+06	3.82E+05
6	2000	---	203	plus_group	1.52E+06	3.72E+05
6	2001	---	204	plus_group	1.27E+06	3.29E+05
6	2002	---	205	plus_group	1.09E+06	3.03E+05
6	2003	---	206	plus_group	9.20E+05	2.86E+05
6	2004	---	207	plus_group	7.27E+05	2.53E+05
6	2005	---	208	plus_group	5.45E+05	2.16E+05

Table 12. Pacific sardine instantaneous rates of fishing mortality at age (yr^{-1}) for biological years 1982-2005. The biological year begins on July 1st and extends through June 30th of the labeled year.

Biological	----- Instantaneous Fishing Mortality Rate at Age (yr^{-1}) -----					
Year	0	1	2	3	4	5+
1982-83	0.010	0.063	0.198	0.131	0.064	0.031
1983-84	0.004	0.023	0.075	0.049	0.024	0.012
1984-85	0.033	0.080	0.114	0.078	0.050	0.013
1985-86	0.005	0.021	0.055	0.037	0.019	0.008
1986-87	0.006	0.022	0.053	0.035	0.019	0.008
1987-88	0.006	0.029	0.081	0.054	0.027	0.012
1988-89	0.004	0.016	0.039	0.026	0.014	0.006
1989-90	0.014	0.036	0.059	0.040	0.024	0.007
1990-91	0.016	0.042	0.070	0.047	0.028	0.009
1991-92	0.033	0.082	0.093	0.062	0.039	0.008
1992-93	0.078	0.196	0.220	0.147	0.089	0.019
1993-94	0.031	0.080	0.089	0.059	0.035	0.008
1994-95	0.045	0.122	0.136	0.089	0.049	0.011
1995-96	0.034	0.089	0.099	0.066	0.037	0.009
1996-97	0.030	0.078	0.087	0.058	0.033	0.008
1997-98	0.072	0.187	0.210	0.139	0.080	0.018
1998-99	0.083	0.220	0.246	0.164	0.094	0.022
1999-00	0.106	0.287	0.322	0.214	0.122	0.031
2000-01	0.085	0.232	0.279	0.213	0.167	0.066
2001-02	0.090	0.251	0.309	0.246	0.205	0.087
2002-03	0.085	0.243	0.319	0.280	0.270	0.127
2003-04	0.052	0.147	0.222	0.231	0.270	0.139
2004-05	0.064	0.185	0.278	0.290	0.338	0.174
2005-06	0.063	0.178	0.262	0.265	0.301	0.152

Table 13. Pacific sardine population numbers at age (millions), Age 1+ biomass (mt), and spawning stock biomass (SSB, mt) at the beginning of each biological year, 1982 to 2005. Total landings during the course of each biological year are also provided (landings for 2005-06 are projected). Recruitment is shown as Age-0 population numbers. The biological year begins on July 1st and extends through June 30th of the labeled year. The Age 1+ biomass estimated for 2005 (bold) serves as the basis for setting a harvest guideline for the U.S. fishery in calendar year 2006 (see Table 14).

Biological	--- Population Numbers-at-age (millions) ---						Age 1+		Total
Year	0	1	2	3	4	5+	Biomass	SSB	Landings
1982-83	169	15	9	5	3	2	4,680	7,246	487
1983-84	321	112	9	5	3	3	14,904	14,871	372
1984-85	457	214	73	6	3	4	35,138	34,686	3,571
1985-86	504	296	133	44	4	5	58,868	56,213	1,838
1986-87	1,216	336	195	84	28	6	83,202	85,527	2,667
1987-88	1,329	810	220	124	54	22	150,063	143,450	5,887
1988-89	2,383	885	528	136	79	50	214,092	214,310	4,795
1989-90	2,329	1,591	584	340	89	86	337,541	349,300	15,322
1990-91	2,821	1,540	1,029	369	219	115	430,119	409,240	20,602
1991-92	4,741	1,861	990	644	236	219	525,168	463,370	35,022
1992-93	3,774	3,073	1,149	605	405	298	710,205	441,710	74,214
1993-94	6,857	2,340	1,694	618	350	444	733,519	464,730	31,540
1994-95	9,457	4,457	1,449	1,039	390	522	1,007,344	598,180	66,295
1995-96	6,512	6,058	2,646	848	637	595	1,371,383	741,050	62,677
1996-97	5,370	4,222	3,716	1,606	532	807	1,486,348	975,310	65,968
1997-98	6,372	3,494	2,618	2,283	1,016	882	1,460,963	928,060	131,380
1998-99	6,571	3,976	1,942	1,423	1,332	1,209	1,379,803	757,010	113,901
1999-00	4,654	4,053	2,139	1,018	810	1,606	1,329,681	584,550	119,258
2000-01	3,415	2,804	2,039	1,039	551	1,525	1,130,737	686,100	121,295
2001-02	6,500	2,103	1,490	1,034	563	1,269	933,416	668,820	125,612
2002-03	2,907	3,982	1,097	734	542	1,088	982,860	631,000	141,775
2003-04	10,042	1,790	2,093	535	372	920	810,115	661,010	106,550
2004-05	3,943	6,394	1,036	1,124	284	727	1,179,103	648,240	140,977
2005-06	4,131	2,479	3,563	526	564	545	**1,061,391**	677,500	*135,762*

Table 14. Proposed harvest guideline for Pacific sardine for the 2005 management year. See 'Harvest Guideline' section for methods used to derive harvest guideline.

Stock biomass (age 1+, mt)	Cutoff (mt)	Fraction	Distribution	Harvest guideline (mt)
1,061,391	150,000	15%	87%	118,937

Table 15. Coast-wide harvest (mt) of Pacific sardine for calendar years1983 through 2004.

Calendar Year	Ensenada (mt)	U.S. (mt)	Canada (mt)	Total (mt)
1983	274	1	0	274
1984	0	1	0	1
1985	3,722	6	0	3,728
1986	243	388	0	631
1987	2,432	439	0	2,871
1988	2,035	1,188	0	3,223
1989	6,224	837	0	7,061
1990	11,375	1,664	0	13,040
1991	31,392	7,587	0	38,979
1992	34,568	17,950	0	52,518
1993	32,045	15,345	0	47,390
1994	20,877	11,644	0	32,520
1995	35,396	40,327	25	75,748
1996	39,065	32,553	88	71,706
1997	68,439	43,245	34	111,718
1998	47,812	42,956	745	91,514
1999	58,569	60,039	1,250	119,858
2000	67,845	67,985	1,718	137,549
2001	46,071	75,800	1,600	123,472
2002	46,845	96,896	1,044	144,785
2003	41,342	71,864	954	114,159
2004	41,897	89,338	4,259	135,494

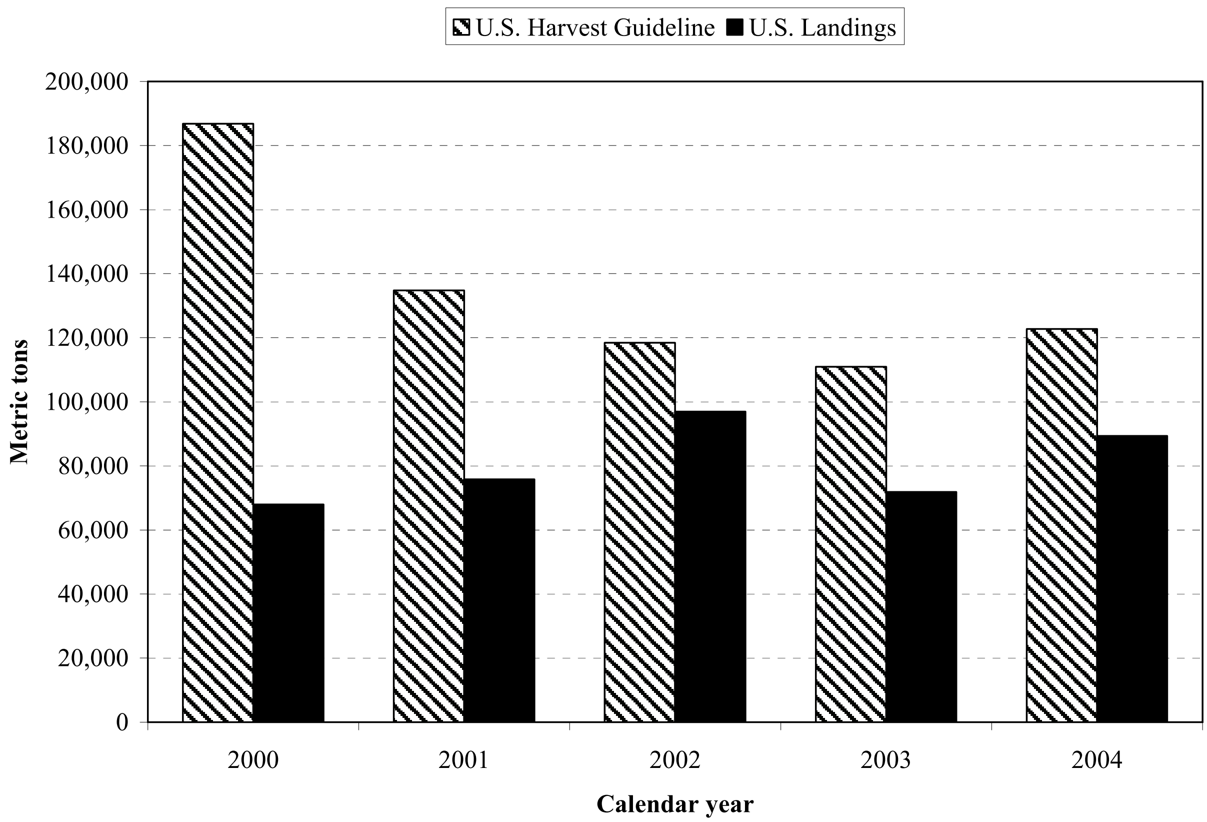


Figure 1. U.S. Pacific sardine harvest guidelines and resultant landings (mt) since the onset of PFMC management in calendar year 2000.

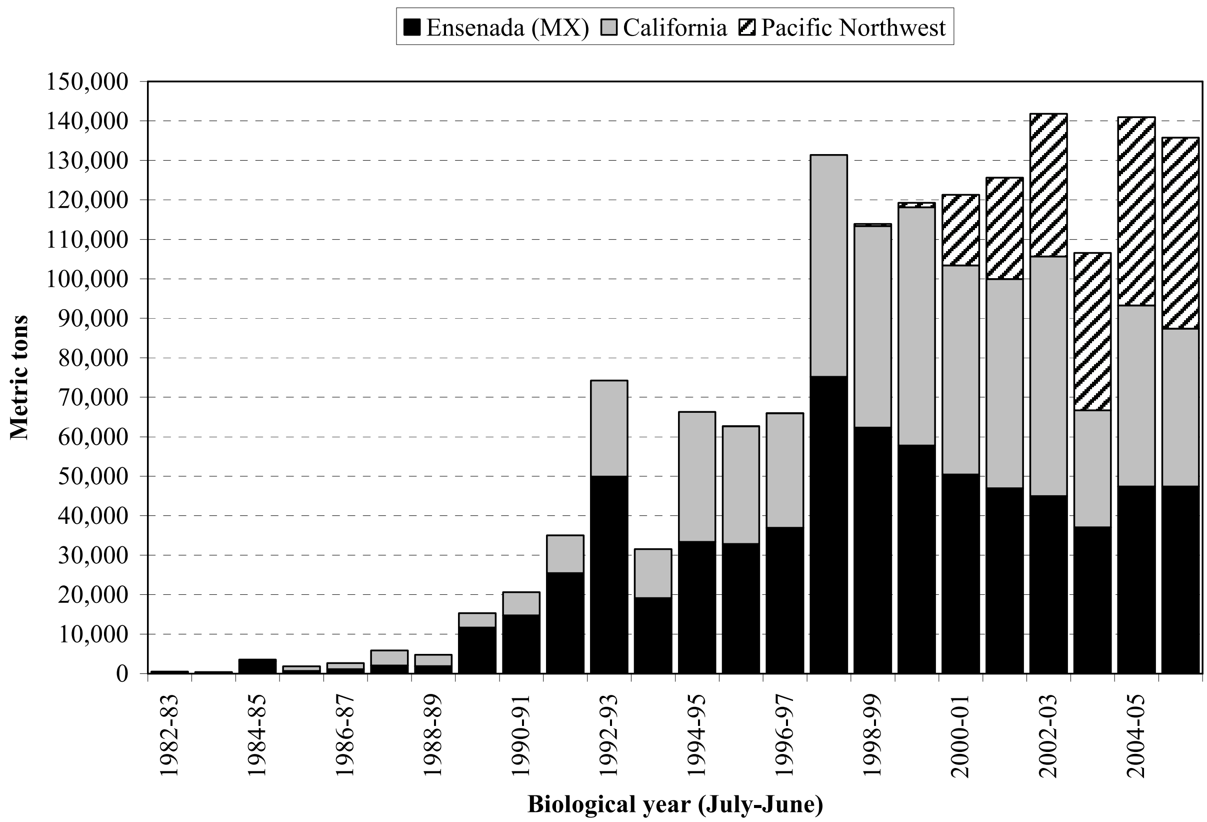


Figure 2. Pacific sardine landings (mt) by fishery for biological years 1982-2005 (July-June). Landings for 2005-06 were projected.

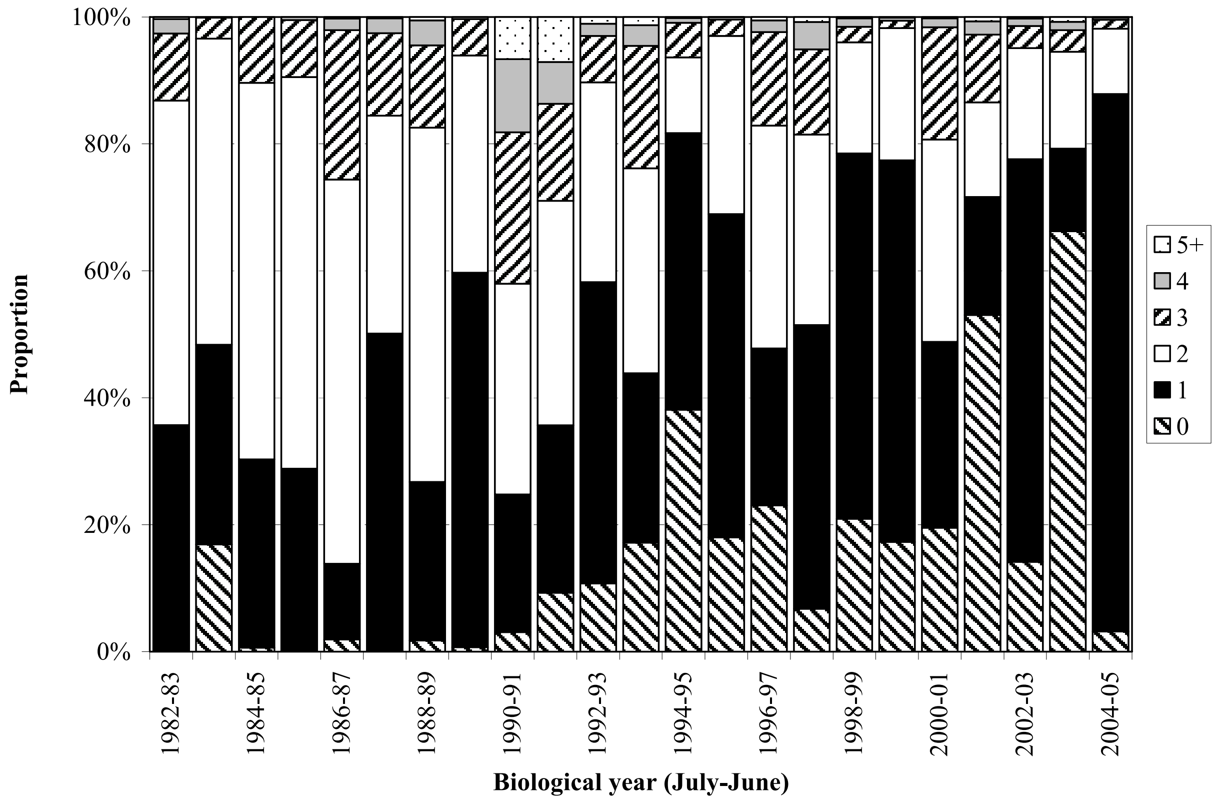


Figure 3. Catch-at-age proportions for the Pacific sardine fishery in California (San Pedro and Monterey) for the biological years 1982-2004 (July-June). See also Table 3.

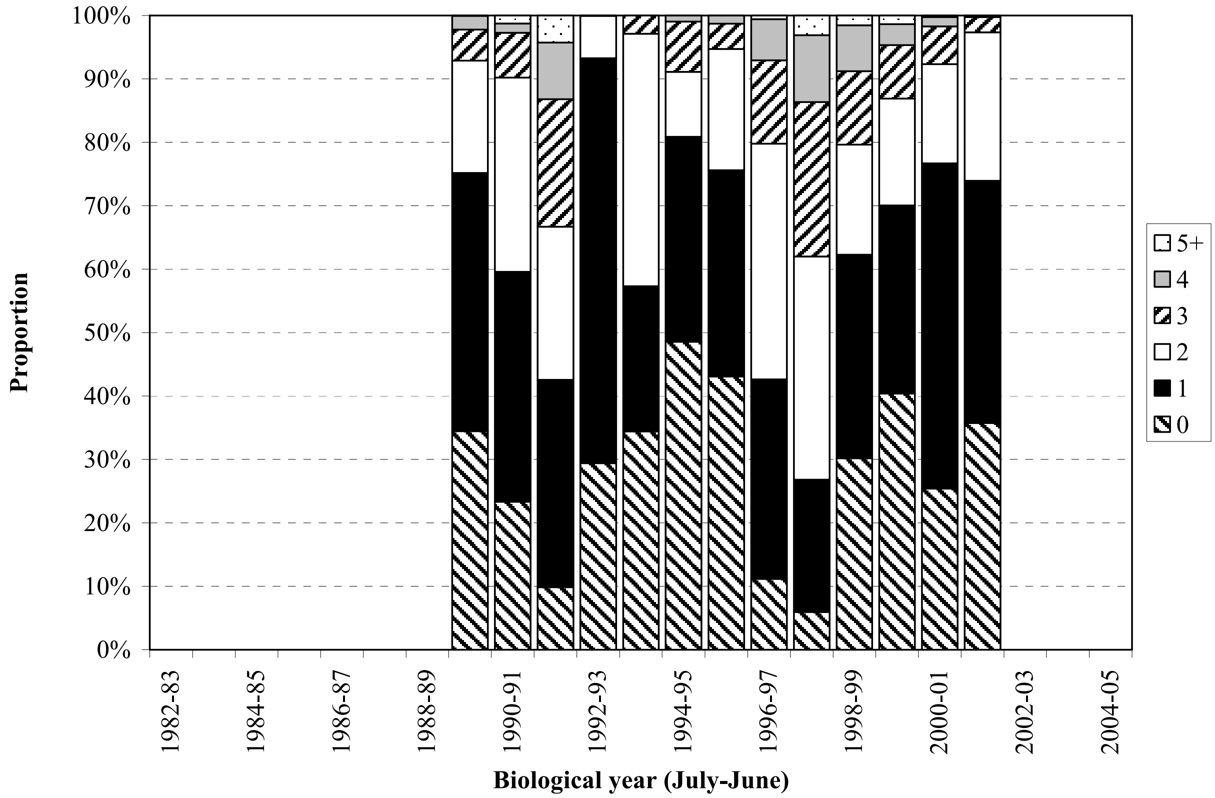


Figure 4. Catch-at-age proportions for the Pacific sardine fishery in Ensenada (Baja California, Mexico) for the biological years 1989-2001 (July-June). See also Table 4.

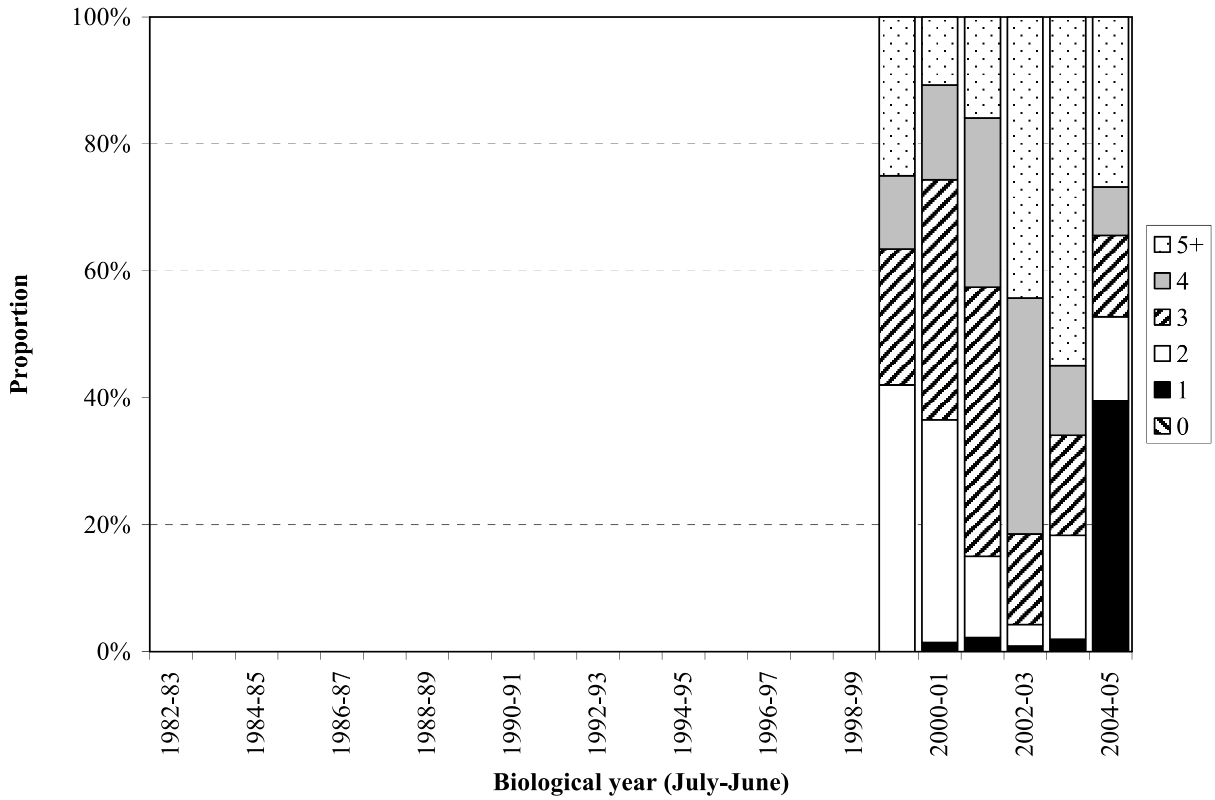


Figure 5. Catch-at-age proportions for the Pacific sardine fishery in the Pacific Northwest for biological years 1999-2004 (July-June). See also Table 5.

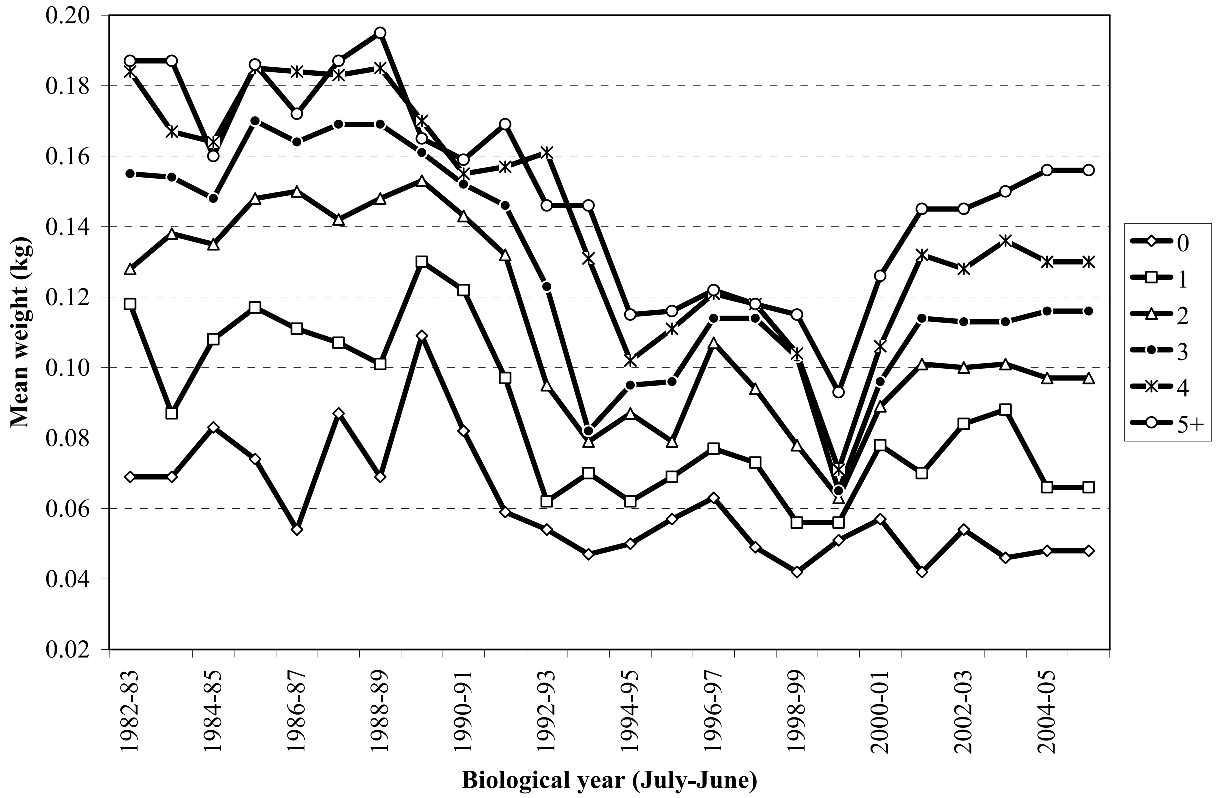


Figure 6. Pooled fishery weight-at-age (kg) for Pacific sardine as applied in the ASAP base model. Whole body weights were averaged across the three fisheries using respective landings to weight the data.

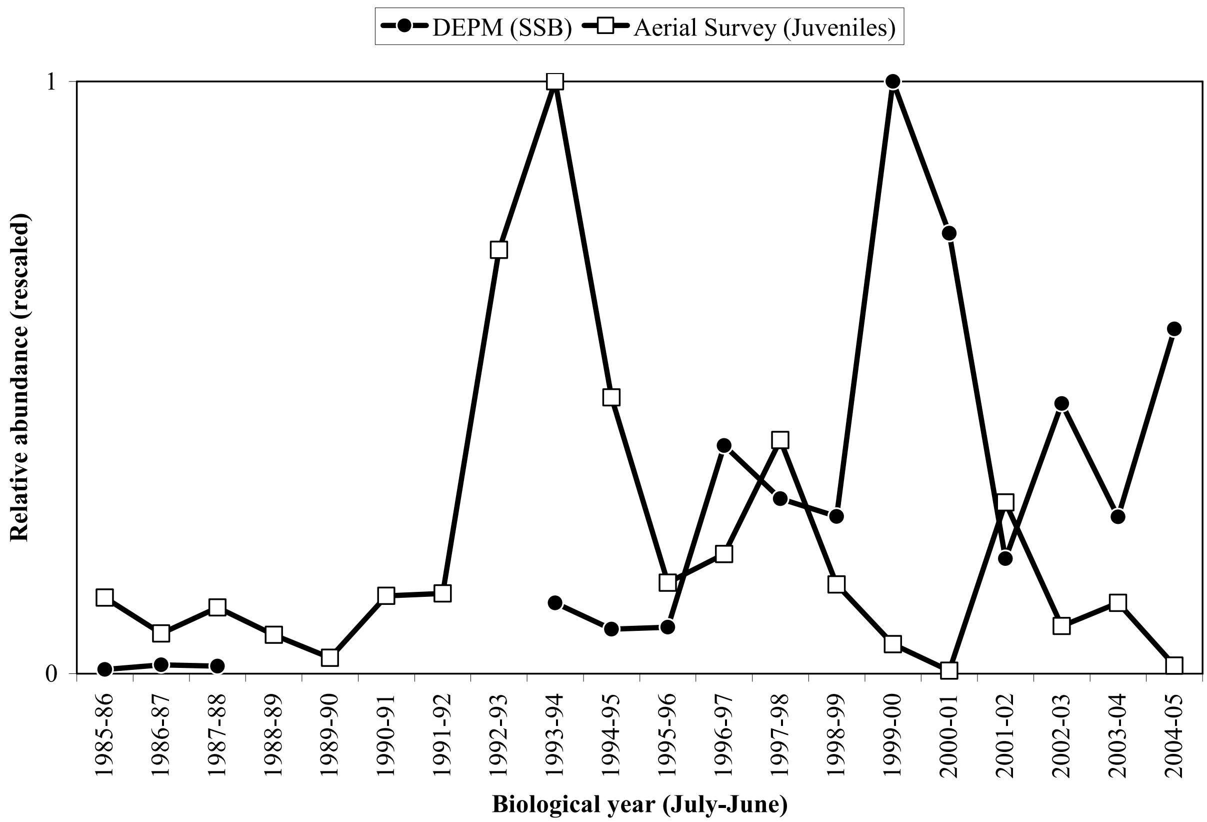


Figure 7. Indices of relative abundance for Pacific sardine applied in ASAP. Both indices are rescaled to a maximum value of 1 for comparison.

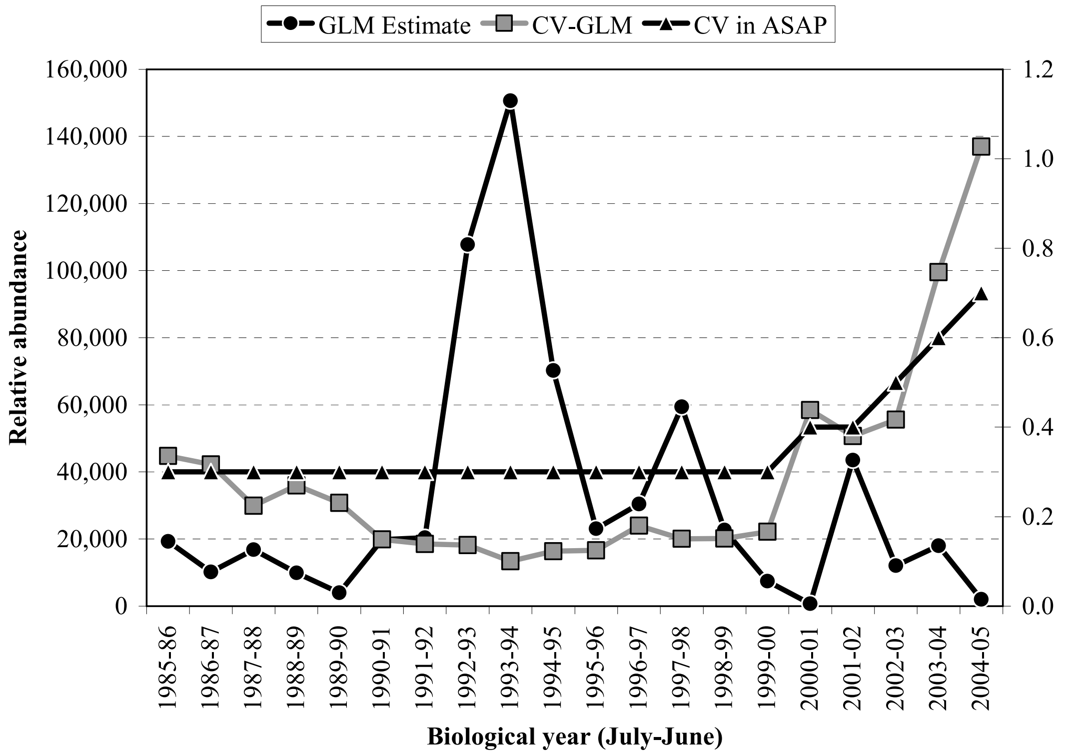


Figure 8. Aerial spotter survey index of relative abundance and coefficients of variation (CVs) from the GLM. CVs applied in the ASAP model are also displayed.

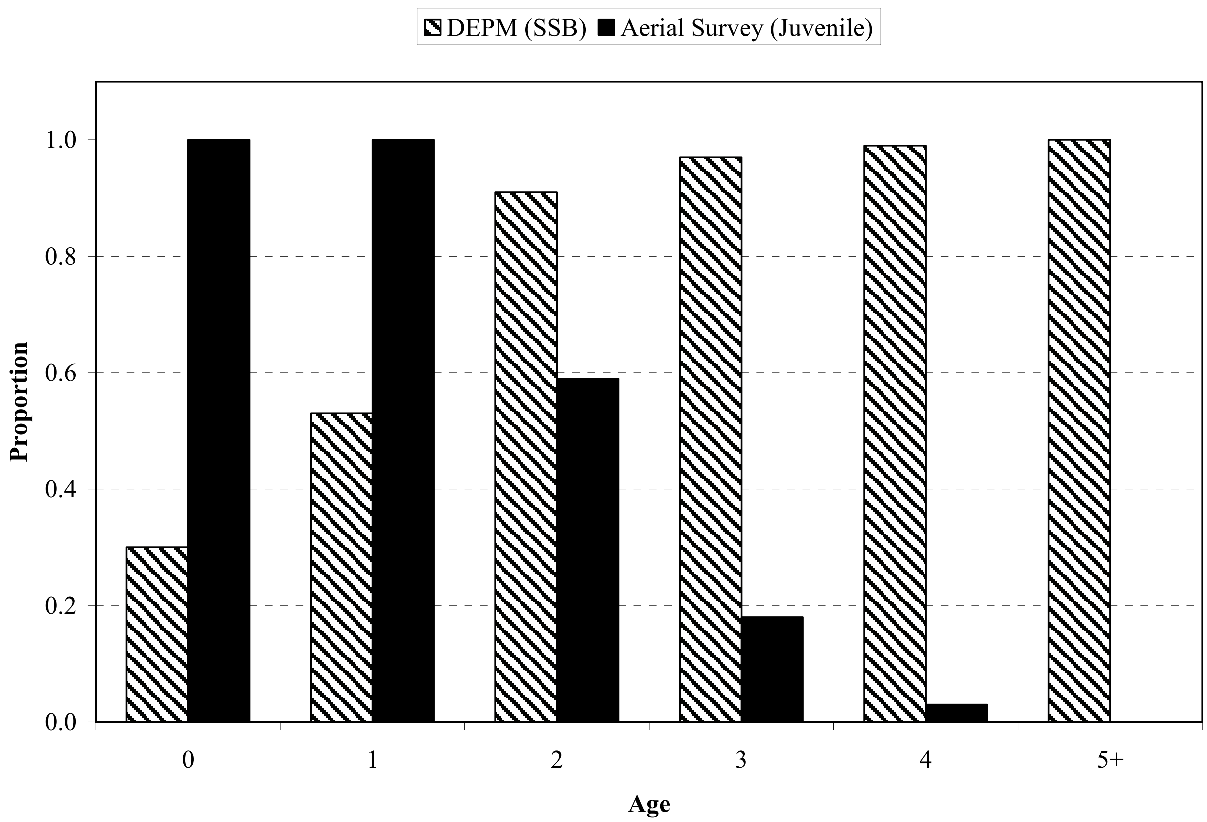
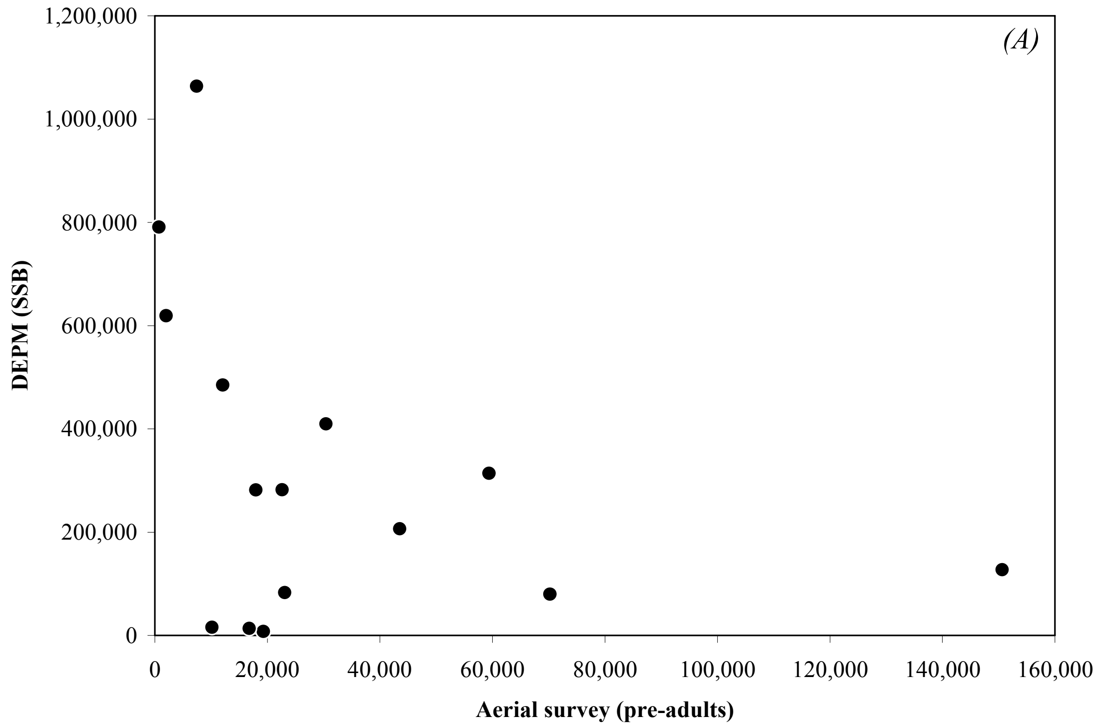


Figure 9. Selectivity ogives applied to Pacific sardine survey data in ASAP.



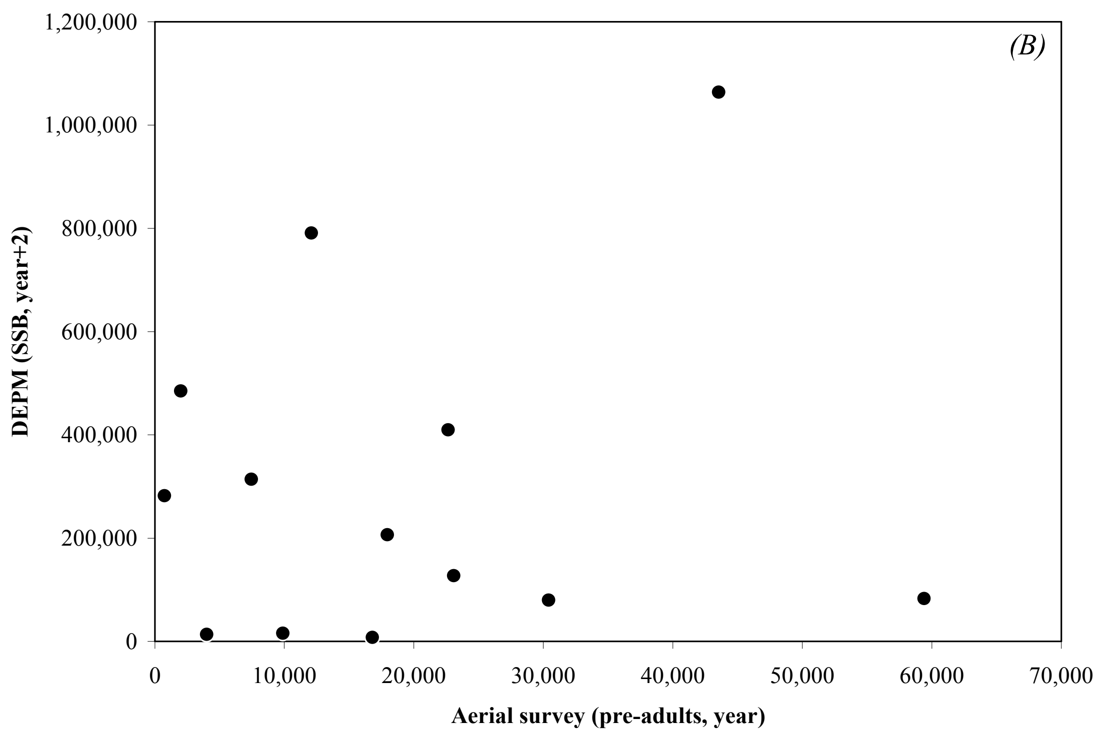


Figure 10. Comparisons of observed values for the DEPM survey (index of spawning stock biomass) and Aerial Spotter survey (index of young sardine): (A) year by year comparisons, and (B) surveys lagged two years, i.e. the aerial spotter index values were plotted against the DEPM index two years later.

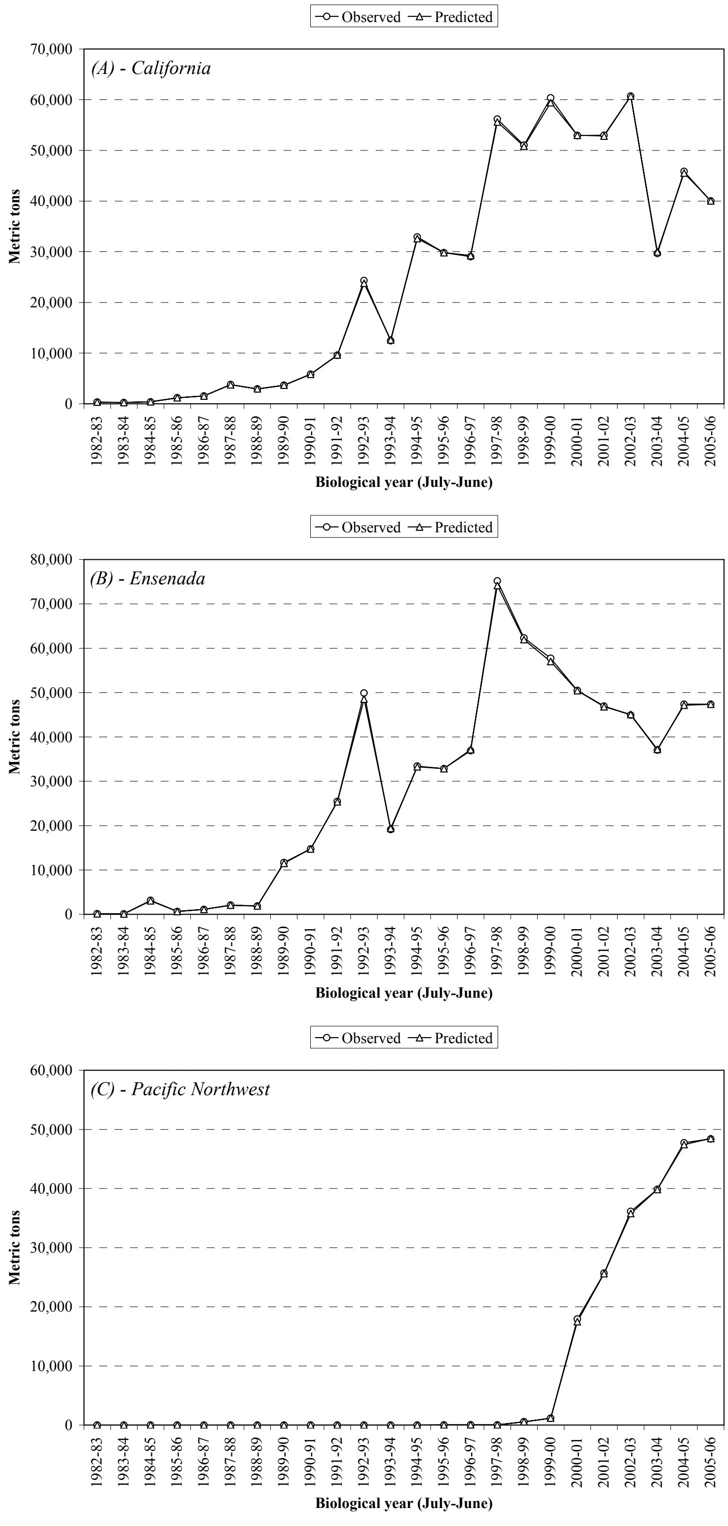


Figure 11. Observed and predicted estimates of total catch (mt) for the California fishery from the ASAP model (1982-2005): (A) California, (B) Ensenada, and (C) Pacific Northwest.

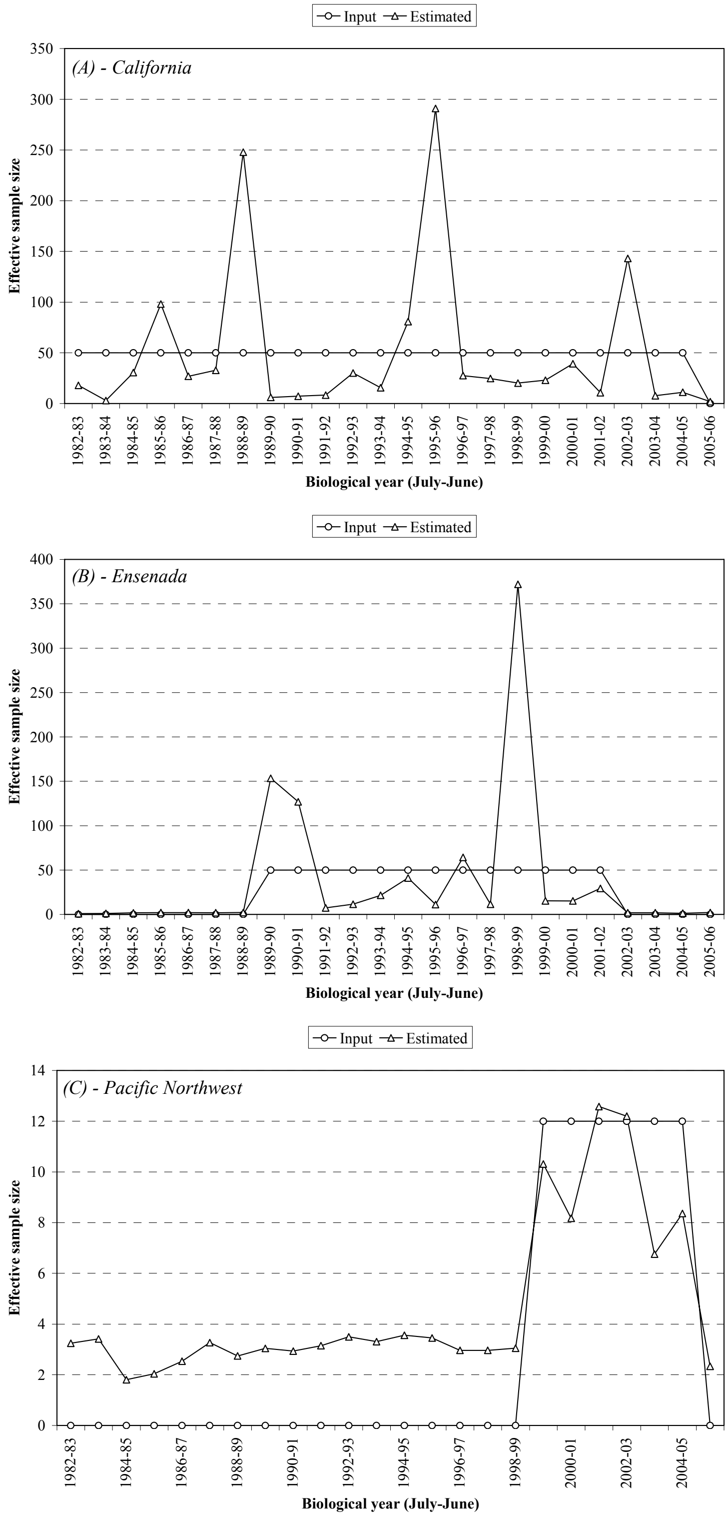


Figure 12. Effective sample sizes estimated for catch-at-age data from the (A) California, (B) Ensenada, and (C) Pacific northwest fisheries.

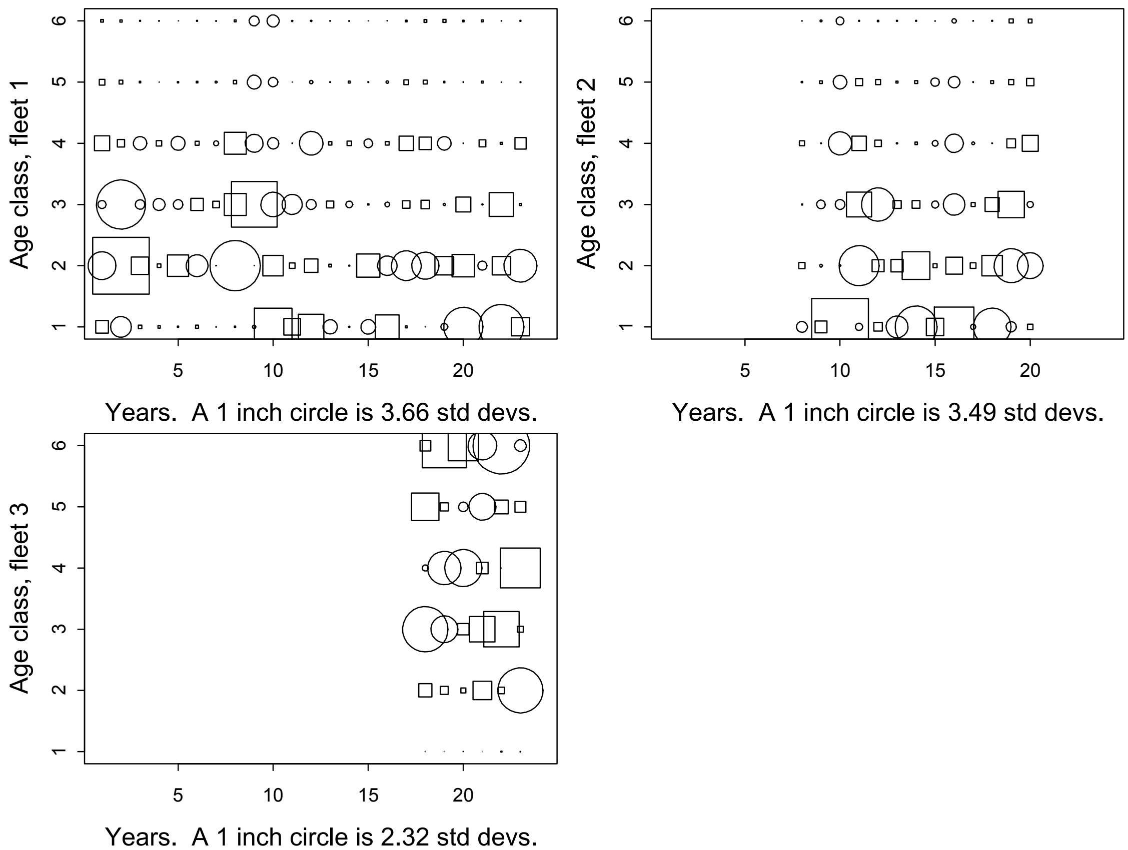
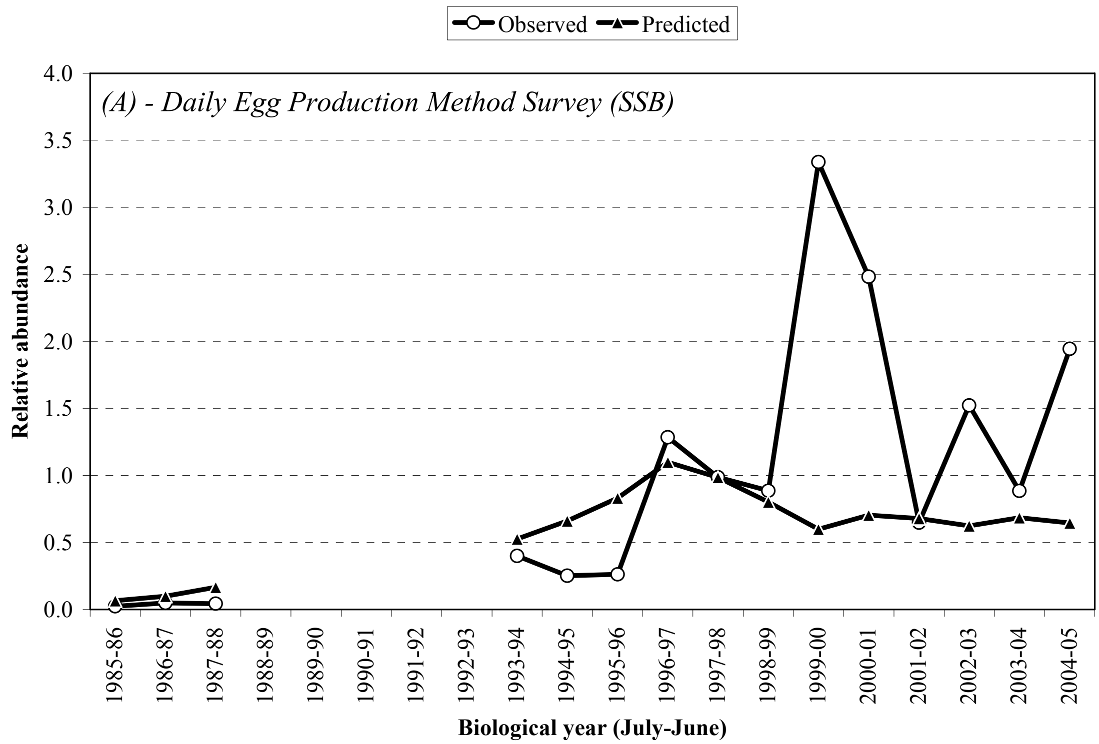


Figure 13. Standardized residuals from ASAP model fit to catch-at-age data for the three sardine fisheries (Fleet-1=CA; Fleet-2=MX; and Fleet-3=NW). Symbol size is proportional to the magnitude of the residual. Circles are positive and squares are negative residuals. Coded ages are shown on the ordinate of each plot (coded-age-1=true-age-0, coded-age-2=true-age-1, ..…, coded-age-6=true-ages-5+). Biological years are shown on the abscissa of each plot (1=1982, 2=1983, ..…, 23=2005).



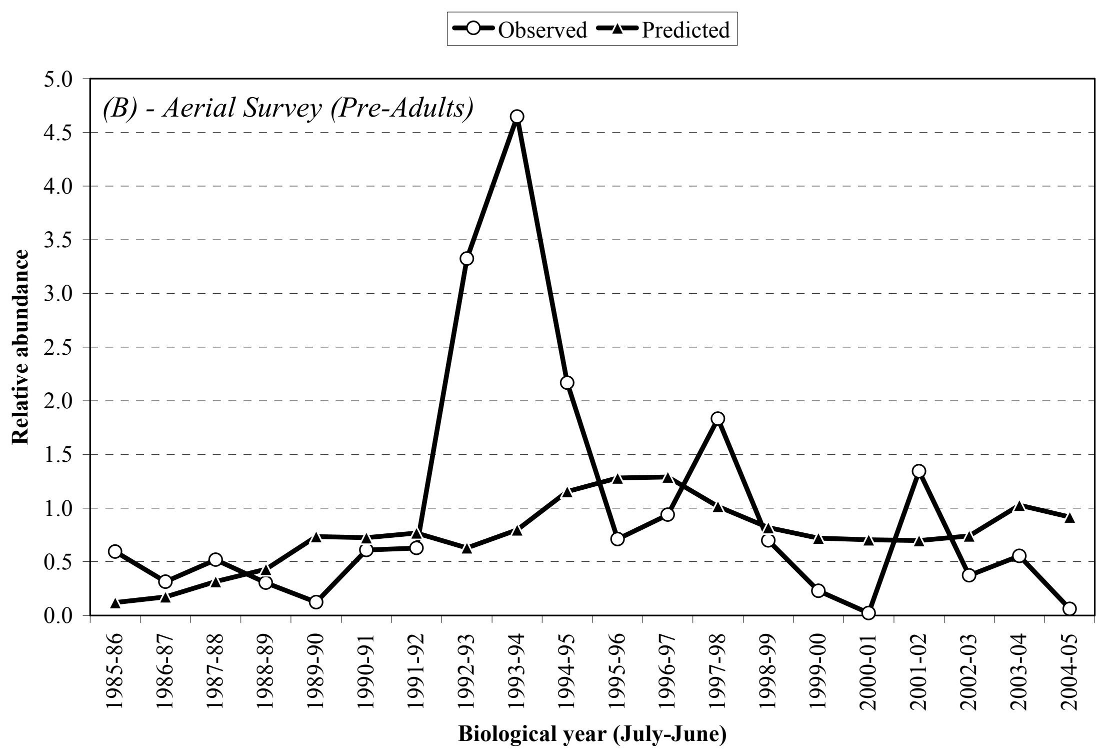


Figure 14. ASAP model fits to survey data: (A) Index of relative abundance of sardine spawning stock biomass (mt) based on daily egg production method (DEPM) estimates from ichthyoplankton survey data, 1985-85 to 2004-05; (B) Index of relative abundance of sardine pre-adult biomass (primarily age 0-2 fish) based on aerial spotter plane survey.

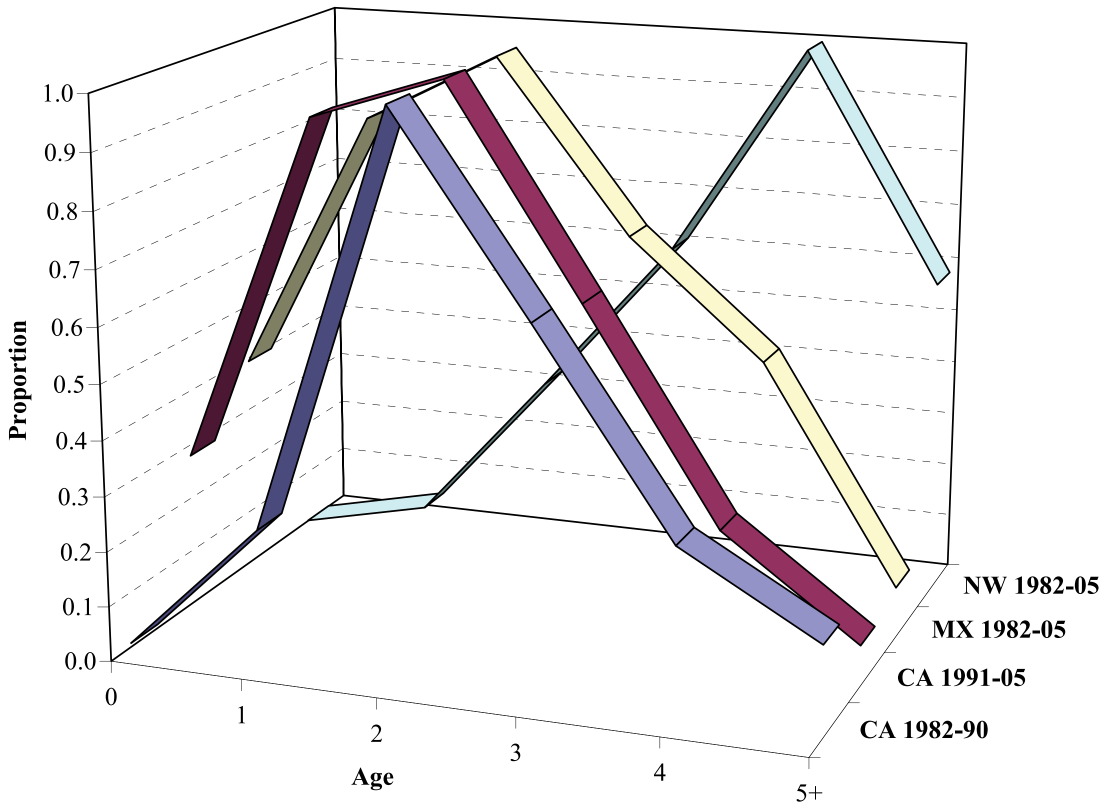


Figure 15. Estimated selectivities for the three modeled fisheries from the ASAP baseline model. The California fishery selectivity was estimated for two periods: 1982-91 (incidental fishery) and 1992-2005 (directed fishery).

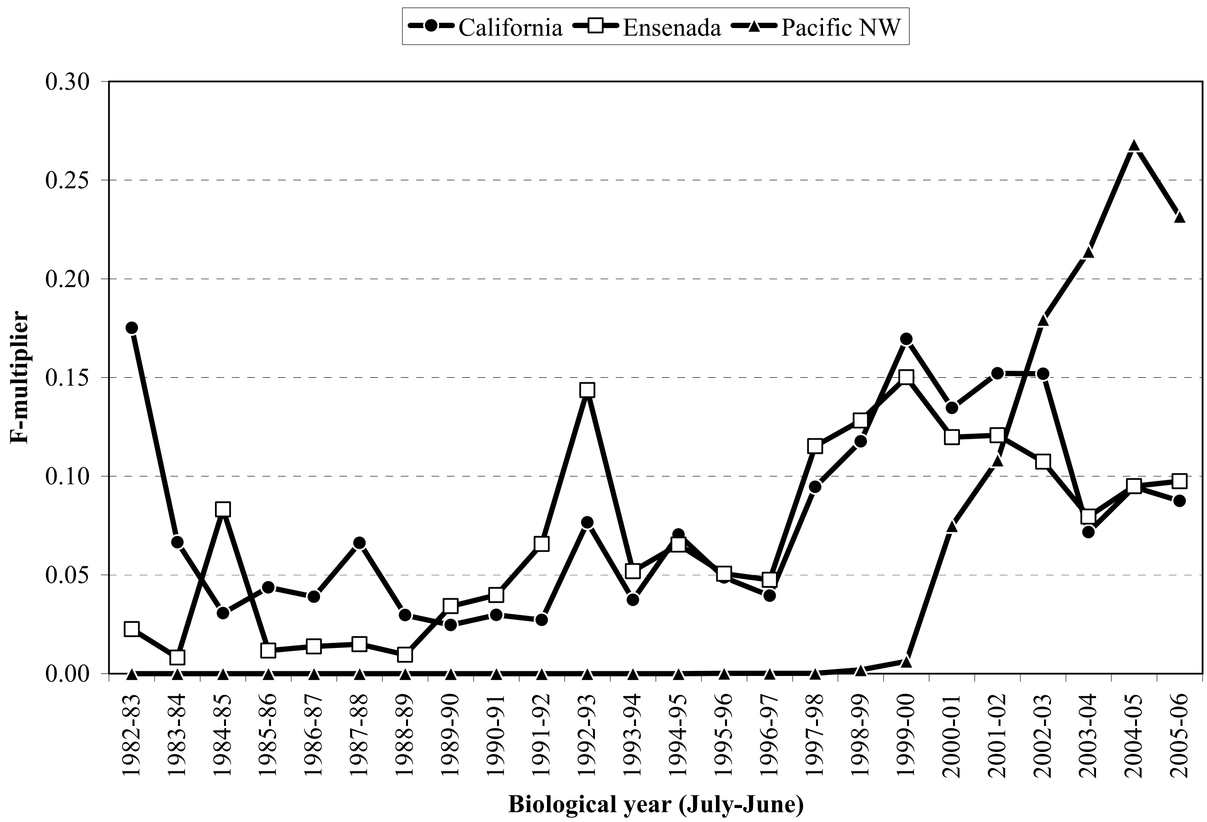


Figure 16. ASAP baseline model estimates of instantaneous rate of fishing mortality (yr^{-1}) for fully-selected age(s) in the three modeled fisheries.

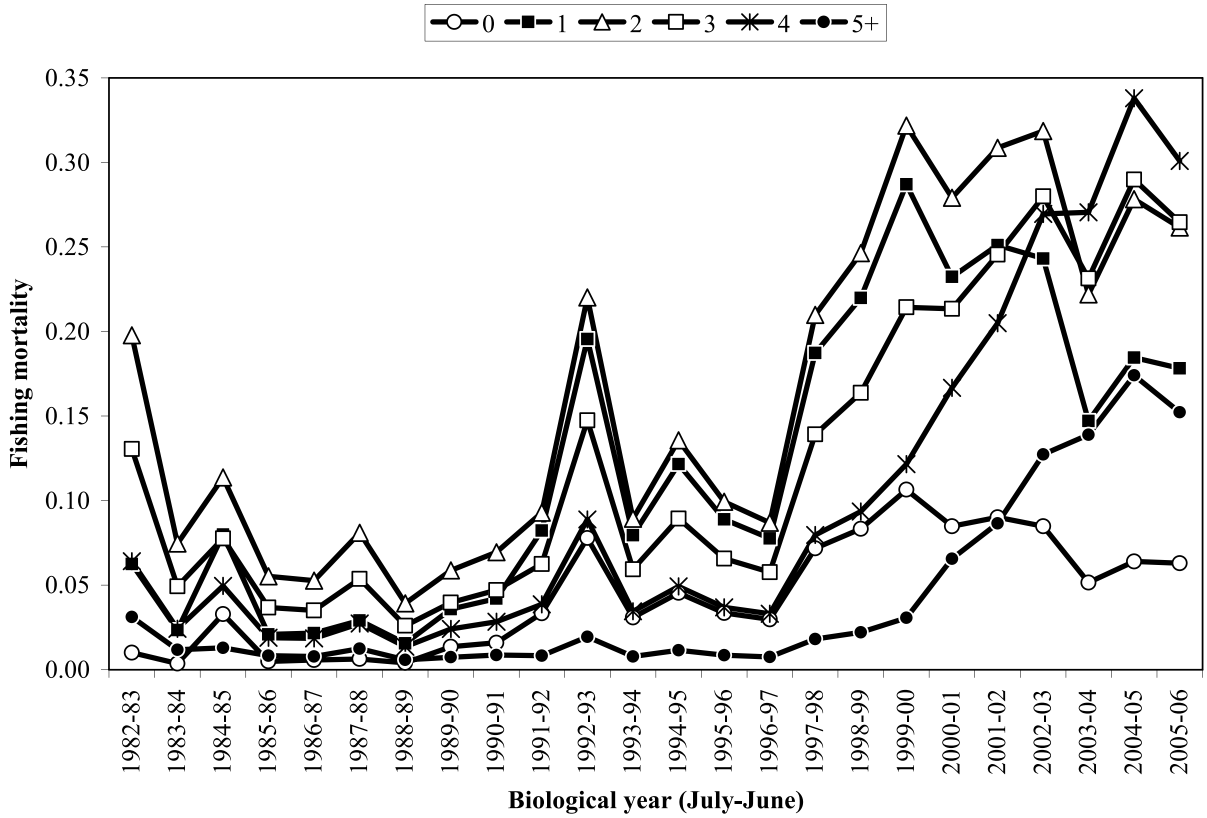


Figure 17. Estimated instantaneous rate of fishing mortality (yr^{-1}) by age and year for all fisheries combined from the ASAP baseline model.

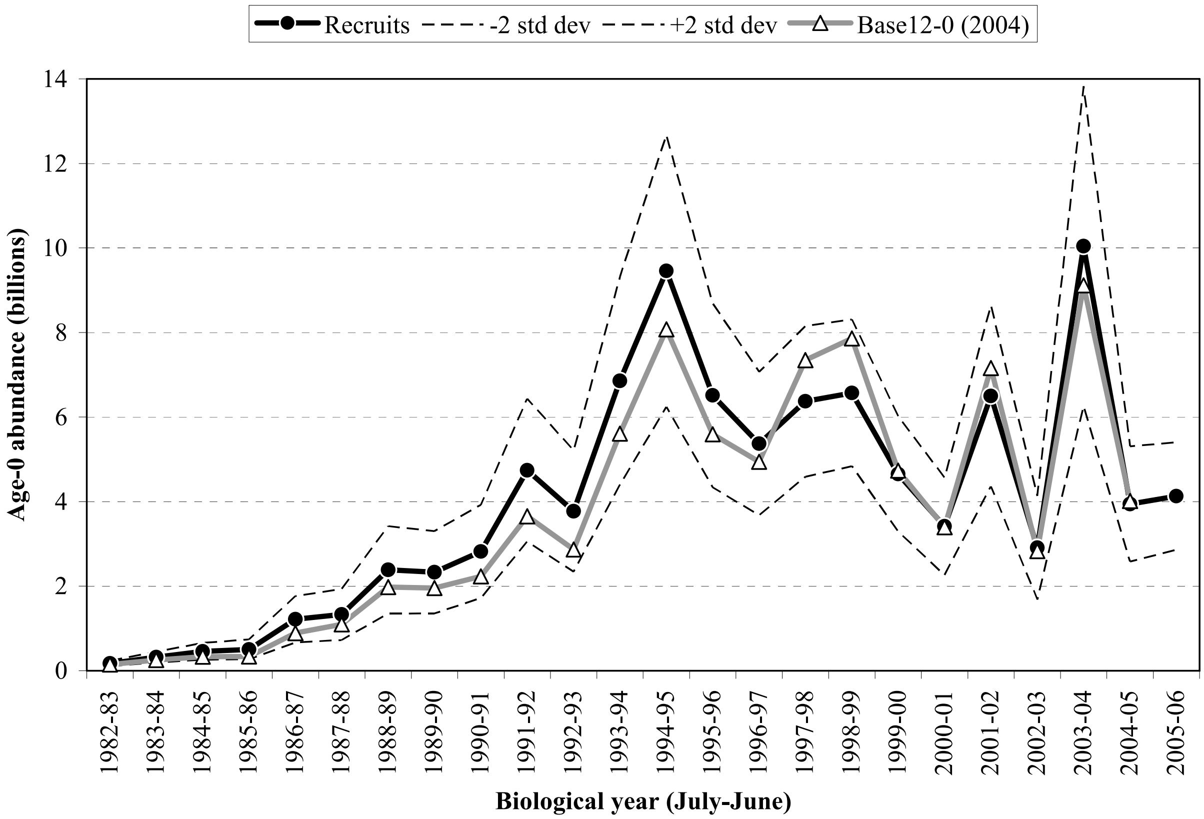


Figure 18. Pacific sardine recruitment estimates (age 0 abundance in billions) from the ASAP baseline model (solid circles) along with a 2-standard error uncertainty envelope (dashed lines). Corresponding estimates from Conser et al. (2004) are shown for comparison (triangles).

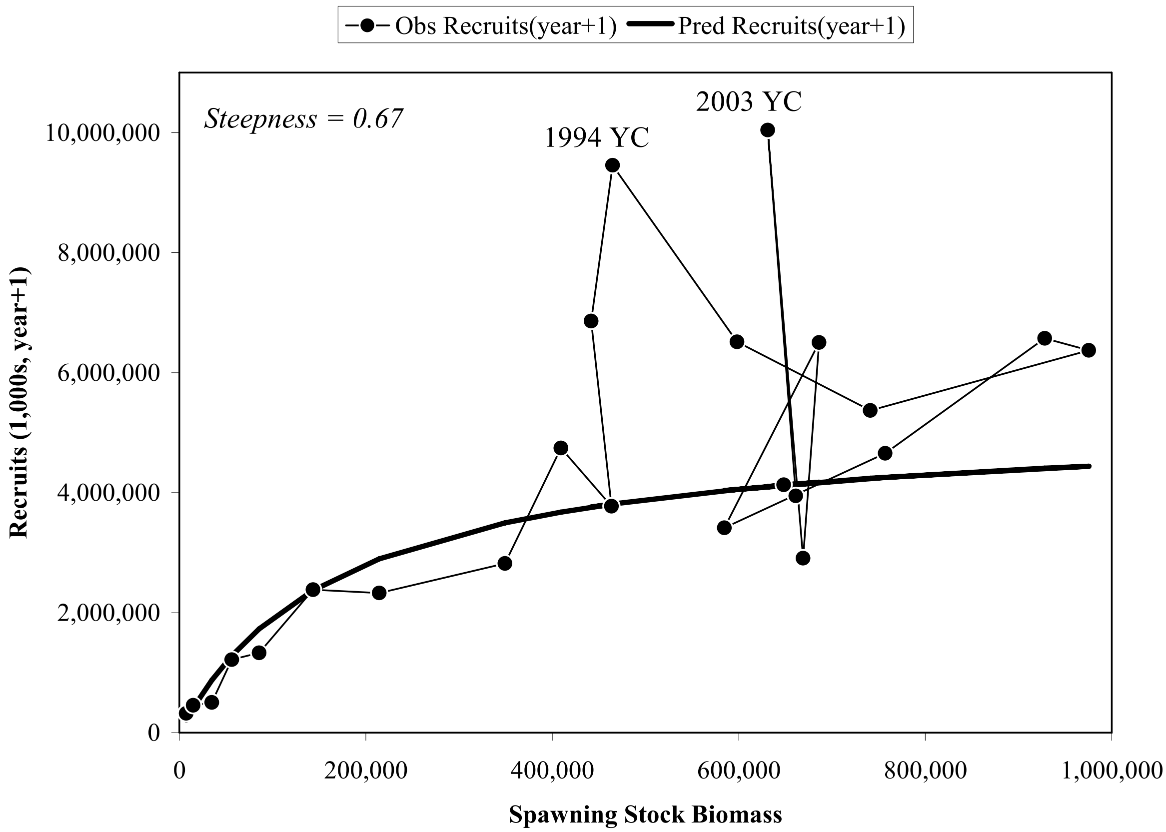


Figure 19. Sardine spawning stock biomass and recruitment estimates from the baseline model. Estimated recruitments from the Beverton-Holt stock-recruitment relationship are also shown. Year labels indicate the biological year associated with the spawning stock biomass.

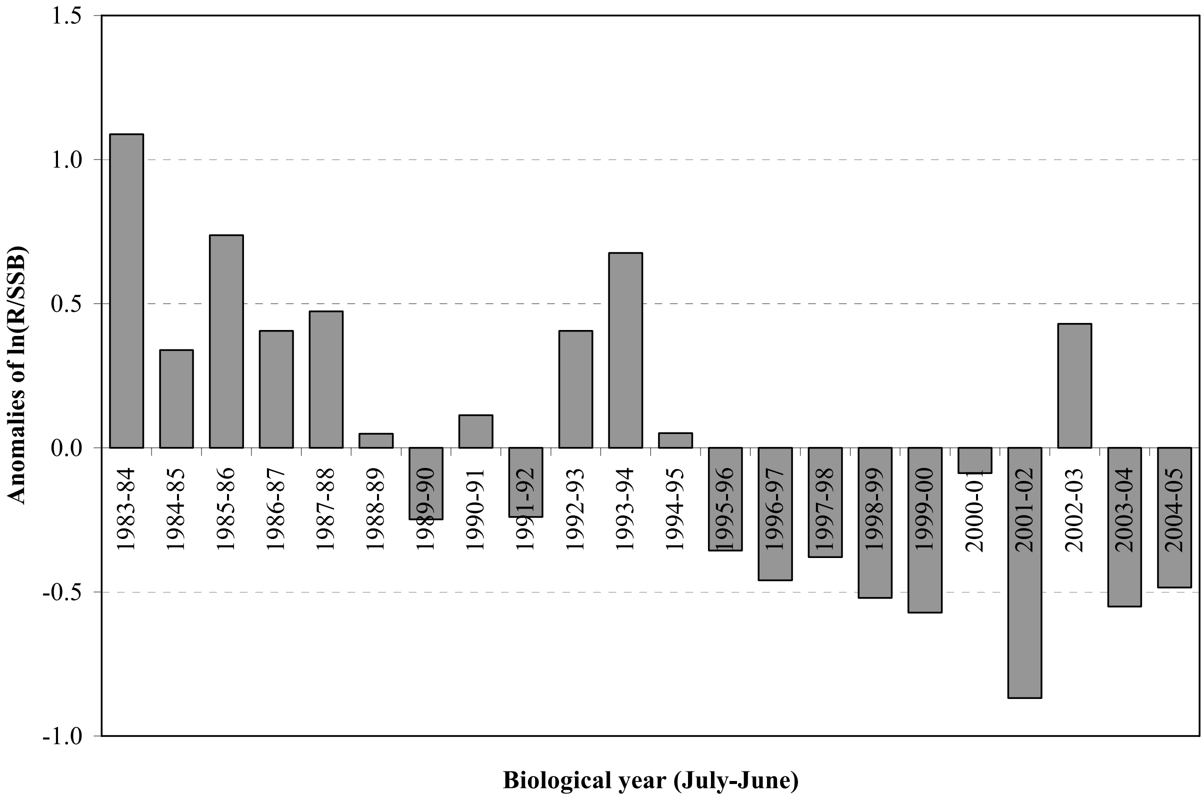
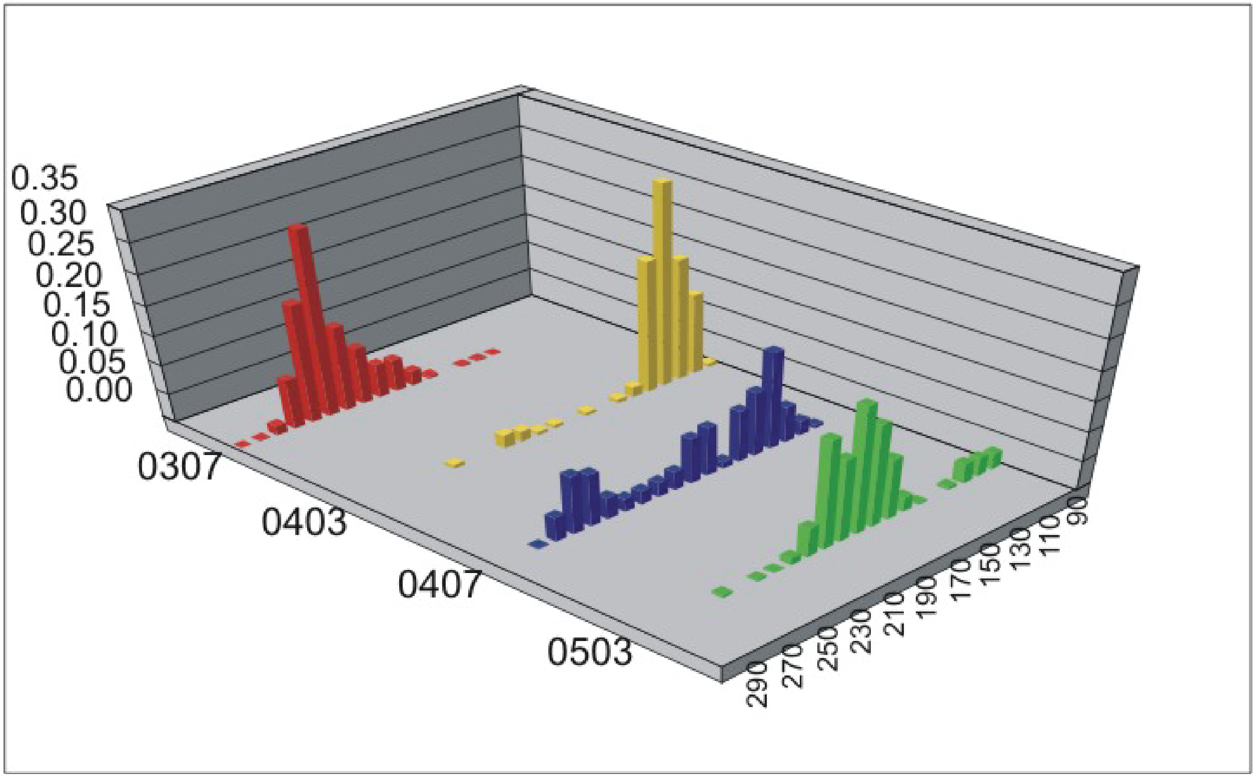


Figure 20. Relative reproductive success of Pacific sardine, 1982-83 to 2004-05.



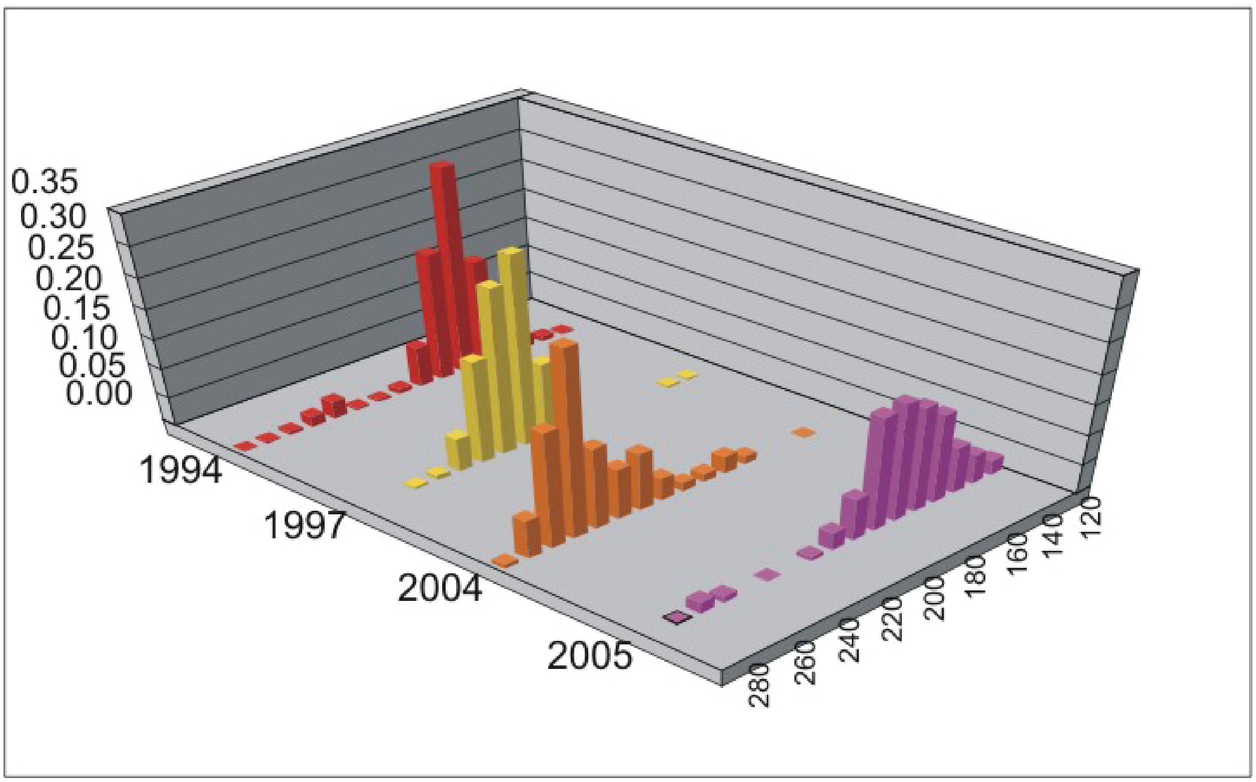


Figure 21. Length compositions of Pacific sardine collected during fishery-independent surveys, with evidence for a relatively strong 2003 year class in both areas: (top) Pacific northwest surveys in July 2003, March 2004, July 2004, and March 2005; (bottom) April surveys conducted in California offshore waters in 1994, 1997, 2004, and 2005.

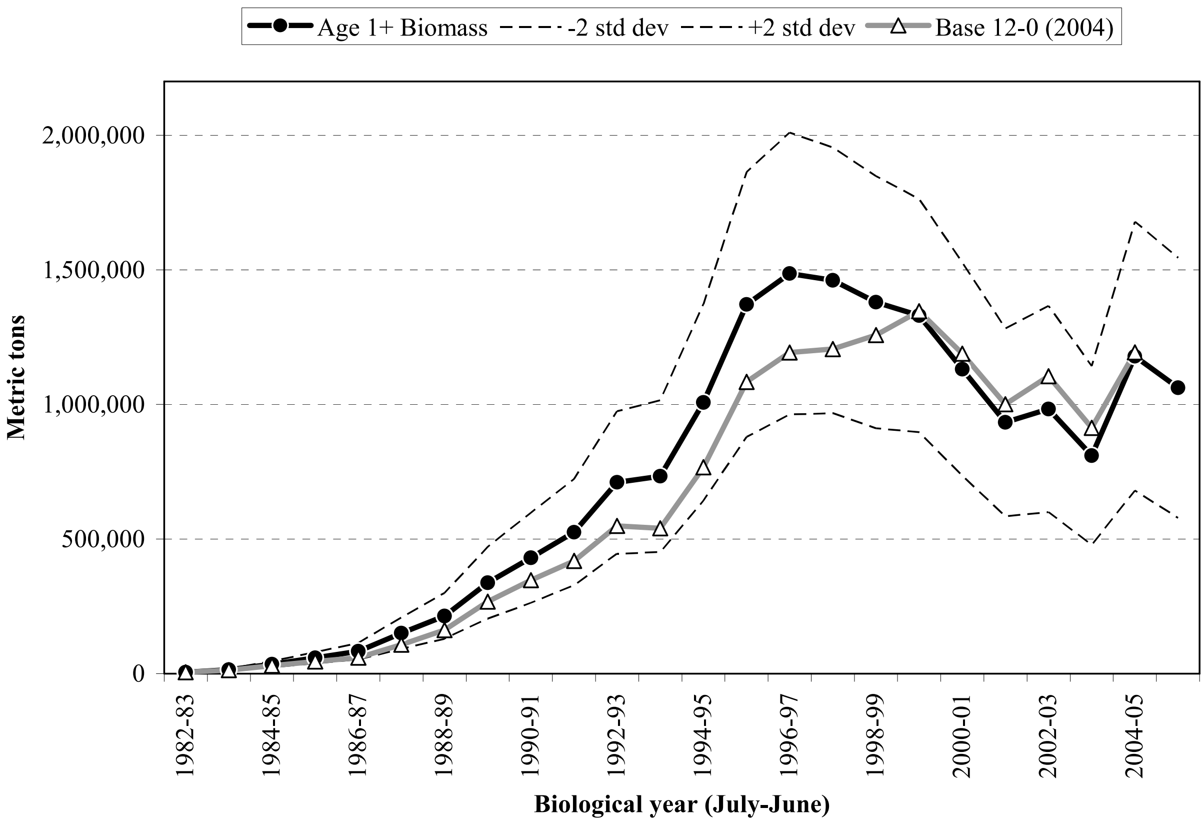


Figure 22. Pacific sardine stock (ages 1+) biomass estimates from the ASAP baseline model (solid circles) along with a 2-standard deviation uncertainty envelope (dashed lines). Corresponding estimates from Conser et al. (2004) are shown for comparison (triangles).

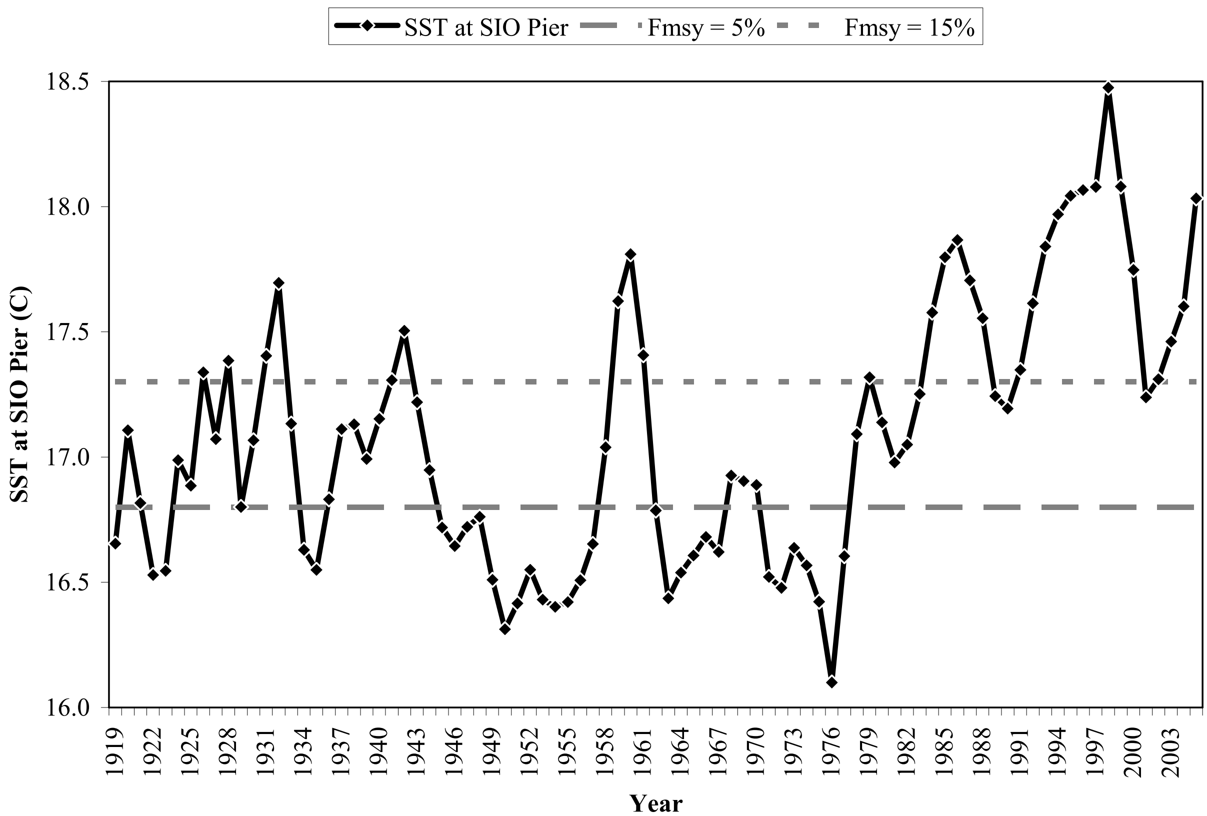


Figure 23. Three-season (July-June) running average of sea surface temperature (SST) data collected daily at Scripps Institution of Oceanography pier since 1916. For any given year, SST is the running average temperature during the three preceding years, e.g. the 2005 estimate is the average from July 1, 2002 through June 30, 2005. The 2005 value used for management in 2006 is 18.0 °C, so a 15% exploitation fraction (F_{msy}) should be applied in the harvest control rule.

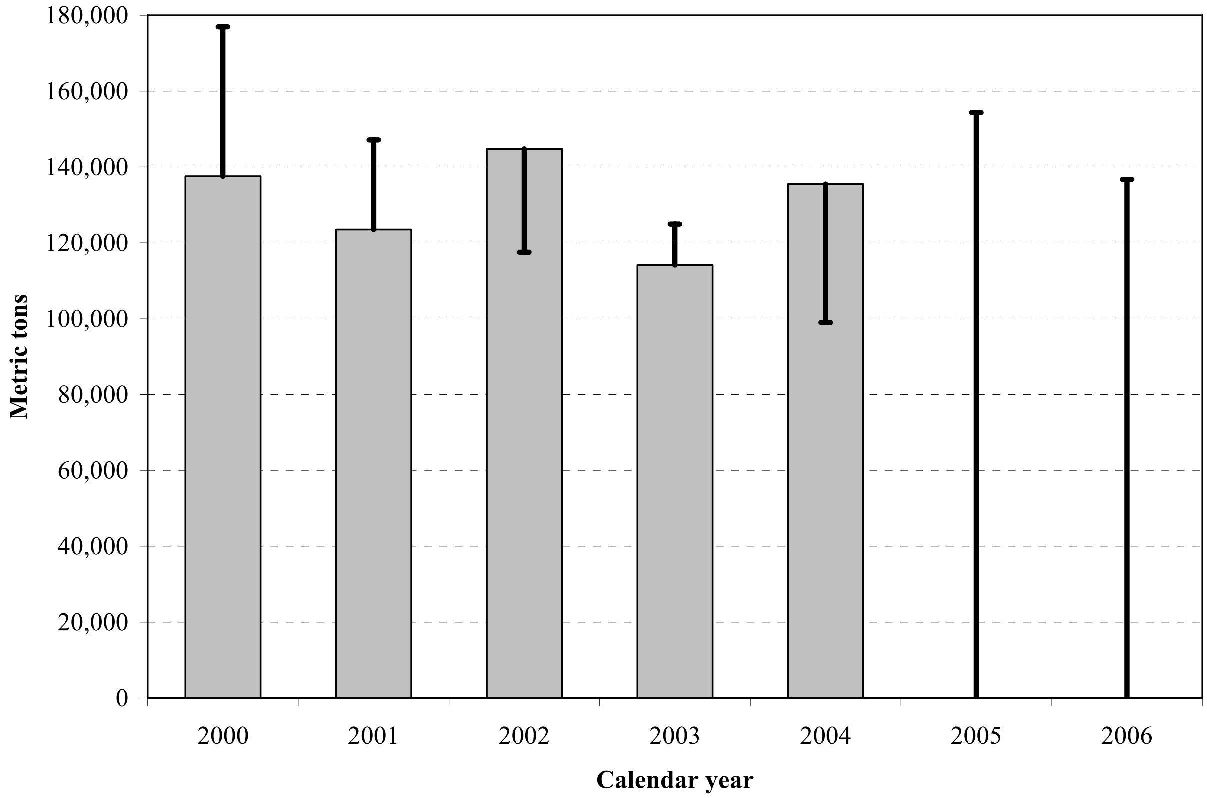


Figure 24. Coast-wide harvest of Pacific sardine relative to retrospective harvest guidelines (HGs) based on the biomass time series from the current assessment. Total HGs are based on the same formula presented in 'HARVEST GUIDELINE FOR 2006' but are not prorated for assumed U.S. Distribution and therefore represent the sustainable harvest for the west coast of North America.

APPENDICES

ICCAT WORKING DOCUMENT
SCRS/98/58

A Flexible Forward Age-Structured Assessment Program

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

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

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

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Sustainable Fisheries Division Contribution SFD-98/99-16

Summary

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

Introduction

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

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

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

The Model

Population dynamics

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

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

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

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

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

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

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

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

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

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

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

The catch by age, year and fleet is

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

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

The yield by age, year and fleet is

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Time-varying parameters

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

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

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

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

as do the fleet specific fishing mortality rate multipliers

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

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

Parameter estimation

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

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

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

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

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

and indices of abundance (lognormally distributed)

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

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

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

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

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

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

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

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

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

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

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

and over time

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

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

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

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

Additional Features

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

Example: Western Atlantic Bluefin Tuna

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

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

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

(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

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

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

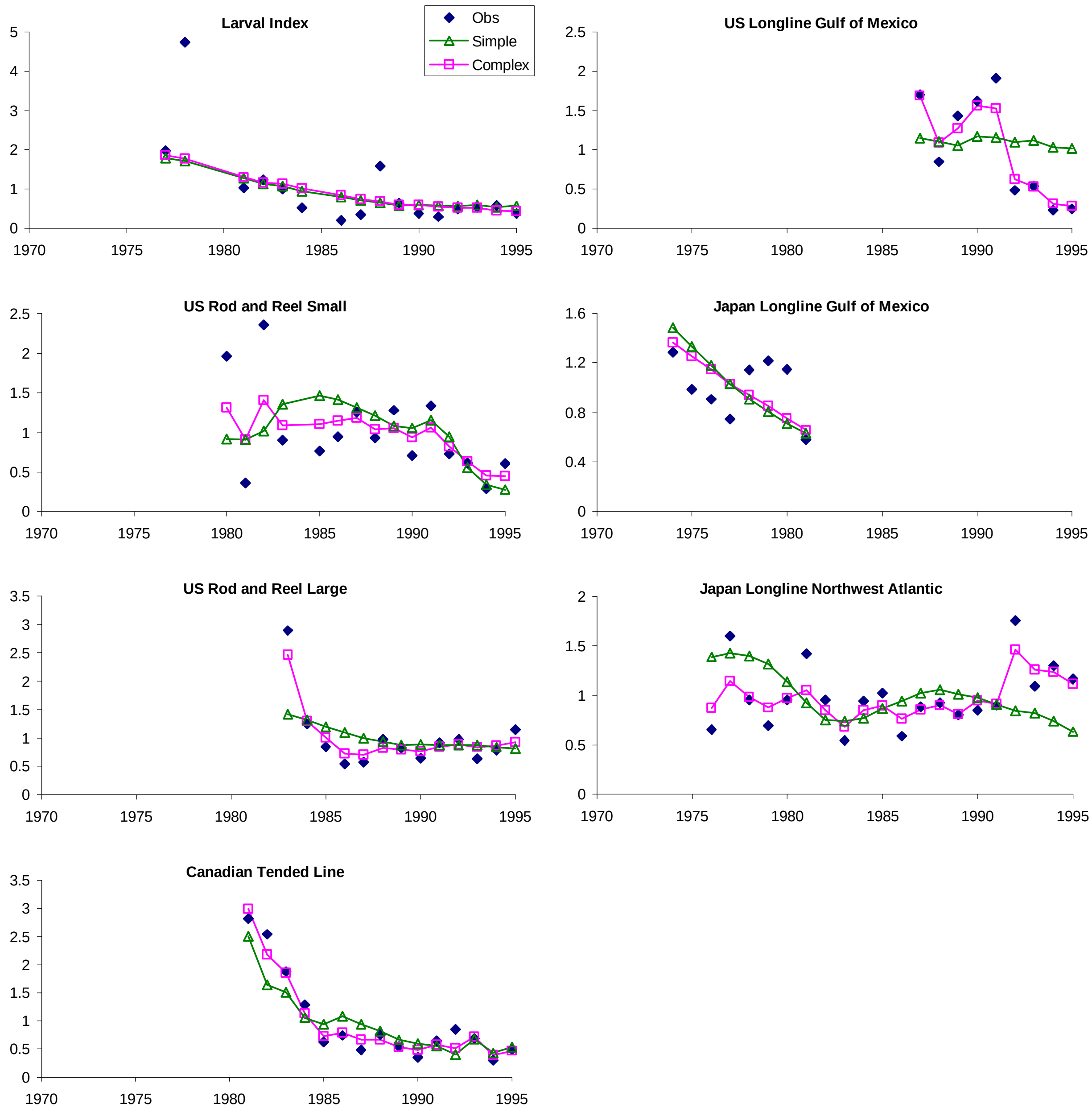

Figure 1. Observed and predicted indices for the simple and complex ASAP analyses.

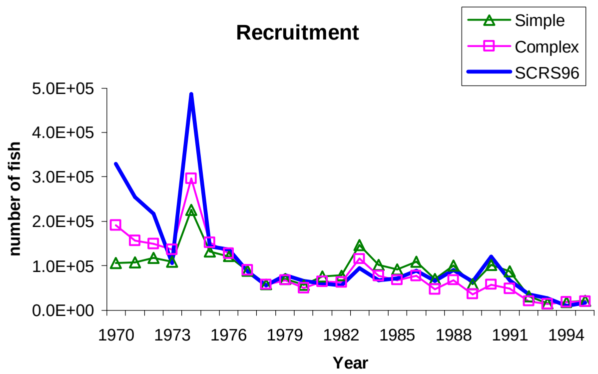

Figure 2. Estimated recruitment from two ASAP analyses and the SCRS 1996 assessment.

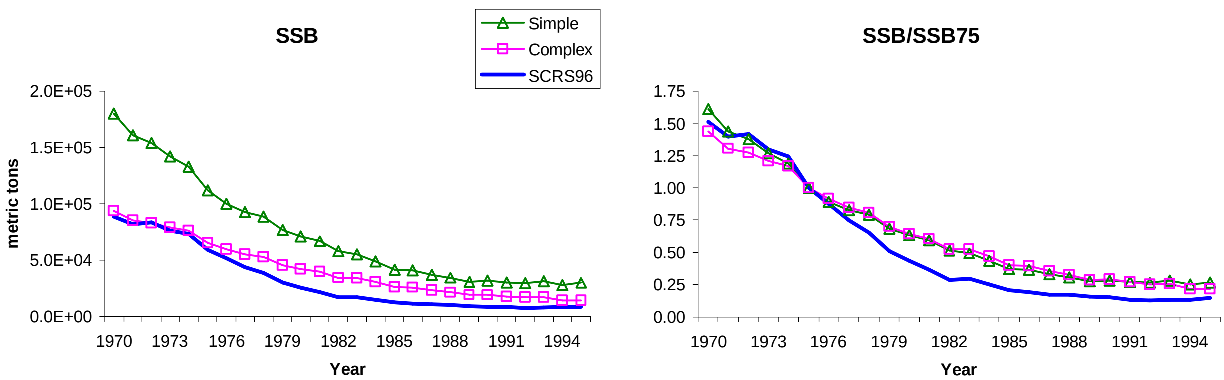

Figure 3. Spawning stock biomass (SSB) from two ASAP analyses and SCRS 1996.

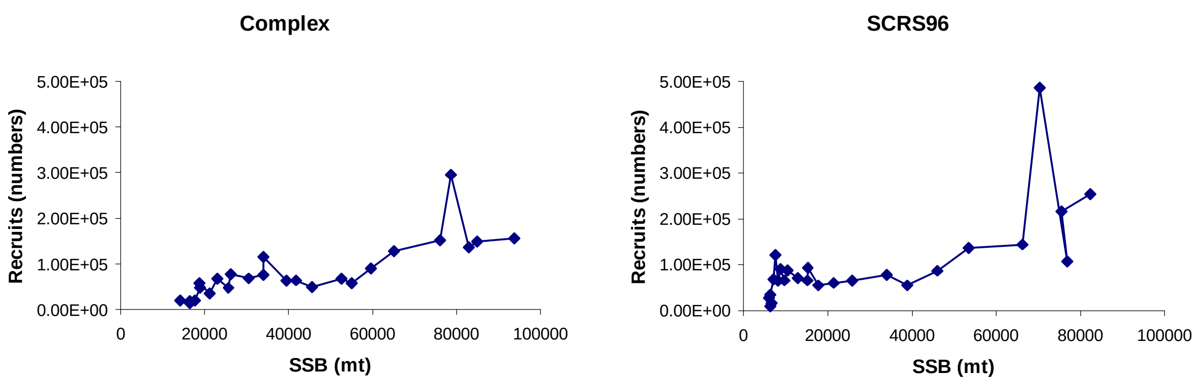

Figure 4. Complex ASAP analysis and SCRS 1996 stock-recruitment relationships.

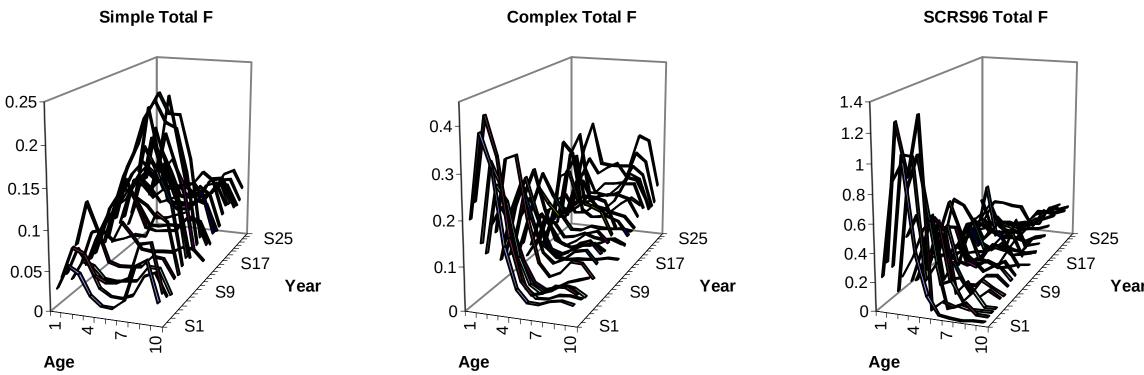

Figure 5. Estimated fishing mortality rates by age and year for two ASAP analyses and SCRS 1996.

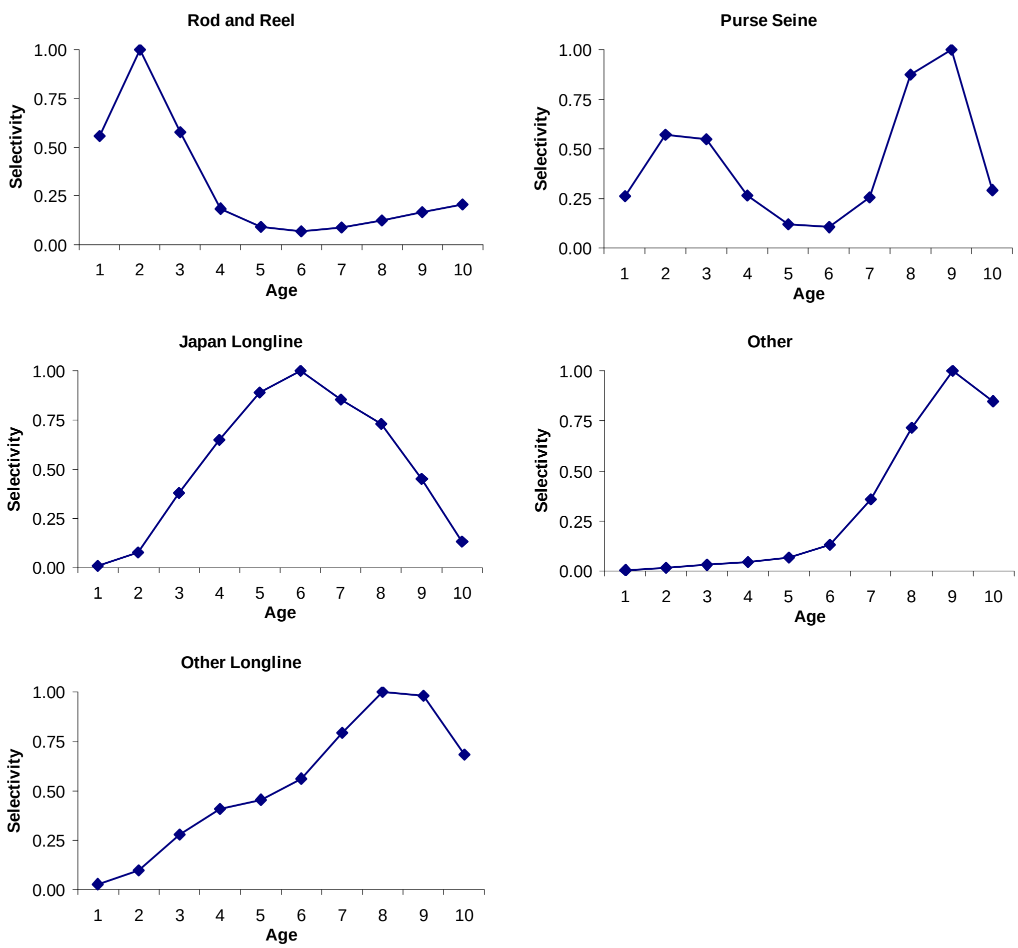

Figure 6a. Selectivity at age for the simple ASAP analysis, constant over all years for each fleet.

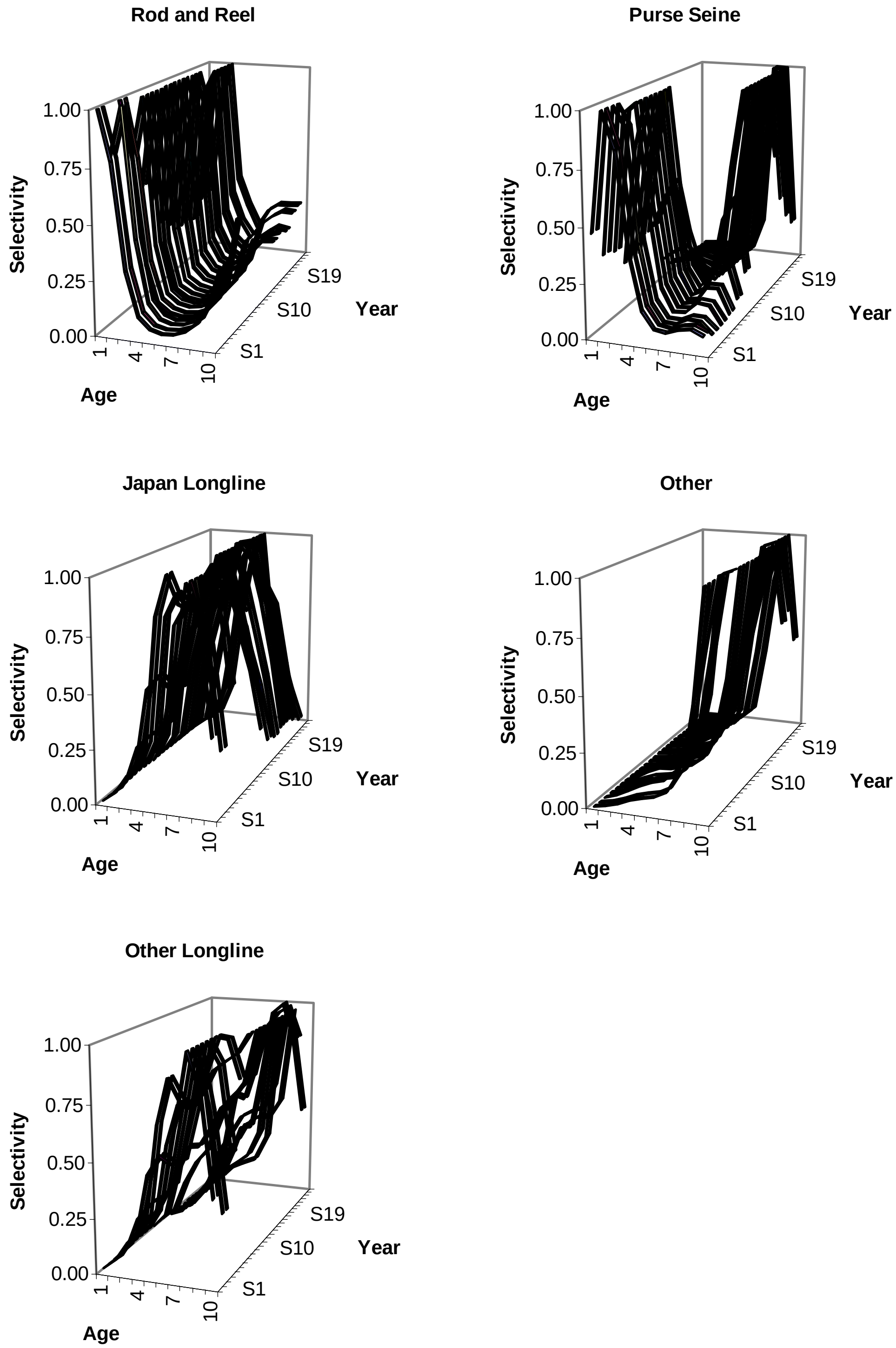

Figure 6b. Selectivity at age for the complex ASAP analysis.

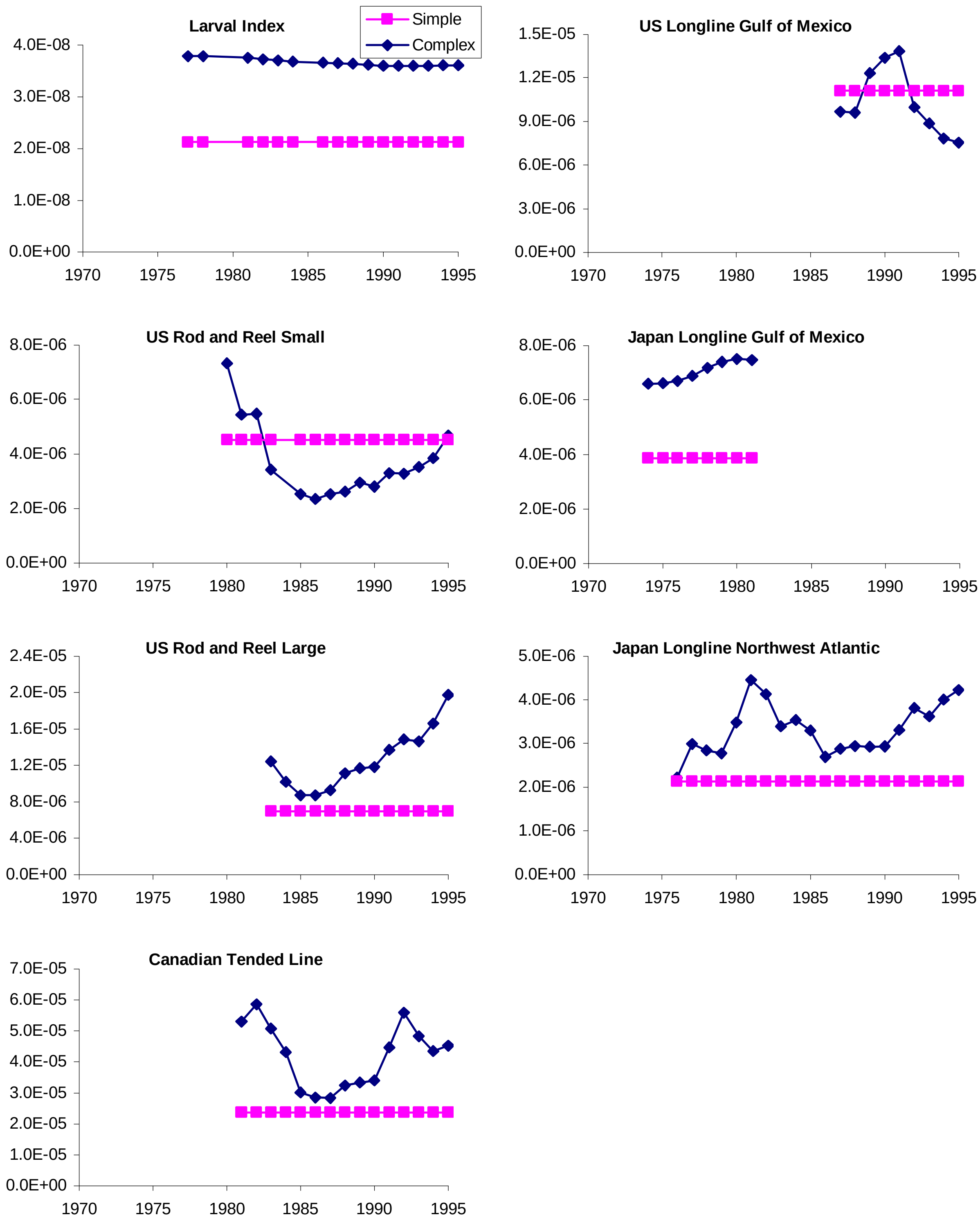

Figure 7. Catchability for each tuning index from the two ASAP analyses.

APPENDIX II

ASAP ADMB TEMPLATE FILE (BASELINE MODEL)

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


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


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

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

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

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

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

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

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

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


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

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

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


  objective_function_value obj_fun

PRELIMINARY_CALCS_SECTION                  // this section requires ;
```

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


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


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

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


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

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

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

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

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


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

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

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

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


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

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


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

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

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

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

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

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

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

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

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


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


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

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

   }


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


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


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

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

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


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

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


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

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

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

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

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

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

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


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

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

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

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


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

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

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

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

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

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

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


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

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

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

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

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

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

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

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

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

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


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

APPENDIX III

ASAP INPUT FILE (BASELINE MODEL)

```
# Base-D5
# Number of Years
   24
# 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
# 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   0.066   0.097   0.116   0.130   0.156
   0.048   0.066   0.097   0.116   0.130   0.156
# 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
   27553.5  734285.5  88954.32  12511.99  2852.849   892.991  45851.21
         0         0         0         0         0         0  39998.71
# 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  47379.38
# 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  141867.4  47637.46  46185.43  27291.91  96306.36  47746.33
        0         0         0         0         0         0  48383.97
# 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
# 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
```

```
# 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
# 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
# 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
# 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
# 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      -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
# 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
   0.4
   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
         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
# 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
   2007
# Year Projected Recruits, What Projected, Target, non- directed F mult
      2006         2         2         2        -1
      2007         2         2         2        -1
# Test Value
   -23456
#####
# ---- FINIS ----
```

APPENDIX IV

ASAP REPORT FILE (BASELINE MODEL D5)

```
obj_fun        = 531.134
Component          RSS      nobs  Lambda  Likelihood
  Catch_Fleet_1        0.00208638   24   100   0.208638
  Catch_Fleet_2        0.00550447   24   100   0.550447
  Catch_Fleet_3        0.121723   24   100   12.1723
Catch_Fleet_Total     0.129314   72   100   12.9314
  Discard_Fleet_1        0   24   0   0
  Discard_Fleet_2        0   24   0   0
  Discard_Fleet_3        0   24   0   0
Discard_Fleet_Total     0   72   0   0
CAA_proportions      N/A            432    see_below      208.244
Discard_proportions      N/A            432    see_below      0
  Index_Fit_1         12.3232   15   1   62.3062
  Index_Fit_2         35.2134   20   1   127.331
Index_Fit_Total     47.5366   35   2   189.637
  Selectivity_devs_fleet_1   15.0597  1   0  0
  Selectivity_devs_fleet_2   0  1   0  0
  Selectivity_devs_fleet_3   0  1   0  0
Selectivity_devs_Total   15.0597  3   0  0
  Catchability_devs_index_1  0  15  10  0
  Catchability_devs_index_2  0  20  10  0
Catchability_devs_Total  0  35  20  0
  Fmult_fleet_1     6.5107   23   1  6.5107
  Fmult_fleet_2     15.2223   23   1  15.2223
  Fmult_fleet_3     53.8653   23   1  53.8653
Fmult_fleet_Total   75.5983   69   3  75.5983
N_year_1            0   5   0   0
Stock-Recruit_Fit   14.5603  24   1   30.1618
Recruit_devs        14.5603   24   1   14.5603
SRR_steepness       0.00136192       1 0   0
SRR_virgin_stock    0.0600861      1 0  0
Curvature_over_age  20.6278   12   0   0
Curvature_over_time 30.1193   396   0   0
F_penalty           1.94786    144     0.001     0.00194786
Mean_Sel_year1_pen  0   18      1000  0
Max_Sel_penalty     2.55118        1       100 0
Fmult_Max_penalty   0        ?       100 0

 Input and Estimated effective sample sizes for fleet 1
1982  50  17.919
1983  50  2.96175
1984  50  30.5749
1985  50  98.1246
1986  50  26.859
1987  50  32.834
1988  50  247.87
1989  50  6.13538
1990  50  7.18174
1991  50  8.36063
1992  50  30.1422
1993  50  15.6734
1994  50  80.761
1995  50  290.86
1996  50  27.4998
1997  50  24.6476
1998  50  20.1654
1999  50  22.9873
2000  50  39.3734
2001  50  10.6757
2002  50  143.035
2003  50  7.70316
2004  50  11.0858
2005  0  1.96606
 Total  1150  1205.4
 Input and Estimated effective sample sizes for fleet 2
```

```
1982  0  0.846326
1983  0  1.21895
1984  0  1.72666
1985  0  2.09459
1986  0  2.01282
1987  0  1.93517
1988  0  2.18841
1989  50  153.435
1990  50  127.03
1991  50  7.39227
1992  50  11.589
1993  50  21.6126
1994  50  41.1105
1995  50  11.2197
1996  50  64.2595
1997  50  11.5448
1998  50  371.973
1999  50  15.3386
2000  50  15.1556
2001  50  29.3669
2002  0  1.92541
2003  0  1.92356
2004  0  1.36766
2005  0  2.24147
 Total  650  900.508
 Input and Estimated effective sample sizes for fleet 3
1982  0  3.24216
1983  0  3.41431
1984  0  1.80781
1985  0  2.03931
1986  0  2.5376
1987  0  3.27036
1988  0  2.74197
1989  0  3.04451
1990  0  2.93179
1991  0  3.1445
1992  0  3.4953
1993  0  3.30641
1994  0  3.55941
1995  0  3.45341
1996  0  2.96394
1997  0  2.96576
1998  0  3.04895
1999  12  10.309
2000  12  8.16719
2001  12  12.5777
2002  12  12.1919
2003  12  6.75693
2004  12  8.35822
2005  0  2.3357
 Total  72  111.664

 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
 Total  0  2.4e+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
 Total  0  2.4e+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
 Total  0  2.4e+16

Observed and predicted total fleet catch by year
 fleet 1 total catches
1982  337.2  333.582
1983  248.21  248.237
1984  396.98  401.64
1985  1191.13  1186.13
1986  1548.2  1559.48
1987  3810.27  3763.04
1988  2918.96  2937.78
1989  3658.77  3668.08
1990  5855.6  5834.47
```

```
1991  9574.24  9656.14
1992  24319.9  23764.8
1993  12431.2  12616.5
1994  32902.4  32588.1
1995  29819.7  29817.9
1996  29026.8  29262.2
1997  56172.3  55589.5
1998  51005.2  50779.7
1999  60360.5  59414
2000  52915.6  52976.5
2001  52980.7  52819
2002  60713.6  60689.9
2003  29649.7  29984.7
2004  45851.2  45524.9
2005  39998.7  40032.4
 fleet 2 total catches
1982  149.5  147.872
1983  124.1  128.395
1984  3174.2  3041.47
1985  647.3  661.607
1986  1118.4  1117.93
1987  2076.8  2067.39
1988  1875.7  1908.1
1989  11663.2  11512.2
1990  14746.3  14750.7
1991  25447.3  25385.5
1992  49889.8  48545.7
1993  19108.4  19383.1
1994  33392.7  33254
1995  32834.8  32840.7
1996  36897.2  37118.5
1997  75179.4  74154.2
1998  62333.2  61941
1999  57743  57012.4
2000  50456.8  50439.3
2001  46948.1  46805.8
2002  44937.9  45062.3
2003  37040.3  37220.1
2004  47379.4  47150.5
2005  47379.4  47369.9
 fleet 3 total catches
1982  0  0.00111185
1983  0  0.00137158
1984  0  0.00315959
1985  0  0.00700038
1986  0  0.0118713
1987  0  0.0172469
1988  0  0.0271529
1989  0  0.0420554
1990  0  0.0722626
1991  0  0.172836
1992  4.08  3.71289
1993  0  0.197065
1994  0  0.239587
1995  22.68  21.7206
1996  43.54  43.193
1997  28.03  29.1286
1998  562.84  552.129
1999  1154.59  1169.34
2000  17923  17492.3
2001  25682.9  25608.4
2002  36123  35775.1
2003  39860.2  39846.9
2004  47746.3  47430.7
2005  48384  48460.4
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
 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
 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
```

```
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  0.0240338  0.0649964
1986  0.0861777  0.0492788  0.0989761
1987  0.0861777  0.0424443  0.165001
1993  0.0861777  0.398843  0.526345
1994  0.0861777  0.251029  0.66109
1995  0.0861777  0.261004  0.830341
1996  0.0861777  1.28525  1.09808
1997  0.0861777  0.98528  0.984589
1998  0.0861777  0.885687  0.800589
1999  0.0861777  3.33829  0.598004
2000  0.0861777  2.4819  0.704309
2001  0.0861777  0.647468  0.677795
2002  0.0861777  1.5223  0.62322
2003  0.0861777  0.883776  0.684944
2004  0.0861777  1.94341  0.643961
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  0.119643
1986  0.0861777  0.313972  0.173185
1987  0.0861777  0.518515  0.316415
1988  0.0861777  0.304809  0.430304
1989  0.0861777  0.123374  0.735195
1990  0.0861777  0.610266  0.723418
1991  0.0861777  0.628869  0.768527
1992  0.0861777  3.32399  0.630405
1993  0.0861777  4.6471  0.798455
1994  0.0861777  2.16698  1.1549
1995  0.0861777  0.712013  1.28059
1996  0.0861777  0.938306  1.28884
1997  0.0861777  1.83277  1.01714
1998  0.0861777  0.698808  0.817795
1999  0.0861777  0.229964  0.71977
2000  0.14842  0.022799  0.705251
2001  0.14842  1.34335  0.698533
2002  0.223144  0.372743  0.741045
2003  0.307485  0.554055  1.02656
2004  0.398776  0.0618565  0.917274

Selectivity by age and year for each fleet rescaled so max=1.0
 fleet 1 selectivity at age
 0.00730696 0.244723 1 0.656097 0.304155 0.165323
 0.00730696 0.244723 1 0.656097 0.304155 0.165323
 0.00730696 0.244723 1 0.656097 0.304155 0.165323
 0.00730696 0.244723 1 0.656097 0.304155 0.165323
 0.00730696 0.244723 1 0.656097 0.304155 0.165323
 0.00730696 0.244723 1 0.656097 0.304155 0.165323
 0.00730696 0.244723 1 0.656097 0.304155 0.165323
 0.00730696 0.244723 1 0.656097 0.304155 0.165323
 0.00730696 0.244723 1 0.656097 0.304155 0.165323
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
```

```
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 0.280103 0.918766 1 0.628673 0.251612 0.0748516
 fleet 2 selectivity at age
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 0.392676 0.871912 1 0.691726 0.484333 0.0952606
 fleet 3 selectivity at age
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875
 0.000971691 0.0557258 0.330689 0.614013 1 0.588875

Fmult by year for each fleet
1982   0.175218 0.0225305 7.80429e-07
1983   0.0664935 0.0081279 7.17755e-07
1984   0.0305716 0.0831405 6.60239e-07
1985   0.0436678 0.0116093 6.07935e-07
1986   0.0389127 0.013789 5.62496e-07
1987   0.0661842 0.0148198 5.27708e-07
1988   0.0295708 0.00955955 5.09635e-07
1989   0.0246251 0.0341382 5.28302e-07
1990   0.0296828 0.0398384 6.46711e-07
1991   0.0271662 0.0656579 1.26691e-06
1992   0.0765875 0.143562 2.6008e-05
1993   0.0373671 0.0519217 1.449e-06
1994   0.070369 0.0652858 1.55968e-06
1995   0.048704 0.050584 0.000106625
1996   0.0395033 0.0474252 0.000139868
```

```
1997   0.094533 0.115216 8.54774e-05
1998   0.117611 0.128126 0.00189563
1999   0.169563 0.150157 0.00623072
2000   0.134645 0.119688 0.0749077
2001   0.152124 0.120677 0.108151
2002   0.151935 0.107303 0.179376
2003   0.0716649 0.0795068 0.213875
2004   0.0946106 0.0948629 0.268231
2005   0.0874769 0.0974523 0.231623

Directed F by age and year for each fleet
 fleet 1 directed F at age
 0.00128031 0.0428799 0.175218 0.11496 0.0532933 0.0289676
 0.000485865 0.0162725 0.0664935 0.0436262 0.0202243 0.0109929
 0.000223385 0.00748158 0.0305716 0.0200579 0.00929849 0.00505419
 0.000319079 0.0106865 0.0436678 0.0286503 0.0132818 0.0072193
 0.000284333 0.00952284 0.0389127 0.0255305 0.0118355 0.00643316
 0.000483605 0.0161968 0.0661842 0.0434232 0.0201302 0.0109418
 0.000216073 0.00723668 0.0295708 0.0194013 0.00899411 0.00488875
 0.000179934 0.00602633 0.0246251 0.0161564 0.00748983 0.0040711
 0.000216891 0.00726408 0.0296828 0.0194748 0.00902816 0.00490726
 0.00760934 0.0249594 0.0271662 0.0170787 0.00683536 0.00203343
 0.0214524 0.070366 0.0765875 0.0481485 0.0192704 0.00573269
 0.0104666 0.0343317 0.0373671 0.0234917 0.00940204 0.00279699
 0.0197106 0.0646527 0.070369 0.0442391 0.0177057 0.00526723
 0.0136421 0.0447476 0.048704 0.0306189 0.0122545 0.00364557
 0.011065 0.0362943 0.0395033 0.0248347 0.00993952 0.00295688
 0.026479 0.0868537 0.094533 0.0594304 0.0237857 0.00707594
 0.0329431 0.108057 0.117611 0.0739387 0.0295923 0.00880335
 0.0474952 0.155789 0.169563 0.1066 0.0426642 0.0126921
 0.0377143 0.123707 0.134645 0.0846474 0.0338783 0.0100784
 0.0426103 0.139766 0.152124 0.095636 0.0382762 0.0113867
 0.0425575 0.139593 0.151935 0.0955176 0.0382288 0.0113726
 0.0200736 0.0658433 0.0716649 0.0450538 0.0180318 0.00536423
 0.0265007 0.0869251 0.0946106 0.0594792 0.0238052 0.00708175
 0.0245025 0.0803708 0.0874769 0.0549944 0.0220103 0.00654778
 fleet 2 directed F at age
 0.00884719 0.0196446 0.0225305 0.015585 0.0109123 0.00214627
 0.00319163 0.00708681 0.0081279 0.00562228 0.00393661 0.000774269
 0.0326472 0.0724912 0.0831405 0.0575104 0.0402677 0.00792001
 0.00455871 0.0101223 0.0116093 0.00803049 0.0056228 0.00110591
 0.0054146 0.0120228 0.013789 0.0095382 0.00667847 0.00131355
 0.00581937 0.0129216 0.0148198 0.0102512 0.00717773 0.00141174
 0.0037538 0.00833508 0.00955955 0.00661258 0.00463001 0.000910648
 0.0134053 0.0297655 0.0341382 0.0236143 0.0165343 0.00325203
 0.0156436 0.0347356 0.0398384 0.0275572 0.0192951 0.00379503
 0.0257823 0.0572479 0.0656579 0.0454173 0.0318003 0.00625461
 0.0563731 0.125173 0.143562 0.0993052 0.0695316 0.0136758
 0.0203884 0.0452712 0.0519217 0.0359156 0.0251474 0.0049461
 0.0256361 0.0569235 0.0652858 0.0451599 0.0316201 0.00621916
 0.0198631 0.0441048 0.050584 0.0349903 0.0244995 0.00481867
 0.0186227 0.0413506 0.0474252 0.0328052 0.0229696 0.00451775
 0.0452425 0.100458 0.115216 0.0796979 0.055803 0.0109755
 0.0503118 0.111714 0.128126 0.0886277 0.0620555 0.0122053
 0.0589631 0.130924 0.150157 0.103868 0.0727262 0.0143041
 0.0469984 0.104357 0.119688 0.0827909 0.0579687 0.0114015
 0.0473869 0.10522 0.120677 0.0834754 0.0584479 0.0114958
 0.0421352 0.0935585 0.107303 0.074224 0.0519703 0.0102217
 0.0312204 0.0693229 0.0795068 0.0549969 0.0385078 0.00757386
 0.0372503 0.0827121 0.0948629 0.0656191 0.0459453 0.0090367
 0.0382671 0.0849699 0.0974523 0.0674103 0.0471994 0.00928337
 fleet 3 directed F at age
 7.58336e-10 4.349e-08 2.5808e-07 4.79193e-07 7.80429e-07 4.59575e-07
 6.97436e-10 3.99975e-08 2.37354e-07 4.40711e-07 7.17755e-07 4.22668e-07
 6.41548e-10 3.67923e-08 2.18334e-07 4.05395e-07 6.60239e-07 3.88798e-07
 5.90725e-10 3.38777e-08 2.01038e-07 3.7328e-07 6.07935e-07 3.57998e-07
 5.46572e-10 3.13455e-08 1.86011e-07 3.4538e-07 5.62496e-07 3.3124e-07
 5.12769e-10 2.9407e-08 1.74508e-07 3.2402e-07 5.27708e-07 3.10754e-07
 4.95208e-10 2.83998e-08 1.68531e-07 3.12923e-07 5.09635e-07 3.00111e-07
 5.13346e-10 2.944e-08 1.74704e-07 3.24384e-07 5.28302e-07 3.11104e-07
 6.28403e-10 3.60385e-08 2.1386e-07 3.97089e-07 6.46711e-07 3.80832e-07
```

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 1.23105e-09 7.05997e-08 4.18955e-07 7.77901e-07 1.26691e-06 7.46053e-07
 2.52718e-08 1.44932e-06 8.60059e-06 1.59693e-05 2.6008e-05 1.53155e-05
 1.40798e-09 8.07468e-08 4.7917e-07 8.89707e-07 1.449e-06 8.53282e-07
 1.51553e-09 8.69143e-08 5.15769e-07 9.57662e-07 1.55968e-06 9.18455e-07
 1.03607e-07 5.94176e-06 3.52597e-05 6.54691e-05 0.000106625 6.27887e-05
 1.35908e-07 7.79424e-06 4.62528e-05 8.58806e-05 0.000139868 8.23646e-05
 8.30576e-08 4.76329e-06 2.82665e-05 5.24842e-05 8.54774e-05 5.03355e-05
 1.84196e-06 0.000105635 0.000626863 0.00116394 0.00189563 0.00111629
 6.05433e-06 0.000347212 0.00206043 0.00382574 0.00623072 0.00366911
 7.27871e-05 0.00417429 0.0247712 0.0459943 0.0749077 0.0441112
 0.000105089 0.0060268 0.0357644 0.0664061 0.108151 0.0636874
 0.000174298 0.00999587 0.0593178 0.110139 0.179376 0.10563
 0.00020782 0.0119184 0.0707262 0.131322 0.213875 0.125946
 0.000260638 0.0149474 0.0887013 0.164698 0.268231 0.157955
 0.000225066 0.0129074 0.0765952 0.142219 0.231623 0.136397
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
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 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 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
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 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 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
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 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 0 0 0 0 0 0
 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
 0.0101275 0.0625246 0.197749 0.130545 0.0642064 0.0311143
 0.00367749 0.0233594 0.0746217 0.0492489 0.0241616 0.0117676
 0.0328706 0.0799728 0.113712 0.0775687 0.0495669 0.0129746
 0.00487779 0.0208089 0.0552774 0.0366812 0.0189052 0.00832557
 0.00569893 0.0215457 0.0527018 0.035069 0.0185145 0.00774704
 0.00630298 0.0291184 0.0810041 0.0536748 0.0273085 0.0123538
 0.00396987 0.0155718 0.0391306 0.0260142 0.0136246 0.00579969
 0.0135852 0.0357919 0.0587635 0.0397711 0.0240247 0.00732344
 0.0158605 0.0419997 0.0695214 0.0470324 0.0283239 0.00870267
 0.0333916 0.0822074 0.0928245 0.0624967 0.0386369 0.00828879
 0.0778255 0.19554 0.220158 0.14747 0.088828 0.0194238
 0.0308551 0.0796029 0.0892894 0.0594082 0.0345509 0.00774394
 0.0453467 0.121576 0.135655 0.0893999 0.0493274 0.0114873
 0.0335054 0.0888583 0.0993233 0.0656746 0.0368607 0.00852702
 0.0296878 0.0776526 0.0869747 0.0577257 0.033049 0.007557
 0.0717216 0.187317 0.209777 0.139181 0.0796741 0.0181018
 0.0832567 0.219877 0.246363 0.16373 0.0935434 0.022125
 0.106464 0.28706 0.321781 0.214293 0.121621 0.0306653
 0.0847855 0.232238 0.279103 0.213433 0.166755 0.0655911
 0.0901023 0.251013 0.308565 0.245518 0.204875 0.0865699
 0.084867 0.243147 0.318556 0.279881 0.269575 0.127224
 0.0515018 0.147085 0.221898 0.231373 0.270415 0.138884
 0.0640117 0.184585 0.278175 0.289796 0.337982 0.174073
 0.0629948 0.178248 0.261524 0.264624 0.300832 0.152228

Population Numbers at the Start of the Year
 168810 15000 9000 5400 3240 1944
 320687 112017 9445.38 4950.44 3176.73 3299.95
 456896 214174 73353.3 5876.16 3158.91 4264.74
 503714 296363 132531 43885.1 3644.92 4836.97
 1.2159e+06 336007 194567 84060.7 28357.6 5612.95
 1.32859e+06 810411 220431 123727 54405.7 22393.4
 2.38328e+06 884985 527645 136262 78602.1 50313.3
 2.32866e+06 1.59123e+06 584057 340118 88993.8 85506.5
 2.821e+06 1.53988e+06 1.02913e+06 369162 219099 115137
 4.74065e+06 1.86122e+06 989759 643517 236088 219275
 3.77379e+06 3.0734e+06 1.14915e+06 604643 405229 298027
 6.85747e+06 2.34024e+06 1.69425e+06 618081 349732 444476
 9.45675e+06 4.45703e+06 1.44868e+06 1.03868e+06 390416 522114
 6.51247e+06 6.05801e+06 2.64563e+06 847890 636706 595093
 5.36966e+06 4.2216e+06 3.71554e+06 1.60574e+06 532230 806867
 6.37228e+06 3.49411e+06 2.61839e+06 2.28313e+06 1.01598e+06 881954
 6.57114e+06 3.97584e+06 1.94208e+06 1.42302e+06 1.33158e+06 1.20947e+06
 4.65358e+06 4.05289e+06 2.13904e+06 1.01755e+06 809817 1.60587e+06
 3.41459e+06 2.80435e+06 2.03882e+06 1.03933e+06 550518 1.52461e+06
 6.50033e+06 2.1028e+06 1.49024e+06 1.03383e+06 562787 1.26944e+06
 2.90672e+06 3.98187e+06 1.09665e+06 733718 542129 1.08773e+06
 1.00424e+07 1.7899e+06 2.09301e+06 534567 371758 919550
 3.94299e+06 6.39368e+06 1.0357e+06 1.12379e+06 284316 726618
 4.13083e+06 2.47918e+06 3.56344e+06 525660 563781 545175
```

```
q by index
 index 1 q over time
1985  1.65487e-06
1986  1.65487e-06
1987  1.65487e-06
1993  1.65487e-06
1994  1.65487e-06
1995  1.65487e-06
1996  1.65487e-06
1997  1.65487e-06
1998  1.65487e-06
1999  1.65487e-06
2000  1.65487e-06
2001  1.65487e-06
2002  1.65487e-06
2003  1.65487e-06
2004  1.65487e-06
 index 2 q over time
1985  1.72505e-06
1986  1.72505e-06
1987  1.72505e-06
1988  1.72505e-06
1989  1.72505e-06
1990  1.72505e-06
1991  1.72505e-06
1992  1.72505e-06
1993  1.72505e-06
1994  1.72505e-06
1995  1.72505e-06
1996  1.72505e-06
1997  1.72505e-06
1998  1.72505e-06
1999  1.72505e-06
2000  1.72505e-06
2001  1.72505e-06
2002  1.72505e-06
2003  1.72505e-06
2004  1.72505e-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 =  0.0696658 0.202348 0.466437 0.189295 0.0542792 0.0179753
Year 2 Obs  =  0.169036 0.314323 0.482457 0.0330455 0.00113799 0
Year 2 Pred =  0.0540834 0.626937 0.210952 0.0733944 0.0220891 0.0125444
Year 3 Obs  =  0.00623416 0.296401 0.593645 0.10372 0 0
Year 3 Pred =  0.0255362 0.392277 0.540565 0.0288863 0.00729247 0.0054431
Year 4 Obs  =  0.00241776 0.285805 0.616905 0.0899026 0.00496916 0
Year 4 Pred =  0.0156351 0.305814 0.549965 0.120515 0.0046787 0.00339148
Year 5 Obs  =  0.0189627 0.119253 0.605573 0.235668 0.0178412 0.00270213
Year 5 Pred =  0.0257688 0.236743 0.552139 0.157793 0.0248674 0.00268886
Year 6 Obs  =  0.00130323 0.499856 0.343311 0.130117 0.0233988 0.00201374
Year 6 Pred =  0.018728 0.37856 0.410783 0.153195 0.0316125 0.00712186
Year 7 Obs  =  0.0177527 0.249386 0.558377 0.129822 0.0392278 0.00543565
Year 7 Pred =  0.019959 0.246884 0.594936 0.101418 0.0272774 0.00952521
Year 8 Obs  =  0.00703147 0.589819 0.342294 0.0574598 0.00339551 0
Year 8 Pred =  0.0137671 0.311837 0.462762 0.178368 0.0217945 0.011471
Year 9 Obs  =  0.0308006 0.216845 0.332065 0.238511 0.115201 0.0665783
Year 9 Pred =  0.0119783 0.216345 0.583352 0.138726 0.0385011 0.0110982
Year 10 Obs  =  0.0925943 0.264054 0.353626 0.152843 0.0658885 0.0709947
Year 10 Pred =  0.299222 0.376742 0.216997 0.089944 0.0133532 0.00374193
Year 11 Obs  =  0.107367 0.47486 0.314778 0.0729923 0.0192408 0.0107617
Year 11 Pred =  0.199327 0.50467 0.20312 0.0694316 0.0191296 0.00432179
Year 12 Obs  =  0.171705 0.266947 0.322688 0.193097 0.0324528 0.0131112
Year 12 Pred =  0.310954 0.340326 0.266977 0.0620787 0.0142212 0.00544417
Year 13 Obs  =  0.380979 0.436043 0.119058 0.0547803 0.00753916 0.00160051
Year 13 Pred =  0.30203 0.450834 0.158471 0.0729583 0.0111802 0.00452674
Year 14 Obs  =  0.180045 0.509112 0.280958 0.0258238 0.00380215 0.000259252
Year 14 Pred =  0.172967 0.514441 0.243356 0.0497966 0.0151668 0.00427297
Year 15 Obs  =  0.230241 0.247479 0.351243 0.147211 0.018383 0.00544268
Year 15 Pred =  0.148808 0.375331 0.358007 0.0985878 0.0132287 0.00603722
```

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Year 16 Obs  =  0.067421 0.446998 0.300266 0.134368 0.0430546 0.00789294
Year 16 Pred =  0.19825 0.338255 0.273115 0.154574 0.0282897 0.00751674
Year 17 Obs  =  0.209362 0.575347 0.175449 0.0243546 0.0135849 0.00190237
Year 17 Pred =  0.220002 0.410344 0.215592 0.103074 0.039858 0.0111311
Year 18 Obs  =  0.172698 0.601383 0.208442 0.0114978 0.00488724 0.00109176
Year 18 Pred =  0.171195 0.450835 0.255039 0.0800069 0.0265763 0.0163484
Year 19 Obs  =  0.195086 0.292953 0.318977 0.176777 0.0141252 0.00208159
Year 19 Pred =  0.15683 0.395144 0.306213 0.101055 0.0218791 0.0188786
Year 20 Obs  =  0.530444 0.185772 0.149451 0.106517 0.0207639 0.0070519
Year 20 Pred =  0.313765 0.309541 0.232743 0.104388 0.0231615 0.0164009
Year 21 Obs  =  0.141362 0.634408 0.175105 0.0350454 0.0112822 0.00279752
Year 21 Pred =  0.139554 0.583655 0.1692 0.0723961 0.0215072 0.0136872
Year 22 Obs  =  0.662539 0.129821 0.152872 0.0339351 0.0133549 0.00747706
Year 22 Pred =  0.414633 0.232011 0.285479 0.0456443 0.012485 0.00974702
Year 23 Obs  =  0.0317784 0.846877 0.102594 0.0144305 0.00329029 0.00102992
Year 23 Pred =  0.132157 0.665272 0.112481 0.0763338 0.00756678 0.00618891
Year 24 Obs  =  0 0 0 0 0 0
Year 24 Pred =  0.164287 0.306829 0.462408 0.042824 0.0180894 0.00556213
 fleet 2
Year 1 Obs  =  0 0 0 0 0 0
Year 1 Pred =  0.716171 0.13791 0.0892262 0.0381773 0.0165342 0.00198132
Year 2 Obs  =  0 0 0 0 0 0
Year 2 Pred =  0.531259 0.408287 0.0385593 0.014144 0.00642945 0.00132122
Year 3 Obs  =  0 0 0 0 0 0
Year 3 Pred =  0.40895 0.416491 0.161088 0.00907559 0.00346052 0.000934635
Year 4 Obs  =  0 0 0 0 0 0
Year 4 Pred =  0.321161 0.416465 0.210213 0.048566 0.00284774 0.000746953
Year 5 Obs  =  0 0 0 0 0 0
Year 5 Pred =  0.463467 0.282295 0.184789 0.0556777 0.0132528 0.000518533
Year 6 Obs  =  0 0 0 0 0 0
Year 6 Pred =  0.337514 0.452308 0.137757 0.0541641 0.0168815 0.00137618
Year 7 Obs  =  0 0 0 0 0 0
Year 7 Pred =  0.396819 0.32542 0.220103 0.0395582 0.0160697 0.00203053
Year 8 Obs  =  0.344479 0.407095 0.177018 0.0490113 0.0216422 0.000754415
Year 8 Pred =  0.290934 0.436896 0.181975 0.0739495 0.0136474 0.00259917
Year 9 Obs  =  0.23302 0.362699 0.30618 0.0708474 0.0145262 0.0127277
Year 9 Pred =  0.291031 0.348492 0.263741 0.0661258 0.0277186 0.0028912
Year 10 Obs  =  0.0986565 0.326966 0.241201 0.201222 0.0892526 0.0427021
Year 10 Pred =  0.373388 0.318247 0.193155 0.0880913 0.0228797 0.00423897
Year 11 Obs  =  0.294107 0.638161 0.0669132 0.000492181 0.000327089 0
Year 11 Pred =  0.258687 0.443372 0.188038 0.0707227 0.0340887 0.00509177
Year 12 Obs  =  0.344222 0.228855 0.398122 0.0288015 0 0
Year 12 Pred =  0.386294 0.286199 0.236581 0.0605282 0.024258 0.00613974
Year 13 Obs  =  0.485498 0.323118 0.102549 0.0791029 0.00973217 0
Year 13 Pred =  0.378967 0.382931 0.141835 0.0718487 0.0192618 0.00515624
Year 14 Obs  =  0.430594 0.325179 0.191424 0.039749 0.0130531 0
Year 14 Pred =  0.22801 0.45907 0.228833 0.0515211 0.0274525 0.00511349
Year 15 Obs  =  0.111799 0.314561 0.371607 0.131316 0.0650148 0.00570222
Year 15 Pred =  0.195986 0.334628 0.336336 0.101909 0.0239227 0.00721823
Year 16 Obs  =  0.0591969 0.208714 0.352109 0.243401 0.105662 0.0309165
Year 16 Pred =  0.251256 0.290202 0.246907 0.153757 0.0492299 0.00864829
Year 17 Obs  =  0.301735 0.320996 0.173528 0.115662 0.0726467 0.015432
Year 17 Pred =  0.275934 0.3484 0.192884 0.101466 0.0686421 0.012674
Year 18 Obs  =  0.403808 0.296637 0.168649 0.08413 0.0328356 0.01394
Year 18 Pred =  0.22163 0.3951 0.23552 0.081294 0.0472421 0.0192136
Year 19 Obs  =  0.253774 0.513221 0.156041 0.0597002 0.0144516 0.00281227
Year 19 Pred =  0.203876 0.347732 0.283952 0.103107 0.0390537 0.0222794
Year 20 Obs  =  0.357241 0.381996 0.234345 0.0236504 0.00276754 0
Year 20 Pred =  0.3836 0.256179 0.202971 0.100166 0.038881 0.0182028
Year 21 Obs  =  0 0 0 0 0 0
Year 21 Pred =  0.185054 0.523919 0.160044 0.0753466 0.0391594 0.0164766
Year 22 Obs  =  0 0 0 0 0 0
Year 22 Pred =  0.495294 0.187612 0.243253 0.0427936 0.0204778 0.0105698
Year 23 Obs  =  0 0 0 0 0 0
Year 23 Pred =  0.178915 0.609684 0.108621 0.081108 0.0140657 0.00760614
Year 24 Obs  =  0 0 0 0 0 0
Year 24 Pred =  0.21466 0.271391 0.43098 0.0439166 0.0324541 0.0065976
 fleet 3
Year 1 Obs  =  0 0 0 0 0 0
Year 1 Pred =  0.0147233 0.0732271 0.245135 0.281542 0.283617 0.101756
Year 2 Obs  =  0 0 0 0 0 0
```

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Year 2 Pred =  0.0177274 0.351879 0.171947 0.169302 0.179009 0.110136
Year 3 Obs  =  0 0 0 0 0 0
Year 3 Pred =  0.00993293 0.261278 0.522874 0.0790736 0.0701309 0.0567107
Year 4 Obs  =  0 0 0 0 0 0
Year 4 Pred =  0.00527937 0.176818 0.46179 0.286379 0.0390589 0.0306738
Year 5 Obs  =  0 0 0 0 0 0
Year 5 Pred =  0.00715506 0.11256 0.381239 0.308336 0.170712 0.019998
Year 6 Obs  =  0 0 0 0 0 0
Year 6 Pred =  0.00500897 0.173372 0.27321 0.288348 0.209039 0.0510208
Year 7 Obs  =  0 0 0 0 0 0
Year 7 Pred =  0.00559795 0.118569 0.414943 0.200181 0.18915 0.0715585
Year 8 Obs  =  0 0 0 0 0 0
Year 8 Pred =  0.00362307 0.140524 0.302844 0.330344 0.141806 0.0808596
Year 9 Obs  =  0 0 0 0 0 0
Year 9 Pred =  0.0029514 0.0912787 0.357431 0.240551 0.234542 0.0732457
Year 10 Obs  =  0 0 0 0 0 0
Year 10 Pred =  0.00390227 0.0859032 0.269766 0.330247 0.199511 0.11067
Year 11 Obs  =  0 0 0 0 0 0
Year 11 Pred =  0.00250251 0.110779 0.243094 0.24542 0.275152 0.123051
Year 12 Obs  =  0 0 0 0 0 0
Year 12 Pred =  0.0039954 0.076454 0.327 0.224569 0.209343 0.158638
Year 13 Obs  =  0 0 0 0 0 0
Year 13 Pred =  0.00451423 0.117813 0.225784 0.307009 0.191444 0.153437
Year 14 Obs  =  0 0 0 0 0 0
Year 14 Pred =  0.00235483 0.122454 0.315827 0.190871 0.236564 0.131929
Year 15 Obs  =  0 0 0 0 0 0
Year 15 Pred =  0.00152715 0.0673455 0.350232 0.284852 0.155535 0.140509
Year 16 Obs  =  0 0 0 0 0 0
Year 16 Pred =  0.00158443 0.0472658 0.208073 0.347808 0.259029 0.136239
Year 17 Obs  =  0 0 0 0 0 0
Year 17 Pred =  0.00172047 0.0561062 0.160718 0.22694 0.357104 0.197411
Year 18 Obs  =  0 0 0.419829 0.214478 0.115201 0.250492
Year 18 Pred =  0.0013985 0.0643915 0.198603 0.184009 0.248727 0.302871
Year 19 Obs  =  0 0.0140967 0.351258 0.378068 0.149171 0.107407
Year 19 Pred =  0.00118285 0.0521071 0.220158 0.214587 0.189054 0.322911
Year 20 Obs  =  0.00106905 0.0209877 0.127875 0.424182 0.266532 0.159355
Year 20 Pred =  0.00259242 0.0447156 0.183311 0.242826 0.219243 0.307313
Year 21 Obs  =  0 0.00873497 0.0336332 0.142704 0.37185 0.443078
Year 21 Pred =  0.00136102 0.0995221 0.157302 0.198783 0.240306 0.302726
Year 22 Obs  =  0 0.0192919 0.16383 0.157459 0.109995 0.549424
Year 22 Pred =  0.00512249 0.0501149 0.336203 0.158762 0.17671 0.273087
Year 23 Obs  =  0 0.394856 0.132588 0.128547 0.075961 0.268047
Year 23 Pred =  0.00198192 0.174435 0.160798 0.322295 0.130006 0.210484
Year 24 Obs  =  0 0 0 0 0 0
Year 24 Pred =  0.00172928 0.0564674 0.463977 0.126908 0.218144 0.132774

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
 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
 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

F Reference Points Using Final Year Selectivity Scaled Max=1.0
 refpt          F        slope to plot on SRR
  F0.1      0.669761     12.9068
  Fmax      9.99999     57.798
  F30%SPR  1.00511     16.5488
  F40%SPR  0.626559     12.4117
  Fmsy      0.546756     11.4826    SSmsy    282447     MSY   98314.8
  Foy       0.410067     xxxxxx    SSoy    357679     OY   95534.9
  Fcurrent 0.300832     8.52991

Stock-Recruitment Relationship Parameters
 alpha     = 5.22591e+06
 beta      = 172667
 virgin    = 1.25811e+06
 steepness = 0.674436
Spawning Stock, Obs Recruits(year+1), Pred Recruits(year+1)
1982  7246.41  320687  210485
1983  14871.3  456896  414400
```

```
1984  34686.3  503714  874196
1985  56213.1  1.2159e+06  1.28349e+06
1986  85526.7  1.32859e+06  1.73108e+06
1987  143446  2.38328e+06  2.37141e+06
1988  214315  2.32866e+06  2.89417e+06
1989  349304  2.821e+06  3.49719e+06
1990  409243  4.74065e+06  3.67525e+06
1991  463372  3.77379e+06  3.80722e+06
1992  441712  6.85747e+06  3.7572e+06
1993  464726  9.45675e+06  3.81023e+06
1994  598183  6.51247e+06  4.05533e+06
1995  741053  5.36966e+06  4.23836e+06
1996  975308  6.37228e+06  4.43988e+06
1997  928064  6.57114e+06  4.40614e+06
1998  757011  4.65358e+06  4.25531e+06
1999  584545  3.41459e+06  4.03425e+06
2000  686100  6.50033e+06  4.17517e+06
2001  668820  2.90672e+06  4.15359e+06
2002  630998  1.00424e+07  4.10313e+06
2003  661014  3.94299e+06  4.14355e+06
2004  648243  4.13083e+06  4.12671e+06
2005  677503       xxxx   4.16454e+06

average F (ages 4 to 8 unweighted) by year
Projection into Future
Projected NAA
 2 2.59993e+06 1.39052e+06 1.83896e+06 270435 593571
 2 1.34064 1.74278e+06 932091 1.23269e+06 579159
Projected Directed FAA
 9.98504e-07 2.82534e-06 4.14532e-06 4.19445e-06 4.76837e-06 2.4129e-06
 9.98504e-07 2.82534e-06 4.14532e-06 4.19445e-06 4.76837e-06 2.4129e-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
 1.64593e-06 6.05429 4.75081 6.35739 1.06283 1.18044
 1.64593e-06 3.12186e-06 5.95431 3.22229 4.84456 1.15178
Projected Discards at Age (in numbers)
 0 0 0 0 0 0
 0 0 0 0 0 0
Projected Yield at Age
 7.90048e-08 0.399583 0.460828 0.737457 0.138168 0.184149
 7.90048e-08 2.06043e-07 0.577568 0.373786 0.629793 0.179678
Year, Total Yield (in weight), Total Discards (in weight), SSB, proj_what, SS/SSmsy
2006  1.92019  0  548009  2  1.94022
2007  1.76082  0  507710  2  1.79754

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
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 0.3 0.53 0.91 0.97 0.99 1
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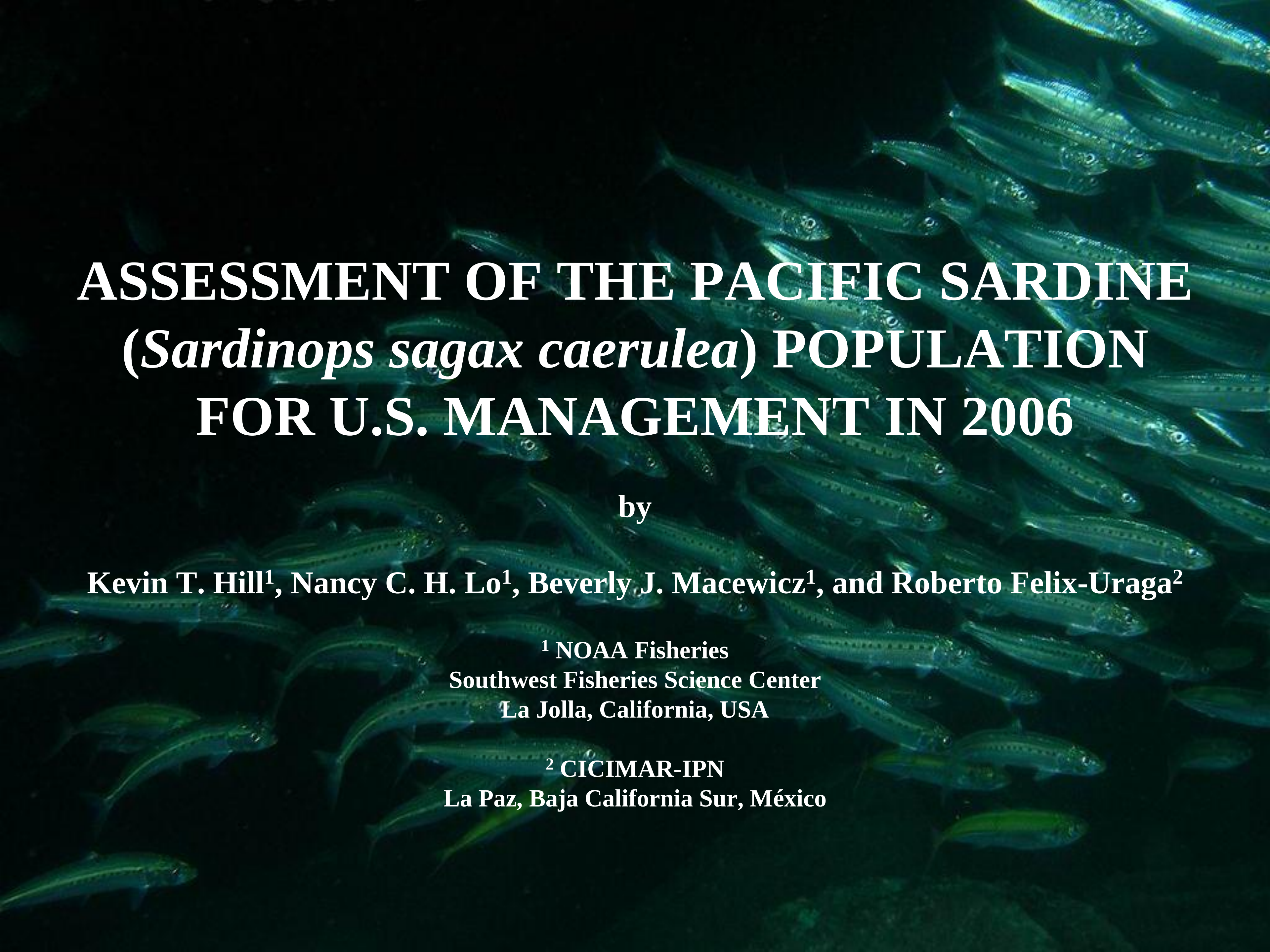
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
 0.3 0.53 0.91 0.97 0.99 1
```

```
 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 0.066 0.097 0.116 0.13 0.156
 0.048 0.066 0.097 0.116 0.13 0.156
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 0.03498 0.08827 0.11252 0.1287 0.156
 0.0144 0.03498 0.08827 0.11252 0.1287 0.156

SSmsy_ratio = 3.28819
Fmsy_ratio =  0.550214
that's all
```



ASSESSMENT OF THE PACIFIC SARDINE (*Sardinops sagax caerulea*) POPULATION FOR U.S. MANAGEMENT IN 2006

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

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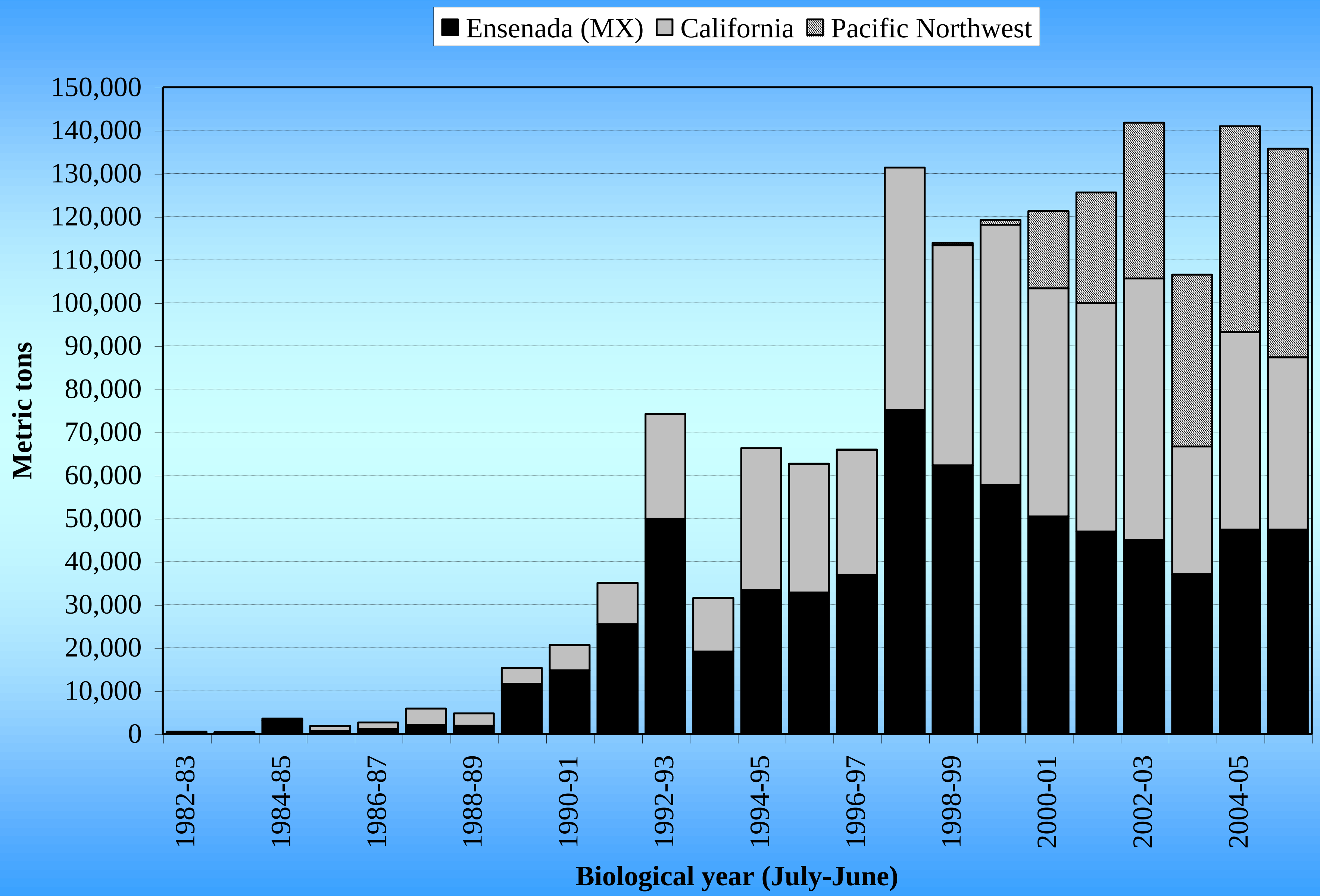
- Centro Interdisciplinario de Ciencias Marinas – La Paz
- Instituto Nacional de la Pesca – Ensenada
- SEMARNAP - Ensenada
- California Department of Fish and Game
- Oregon Department of Fish and Wildlife
- Washington Department of Fish and Wildlife
- Canada Department of Fisheries and Oceans
- Southwest Fisheries Science Center – La Jolla
- Scripps Institution of Oceanography

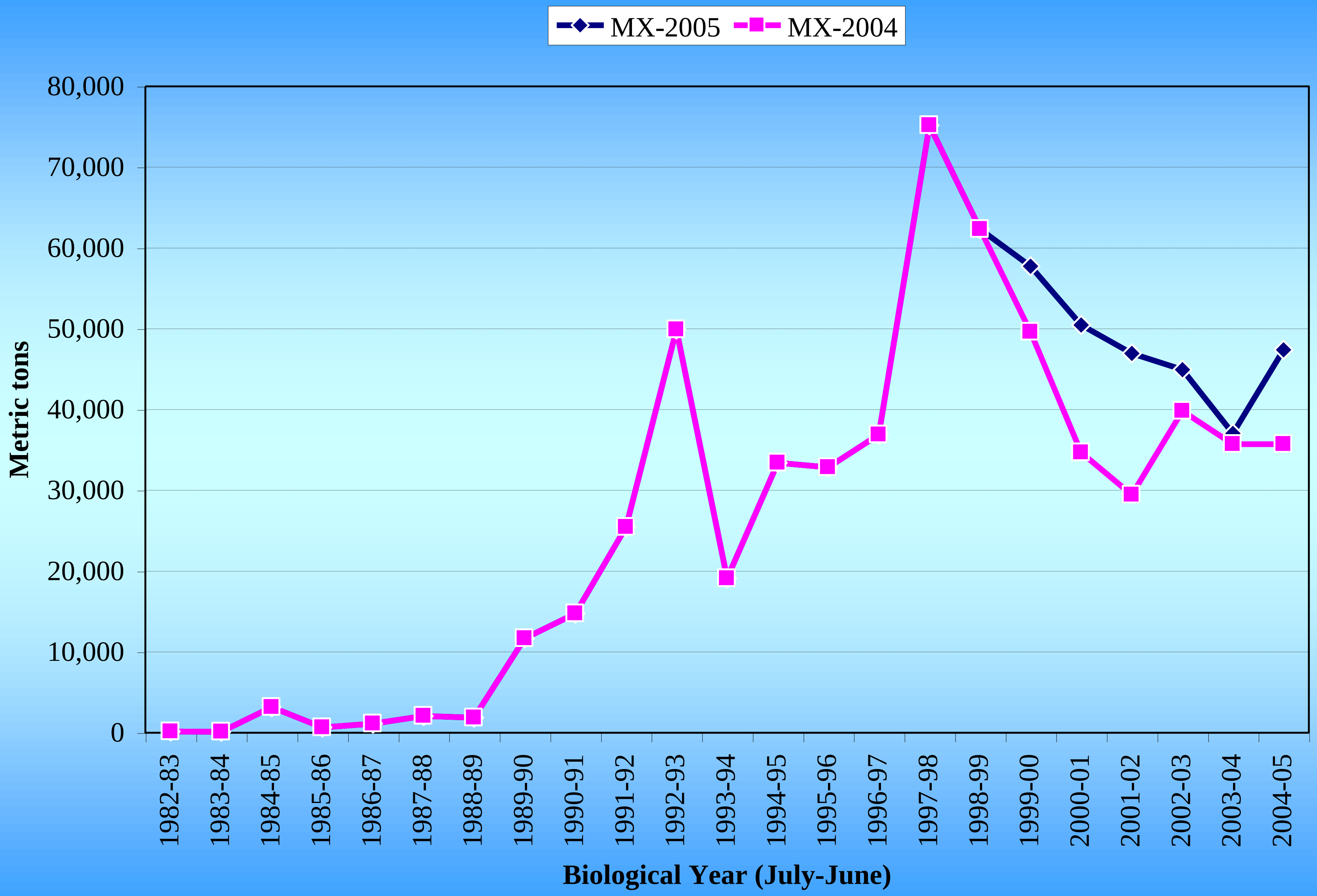
2005 Stock Assessment
Data Sources and Changes from 2004

- **Three Fisheries:**
  - **California, Ensenada (No. Baja), and Pacific NW (OR+WA+Canada)**
    - ***New landings and port samples from CA & NW for 2004-05;***
    - ***New landings data from Ensenada for Jan 2000 through July 2005.***
- **Two Indices of Abundance (Central & Southern CA):**
  - **Annual egg production surveys (DEPM estimates of SSB)**
    - ***New estimate from April 2005 survey;***
  - **Spotter pilot index (pre-adults)**
    - ***New So. Cal. data in 2004 & 2005; updated GLM through 2004-05;***
- **Environmental Data:**
  - **SST at Scripps Pier (La Jolla)**
    - ***Complete 3-year running average recalculated through June 2005.***

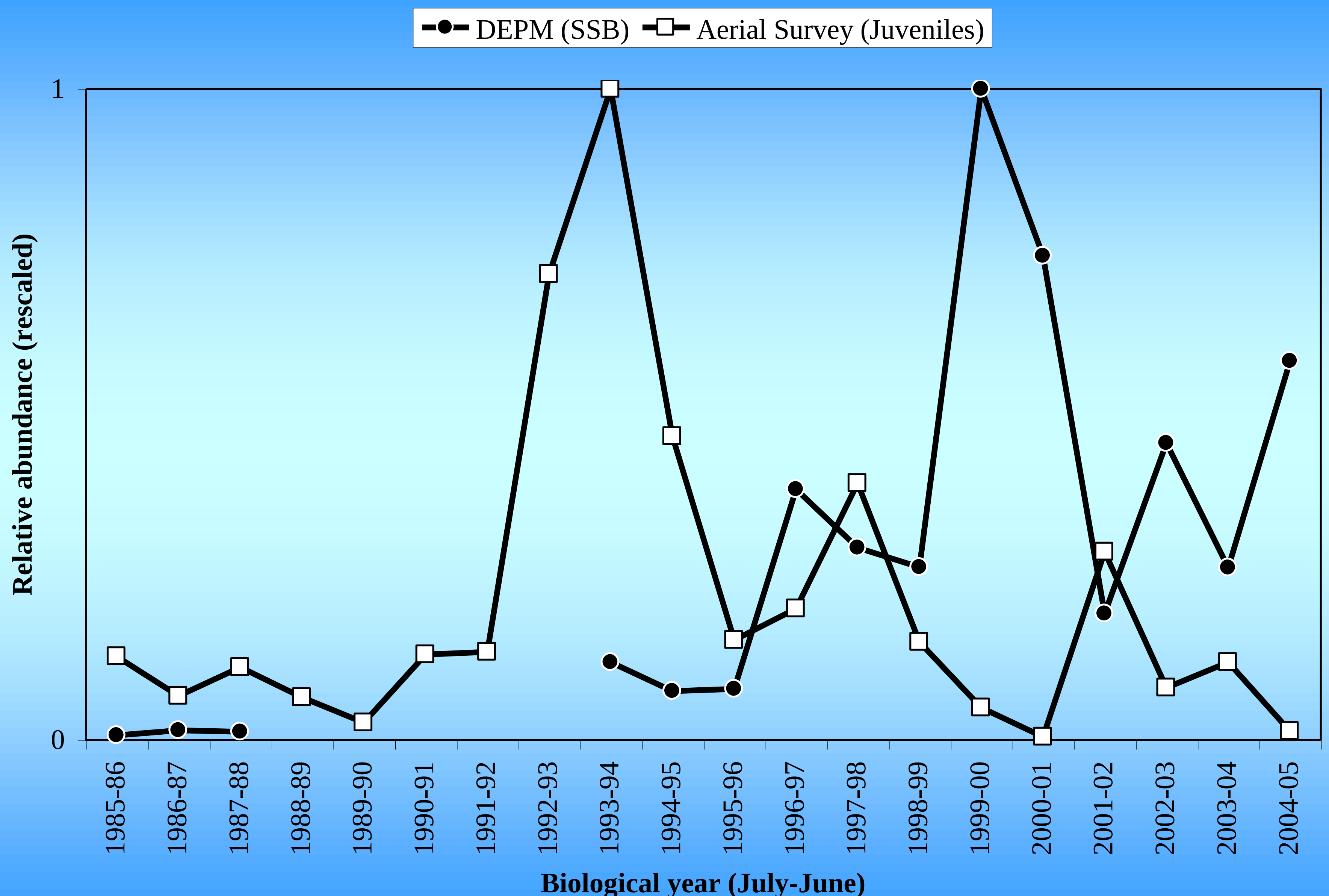
Landings by Fishery



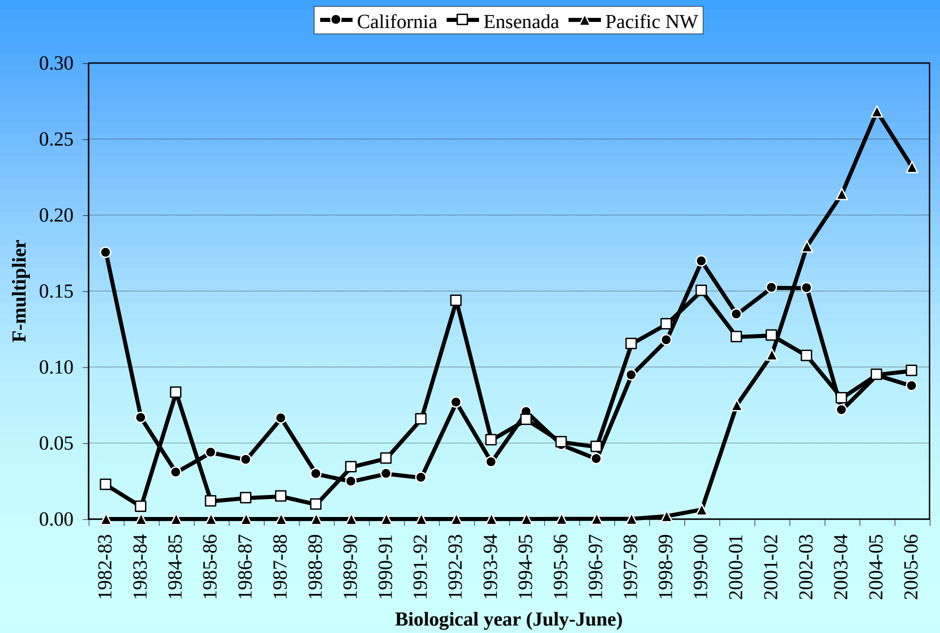
New Landings Data - Ensenada

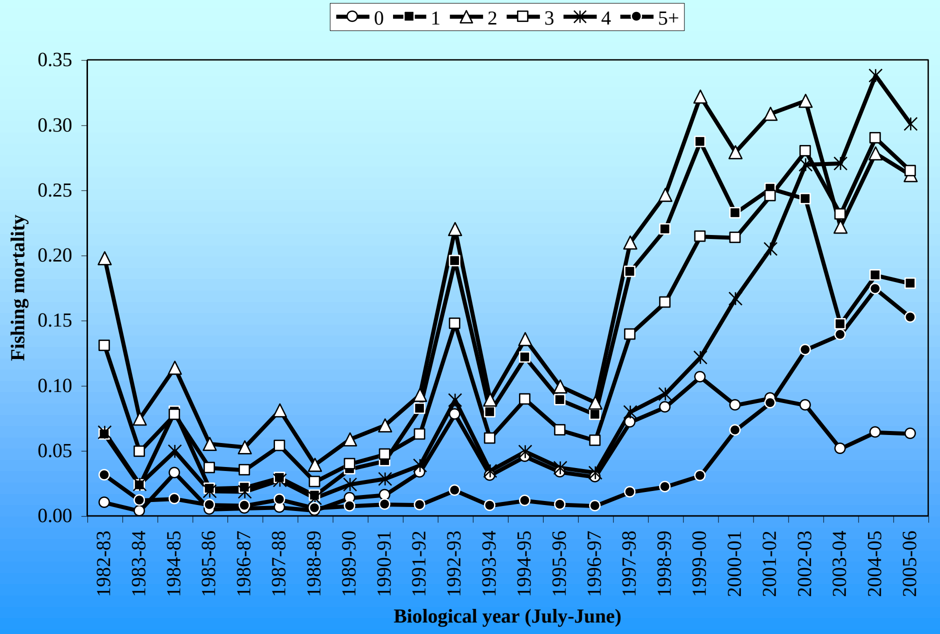


Indices of Relative Abundance

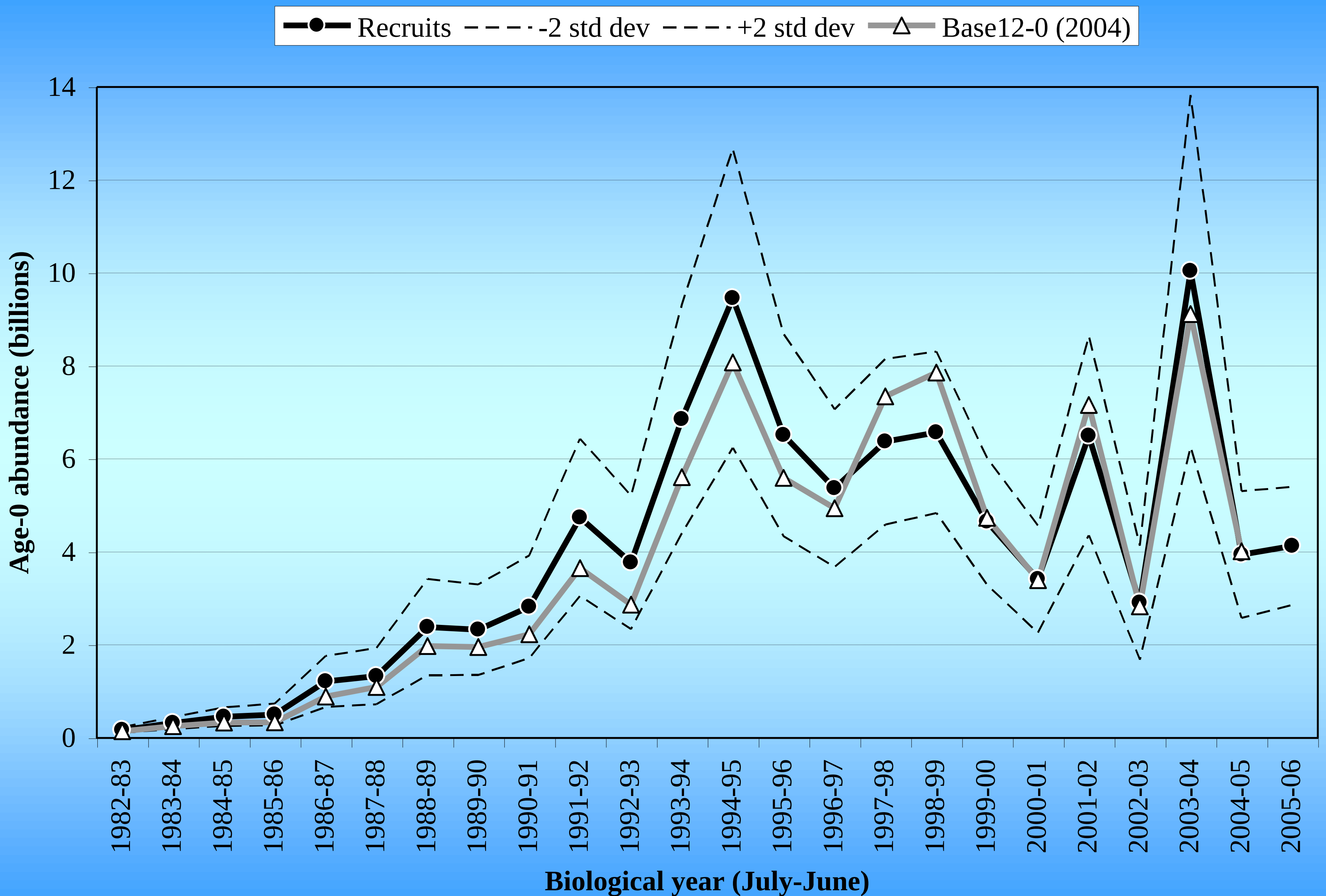


Fishing Mortality by Fishery and Age

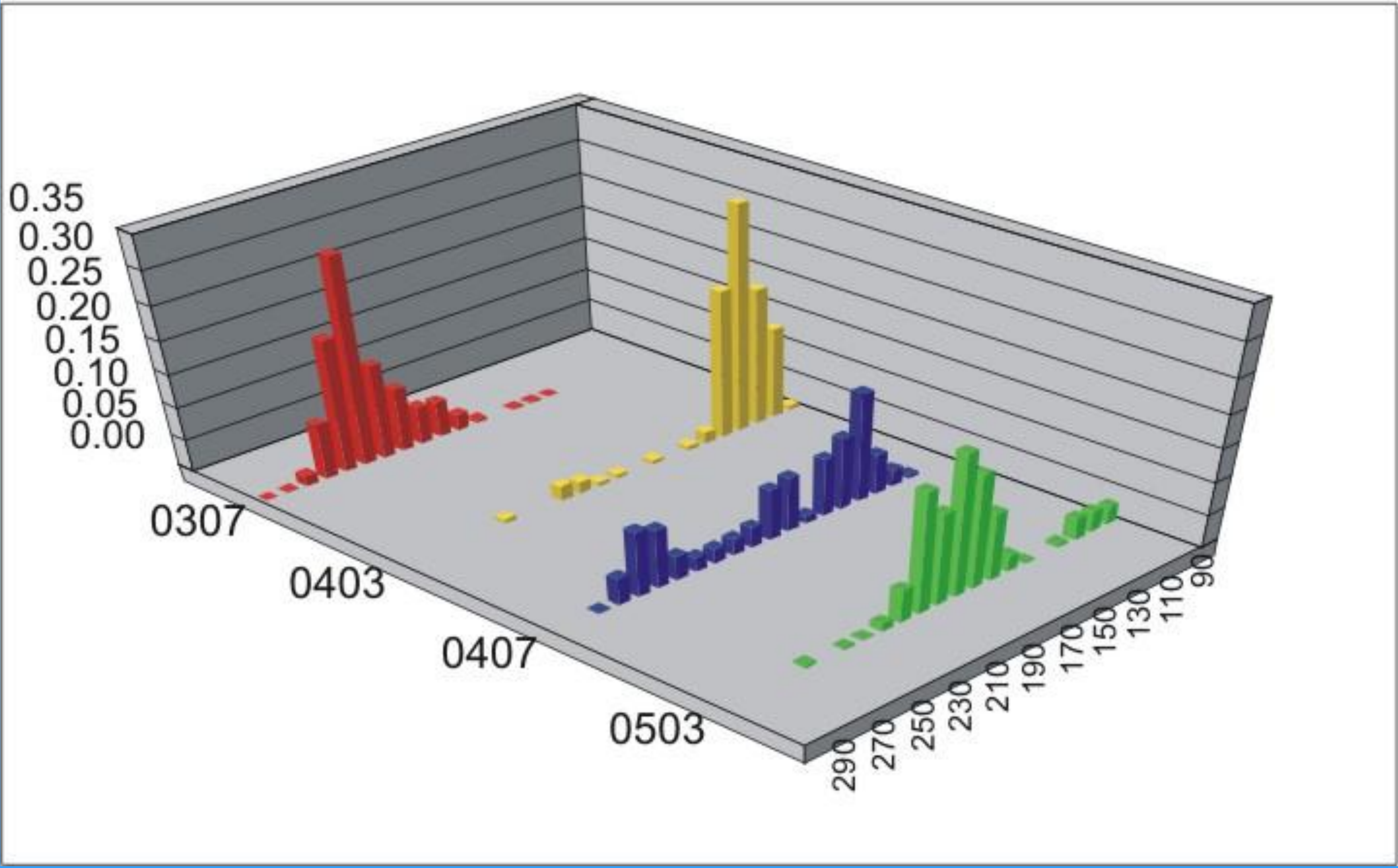




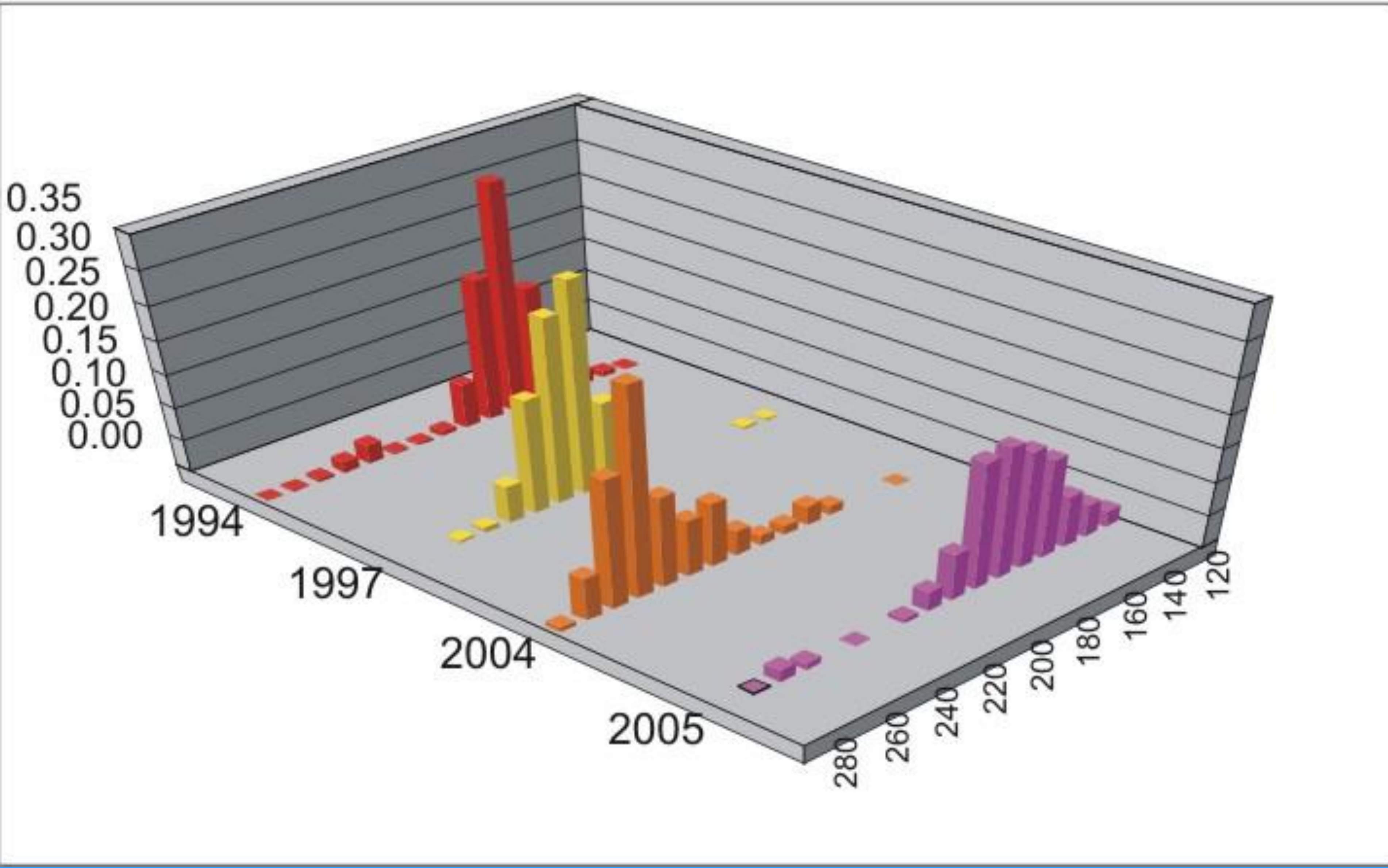
Recruitment



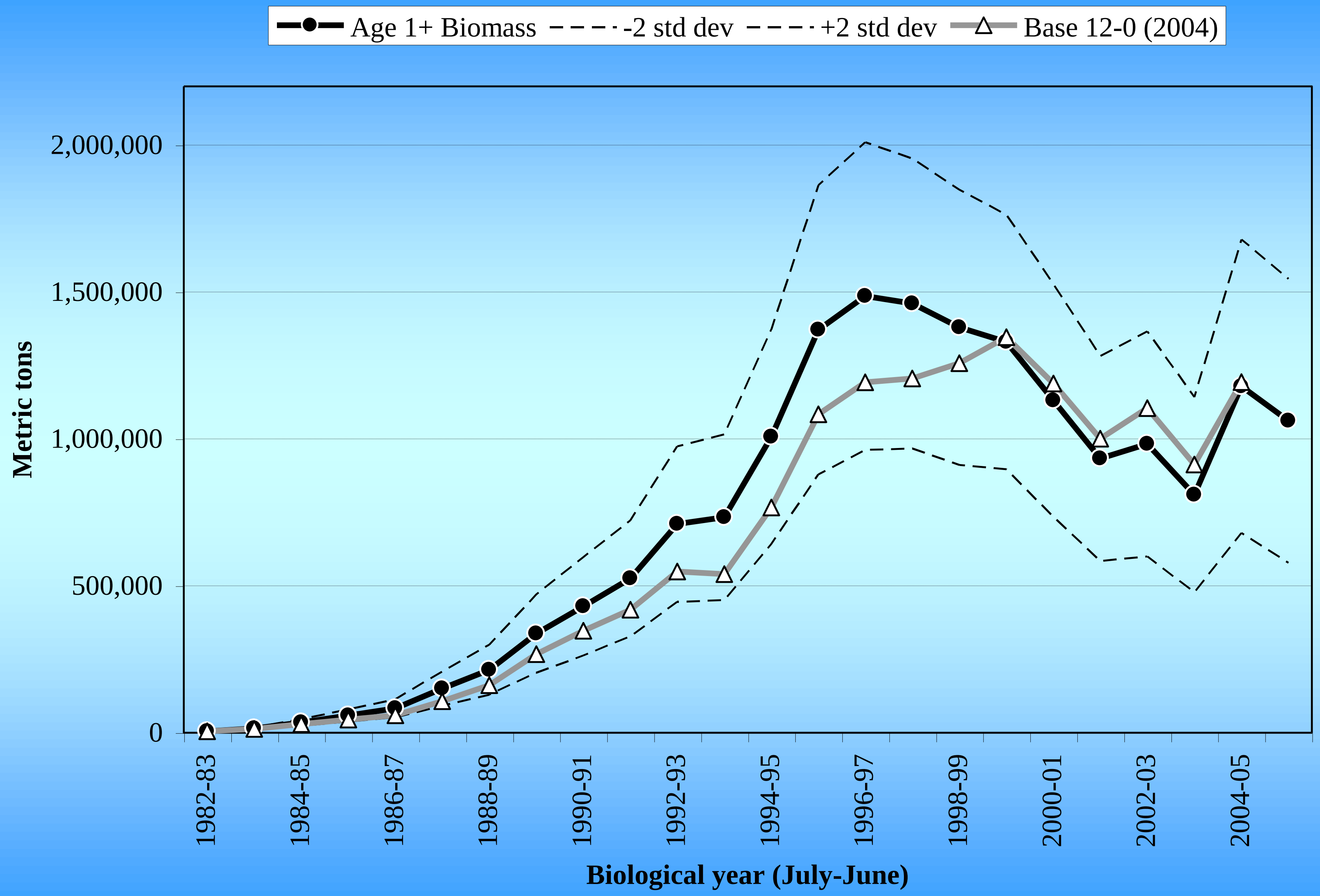
Sardine Lengths: Pacific NW Surveys



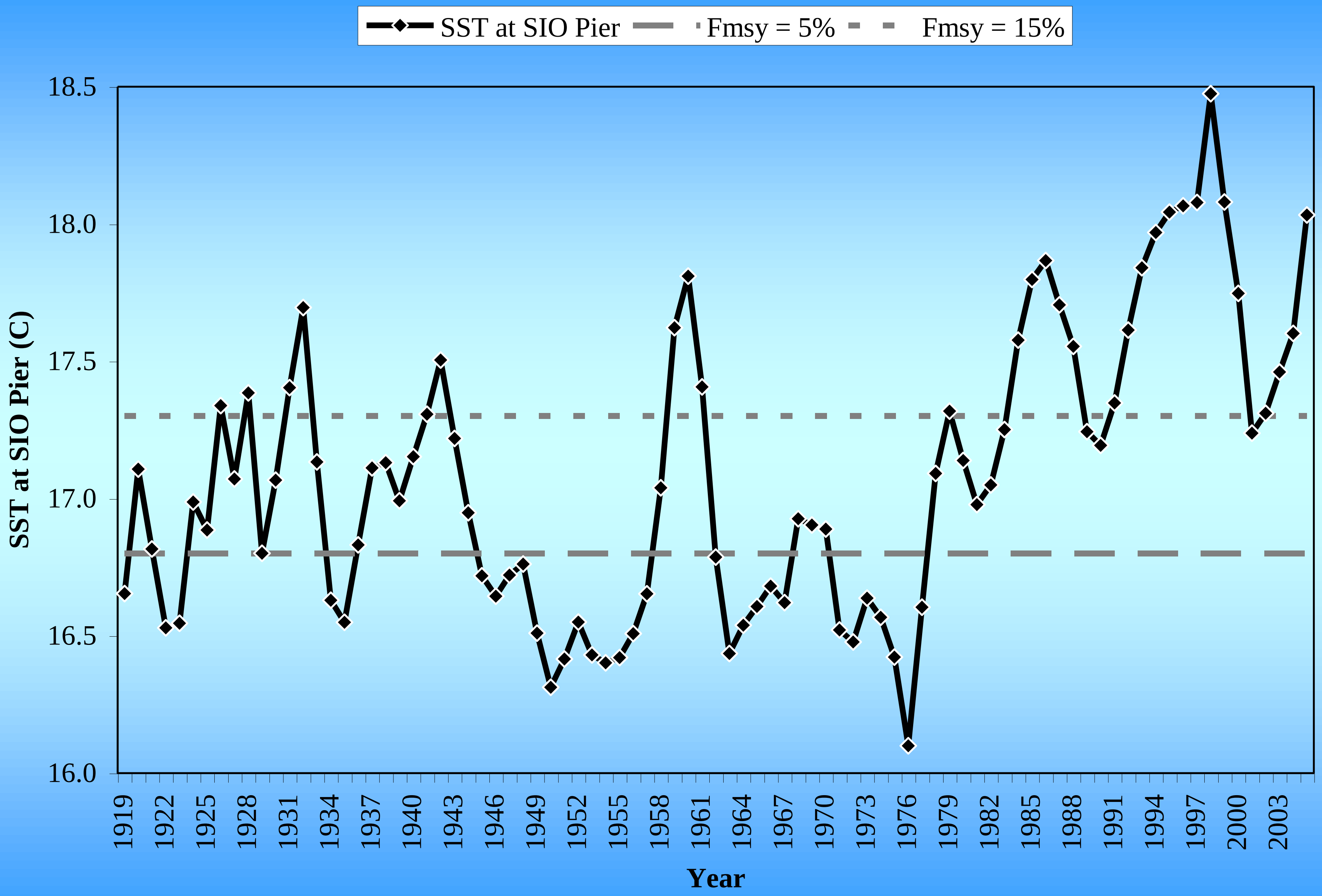
Sardine Lengths: California Surveys



Stock Biomass (age 1+)



Sea Surface Temperature at SIO Pier



U.S. Harvest Guideline for 2006

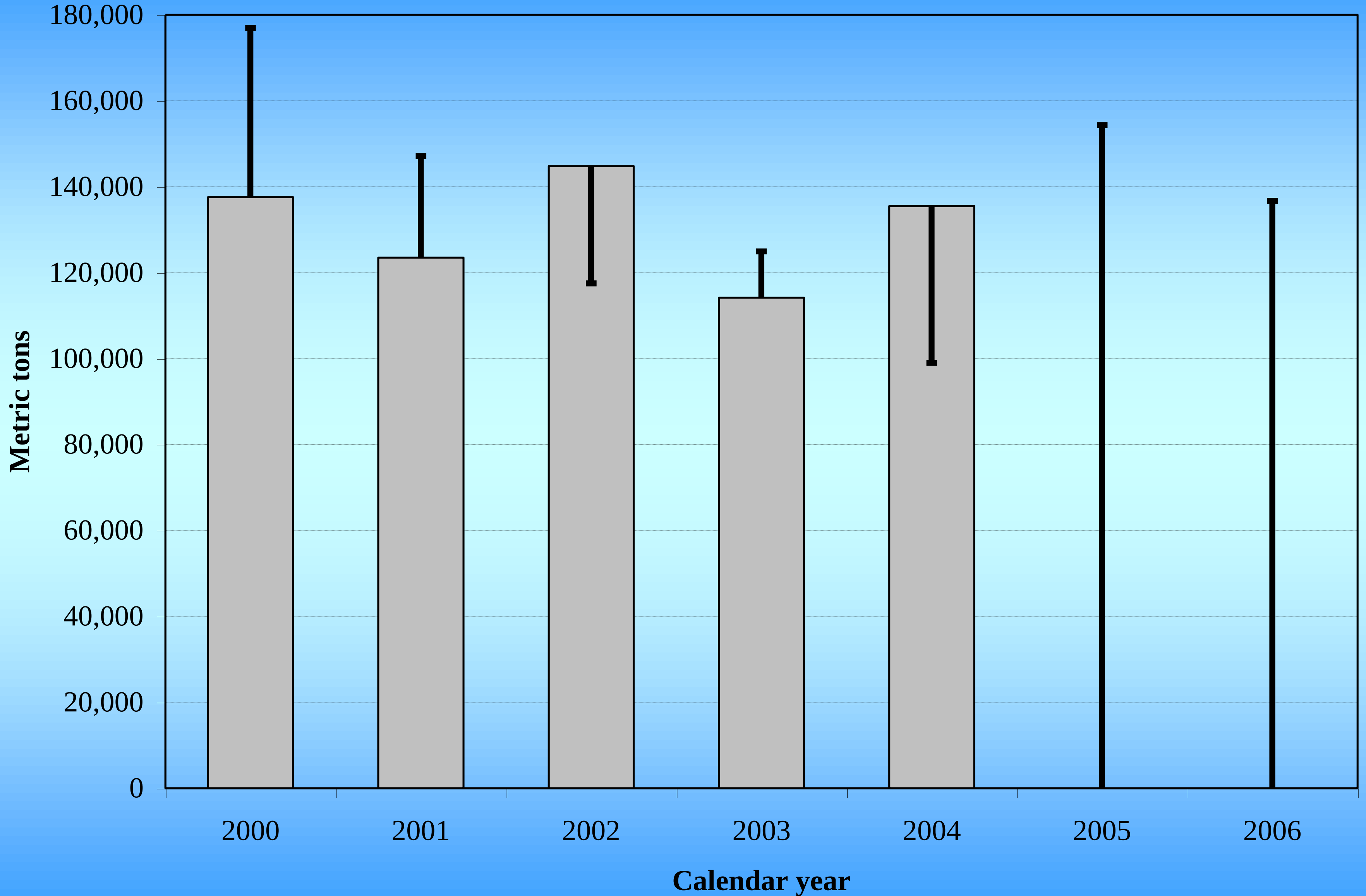
HG_{2006} = (Biomass$_{July\ 2005}$ - Cutoff) • Fraction • Distribution

HG_{2006} = (1,061,391 - 150,000) • 0.15 • 0.87

HG_{2006} = 118,937 mt

- 13% lower than 2005 HG
- 22,049 mt higher than peak U.S. harvest (2002)

Coast-wide Harvest & Retrospective HGs



Principal Assessment Limitations:

- Consistent fishery-independent surveys have been limited to waters off central & southern California. A synoptic fishery-independent index of abundance is still needed (Baja California to British Columbia);

- Biological sampling of adults has been sparse in offshore waters outside the range of the U.S., Mexican, and Canadian fisheries. Population-wide life history characteristics (growth and maturation) need refinement.

- Stock structure, migration rates, and distribution are not well understood, but should be accounted for in both the population assessment and harvest control rule.

Improving Coastwide Sardine Data and Stock Assessment Modeling

<u>6th Trinational Sardine Forum</u>
(USA, Mexico, and Canada)
Ensenada, Baja California, México
November 14-16, 2005

<u>Coast-wide Sardine Survey – April 2006</u>
U.S. - *David Starr Jordan* & *Oscar Dyson*
México (?) – *Puma* & *Francisco Ulloa*

<u>Pacific Sardine Stock Assessment Workshop</u>
Organized through MEXUS-Pacifico (INP & NMFS)
La Paz, Baja California Sur, México
2006 (dates TBD)

National Marine Fisheries Service, Southwest Region
California Coastal Pelagic Species Pilot Observer Program
Informational Report – October 12, 2005

Background

The National Marine Fisheries Service (NMFS), Southwest Region (SWR) initiated a pilot observer program for California-based commercial purse seine fishing vessels targeting coastal pelagic species (CPS) in July 2004. SWR personnel trained the first group of CPS observers in mid-July in Long Beach, California. Frank Orth and Associates (FOA), a private contractor, hired and provided observers for training and subsequent deployment. Six observers who had previous experience in other SWR-observed fisheries attended and completed the course. The training course emphasized a review of ongoing observer programs (drift gillnet, pelagic longline) and introduction to the soon-to-be observed fisheries (purse seine, albacore hook-and-line). The training curriculum included vessel safety, fishing operations, species identification, and data collection.

Near the end of the one-week observer training, SWR and FOA staff participated in meetings with CPS stakeholders in Long Beach and Monterey, California. The SWR had previously sent, via certified mail, a letter introducing the CPS observer program and inviting interested parties to the informational meeting. The mailing list was a combination of CPS Limited Entry Permit holders, Marine Mammal Exemption Certificate holders identified as using purse seine gear, fish processors, and CPS fishing industry representatives. Approximately twenty-five people in total attended the meetings. SWR staff explained the objectives of the CPS observer program; monitoring of bycatch discarded at sea and of protected species interactions with the CPS fleet. NMFS personnel detailed the Marine Mammal Authorization Program and the necessity for all observed vessels to obtain a current Vessel Safety Decal through the U.S. Coast Guard dockside vessel safety examination program. NMFS also introduced the contractor, FOA, who would be responsible for deploying observers aboard CPS vessels. SWR and FOA staff then enjoyed the opportunity to receive feedback and answer questions from those in attendance.

Observer Protocol

In late July, observers began going to sea aboard CPS vessels. Observers recorded data on trip specifics and protected species sightings/interactions which were recorded on data forms. Observers used the Oregon Department of Fish and Wildlife 'Sardine Bycatch Observations' form to record data on fishing gear characteristics, fishing operations, and target/non-target species catch and disposition. Observers had access to data field definitions in their SWR observer program Field Manuals. Most data detailing length, volume, or weight are obtained verbally from the vessel operator. Position and time data are recorded by the observer directly from hand-held or on-board electronics. Data fields include:

Trip Number
Set Number
Observer ID

Vessel ID
Vessel Operator
Port/Date/Time of trip beginning and end, including port stops
Net Length and Net Depth in fathoms
Mesh Size
Date of Set
Set Position (latitude and longitude) in degrees, minutes, and tenths of minutes
Set Time
Target Species
Catch by species and Disposition (kept, returned alive/dead/unknown)
- catch is recorded in units of tons, pounds, or number of individuals

Protected Species Sightings and Interactions
- a protected species (e.g., marine mammal, seabird, sea turtle) take occurs when the animal is caught under the net canopy (e.g., a California Sea Lion observed breathing at the surface through the net mesh) or otherwise injured or killed by the fishing gear – an animal simply jumping into and out of the encircled net during fishing operations is not counted as caught, but recorded as a sighting/interaction.

After one month of observer deployments, SWR and FOA staff held a meeting with all of the observers to share their experiences and discuss refinements to data collection. For example, the observers suggested recording the times of significant events during the set, not just the beginning and end of the set. Observers now record the following times; skiff released, net circled, 'rings up', begin pumping of catch into the fish hold, and all gear aboard. NMFS has since trained seven more observers for the CPS program. In July of 2005, NMFS and FOA also invited stakeholders to meetings in Long Beach and Monterey to share results and receive feedback from the fleet. Future needs of the CPS observer program include; standardization of data fields, development of a fishery-specific Observer Field Manual, construction of a relational database for the observer data, and creation of a statistically reliable sampling plan.

Data Collected

Below is the data collected to starting in July of 2005 and ending in September 2005. Data is shown by target species (i.e., Pacific sardine, Pacific mackerel, squid or anchovy).

NMFS/SWR Coastal Pelagic Species Pilot Observer Program
Observed Catch Summary - July 2004 to September 2005
Target Species = Pacific Mackerel
2 Observed Trips: 2 Los Angeles
Observed Sets = 3

Species	Target Catch	Incidental Catch	Bycatch Returned		
			Alive	Dead	Unknown
Pacific Mackerel	23.5 tons				
Spanish Mackerel	17 tons				
Bat Ray			2		
California Yellowtail			1		
Midshipman			1		
Sardine		17 tons			
Sea Cucumber		3			
Unid. Crab		1			
Unid. Flatfish		1	2	1	
Unid. Shark				1	

NMFS/SWR Coastal Pelagic Species Pilot Observer Program
Observed Catch Summary - July 2004 to September 2005
Target Species = Pacific Sardine

27 Observed Trips: 12 Los Angeles, 3 Ventura, 7 Moss Landing,
1 Newport Beach, 1 Dana Point, 3 San Diego
Observed Sets = 56

Species	Target Catch	Incidental Catch	Bycatch Returned		
			Alive	Dead	Unknown
Sardine	946 tons		48 tons	8 tons	100 lb.
Anchovy		1.5 tons	4.5 tons		
Bat Ray		3	147	14	1
Bat Star			5		
CA Barracuda				3	
CA Halibut		5			
Giant Sea Bass			2		
Jacksmelt		1			
Midshipman				3	1
Pacific Bonito			10 lb.		
Pacific Electric Ray			1		
Pacific Mackerel		36 lb.	100 lb.		
Sanddab			25 lb.		
Scorpionfish/Sculpin		1			2
Sculpin				1	3
Seastar			3		1
Shovelnose Guitarfish			1		
Squid		3			
Starry Flounder			2		
Thornback Ray			2		
Unid. Crab					1
Unid. Croaker		15	1		
Unid. Flatfish		9	8		11
Unid. Mackerel		2 tons			
Unid. Octopus					2
Unid. Ray					2
Unid. Skate				3	
White Croaker		30			
Yellowfin Croaker		10			
California Sea Lion			45		
Unid. Gull			3	1	

NMFS/SWR Coastal Pelagic Species Pilot Observer Program
Observed Catch Summary - July 2004 to September 2005
Target Species = Market Squid

37 Observed Trips: 19 Ventura, 1 Morro Bay, 2 Moss Landing, 3 Monterey, 6 Los Angeles, 1 Santa Barbara, 1 Channel Islands Harbor, 4 Port Hueneme

Observed Sets = 91

Species	Target Catch	Incidental Catch	Bycatch Returned		
			Alive	Dead	Unknown
Squid	801 tons		8.5 tons		
Anchovy			120 lb.		
Bat Ray			53	1	
Brittle Star				3000	
Jack Mackerel		175 lb.	15 lb.		
Octopus		1			
Pacific Mackerel		220 lb.	40 lb.	30 lb.	1
Pelagic Stingray			61		
Sanddab		3	2		4
Sardine		9 tons	12 tons	200	16
Seastar		2			52
Spanish Mackerel		20 lb.			
Squid Eggs					500 lb.
Unid. Crab		1	1		91
Unid. Flatfish		1	1		5
Unid. Mackerel		700 lb.	1 ton		
Unid. Ray			3		1
Unid. Skate		2	2	1	
Unid. Smelt		14			
Unid. Sole					1
Unid. Stingray			12		1
Unid. Thresher Shark		1			
California Sea Lion			81		
Harbor Seal			1		
Unid. Common Dolphin				1	
Unid. Gull			15	1	

NMFS/SWR Coastal Pelagic Species Pilot Observer Program Observed Catch Summary - July 2004 to September 2005 Target Species = Anchovy or Anchovy/Sardine 7 Observed Trips: 2 Los Angeles, 2 Newport Beach, 1 Dana Point, 1 San Diego, 1 Moss Landing Observed Sets = 10					
Species	Target Catch	Incidental Catch	Bycatch Returned		
			Alive	Dead	Unknown
Anchovy	30.5 tons		5.5 tons		
Sardine	38 tons	5 tons	3.5 tons		
Bat Ray			4		
Midshipman			1		
Pacific Bonito			25 lb.		
Pacific Mackerel		8.5 tons			
Queenfish		55 lb.	10 lb.		
Round Stingray			1		
Sanddab			1		
Sculpin		2			
Seastar			1		
Spiny Dongish			1		
Unid. Croaker		35	65		
Unid. Fish		1			
Unid. Flatfish		15	1		
Unid. Rockfish			59		
Unid. Skate			1		
Unid. Turbot			1	1	
White Croaker		50 lb.	10 lb.		
Yellowfin Croaker		50 lb.	10 lb.		
California Sea Lion			5	1	
California Sea Otter			1		

MAKAH TRIBE

P.O. BOX 115 • NEAH BAY, WA 98357 • 360-645-2201

IN REPLY REFER TO:

Dr. Steve Freese
Acting Regional Administrator, NW Region
National Marine Fisheries Service
7600 Sand Point Way,
Seattle, WA 98114

October 27, 2005

Dear Dr. Freese,

I am writing to inform you of groundfish management measures for the Makah Tribe for 2006 and 2007/2008 fisheries, that we will be presenting to Pacific Fishery Management Council (Council) next week. In addition, I am updating you on our plans for the sardine fishery in 2006.

Sardines – 2006

For sardines, the Makah Tribe plans to have possibly two vessels participating in the fishery in 2006. We are not seeking a specific treaty allocation for 2006, so Makah vessels will fish under the coastwide allocation plan and season established by the Council. We will work closely with the Washington Department of Fish and Wildlife (WDFW) in management of this fishery but will not be subject to any specific restrictions that WDFW has in place for the non-tribal fishery. As with other fisheries, we will work closely with state and federal agencies including observing, monitoring and reporting the catch.

Groundfish 2006

For groundfish we are proposing slight modifications for Pacific cod and thorney head rockfish (short/long spine thorney head). Pacific cod management for 2006 should include a specific tribal harvest guideline of 350-400 m.t. We believe this represents an equal treaty/non-treaty sharing of the Pacific cod in the north Washington coast fishery.

Thorneyhead rockfish are currently subject to a trip limit of 300 pounds for tribal fisheries. We want to eliminate the 300-pound trip limit and apply the limited entry trawl cumulative trip limit to Makah vessels.

Additionally, we plan to have one or two Makah vessels participating in the dogfish fishery in 2006 and intend to manage this fishery with the trip limits or other measures established by the Council.

Groundfish – 2007/08

Management measures for 2007/08 fisheries should include the above modifications proposed for 2006 in addition to a change in the arrowtooth (and possibly other flatfish) trip limits for Makah trawlers. We have limited the harvest of arrowtooth and other flatfish species in previous years due to bycatch concerns. The tribe is now conducting gear tests to reduce bycatch in this developing fishery. To assist in this effort we propose combining the limited entry trawl cumulative trip limits for the Makah vessels (as we did in past years with yellowtail rockfish) and apportioning the harvest throughout the year to meet the needs of our gear tests and time/area management to reduce bycatch. As with yellowtail rockfish, Makah harvest of arrowtooth would not exceed the combined cumulative trip limits for the fleet.

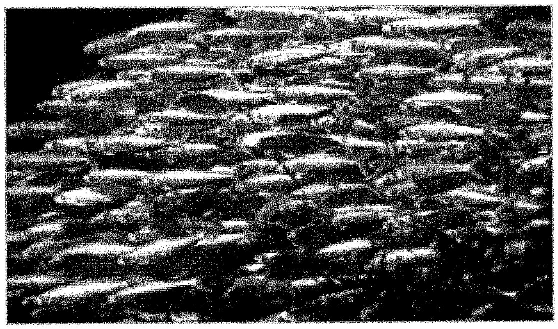
We will be available to discuss these measures at the Council meeting in San Diego next week.

Sincerely,

Russ Svec
Fishery Manager

Agenda Item D.1.b
Tribal comment
November 2005

CPS
SARDINE



At the September Council meeting, the tribes indicated that their tentative approach in getting into the sardine fishery was with some caution.

During the NOAA/Tribal caucus, the discussion was as follows:

4. Tribal Sardine Fishery Proposals: The tribes will not be seeking an allocation for sardines in the 2006 fishing season. The tribes would like to do a "test fishery" in 2006 to see how many fish are available in the Tribal U&A's. The tribes will not be following the state landing restrictions, and will develop tribal regulations and procedures in 2006. A state and tribal meeting has been set up for a later date to discuss the tribes 2006 "test fishery".

The two potential tribes that may participate in the sardine fishery are Makah and Quinault.

COASTAL PELAGIC SPECIES ADVISORY SUBPANEL REPORT ON SARDINE ASSESSMENT AND HARVEST GUIDELINE

The Coastal Pelagic Species Advisory Subpanel (CPSAS) met October 6, 2005 in La Jolla, California. 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 118,937 mt for the 2006 fishery. The CPSAS unanimously agrees the 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). However, the CPSAS vocied unanimous and strong concern that research on Pacific Northwest (PNW) sardine has not been adequately incorporated in the model to date. Furthermore, additonal research is needed to evaluate the migration rates, spawning contribution, and relationship of PNW sardine to the spawning biomass as a whole.

The CPSAS is encouraged about plans for a synoptic surveys of the sardine resource in April 2006. The CPSAS recommends that data collected during research surveys in the PNW be analyzed and included in the assessment model for the next year’s stock assessment. The CPSAS recommends further that a spotter pilot program similar to the California program be included in the PNW in future years. The PNW industry has offered to collaborate to implement this program.

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

The CPSAS continues to strongly believe 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.

PFMC
10/14/05

COASTAL PELAGIC SPECIES MANAGEMENT TEAM REPORT ON PACIFIC SARDINE STOCK ASSESSMENT AND HARVEST GUIDELINE FOR 2006

The Coastal Pelagic Species Management Team (CPSMT) met October 5, 2005 in La Jolla, California and received a presentation from Dr. Kevin Hill on results from the latest Pacific sardine stock assessment, which will be used to set a harvest guideline (HG) for the 2006 season. The report included the recommended preliminary HG of 118,937 mt for the 2006 fishery. The CPSMT agrees the stock assessment is as complete as the best available science and the new Age-Structured Assessment Program (ASAP) model allows. The CPSMT supports the recommended preliminary HG, which is based on the harvest formula, defined in the Coastal Pelagic Species (CPS) Fishery Management Plan (FMP). The HG of 118,937 mt is 13% below the 2005 HG but 22,049 mt above the peak U.S. harvest in 2002.

The CPSMT was encouraged by reports from National Marine Fisheries Service (NMFS), Southwest Fisheries Science Center that a coastwide Pacific sardine survey is planned for April of 2006. The CPSMT notes that the results of this survey could improve Pacific sardine stock assessments in the future, particularly if repeated over several years. The CPSMT noted that existing data from surveys in the Pacific Northwest in recent years are still unprocessed and not available for use in assessment efforts.

The CPSMT reviewed recent landings of Pacific sardine in the U.S., Canada, and Mexico and reports that while U.S. fisheries have remained below the established HGss, at the international level, the Pacific sardine HG has been exceeded in recent years. The CPSMT notes informal international collaboration is occurring, but recommends the Council and NMFS continue to pursue cooperative arrangements with Mexican fishery management agencies to establish formal government-to-government arrangements.

PFMC
10/14/05

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON PACIFIC SARDINE STOCK ASSESSMENT AND HARVEST GUIDELINE FOR 2006

Dr. Kevin Hill (Southwest Fisheries Science Center) presented the stock assessment of Pacific sardine to the Scientific and Statistical Committee (SSC). The assessment is based on the age-structured assessment program (ASAP) model and is an update to last year's assessment which was based on the same methodology. This model was reviewed by a Stock Assessment Review (STAR) Panel during June 2004. The new data included in the assessment are 2004-05 catches for the U.S. fisheries, revised catches for the Ensenada fishery for 2000-2005, a recalculated series of spotter plane indices, and a daily egg production method estimate of abundance for 2005.

The assessment presented by Dr. Hill represents the best available science regarding the status of the Pacific sardine resource. The SSC endorses the use of the harvest guideline (118,937 mt) estimated using the fishery management plan control rule and the biomass estimate of 1.1 million mt for management of the Pacific sardine fishery for 2006. This harvest guideline is 13% lower than the 2005 harvest guideline. The SSC notes that the U.S. catches have been below the Council-specified harvest guidelines. However, after accounting for catches by Canada and Mexico, the total catches for 2002 and 2004 are now estimated to have been greater than the retrospective estimates of the stockwide harvest guidelines calculated as part of this assessment.

The biomass time-series from the assessment is similar to that from last year's assessment for the years after 1998-1999 and somewhat higher for the years prior to this. Last year's assessment estimated the 2003-2004 recruitment to be the largest in the time-series, but that estimate was based on a very limited amount of data (primarily the number of age-0 fish caught during 2003-2004). The data on which the 2006 assessment are based have now confirmed that there was a strong recruitment during 2003-2004.

The SSC notes that the harvest guideline depends on population weight-at-age, which is poorly known. The SSC supports regular systematic sampling, such as the proposed coastwide survey planned for 2006, which can provide annual estimates of population weight-at-age and as well as of maturity-at-age.

The next STAR Panel to review the Pacific sardine assessment is scheduled for 2007. The SSC anticipates that it should be possible to include the results from the coastwide survey in the assessment to be reviewed by this STAR Panel. The SSC recommends that review of the Pacific sardine and mackerel assessments will be enhanced if the SSC Coastal Pelagic Species subcommittee can meet to discuss the draft assessments prior to the Council meetings at which these assessment are to be presented.

PFMC
10/31/05

Agenda Item D.1.d
Supplemental Public Comment
November 2005

CALIFORNIA WETFISH PRODUCERS ASSOCIATION

Representing California's Historic Fishery

October 24, 2005

Dr. Don McIsaac, Executive Director
Mr. Don Hansen, Chair
Members of the Pacific Fishery Management Council
7700 NE Ambassador Place #200
Portland, OR 97220-1384

RE: Agenda Items D.1.d SARDINE STOCK ASSESSMENT and HARVEST GUIDELINE and D.2.d ALTERNATIVES FOR KRILL MANAGEMENT

Dear Dr. McIsaac, Chairman Hansen and Council members,

These comments are submitted on behalf of the California Wetfish Producers Association, which represents the majority of wetfish processors and fishermen in Monterey and southern California. We appreciate this opportunity to present our views and concerns regarding the CPS agenda items noted above.

Re: D.1.d – Pacific Sardine Stock Assessment and Harvest Guideline, we fully support the statement of the CPS Advisory Subpanel, with emphasis on the underlined portions:

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). However, the CPSAS voiced unanimous and strong concern that research on Pacific Northwest (PNW) sardine has not been adequately incorporated in the model to date. Furthermore, additional research is needed to evaluate the migration rates, spawning contribution, and relationship of PNW sardine to the spawning biomass as a whole.
The CPSAS is encouraged about plans for a synoptic survey of the sardine resource in April 2006. The CPSAS recommends that data collected during research surveys in the PNW be analyzed and included in the assessment model for the next year's stock assessment.
And:
The CPSAS recommends the Council encourage National Marine Fisheries Service to continue to fund comprehensive annual CPS research, including the survey off the PNW and explore a possibility to encourage similar surveys in Canada and Mexico.

PO Box 1951 Buellton, CA 93427 Telephone 805-693-5430 Fax 805-686-9312
Email <dplesch@earthlink.net>

The CPSAS continues to strongly believe 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.

We would greatly appreciate the Council's continued appeals to the NMFS and the State Department, stressing the critical importance of trinational sardine research and transboundary cooperative management to avoid overfishing the Pacific sardine resource.

Re: D.2.d. – Alternatives for Krill Management

As a member of the Coastal Pelagic Species Advisory Subpanel, I supported the CPSAS statement presented to the Council on this issue. However, because I'm unable to attend the November Council meeting in person, I appreciate this opportunity to offer the following clarification of the CPSAS statement from the perspective of CWPA and California's wetfish industry.

First, CWPA members agree that krill is critically important to the ecosystem as forage for other marine life, and in order to avoid potentially negative effects to other species, the Council should explore measures to protect krill from overharvest. However, we're concerned that implementing a ban on krill fishing through the CPS Fishery Management Plan, with scant information on the resource, could set a potentially damaging precedent for other CPS fisheries.

We understand that, to date, the Council has received no proposals to begin a krill fishery off the west coast. We further understand that all three west coast states have longstanding prohibitions against landing krill in any west coast port. Thus the recent interest in regulating krill is driven by a fear that a fishery could develop at some future time, through a loophole in the "national" list of fisheries at 50 CFR 600.725 that provides a general category of "fishing with trawl gear" for unspecified species among the fisheries listed by NMFS for waters under the jurisdiction of the PFMC. Thus, someone wanting to engage in fishing for krill with trawl gear (the principal gear used in other krill fisheries) off the West Coast would not need any permits from NMFS and, as with a factory-trawl catcher-processor vessel, could avoid landing the catch on the west coast.

We understand and support the Council's interest in acting to protect krill from the unintended consequence of unregulated fishing. However, we also agree with and support the concern expressed by the CPSAS re: diverting funding and resources to krill management at a time when considerable work and research on other CPS, specifically sardine, have been repeatedly requested and are currently under-funded and incomplete.

If there could be some benefit to including krill within the CPS FMP, especially with regard to providing additional resources to enhance research on the complex of species including sardine, we could support the proposal to amend the CPS FMP to include krill. However, we also agree with and reiterate the CPSAS recommendation that krill be included under a third category of management rather then as an "active" or "monitored" species. This third category, such as a research category, would need to be created.

Our first preference, however, is to investigate other examples of alternative categories or strategies that may have utility for krill management on the West Coast.

Perhaps the most direct and immediate action would be to close the existing loophole by amending the list of fisheries to clarify that the general category of "fishing with trawl gear" for unspecified species does not include krill. Then anyone wanting to engage in krill fishing with any other gear (e.g., purse seine) would be required to notify the Council 90 days in advance. The Council would have opportunity at that time, based on real, rather than hypothetical, interest, to advise NMFS on how to control the activity.

We have read with interest the public comment submitted in support of prohibiting fishing on krill by listing it as forage in other FMP-managed fisheries. While we appreciate the concern expressed for krill's importance in the ecosystem, we also agree with the conclusion reached in the alternatives analysis that many species could be so categorized – in fact, virtually every organism in the marine environment is forage for something else. We suggest that perhaps the most direct and immediate approach is to clarify the list of fisheries, which would buy additional time to further investigate the best solution to regulate krill.

Thank you very much for your consideration of these comments.

Best regards,

Diane Pleschner-Steele
Executive Director

Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 200
Portland, OR 97220-1384

RECEIVED
SEP 2 7 2005
PFMC

Re: Request to Protect Krill as a Forage Species

Dear Pacific Fishery Management Council Members,

The West coast of the United States supports some of the world's most important commercial fisheries. These fisheries are made possible by the extremely productive waters of the California Current System off the coast of Washington, Oregon, and California and the Alaska Current in the Gulf of Alaska. Euphausiids, or krill, play a central role in these marine ecosystems. **Krill form a key link between phytoplankton and commercial and recreationally important fish, marine mammals, and seabirds. Most species (including humans) are only one or two feeding levels away from krill, and it is the primary prey of most of the commercial fish, marine mammal, and seabird species of Alaska, Washington, Oregon, and California.** Commercially important species that directly or indirectly depend upon krill include salmon, pollock, rockfish, hake, flatfish, squid, mackerel, sardine, and herring. The combined economic value of these resources exceeds $5 billion annually.

Krill production in these waters support some of the most diverse fish, marine mammal and seabird communities in the world including 6 species of threatened or endangered marine mammals and 1 species of endangered seabird – all of which either directly or indirectly depend upon krill resources. As a group of fishermen, marine biologists, and conservationists we believe that krill is a trophic key for Pacific Coast ecosystems – for both fished and protected species. In order to effectively protect these important marine resources and the ecosystem upon which they depend, it is critical to protect the integrity and health of krill off the West coast of the United States. **Commercial and recreational fisheries can only recover if the ecosystems upon which they depend are intact.**

In recognition of its importance in marine food webs, krill fishing has been banned in the state waters of Washington, Oregon, and California. Recently the PFMC was asked to consider a similar ban for Federal waters. Based primarily on the advice of NMFS, at the November 2004 meeting, the Council

"directed staff to begin development of management measures to regulate directed fisheries for krill within Council-managed waters. These measures would be incorporated into an amendment to the CPS FMP as described in Option 2 of Options for Controlling Fishing for Krill (Agenda Item H.4.b, November 2004)." *PFMC decisions, November 2004, PFMC website.*

If formally adopted, this option (amending the CPS FMP for krill) could open the door for directed commercial krill fishing in Federal waters. It is not clear why the Council is tentatively adopting option 2 rather than option 3 – designating krill as forage under one or more FMPs and thereby prohibiting fishing for krill. This would a) protect this important forage species for commercially important and protected resources, b) be consistent with ecosystem management goals for the Pacific fisheries, and c) be consistent with the ban established by state regulatory authorities in Washington, Oregon, and California.

The Presidentially-appointed US Commission on Ocean Policy recommended that marine resources should managed on an ecosystem basis "to reflect the relationships among all ecosystem components, including humans and nonhuman species and the environments in which they live." (US Oceans Commission Report – Executive Summary, September 2004). Protecting krill resources is the most direct means to achieve such a policy. While fully protecting krill will have no economic impact on existing commercial or recreational marine resources, the initiation of a fishery may have severe impacts. While not particularly controversial, fully protecting krill will help preserve and maintain the health of the marine ecosystem upon which commercial and recreational users depend.

In its April 2005 meeting the Council:

"reviewed a progress update from National Marine Fisheries Service (NMFS) Southwest Region (SWR) on a proposed course of action for management of krill in the West Coast Exclusive Economic Zone and National Marine Sanctuaries under the auspices of the Coastal Pelagic Species FMP. The Council approved a draft outline for an alternatives analysis. The Council will provide guidance on a preferred schedule at the April meeting following a progress update from NMFS SWR on the alternatives analysis." *PFMC decisions, March 2005, PFMC website.*

This decision resulted in the issuing of a Statement of Work for the development of a NEPA-consistent Alternatives Analysis for krill management (Agenda Item F.1.a NMFS Report 2 April 2005). It is not at all clear to us how the Council has decided to tentatively move forward with Option 2 of the Options for Controlling Fishing for Krill (Agenda Item H.4.b, November 2004) before the Alternatives Analysis that should provide the information upon which to base any management decision has been completed. This concern was underlined by PFMC and NMFS moving forward with a meeting that was held on June 6, 2005 at the Southwest Fisheries Science Center to:

"discuss the status, distribution, existing data sets and potential stock assessment methods, and management research needs for these two species in the EEZ. The Pacific Fisheries Management Council hopes to develop a program to regulate potential krill fishing in federal waters under the Magnuson-Stevens Act." *Summary of a Meeting on California Current Krill off the U.S. West Coast, June 6, 2005. NMFS Southwest Fisheries Science Center, Large Conference Room.*

We strongly feel that Option 3 is the better management approach, and believe that any actions to develop a stock assessment analyses – tentative or otherwise – for krill management should not be made until the Alternatives Analysis described in Agenda Item F.1.a NMFS Report 2 April 2005 has been completed.

Specifically, as a group of researchers, commercial stakeholders, and non-government organizations, we would like to urge the PFMC to fully consider and adopt Option 3 (protect krill as a forage species) as the approach that a) protects coastal pelagic ecosystems, b) insures the long-term sustainability of coastal pelagic commercial fisheries, c) assures the protection and recovery of threatened or endangered marine species, d) is consistent with management policies already adopted by Washington, Oregon and California State regulatory authorities, and e) is a comparatively painless way for the Council to proactively enact an ecosystem-based management approach to marine resources . Thank you for your consideration.

Sincerely,

Donald A. Croll
Associate Professor
University of California, Santa Cruz

Leon Panetta
Director
Panetta Institute

Zeke Grader
Executive Director
Pacific Coast Federation of Fishermen's Associations

Susan Williams
Director, Bodega Marine Laboratory
University of California

Tim Eichenberg
Acting Director
Pacific Regional Office
The Ocean Conservancy

Jennifer Bloesser
Science Director
Pacific Marine Conservation Council

Rod Fujita
Scientist
Environmental Defense

Caroline Karp
Chair
Sierra Club Marine Wildlife and Habitat Committee

Gary Griggs
Director, Institute of Marine Sciences
University of California Santa Cruz

William Sydeman
Research Director
Point Reyes Bird Observatory

Baldo Marinovic
Research Biologist
University of California Santa Cruz

Bernie Tershy
Executive Director
Island Conservation

James Ayers
Pacific Director
Oceana

Brendan Cummings
Marine Biodiversity Program Director
Center for Biological Diversity

James Harvey
Professor
Moss Landing Marine Laboratories

John Calambokidis
Director
Cascadia Research

Kenneth Coale
Director
Moss Landing Marine Laboratories, California State University

Roy Thomas
President
Carmel River Steelhead Association

Darus Peake
Chairman
Oregon Salmon Commission
And
Commissioner President
Port of Garibalidi, Oregon

Mike McCorkle
President
Southern California Trawler's Association

Steph Dutton and Heidi Tiura
Captains
Sanctuary Cruises

Jan Hodder
Professor
University of Oregon Institute of Marine Biology

Ernie Koepf
President
California Herring Fishermen's Association

Dan Wolford
Science Director
Coastside Fishing Club

PACIFIC SARDINE STOCK ASSESSMENT AND HARVEST GUIDELINE FOR 2006

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) for the 2006 Pacific sardine fishing season. The current HG (which expires December 31, 2005) is 136,175 mt. The results of the most recent stock assessment, as presented to the CPS Advisory Bodies in October 2005, indicate a 2006 HG recommendation of 118,937 mt. The stock assessment document was not available for the briefing book. The Executive Summary of the 2005 Pacific Sardine Stock Assessment will be presented in the supplemental materials (Agenda Item D.1.a, Supplemental Attachment 1).

In June 2005, the Council approved a new long term allocation formula for Pacific sardine. 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.

The Coastal Pelagic Species Management Team (CPSMT), and the Coastal Pelagic Species Advisory Subpanel (CPSAS) have reviewed the assessment and the recommended HG and provided statements to be presented under Agenda Item D.1.c. The 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 for 2006.

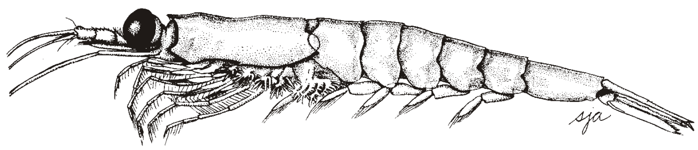
Reference Materials:

1. Agenda Item D.1.a, Supplemental Attachment 1: 2005 Pacific Sardine Stock Assessment Executive Summary.
2. Agenda Item D.1.c, CPSAS Report.
3. Agenda Item D.1.c, CPSMT Report.
4. Agenda Item D.1.c, Supplemental SSC Report.

Agenda Order:

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

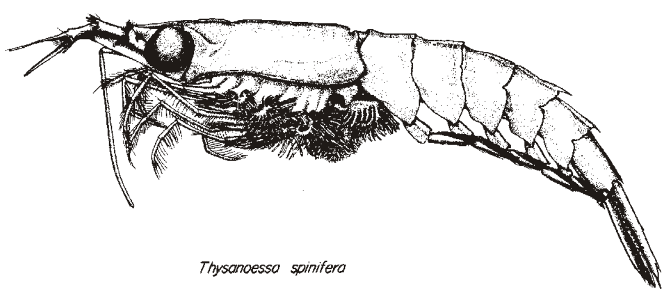
PFMC
10/14/05



Euphausia pacifica

DRAFT

ALTERNATIVES ANALYSIS FOR THE MANAGEMENT OF KRILL FISHING OFF THE U.S. WEST COAST



Thysanoessa spinifera

Draft

ALTERNATIVES ANALYSIS FOR MANAGEMENT OF KRILL FISHING IN THE EXCLUSIVE ECONOMIC ZONE (EEZ) OFF THE U.S. WEST COAST

PREFACE

The Pacific Fishery Management Council (Council) has expressed interest in and support for ecosystem-based fishery management programs that recognize the relationships between different components of the marine environment. Whether looking at management of multi-species fisheries or of fisheries for species that are both predators and prey or at conservation of habitat that is essential for healthy fish stocks, the Council is attempting to incorporate ecosystem conservation principles into its management programs. In this context, the Council is interested in conserving and managing krill resources (see Chapter 3 for information on the species involved) to maintain ecological relationships and ecosystem integrity and to minimize the risk of irreversible adverse impacts on managed fish stocks from adverse impacts on the building blocks (such as krill) of the ecosystem in which those fish stocks exist. It is desirable to maintain krill habitat and krill stocks within the bounds of natural environmental variability to the extent practicable. This document has been prepared to further achievement of that goal.

1.0. PURPOSE AND NEED FOR ACTION

1.1 Purpose and Need

This document is intended to provide the Council with information needed to decide how to control fishing for krill in the EEZ off the West Coast. In making these decisions, the Council needs to review this information, which is believed to be the best scientific information available, and to make decisions considering

- the size, distribution, life history characteristics and productivity of the krill resources involved

- the role and importance of krill in the environment,

- the impacts that krill fishing and other activities could have on fish stocks and other living marine resources and on resource users off the West Coast,

- the likely effects and effectiveness of alternative management approaches and measures in conserving krill and other living marine resources off the West Coast, and the effects of those alternatives on the resource users of the West Coast

- the impacts and implications and the benefits and costs of the alternative approaches and measures.

After consideration of this document, the Council will determine its preferred strategy and possible conservation and management measures. If further action is to be considered, the Council will direct the preparation of a management document for public review, including environmental analysis consistent with the National Environmental Policy Act (NEPA). This will ensure adequate documentation as the Council makes decisions.

1.2 History of Action

In September 2004, managers of the national marine sanctuaries off central California requested that the Council consider prohibiting krill fishing in federal waters of the Cordell Banks, Monterey Bay, and Gulf of the Farallones National Marine Sanctuaries administered by the National Oceanic and Atmospheric Administration (NOAA) (see map 1). The Council was generally receptive to this request but recognized that it needed more substantive analysis of the krill resource and areas of predator dependence EEZ-wide and of the alternative ways to achieve the kinds of controls that might be imposed, before a final decision could be made. It should be noted that waters in the sanctuaries may not be the only areas in which krill conservation and protection is critical.

The Southwest Region (SWR), National Marine Fisheries Service, National Oceanic and tmospheric Administration (NOAA Fisheries or NMFS), and NOAA General Counsel-Northwest subsequently presented the Council with advice on alternative approaches by which krill fishery controls could be implemented. In November 2004, the SWR and the Southwest Fisheries Science Center (SWC), NMFS, urged the Council to use the authority of the Fishery Management Plan for U.S. West Coast Fisheries for Coastal Pelagic Species (CPS FMP) to achieve this control. The Council agreed with this approach, with the commitment that that the SWR would take the lead in overseeing documentation to provide a basis for a regulatory amendment to the CPS FMP to include krill as a species in the FMP management unit and to establish initial fishery controls as needed. Other alternatives were to be fully considered in this documentation.

1.3 Management Decisions

This document is intended to evaluate and compare the effects and effectiveness of alternative management approaches and different types of conservation and measures at several different levels of decision making.

1. At the broadest level, the question is whether to propose Federal regulations to manage krill fishing in EEZ waters off the West Coast. The Council has initially agreed that it is appropriate and necessary to exercise its authority under the Magnuson-Stevens Fishery Conservation and Management Act (M-SA) to control krill fishing. This document presents the rationale for that decision and for rejection of the "No Action" alternative. After review and discussion of the information in this document, the Council will have the opportunity to affirm or amend that decision.

2. At the next level the Council would decide the mechanism by which krill fishery management should be implemented. The Council has initially concluded that its preferred approach is to amend its Fishery Management Plan for Coastal Pelagic Species Fisheries off the West Coast (CPS FMP) to include krill in the management unit and to implement krill fishery conservation and management measures consistent with the CPS FMP. This document presents the rationale for that decision and the reasons for rejection of alternative approaches for managing krill fishing. After review and discussion of the information in this document, the Council will have the opportunity to affirm or amend that decision.

3. At the most specific level, the Council would decide whether to allow krill fishing and, if so, the specific conservation and management measures that should be imposed on krill fishing. The Council has not discussed fully the alternatives other than the option presented by central California National Marine Sanctuaries' managers and the alternative of leaving management in the hands of the West Coast States. This document assesses and compares the potential impacts of different measures and their anticipated benefits and costs. After review and discussion of the information in this document, the Council will have a basis for determining the nature and scope of controls to propose.

This document contains information relevant to the specification of maximum sustainable yield (MSY) and optimum yield (OY) for krill; these specifications are required under the M-SA if the Council maintains its selection of amendment of the CPS FMP as the means by which to control krill fishing. This document also identifies alternatives for designation of essential fish habitat (EFH) for krill and of habitat areas of particular concern (HAPC), as required by the M-SA.

After the Council has affirmed or selected its preferred alternatives, a document will be prepared and disseminated for public review and comment. The Council will receive and consider those comments and make final decisions.

1.4 Current Management Controls

At this time, there are no federal regulations that limit fishing for krill either within federal waters around the sanctuary or in the exclusive economic zone (EEZ) generally. The States of Washington, Oregon and California prohibit their vessels from fishing for krill, and these prohibitions prevent landings of krill into a West Coast port by such vessels at this time. However, these prohibitions would not prevent a vessel from another state from engaging in krill fishing and delivering the product to a port in another area. Under the current regulatory system, krill fishing has not occurred, is not occurring, and is not likely by West Coast vessels due to the State laws noted that prohibit West Coast vessels from landing krill into West Coast ports. As will be discussed in section 3.5, however, there are fisheries for krill and krill products in Japan, Canada and the Antarctic , and there is a potential for development of a fishery off the West Coast. Also, krill fisheries in certain areas such as the Antarctic have generally been conducted by large-scale harvester/processor vessels that process their catch at sea, and such vessels would not have to be dependent on West Coast ports to handle their products. International markets exist for krill and krill products, and while foreign fishing in the EEZ is a remote possibility, it may be that this market could or would be met by a West Coast krill fishery. Depending on the source of information, the market for krill and krill products is either slowly growing or on the verge of major growth.

2.0 SUMMARY OF THE ALTERNATIVES

2.1 Prospective Management Objectives

The recommended objectives of the management program and selected management measures are:

2.1.1. Ensure that the stocks of principal krill species are maintained at levels at which the essential role of krill as forage for important fish and other species is fulfilled.

This means that the risk of driving the stocks down to levels below which that role would be fulfilled should be quite low, and that the risk of adverse impacts of fisheries on species that are dependent on or sensitive to the abundance and availability of krill would be low as well.

2.1.2. Ensure that, if a krill stock is reduced below critical levels, exploitation will be curtailed to promote recovery to that critical level within an appropriate time span, e.g., 3-5 years, with the specific timetable possibly being linked to environmental conditions.

This means that the management strategy, which would be intended to ensure some minimal stock abundance sizes (which could vary by species), should have a response mechanism intended to provide a high probability that the stock will recover to a pre-exploitation size level within a short period to control the risk of long-term adverse effects on dependent species.

2.1.3. Ensure that adequate data are collected for any exploitation activities that are allowed.

This is intended to ensure that any fishing activities are effectively monitored, that removals in time and place are fully recorded with reports to NMFS and/or the States, and that this information is available in a manner that will lead to improved understanding of the stocks and the impacts of the fishery on the stocks.

2.1.4. Provide a foundation for future research and data collection

This is intended to promote the design and implementation of a robust and coordinated program of research and data collection among fishery management agencies and other researchers so that there will be more efficient collection and sharing of data and research results. This is especially critical to ensure proper linkage between data collection and research on fishing and monitoring and assessments of dependent fish and other living marine resources.

2.1.5 Provide protection for key krill predator foraging areas (i.e., topographic and oceanographic features that consistently serve to concentrate krill and facilitate predator feeding).

This is intended to ensure that any areas known to be principal foraging areas for higher level predators (and especially species of special concern such as endangered and threatened species) would be protected from any adverse impacts associated with fishing.

2.2. Alternative Management Strategies

2.2.1. No Action (Rely on Existing Laws and Regulations)

This is the "no action" or *status quo* alternative.

No new federal regulations would be established to control krill harvest off the West Coast.

Management of krill fishing by West Coast vessels currently is under the control of the West Coast states, which now prohibit krill fishing by vessels registered in those states. There has been no directed fishing for krill off the West Coast to date.

As directed by Section 305(a) of the Magnuson-Stevens Fishery Conservation and Management Act (MSA), NMFS has published a "national" list of fisheries at 50 CFR 600.725. The list of fisheries identifies fisheries that existed at the time of the regulation. Under this regulation, a person is prohibited from fishing in an unlisted fishery. An individual fisherman who wanted to engage in "unlisted" fishing activities could notify the appropriate regional fishery management council (regional council) of the intent to use a gear or participate in a fishery not on the list. Ninety days after such notification, the individual could use the gear or participate in that fishery as proposed unless the regional council has proposed regulatory action to prohibit or otherwise control the use of the gear or participation in the fishery (e.g., through emergency or interim regulations). This provides regional councils with an opportunity to take action in the event a new fishery is proposed that might pose new fishery management problems. A general category of "fishing with trawl gear" for unspecified species was among the fisheries listed by NMFS for waters under the jurisdiction of the Council. Thus, someone wanting to engage in fishing for krill with trawl gear (the principal gear used in other krill fisheries) off the West Coast would not need any permits from NMFS and would be subject only to state controls in states where the catch would be landed. Someone wanting to engage in krill fishing with other gear (e.g., purse seine gear) would have to notify the Council 90 days in advance. The Council would then have opportunity to advise NMFS whether to control the activity or allow it as proposed. No such proposals have yet been directed to the Council.

In summary, under the no action alternative, management of krill fisheries would remain under state jurisdiction for West Coast. Vessels from other states would not be controlled if trawl gear were used. Such vessels, however, could not engage in fishing for krill with other gears without first notifying the Council and allowing 90 days for consideration of regulatory action.

The Council has rejected this alternative because it does not provide sufficient assurance of protection of krill and the resources which are dependent on krill. The absence of action would potentially set the stage for a fishery with no limits by vessels that are not tied to West Coast ports and have no interest in conservation of resources off the West Coast. While there is no apparent interest in fishing for krill at this time, it is necessary and appropriate to establish safeguards to prevent an uncontrolled fishery from being started.

2.2.2. Strategic Alternatives for Krill Fishery Management

There are several approaches by which krill fishing in the EEZ could be managed if the Council determines that this is necessary and appropriate.

2.2.2.1 Include Krill in Fishery Management Plan for Coastal Pelagic Species off the West Coast (CPS FMP) (Tentative Preferred Alternative)

Under this alternative, the Council would add krill to the management unit of the CPS FMP. The administrative mechanism would be a regulatory amendment consistent with the framework procedures of the CPS FMP. A regulatory amendment can be achieved through a relatively simple management process requiring two or more meetings of the Council and submission and affirmative action on the Council proposal by NMFS (acting on behalf of the Secretary of Commerce). It should be noted that the Council has discussed this matter at two meetings to date, though not at the level of detail of this document. The proposal would have to meet all documentation and process requirements of the M-SA and other applicable law. These other laws include NEPA, the Endangered Species Act (ESA), the Marine Mammal Protection Act (MMPA), the Regulatory Flexibility Act (RFA), and executive orders pertaining to analysis of the economic impacts of regulations. These requirements will be less or more demanding depending on the complexity and controversiality of those controls and the potential magnitude of impacts of the management controls, especially with respect to potential impacts on non-fish protected species. It appears that, in this situation, action that would allow unlimited or intensive fishing would be more controversial than action to prohibit krill fishing due to the important role of krill in the ecosystem as forage for many species (including some Council-managed fish species) and the current lack of fishing activity.

The principal rationale for using the CPS FMP as the vehicle to achieve management of the krill fishery is that the CPS FMP already embodies the concept of protecting or maintaining the forage value of managed resources in the Council's harvest control strategy. That is, for managed species like Pacific sardine and Pacific mackerel, the CPS FMP establishes that directed harvest should not be permitted unless the spawning biomass is above a minimum size. That minimum biomass level is thought to be appropriate both to provide ample adults for reproductive success and to provide sufficient total biomass to support forage needs of other species (fish and non-fish). The same concept could be applied to krill in a consistent manner through this strategic approach. The CPS FMP could establish controls intended to allow fishing only after it is assured that the krill biomass is sufficiently large to ensure continued productivity of the stock and continued availability of forage for dependent species, such as fish, marine mammals, and seabirds. At the same time, the CPS FMP recognizes that there are economic values that society can derive from use of Pacific sardine and Pacific mackerel when the biomass is sufficiently large to support fisheries. Similarly, the management program for krill could allow krill harvest under controlled circumstances when it is certain that such harvest will be consistent with the management objectives of the CPS FMP and would not adversely affect krill stocks or other important resources. There may be times and/or places where krill harvest will provide economic benefits without ecological or economic harm.

The extent to which specific fishery regulations would be needed to carry out this alternative would depend on the types of harvest controls that the Council deemed necessary and appropriate to achieve the objectives of the amendment. A total prohibition of krill fishing might be a relatively simple rulemaking, at least in the short term; allowing krill fishing in certain times and areas would be more complex due to the need to analyze information for determining the times/areas in which krill fishing would be acceptable; and allowing unlimited fishing for krill might be a very complex rulemaking, given the role of krill in the ecosystem and the potential for severe consequences if the krill resource off the West Coast were to be fished heavily and possibly depleted, even if only in the short term.

One of the complexities of this approach is the need to address MSA requirements to specify maximum sustainable yield (MSY) and optimum yield (OY) for managed species in FMPs. There is limited information available about the abundance, distribution and productivity of krill in the Council's management area (see Chapter 3 for a full discussion). One or both species of concern occur not only in the EEZ but in other nations' waters (e.g., Canada, Mexico, Japan) and on the high seas beyond the EEZ. There have not been prior efforts to estimate biomass or MSY for krill throughout its range or in the EEZ. Scientists have been asked for information and views as to how this might be done with available information (see Appendix A). This document contains the best scientific information available at this time though it is recognized there is considerable uncertainty about the prospective abundance and productivity of kill and the role of krill in the environment. The lack of complete and certain scientific information is not meant to be an impediment to needed management action.

The NMFS Guidelines published at 50 CFR 600 Subpart D recognize that MSY is a theoretical concept and that any MSY values used in determining OY will necessarily be estimates. The Guidelines note that there are many ways to approach the specification of MSY, and that if data are insufficient to estimate MSY directly, there may be other measures of productive capacity that can be used as reasonable proxies for MSY. Further, in the case of a species that extends beyond the EEZ, the specification of OY could be derived by estimating MSY for the species throughout its range and determining OY for the portion of the stock that may be in the EEZ. Therefore, it is anticipated that the lack of a point estimate of MSY at this time will not preclude adoption of the CPS FMP amendment as a viable strategy for exercising control over krill fishing if that is the Council's ultimate choice.

Under this alternative, the Council also would have to designate EFH for krill, evaluate the potential adverse effects of fishing activities on this EFH, and minimize to the extent practicable adverse effects on EFH from fishing if there is evidence that a fishing activity adversely affects EFH in a manner that is more than minimal and not temporary in nature (50 CFR 600.815(a)(2)(i) and (ii)). EFH has already been identified for species in the current CPS FMP; this would provide a point of departure for designating EFH for krill. EFH can only be designated for the EEZ and for waters of the United States as defined in 33 CFR 328.3, though an FMP may describe, identify and propose protection of habitats of managed species beyond the

EEZ. At this point, EFH designation for krill is not thought to be a major problem that would preclude use of the CPS FMP amendment option for controlling krill fishing. Chapter 3 presents alternatives for designation of krill EFH as well as for designation of Habitat Areas of Particular Concern (HAPC) for krill.

Designation of krill as a managed species does not preclude designation of krill as a component of EFH for other species. A comparable situation exists in the Atlantic, where a directed (but controlled) harvest of pelagic sargassum is permitted even though pelagic sargassum is viewed as an EFH component for several fish species managed under FMPs in the Atlantic area.

In any of the scenarios for management measures under the CPS FMP strategy, there could be framework procedures by which krill fishery controls could be modified as more research and possibly experimental fishing results became available. This would presumably be premised on information in periodic Stock Assessment and Fishery Evaluation reports, as called for in the National Standard Guidelines. This would include any results from fishing operations, new research information, and information from any exempted fishing activities permitted in the reporting period. The Council has considerable experience with regulatory amendment procedures, and this is considered in the evaluation of the alternatives.

An option in this alternative is to designate krill as a monitored only species in CPS FMP, similar to northern anchovy. Under this option, there would not be specific fishery controls for krill; the Council would monitor the situation and, if a krill fishery developed, would evaluate the need for conservation and management under the CPS FMP regulatory framework.

2.2.2.2. Designate Krill as Component of EFH for One or More Managed Species

Under the M-SA, each fishery management plan must designate EFH for the species included in the management unit of that FMP. EFH has been designated for all species under management in Council fishery management plans for CPS, groundfish, ocean salmon, and highly migratory species fisheries. EFH can include both non-living (e.g., waters and substrate) and living (e.g., live coral, plankton, forage species) marine resource components. If krill were identified as a component of EFH for one or more managed species, then loss of krill could be an adverse effect on EFH and in turn on managed species because the presence of krill (prey) makes waters and substrate function as habitat for feeding, and the definition of EFH includes waters and substrate necessary to fish feeding. Thus, actions that reduce the availability of a major prey species may be considered adverse effect of EFH if such actions reduce the quantity of EFH.

As krill is a principal forage species for many Council-managed species, krill could be considered as a component of EFH for those species. However, krill has not yet been so designated.

Designation of EFH triggers two requirements that would likely protect krill from harm. First, as noted above, any FMP for which krill is designated a component of EFH would have to evaluate fishing activities that might adversely affect EFH; and identify actions to minimize to the extent practicable adverse effects on EFH from fishing, if there is evidence that a fishing activity adversely affects EFH in a manner that is more than minimal and not temporary in nature. Fishery controls thus might be necessary to ensure that fishing activities (direct or indirect harvest, or incidental impacts) would not have adverse impacts on krill sufficient to adversely affect its ability to be functional EFH . Second, the amendment would have to identify actions other than fishing that may adversely affect EFH. Other Federal agencies would be required to consult with NMFS prior to engaging in any activities (including activities funded or authorized by that agency) that would adversely affect krill as a component of EFH. Those Federal actions might be required to carry out or require permittees or contractors to carry out mitigating actions.

The mechanism by which this alternative would be achieved would be to amend one or more FMPs to identify krill as an EFH component for the species in the management unit involved. Any such amendment would have to meet MSA requirements including consistency with other applicable law as well as documentation requirements of NEPA. Depending on the controls invoked, there could be some need for analyses under E.O. 12088 and the RFA. It does not appear that any requirements under ESA or the MMPA would come into play, especially if krill harvest were tightly controlled as part of the action. Notwithstanding the Council action to date under the EFH provisions of the M-SA, it would still be possible to designate krill as a component of EFH either under the Groundfish FMP or possibly under another FMP. There would not necessarily be any direct linkage to the CPS FMP.

Designation of krill as a component of EFH would not preclude a direct harvest of krill. A comparable situation is that pelagic sargassum in the Atlantic is designated as an EFH component for several managed species, but a directed harvest (albeit at a low level) is permitted. Further, it in not clear if a case could be made that krill as EFH would extend throughout the EEZ. Dependence of species managed under Council FMPs seems limited to species at the shelf and inshore of the shelf.

As acknowledged above, if krill were included in the CPS FMP as a management unit species, then EFH would have to be designated for krill.

The Council has rejected this alternative insofar as EFH for groundfish is concerned. In June 2005, the Council made final selection of alternatives for EFH for groundfish; these will be presented in a final environmental impact statement and will be incorporated as an amendment to the Groundfish FMP. The Council chose not to include krill as a component of EFH for groundfish. This was consistent with the Council decision (subject to amendment) that krill management will be carried out through the CPS FMP.

2.2.2.3. Designate Krill as a Forage Species under One or More FMPs

Under this alternative, the harvest of krill would be controlled or prohibited by designating krill as a forage species under one or more Council fishery management plans (krill is a forage species for many if not most fish species managed under Council FMPs), and establishing conservation and management measures necessary to ensure that the forage values of krill are fully protected under those other plans. These measures could include a prohibition of directed harvest throughout the EEZ or in selected times and areas, depending on the interests of the species that are dependent on krill to some degree. This alternative would be similar to the action taken by the North Pacific Fishery Management Council designating krill and several other species as forage for groundfish. That action also prohibited the direct harvest of krill (and other designated forage species) by any vessel permitted under the North Pacific Council's groundfish FMPs.

Under this alternative, the Council would have to decide whether to limit the forage category to krill or to include other species in the forage category. Krill is only one of several forage species for species managed by the Council. Other such species include other CPS (Pacific sardine and mackerel, northern anchovy, jack mackerel, market squid), the juvenile forms of other managed species, and many fish species managed under States' authorities. Further, other forage components such as lances and herring not managed by the Council could be considered as species in the forage category. The Council could include a measure to allow limited fishing for any forage species including krill. As with the EFH approach, there would also be questions about the ability to designate krill as important forage for managed species throughout the EEZ. Krill may be far more important for species on the shelf, continental slope, and inshore.

The mechanism for carrying out this strategic alternative would be to amend one or more FMPs consistent with the procedural and documentation requirements of the MSA and other applicable law. This might not be a very complex or difficult task. The North Pacific Council was able to complete the documentation for such an action in a fairly short time frame. However, as will be discussed in 4.1.4.10, the legal and factual situation in the north Pacific was quite different from the situation off the West Coast.

The Council has rejected this approach due to its complexity and its limitations. First, implementing this approach would require amendment of all Council FMPs in order to cover all fishing gears under Council management, and even then, there would not be coverage of all fishing vessels that could potentially engage in krill fishing off the West Coast. A vessel from another region could initiate krill fishing. Second, if this approach were adopted, it would be necessary to consider a larger variety of species for forage designation. This could take considerable additional work and the Council does not have the resources to engage in this work at this time. Third, unlike the North Pacific situation in which special M-SA provisions greatly expand the authority of the State of Alaska over non-Alaska vessels in the EEZ, the West Coast States have very little authority over such vessels. It is necessary to implement controls over all vessels in the EEZ under the M-SA to ensure krill conservation throughout the EEZ.

2.2.3 Alternatives Considered but not Analyzed Fully

The Council considered but did not analyze fully the potential for exercising krill conservation on a limited scale within sanctuary waters only through the National Marine Sanctuaries Act. The Council agreed that krill conservation throughout the EEZ is necessary and appropriate and that the M-SA is the appropriate authority for achieving this conservation need.

2.3 Alternative Conservation and Management Measures

The Council has tentatively agreed to include krill as a management unit species under the CPS FMP; therefore, it also needs to decide the appropriate initial conservation and management measures for the fishery. Section 4 evaluates these alternatives fully. In all alternatives that allow fishing for krill in the EEZ, it is presumed that the Council would include permit and reporting requirements to ensure adequate monitoring and future evaluation of the effects and effectiveness of management. In summary, the alternatives evaluated are:

2.3.1 Prohibit Krill Fishing in the EEZ

This alternative would prohibit directed fishing for krill anywhere in the EEZ until and unless the regulations implementing the CPS FMP were amended to specify otherwise. This would not necessarily prohibit fishing under an exempted fishing permit, though any such fishing would be permitted only after opportunity for the Council to review and advise on an application for such fishing.

2.3.2 Prohibit Krill Fishing in Portions of the EEZ within Selected National Marine Sanctuaries but Permit It in the Rest of the EEZ

Under this alternative, krill fishing would be prohibited in the EEZ waters within the Cordell Bank, Monterey, and Farallon Islands National Marine Sanctuaries, but krill fishing would not be limited in other EEZ waters. This would be consistent with the request from the sanctuary managers.

2.3.3 Prohibit Krill Fishing in EEZ Waters in All National Marine Sanctuaries

Under this alternative, krill fishing would be prohibited in the EEZ waters within the Cordell Bank, Monterey, Farallon Islands, Channel Islands, and Olympic National Marine Sanctuaries, but krill fishing would not be limited in other EEZ waters. This would be consistent with the request from the sanctuary managers, except that EEZ waters around the Channel Islands Sanctuary would also be closed to krill fishing. This would establish consistent regulations for all waers within Sanctuaries.

2.3.4 Prohibit Krill Fishing in EEZ Waters in All National Marine Sanctuaries and in Selected Other Predator-dependent Krill Waters (e.g., off Cape Blanco; inshore of Heceta Bank and Bodega Canyon)

Under this alternative, krill fishing would be prohibited in the EEZ waters within the Olympic Coast, Cordell Bank, Monterey Bay, the Gulf of the Farallones, and the Channel Islands National Marine Sanctuaries, and also in inshore of Heceta Bank, Cape Blanco and Bodega Canyon areas. Krill fishing would not be limited in the rest of the EEZ. This would go beyond the request from the sanctuary managers and would encompass additional waters in which krill concentrations appear important for spawning and forage purposes.

2.3.5 Allow Unlimited Krill Fishing Beyond 60 Miles from the Inner Boundary of the EEZ

This alternative would allow krill fishing only in waters 60 miles or more from the inner boundary of the EEZ would be permissible, but krill fishing would not be allowed shoreward of that boundary. This would encompass virtually all waters within National Marine Sanctuaries, the other areas listed in 2.3.3, and waters at or inshore of the shelf break. Thus all waters in which there are or have been krill concentrations would be off limits to fishing. This would go beyond the request from the sanctuary managers and would provide a larger area in which the non-consumptive values of krill would be fully protected.

2.3.6 Allow Unlimited Krill Fishing

Under this alternative, the Council would explicitly decide that any person who wished to do so could engage in fishing for krill in the EEZ without limit as to amount, time, or area fished or gear used. This would effectively supersede states' prohibitions on landing of krill taken by their vessels in the EEZ, though fishing in state waters could still be prohibited.

2.3.7 Controlled Krill Fishing

These are other options under which krill fishing would be allowed subject to more specific limits.

2.3.7.1 Quotas or Harvest Guidelines

The Council could establish an annual or periodic limit on krill harvest, with the limit being set at a minimum level pending more complete information about the species and its potential response to harvests. In setting this level, the Council would have to balance between a catch limit large enough to promote some fishing but small enough to control the risk of adverse effects on krill or on other important resources. Alternatively, the Council could establish a harvest guideline (as it has done in other fisheries) that would serve as a benchmark for determining a need for further consideration of management needs. If fishing occurred at a level higher than the harvest guideline, then the CPS Management Team and advisory subpanel would be asked to review the situation and advise as to the need for a change in conservation and management strategies. Such changes could likely be completed by relatively simple regulatory amendments. Another possible suboption would be to develop a control rule by which, based on a probabilistic model of the likelihood of an exceptional abundance of krill in a given year, the Council would determine whether a fishery should be allowed (and appropriate conditions) based on the likelihood of exceptional krill production. Unfortunately, it does not appear at this time that such a probabilistic model will be developed in the needed timeframe for this action.

2.3.7.2 Limits by Season

Under this alternative, the Council would establish times in which harvest of krill would and would not be permitted. For example, to provide full opportunity for successful reproduction, the Council could prohibit krill fishing in waters off the West Coast or off specific subareas in this time period. However, choosing a season would be difficult. *T. spinifera* is thought to distinct spawning season (May to July) off California, coincident with the strongest upwelling

(Brinton 1981). In this period, it forms extensive inshore surface swarms as fully mature adults during the peak of the upwelling season. These adults are thought to swarm, breed, and then presumably die at the end of their life cycle. Maturing subadults are also known to swarm near the surface in later summer and fall (cites from Smith, p. 2). However, *E. pacifica* can spawn every two months year round. The Council also could decide to prohibit krill fishing at times when key species are known to be feeding heavily. If there is going to be a closed season, it probably would extend from spring through fall, since in the spring and summer in the Gulf of the Farallones, king salmon and Cassins auklets depend on krill (reproductive adults mostly) in that area, and in late summer and fall, the whales move in to prey on swarms of developing juveniles. The timing may also vary from year to year because of the variability in the timing and intensity of upwelling, suggesting a need for longer closures to buffer against this variability.

2.3.7.3 Limits Based on Water Temperatures

Under this alternative, the Council would control fishing triggered by oceanic conditions. This would be analogous to the linkage of the annual sardine harvest guideline to the temperature of the water off the Scripps Pier. It appears that krill are sensitive to extreme El Niño conditions, and as cold water species, do not thrive under warm water conditions. On the other hand, the aggregation and spawning of krill at levels that produce good reproduction and concentrations for feeding by predators may also produce krill at levels sufficient to support fishing without risking either krill or dependent and sensitive species. Therefore, the Council could choose to totally prohibit krill fishing in El Niño years but allow krill fishing in average or cool water years. However, this measure may complicate the management issue unnecessarily, as the direct warm/cold water correlation is an over simplification.

2.3.7.4 Combination of Measures

For the most part, the above listing of management alternatives is limited to one measure at a time. As a practical matter, the Council has indicated a concern about the risk of uncontrolled fishing but has not ruled out the potential of a limited harvest. Therefore, if the Council were to allow any krill fishing, the Council would likely consider a multi-faceted control program, including permits and reporting requirements, a catch limit, time and/or area closures, and observer coverage. The above alternatives are not meant to be mutually exclusive in all instances. Given the many variables involved, it is not possible to evaluate all possible combinations of measures in this document. The general conclusion, however, is that the more "sophisticated" and flexible the combination, the more difficult it would be to implement at a reasonable cost.

2.3.8 Exempted Fishing Permits (EFPs)

There are two options for this element of the management program. First, as currently managed under the CPS FMP, EFPs would be considered under the procedural regulations at 50 CFR 600.675. Under this process, NMFS forwards to the Council (including States, the U.S. Coast Guard, Treaty Tribes, and the U.S. Fish and Wildlife Service) for review and advice any applications that are received requesting an EFP in the CPS fishery. NMFS Regional

Administrators are now authorized to process and issue EFPs, subject to documentation requirements of the M-SA and other applicable law. The Council typically recommends that if a permit is granted, there be reporting and observer coverage to ensure an adequate basis for monitoring and evaluation of the results. It is anticipated that this approach will continue with the addition of krill. The Council might also include a protocol for soliciting and reviewing EFP requests with inputs from the plan team, advisors, and the public as it has done for other FMPs.

However, if the Council so chooses, a separate EFP process could be developed in which EFP applications would be handled like EFP requests in the groundfish fishery. This provides more control and predictability to the process as well as to the types of applications that will be submitted for full Council consideration.

2.3.9 Prohibit Krill Fishing Initially but Establish Process for Future Permitting

As noted above, this alternative is for the Council to prohibit krill fishing in the EEZ until it is demonstrated as a result of research, EFPs, or other analysis that krill fishing can be conducted in a manner that will not adversely affect krill stocks or other living marine resources. Either through existing framework procedures of the CPS FMP or through new framework procedures, criteria and standards for considering opening a fishery would be set and, based on periodic SAFE Reports, the Council would decide whether or not to allow it. This could be limited to allowing fishing at certain times and places to ensure that there is not excessive risk of harm.

2.4 Krill EFH Harvest Controls

If krill were designated as a component of EFH under the Groundfish FMP (or any othe FMP), then harvest controls could be designed to ensure that the EFH value of krill to groundfish would not be harmed by krill harvest. This would entail specification of the EFH value of krill in time and area strata relative to groundfish. It is noted that designation of krill as an EFH component does not preclude some use of krill in a directed or incidental harvest. As demonstrated in the management program for pelagic sargassum of the Atlantic Ocean, limited harvest can occur as long as there is no adverse impact on the EFH value of the resource involved. The Council could consider all of the specific types of harvest controls listed above to minimize the risk of adverse effects. It is not clear if a full prohibition of krill harvest under this alternative would be defensible; if the EFH designation would not extend throughout the EEZ, then it might not be reasonable to conclude that harvest should be limited throughout the EEZ to protect or maintain EFH values.

2.5 Krill Forage Harvest Controls

If krill were designated as forage, then harvest controls could be set to ensure that the forage value for the prey species identified would be protected adequately. This would entail identification of the prey species involved and the times/areas in which predator/prey relationships would appear most important, and designation of controls to ensure that the important prey value is protected and maintained. The Council could consider all of the specific types of harvest controls listed above to minimize the risk of adverse effects. Again, it is not clear that krill serves an important forage function far beyond waters of the shelf break, and therefore, it might not be reasonable to prohibit krill fishing throughout the EEZ to maintain or protect forage values for species under Council FMPs.

3.0 DESCRIPTION OF THE KRILL RESOURCE AND THE AFFECTED ENVIRONMENT

3.1. Krill Biology and Status

3.1.1 Species of Concern and Definition of Krill

Eight species of euphausiid shrimp dominate the krill community in the Transition Zone of the California Current System (Brinton and Townsend 2003), but only two cold-water species, *Euphausia pacifica* and *Thysanoessa spinifera* (Fig. 1), form large, dense surface or near-surface aggregations and are thus likely to become potential fishery targets. High catch densities (e.g., greater than 3 g wet weight $m^{-3)}$ are usually required to support commercial harvesting (Fulton and Le Brasseur 1984). These two species are also the most common euphausiids reported in the diets of a wide variety of California Current seabird, marine mammal and fish species (see Section 3.2.1 below).

The daytime near-surface aggregating behavior of *E. pacifica* and *T. spinifera* has been documented by Boden et al. (1955), Barham (1956), Pearcy and Hosie (1985), Smith and Adams (1988), and others. The sub-tropical and marginally tropical *Nyctiphanes simplex* also aggregates at the surface in large swarms, but is only abundant in U.S. West Coast waters during strong El Nino years, occurring predominantly to the south in Mexico waters (Gendron 1992; Brinton and Townsend 2003). Another euphausiid, *Nematocelis difficilis*, is very abundant in the California Current, but not a vertical migratory, preferring the deeper layers of the thermocline where it is less accessible to harvest than *E. pacifica* and *T. spinifera*. The remaining species (*T. gregaria, E. recurva, E. gibboides, E. eximia*) are less abundant and not likely candidates for exploitation.

The word "krill" comes from the Norwegian meaning "young fish" but it is now the common term used for all euphausiids, a taxonomic group of shrimp-like marine crustaceans found throughout the oceans of the world. The term krill was probably first applied to euphausiids found in stomachs of whales caught in the North Atlantic, and later became a popular term for Antarctic krill (*Euphausia superba*). For the purpose of this document and analysis, the term ‘krill’ is synonymous with ‘euphausiid,’ and when referring to U. S. Pacific Coast euphausiids as a potential management unit, applies only to *E. pacifica* and *T. spinifera*.

3.1.2 Biology

3.1.2.1 Range

E. pacifica ranges throughout the subarctic Pacific, including the Gulf of Alaska as far south as 25 ºN latitude (Brinton 1962a, 1981) (Fig. 2). *T. spinifera* occurs from the southeastern Bering Sea south to northern Baja California, with regions of high density associated with centers of upwelling (Boden et al. 1955; Brinton 1962a)(Fig. 3).

3.1.2.2. Horizontal Distribution EEZ

Distribution of both species within the EEZ is thought to be closely related to bathymetric, topological and oceanographic features favorable for retaining adults, juveniles and larvae in optimum grazing areas. Periodically, distribution and occurrence can also be strongly affected by changes in local and large-scale physical and biological conditions such as anomalously strong upwelling events or extreme El Niño conditions. It is not known whether animals advected offshore are loss to the system, or whether transport of some individuals to the south and west via upwelling filaments or eddies may help to interconnect regional subpopulations and enhance gene flow among isolated stocks. The Scripps Institution of Oceanography has recently assembled a 50-year time series of maps showing spatial densities of these and other euphausiid species in the CalCOFI sampling area (Point Reyes, California, south to the California-Mexico border, E. Brinton, SIO, unpub. data, personal commun. 6/8/05). Similar data on areal distribution have been and are continuing to be gathered off Oregon (Smiles and Pearcy 1971; Gómez-Gutiérrez et al. 2005; Peterson et al. NWFSC, pers. commun., Newport, OR 6/8/05). These and previously published distributional data, indicate that *E. pacifica* generally occurs within the West Coast EEZ over bottom depths greater than 100 fathoms (183 m), although it can also occur further shoreward over the deeper waters of the continental shelf (especially larvae). It is known to occur seaward to the outer boundary of the EEZ from the U.S.-Mexico border north to the U.S.-Canada border and beyond (Boden 1955), but highest densities appear to occur within the inner third of the EEZ (E. Brinton, SIO, unpub. data, pers. comm. 6/6/05). Within this area (< 60-100 nm from the coast), adults and juveniles reportedly can be found throughout both the inshore and offshore area, whereas larvae are often most abundant in upwelled areas much nearer the coast, generally inshore of the 1000 fm (Brinton 1976; Brinton 1967; Smiles and Pearcy 1971; Gómez-Gutiérrez et al. 2005). Off Oregon, the greatest concentration of adults appears to be located near the shelf break (~200 m isobath) (Gómez-Gutiérrez et al. 2005; W. Peterson, NWFSC, Newport Oregon, pers. comm. 6/6/05). Aspects of its life history may differ in the lower part of its range south of 40°N than to the north of that latitude, where environmental characteristics show stronger seasonality than to the south (Brinton 1976).

T. spinifera is more coastal, occurring mainly shoreward of the shelf break, usually over bottom depths less than 200 m deep, although catches can occur further offshore beyond the shelf, especially off central California (Fig. 3). Daytime surface swarms have been observed off California in the San Diego, Santa Barbara Channel Islands, Monterey Bay, Gulf of the Farallones, Cordell Bank, and Tomales Bay areas, and off Oregon (Pearcy and Hosie 1985; Smith and Adams 1988; Brinton et al. 2000; Adams 2001; Howard 2001)

Gómez-Gutiérrez et al (2005) have described the cross-shelf life stage segregation of *E. pacifica* and *T. spinifera* off Central Oregon, which appear to be more tightly associated with the shelf break than in other areas, e.g., off southern California. *E. pacifica* tends to be more offshore extending from 3 to 60 nm miles (5.6-111 km) and beyond from the coast, whereas *T. spinifera* is more coastal, with highest concentrations over the continental shelf and slope. High densities of early life stages (nauplius to juveniles) of both species were primarily recorded in the inshore shelf zone (<18 km from the coast), but older stages were mainly recorded in the outer shelf, slope, and to some extent, beyond. Adult *E. pacifica* (and to some extent, older larval stages) were distributed over the shelf, slope and beyond, with reproductive swarms common along the shelf- break area. *T. spinifera* occurred primarily over shelf and shelf-break waters from 2-74 km (1- 40 nm) from the coast, especially between 5.6- 27.8 km (3 and 15 nm) from shore in water less than 100 m deep. Larvae and juveniles of *T. spinifera* were also generally restricted to relatively shallow inner shelf waters within < 18 km from the coast; while adults occurred generally in outer shelf, shelf break and slope waters beyond 18 km from the coast. They concluded that a strong cross-shelf gradient in euphausiids assemblages and age-segregated distributions for both *T. spinifera* and *E. pacifica* may represent maintenance of egg, nauplius, and metanauplius stages in the rich nearshore area; the offshore drift of older larval stages; and concentration of reproductive adults at the shelf break linking inshore and offshore segments of the populations. Off southern California, larvae of both species occur offshore beyond the shelf as well as inshore (Brinton 1967, 1973). Brinton and Townsend (2003) reported *T. spinifera* (mostly furcilia; rarely adults) disperses extensively offshore toward the main flow of the California. While it is possible that these individuals, especially *T. spinifera*, may be advected there by currents and represent individuals lost from the coastal population (Brinton and Townsend 2003), there may also be significant latitudinal differences in the inshore-offshore dispersion patterns and retention mechanisms off Oregon and California.

Gómez-Gutiérrez et al (2005) and others have suggested that the shelf-break is an important ecological region for both these species, with larger euphausiid patches often recorded there. Off Oregon, the main populations are thought to be concentrated within 10 to 20 nm either side of the shelf break (Peterson, W.T., pers. comm. NMFS, NWFSC, Newport Oregon, 6/6/05), though distribution may be further offshore to the south off central and southern California. Additionally, certain features have been associated with important "hot spots" of krill concentration. These are islands, banks, canyons, and promontories that enhance retentive water circulation patterns that tend to retain and concentrate krill and phytoplankton biomass in nutrient-rich upwelled water. Sometimes, these "hotpots" can also occur far offshore, contained in the meanders of upwelling jets that originate further inshore over the shelf or slope. Krill fishing is likely to be the most profitable in these high krill density areas, but also likely to be in direct competition with associated fish, seabird and cetacean predators concentrated there. Known high krill and krill predator areas include, but may not be limited to the Olympic Coast, Washington (Calambokidis et al. 2004); Heceta Bank and Cape Blanco areas, Oregon (Ainley et al. 2005; Ressler 2005; Tynan et al 2005); Bodega Canyon, Cordell Bank, Gulf of the Farallones, Pescadero Canyon, Ascension Canyon, and Monterey Bay Canyon off northern California (Chess et al 1988; Smith and Adams 1988; Kieckhefer 1992; Schoenherr 1991; Adams 2001; Howard 2001); and around the southern California Channel islands (Armstrong and Smith 1997; Fieldler et al. 1998; Croll et al 1998).

3.1.2.3 Vertical Distribution in the EEZ

E. pacifica performs extensive vertical migrations, usually over depths greater than 200 m. The adults live at a daytime depth of 200-400 m (occasionally down to 1000 m) rising to near the surface at night (Brinton, 1976; Youngbluth 1976), often concentrating in the upper 20 to 50 m. It occasionally amasses near the surface during the day as well (Hanamura et al 1984; Endo et al. 1985; Brinton and Townsend 1991).

T. spinifera generally occurs from the surface to about 200 m deep but most frequently at vertical depths of less than 100 m (Ponomareva 1966; Brinton et al 2000; Alton and Blackburn 1972). It also undertakes diel vertical movements within its relatively shallow range (Alton and Blackburn 1972; Chess et al. 1988). It is the most predictable and extensive daytime surface swarmer along coastal California from Tomales Bay south to the Channel islands off southern alifornia (Brinton 1962a; Smith and Adams 1988; Fielder et al 1998; Howard 2001; Adams 2001). Mass strandings of the species have also been reported along Oregon beaches (Pearcie and Hosie 1985) and as far south as La Jolla, California (Brinton 1962a).

3.1.2.4 Food Requirements and Trophic Transfer

Both species are grazers on microscopic plants and animals and provide an important link in the oceanic food web between phyto- and nanoplankton and upper trophic levels. Phytoplankton is thought to be a major component of the diet, but fish eggs and larvae are also thought to be consumed in large quantities. Theilacker et al (1993) suggests this predation may significantly affect fish recruitment. Field et al (2001), using a top-down Ecopath assessment model for the northern California Current ecosystem[1] (NCCE), estimated euphausiid average annual phytoplankton biomass consumption to be 650 g wet weight m^{-2} during the early 1960s (a cool, productive regime), and 400 g wet weight m^{-2} in the mid-1990s (a warm regime characterized by low productivity).

The phytophagous role of krill has a negative aspect. Bargu et al. (2002) found evidence that California krill (e.g., *E. pacifica*) may be a potential transfer agent of the phycotoxin domoic acid to higher trophic levels in the marine food web in Monterey Bay.

3.1.2.5 Growth, Sexual Maturity, Longevity, Mortality

Analysis of length at age is complicated by the fact that krill can shrink in size as an ecological adaptation to temporarily unfavorable environments (Marinovic and Mangel 1999). Both species are known to shrink in winter when food is scarce; *E. pacifica* is also known to shrink in summer during the reproductive season (W. Peterson and L. Feinberg, NMFS, SWFSC and OSU, pers. commun, 6/6/05). California Current krill can also regressively lose their sexual characteristics, skip developmental stages, or molt several times while remaining at the same stage (ibid). *E. pacifica* can also exhibit a large range of ages at any given size, and females at a given age can vary in size as much as 10 mm (ibid.). These characteristics can have a big impact on field calculations and complicate length frequency progression analyses.

Throughout its range, *E. pacifica* exhibits large variation in longevity and age at first sexual maturity (Table 3.1). According to Brinton (1976), the more abundant spring-summer cohort of *E. pacifica* off southern California generally reaches a maximum length of 22 mm in about 12 or

[1]defined as Cape Mendocino, CA north to the tip of Vancouver Island, Canada.

13 months, and has a one-year life span. Life expectancy for the lesser abundant winter cohort off southern California is shorter at 8 months. Individuals from 10 to 15 mm carapace length tend to predominate in the population. Growth rates of *E. pacifica* off southern California appear similar to those off Oregon (Smiles and Pearcy 1971). Under optimum conditions, sexual maturity could be attained at 11.6 mm length (Brinton 1976), and an adult cohort off southern California can reproduce about three times over a life span of about three years . Growth is thought to be slower and of longer duration to the north in the Subarctic North Pacific.

T. spinifera grows to a larger size—males to 20 mm, females to 38 mm. The difference in male and female growth is observed from the first year. Life span has been variously reported at from 10 months to two years or more (Boden et al. 1955; Nemoto 1957; Summer 1993; Tanasichuk 1998). In subarctic Alaskan waters, Nemoto (1957) reported a two-year life cycle (or at least 1+ yrs), with individuals growing to 10 mm in the first year and attaining sexual maturity at about 20-24 mm at one year of age, with a spawning season from June to September. He found large unfertilized specimens (26-30 mm) in mid July and was unsure whether these specimens represented ages 2+. Mauchline (1980) also estimated the maximum life span to be 2+ years with breeding maturity reached at 2 years of age. Summers (1993), using length frequency analyses of individuals collected in Barkley Sound, B.C., found that *T. spinifera* matures in one year, and some individuals survive to two years of age (most maximum-sized adults she found in the field were closer to 1 year of age). Tanasichuk (1998b) monitoring population structure in Barkley Sound, British Columbia, estimated a shorter life span of 10 months using length frequency progressions and certain initial assumptions about larval stage durations and furciliar growth. He also found more variable and protracted spawning. Annual and seasonal progression in size classes observed in *T. spinifera* collected in the Gulf of the Farallones and Channel Islands off southern California indicate that a 1 to 2 year life span may also be true for populations to the south, but more work is needed.

Few quantitative estimates of instantaneous natural mortality *M* are available for species of krill, although *E. pacifica* off California and Oregon has been better studied than most, and mortality found to be quite high. Brinton (1976) estimated that only 16% of *E. pacifica* larvae survive per month, then survival increases to 67% per month after the larval stage is complete, then mortality increases once again in adulthood, with only about 60% surviving per month. Siegel and Nicol (2000) calculated *M* values based on data published in Brinton (1976) and Jarre-Teichmann (1996), and found $M = 3.0\ y^{-1}$ off California, and much higher ($M = 8.7^{\ y-1}$) off Oregon. Siegel and Nicol (2000) suggest the high mortality rates off Oregon may have been due to data collected under unusually severe El Niño conditions, and may not be representative of an ‘average’ year. No natural mortality estimates are available for *T. spinifera*.

Table 3-1. Estimates of maximum age, age at first maturity/spawning, spawning frequency and natural mortality rate (*M*) of the euphausiids *E. pacifica* and *T. spinifera*.

Species	Cohort	Area	MaxAge	1stMat	Spawning frequency[2]	*M*	References
E. pacifica	Spring	S. Calif.	6-8 months	4 months	3 yr^{-1}; ~ max. every 2 months[3]	3.0 y-1	Brinton 1976 Siegel&Nicol 2000
E. pacifica	Autumn	S. Calif.	10-13 months	7 months	Max. every 2 months	3.0 y-1	Brinton 1976 Siegel&Nicol 2000
E. pacifica	---	Ore. &Wash.	1+yr	~1 yr	1 yr^{-1}	---	Smiles&Pearcy 1971
E. pacifica	---	Ore	---	---	---	8.7y-1	Siegel&Nicol 2000 Jarre-Teichmann 1996
E. pacifica	---	Wash	-- -	---	2 yr^{-1}; mostly spring, less in late summer.	---	Bollens et al 1992
E. pacifica	---	B.C.	---	---	4-6 yr^{-1} Mar-Oct	0.6-1.9 y^{-1}	Tanasichuk 1998a; Siegel&Nicol 2000 Jarre-Teichmann 1996
E. pacifica	---	Aleu-tians; Kam-chatka	2+ yr	~ 1 yr	1yr^{-1} for 2+ years	---	Siegel&Nicol 2000; Iguchi&Ikeda 1995
E. pacifica	---	NW Pacific	2+ yr	~ 1+ yr	1 yr^{-1} for 2+ years	---	Ponamareva 1966; Nemoto

[2] distinct cohorts; egg release pulses
[3] depending on available food conditions

		; Kam-chatka					1957
E. pacifica	---	NE Japan	15 months	---	1 yr^{-1}	---	Iguchi et al 1993
E. pacifica	---	SW Japan	21 months	---	---	---	Iguchi et al 1993
E. pacifica	---	N Japan	2+yr (♀) 1+yr (♂)	1+yr	---	---	Nicol&Endo 1997
T. spinifera	---	Barkley Sound, B.C.	1-2 yr	1 yr	2 pulses yr^{-1} Mar-July	---	Summers 1993
T. spinifera	---	Barkley Sound, B.C	10 months	---	3-4 pulses yr^{-1} Mar-Oct	---	Tanasichuk 1998b
T. spinifera	---	North Pacific	2+ yr	2 yr	---	---	Mauchline 1980
T. spinifera	---	Subarc-tic Alaska	1+ to 2+ yr	1 yr	1 y^{-1} June-Sept	---	Nemoto 1957

3.1.2.6 Reproduction and Recruitment

Both species are batch spawners; eggs are broadcast freely into the water, which sink in the water column. Males must transfer a spermatophore packet to the female for fertilization to take place. After hatching, larvae move toward the food-rich surface layers.

Recruitment of *E. pacifica* can occur year-round off Oregon and California, but distinct peaks are associated with upwelling periods (Brinton 1967; Brinton 1973; Barham 1957). *E. pacifica* appears to be more seasonal in the subarctic North Pacific and off Japan (Nemoto 1957; Ponomareva 1966). Recruitment typically crests off mid Baja California February-April; off southern California May-July; in Monterey Bay also spring and summer, and off Oregon, August-December (Brinton 1976). It may be that under optimal feeding conditions, a female, carrying 20-250 eggs which hatch into larvae could spawn every two months – first at about 11.5 -mm length; second at about 16 mm, and third at 20 mm – during which time it might produce a maximum of 650 eggs. The long duration of maturity (about half of the species' short life expectancy) is thought to contribute to population stability and continuity. Recruitment in California occurs after about 30 days when larvae enter the juvenile phase. There are at least 4 generations each year, at least off southern California. Due to the short life span and relatively few cohort pulses, the maximum stock size is reached immediately after successful recruitment of a single cohort (Brinton 1976; Siegel and Nicol 2000). In general, there is no spawning stock-recruitment relationship, in most years highest recruitment occurs fro m spring and summer cohorts, lesser recruitment occurs in autumn and winter. Off Washington, there is one large recruitment pulse in spring, and a lesser one in late summer (Bollens et al. 1992) and none in winter. This pattern is attributed to reduced phytoplankton levels in summer and low survival of adults into winter to spawn at that time.

Less is known of the population biology of *T. spinifera*. Brinton (1981) reported that the spawning season off California extended from May to July, coincident with the strongest upwelling. During this time, fully mature adults form extensive inshore surface swarms during the peak of the upwelling season off California (Brinton 1981, Smith and Adams 1988). These adults are thought to swarm, breed over a protracted spawning season, then presumably die at the end of their life cycle (Nemoto 1957). Off San Francisco, breeding appears to occur primarily from April through June-July. Spring reproductive swarms in this area contain mostly 18-30 mm fertilized adults in breeding condition, which presumably spawn (probably at intervals) and then die by late summer, when specimens of the size disappear from seabird and salmon diets, and from plankton collections. Swarms off central and southern California have also been sampled during late summer and fall (Aug-October) in association with blue and humpback whales, but these late summer and fall individuals are mostly immature or sexually developing individuals (14-20 mm). Maturing subadults are also known to swarm near the surface in late summer and fall (Schoenherr 1991; Kieckhefer 1992; Fiedler et al. 1998). Summers (1993) describes a distinct and extended spawning period off British Columbia from March through July with a late May peak. Unlike *E. pacifica*, the eggs of *T. spinifera* are quite adhesive, a possible mechanism to maintain recruits in the neritic zone and prevent offshore dispersal to less productive waters (Summers 1993).

To the north of the U.S. EEZ, Tanasichuk (1998b) has studied the population biology of *T. spinifera* in Barkley Sound, Canada, including stock recruitment, biomass and productivity. He found neither the Ricker nor Beverton and Holt stock-recruitment models described the relationship between larval and parental abundances of this species he observed. Population production to biomass ratios (P:B) fluctuated between 14.4 and 44.7,with variations following the proportion of the biomass accounted for by larvae (e.g., the lowest P:B ratio was in 1994 when larvae accounted for only 0.05 of mean annual biomass).

3.1.2.3 Food Requirements and Trophic Transfer

Both species are grazers on microscopic plants and animals and provide an important link in the oceanic food web between phyto- and nanoplankton and upper trophic levels. Phytoplankton is thought to be a major component of the diet, but fish eggs and larvae are also thought to be consumed in large quantities. Theilacker et al. (1993) suggests this predation may significantly affect fish recruitment. Field et al. (2001) using a top-down Ecopath assessment model for the northern California Current ecosystem[4] (NCCE), estimated euphausiid average annual phytoplankton consumption (Q) to be 650 g wet weight m^{-2} during the early 1960s (a cool, productive regime), and 400 g wet weight m^{-2} in the mid-1990s (a warm regime characterized by low productivity).

[4]defined as Cape Mendocino, CA north to the tip of Vancouver Island, Canada.

The phytophagous role of krill has a negative aspect. Bargu et al. (2002) found evidence that

California krill (e.g., *E. pacifica*) may be a potential transfer agent of the phycotoxin domoic acid to higher trophic levels in the marine food web in Monterey Bay.

3.1.3 Status of Principal Species

3.1.3.1 Determination Criteria and Available Data

Each FMP must specify the MSY and OY from the fishery and, to the extent possible, objective and measurable status determination criteria for each stock or stock complex covered by that FMP and provide an analysis of how the status determination criteria were chosen and how they relate to reproductive potential. Status determination criteria must be expressed in a way that enables the Council and the Secretary of Commerce to monitor the stock or stock complex and determine annually whether overfishing is occurring and whether the stock or stock complex is overfished. In all cases, status determination criteria must specify both of the following:

- A maximum fishing mortality threshold (MFMT) or reasonable proxy thereof.

The MFMT may be expressed either as a single number or as a function of spawning biomass or other measure of productive capacity. The MFMT must not exceed the fishing mortality rate or level associated with the relevant MSY control rule. Exceeding the MFMT for a period of 1 year or more constitutes overfishing.

- A minimum stock size threshold (MSST) or reasonable proxy thereof.

The MSST threshold should be expressed in terms of spawning biomass or other measure of productive capacity. To the extent possible, the stock size threshold should equal whichever of the following is greater:

One-half the MSY stock size, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock or stock complex were exploited at the maximum fishing mortality threshold previously specified. Should the actual size of the stock or stock complex in a given year fall below this threshold, the stock or stock complex is considered overfished.

Status determination criteria must be based on the best scientific information available. When data are insufficient to estimate MSY, Councils should base status determination criteria on reasonable proxies thereof to the extent possible. In cases where scientific data are severely limited, effort should also be directed to identifying and gathering the needed data.

After a review of the available literature and individual consultation with California Current krill experts from federal and state government agencies, academia, and the private sector (see Appendix A), it was determined that reliable input parameters for a suitable model to determine minimum stock size threshold and maximum fishing mortality threshold, based on spawning biomass or other measure of productive capacity, still need to be developed for these two species, and agreed upon. Thus a benchmark status determination could not be made as of Sept 1 2005. The control rule management approach implies an ability to determine the level of biomass B relative to its initial biomass level B_0 and relative to B_{MSY} , and to determine the potential level of mortality *F* relative to some target level like F_{MSY}. No catch histories or sufficient information on stock and recruitment (e.g., percent spawning potential ratio, or proxies based on spawning potential ratios) are available on which to make such calculations. *MSY* levels of *B* or *F* could be estimated as fractions of B_0 but no comprehensive EEZ-wide or stock-wide biomass estimates for any California krill species have been made for these species.

Even if reliable data were readily available, the MSY yield model based on traditional surplus production theory is inappropriate to set adequate catch levels of krill, for the following reasons:

- Most current single-species modeling assumes the equilibrium condition from which a MSY can be derived and applied for managing harvest. This condition rarely if ever exists for these two species, which exhibit constantly fluctuating and extreme ranges of standing stock densities, depending on what environmental regime is prevailing that particular season, year, or group of years.
- Instead of maximizing yield the goal should be to allow sufficient escapement to meet the requirements of predators, including not only commercially important fishes and invertebrates such as Pacific hake, salmonids, rockfishes and squid, but also recreationally important species as well as seabirds and marine mammals under council and/or Federal management.
- Krill have unusual growth and molting patterns, and lengths at maturity vary (unlike other commercially important crustaceans). This makes it difficult to estimate vital rates and to calculate MSY for krill.
- No information exist on the extent to which population 'seeding' occurs from populations that lie to the north and west outside the U.S. EEZ and the year-to-year variability of the rate of immigration or emigration from the system.
- The lack of a harvest history precludes using average stock-wide catch levels as rough proxy MSY values.
- Data are available from diverse sources on average densities for certain EEZ areas and times, and even the historical range of densities of these species (especially off central and southern California and central Oregon), but there is no consensus on overall representative densities or range of densities, and habitat area utilized over which to expand these densities into EEZ-wide or range-wide B_0 estimates.

While a reliable MSY cannot be determined at this time (and may not be the appropriate management benchmark in any case), there are considerable data available on natural variability of abundance, food web dynamics, and preliminary data on vital rates that can be used to obtain bounding values for initial modeling. To meet minimum M-SA requirements, first-round provisional approximations of B_0 and $B_{MSY,}$ based on rough estimates of average adult krill densities and presumed habitat occupied, are presented in section 3.1.3.4. Other measures of abundance and MSY, expressed as a range of average densities (all life phases) during El Niño versus La Niña years, are provided in section 3.1.3.3. These estimates are provisional, pending a more comprehensive stock assessment. It should be noted that available methods and units of abundance are far from standardized, and estimates are based on many assumptions that may or may not be valid, including a lack of accounting for predator needs. More thorough analyses and standardization of density and biomass estimates are required to obtain more valid biomass estimates, as well as analyses to determine impacts on dependent predators and the ecosystem.

3.1.3.2 Annual and Decadal Variability in Abundance

Both species exhibit extremes in abundance and distribution patterns, depending on seasonal, annual, or multi-annual oceanographic conditions and regimes (e.g., Abraham et al 2004; Ainley et al 1966; Brinton 1981; 1996; Mullin and Conversi 1989; Brinton and Townsend 1991,2003; Marinovic et al. 2002). Brinton and Townsend (2003), using the CalCOFI data series, published a time series analysis of fluctuations in abundance of the major California Current euphausiid species relating to decadal oceanographic variability over the last 52 years. They studied fluctuations in densities ($\log_{10} +1$ number animals $10m^{-2}$) of dominant euphausiids in four sectors between about 26º and 38ºN (Central California, Southern California, Northern Baja California, and Central Baja California) between 1951 and 2002 (Fig. 4). In the southern and central California areas, cold-water *E. pacifica* and *T. spinifera* declined dramatically during extreme warm water events, although they appeared to be quite resilient in an ability to rebound from periods of unfavorable oceanographic conditions (Figs. 5-7). Abundances varied similarly over the five survey decades, both species having marked post-El Niño recoveries once cooler water periods returned. Periods of population depletion became increasingly frequent, though irregular, after a cool water regime shifted to a warm water regime in the 1970s. The more numerically abundant *E. pacifica* uniformly collapsed by as much as 90% during warm-water El Niño periods, but recovered to irregular but distinct bi-decadal peaks in abundance during six strong cold-water La Niña episodes, including the most recent cool-water episode from 1999 through at least spring 2002. Although both species reacted negatively to extreme El Niño conditions (slightly less so off central than southern California), abundance relationships with the Pacific Decadal Oscillation (PDO) varied, with *E. pacifica* showing a weak but significant ($P < 0.05$) negative association with the PDO, and *T. spinifera* showed no relationship. *T. spinifera* mean pre-and post-climate shift abundances off southern and Central California were similar, although this species' central and southern California numbers greatly decreased during the 1983 El Niño, and certain positive anomalies were associated with cooler years, especially during the most recent 1999-2002 cooling period. Over five decades, the more abundant *E. pacifica* approached or surpassed a high baseline density of 20,000 x $10m^{-2}$ (log 4.30) off southern California in spring once per decade (except twice in the 1980s), at intervals varying from 4 to 11 years, and these high density years (1957, 1968-69, 1980, and 1996) were followed by declines to densities of 2,000 x $10m^{-2}$ (log 3.30), and were associated with 3 of the strongest recorded El Niño events in 1957-58, 1982-83, 1997-1998, and a weaker one in 1969-70. CalCOFI net sampling off southern and central California suggests *E. pacifica* occurs at greater than 100 times *T. spinifera* amounts, although relative densities of the latter species which is larger and more efficient at avoiding nets, are likely underestimated.

3.1.3.3 Frequency Distributions of Krill Abundance off California

The above time series (Brinton and Townsend 2003) has recently been updated through spring 2004, and presented as a series of frequency distributions of abundances (Mark D. Ohman and Annie Townsend, unpub. analysis, 8/5/05, Pelagic Invertebrates Collection, Scripps Institution of Oceanography Long Term Ecological Research LTER Site).

Frequency distributions of abundances for both species for the two regions are illustrated in Figs. 8-11. Only spring nighttime collections are used, with all life history phases combined. The data are subdivided in two ways, first chronologically into three successive time periods: 1950-1976, 1977-1998, and 1999-2004, chosen because these have been hypothesized to reflect different ecosystem states in the Northeast Pacific. The second subdivision is by El Niño versus non-El Niño years. In the latter comparison, data from only the relatively strong El Niño's in mid-latitudes (1958, 1978, 1983, 1993, and 1998) are grouped together according to the springtime of the year when the Niño effect was the most pronounced. Samples were not available for Central California in 1993. All other years are grouped together as non-Niño years.

Statistical analysis by Analysis of Variance, following log (X+1) transformation of the euphausiid abundances has revealed the following:

- During El Niño springs, mean abundances of *E. pacifica* were significantly lower than in non-Niño springs in both Southern California ($P < 0.00001$) and Central California ($P < 0.01$).

- During El Niño springs, the mean abundance of *T. spinifera* was lower than in non-Niño springs in Southern California ($P < 0.0001$), but there was no significant El Niño effect in Central California ($P > 0.10$).

- For both euphausiid species and both regions of the California Current, there was significant heterogeneity of mean abundances among the 3 time periods hypothesized to represent different regimes of the California Current ($0.00001 < P < 0.05$). In all cases, mean abundances were significantly higher in the most recent time period (1999-2004) that in the two preceding time periods (1950-1976, 1977-1998).

Note that the sample sizes for some of these comparisons are small, especially in Central California in more recent years when only abundances from 2003 and 2004 are available. Therefore these comparisons should be treated with caution. Also note that data are not yet available for 2005, and there is some suggestion that oceanographic conditions were anomalous in this year.

The implications of these summaries are that both the presence of strong El Niños and the longer term "regime" state of the California Current influence expected abundances of these two species of euphausiids. Accordingly, any guidelines for euphausiid harvest should explicitly take into consideration the oceanographic conditions in the California Current.

Average numbers of *E. pacifica* (larvae, juveniles, adults) within southern and central California sectors during El Niño years were estimated to be 105 individuals 1000 m^{-3} and 566 individuals 1000 m^{-3}, respectively; while during non-El Niño years, were 1,471 individuals 1000 m^{-3} and 1,565 individuals 1000 m^{-3}, respectively. It must be noted that very large confidence limits are associated with these mean values. Approximately 7% (± 4%) of these individuals were estimated to be adults (Brinton and Townsend (2003, their Table 1). The average number of *T. spinifera* off southern and central California during El Niño years was 1.6 individuals 1000 m^{-3} and 6.7 individuals 1000 m^{-3}, respectively, while during more productive non-El Niño years, was 4.8 individuals 1000 m^{-3} and 15.7 individuals 1000 m^{-3}, respectively. *T. spinifera* densities are quite likely underestimated because adults and large juveniles of this larger species are thought to be very mobile and adept at avoiding towed nets, and thus likely to be underestimated when extrapolating abundance from net tows (Brinton 1965; and Brinton and Townsend 2003). These average densities, considered within the context of their respective distributions (Fig. 8-11) and averaged for the northern and southern California areas, provide an estimate of standing stock density and MSY expressed as a range of average densities (all life phases combined) observed during El Niño versus and non- El Niño years (1950-2004) (Table 3-2).

Table 3-2. Estimates of standing stock (D_0) and MSY ($0.5D_0$) expressed as overall average springtime densities, based on CalCOFI net sampling data (life phases combined) off central and southern California, El Niño versus non-El Ni2o years (1950-2004). Data based on Brinton and Townsend (2003) and M. Ohman and A. Townsend (8/2005, unpubl. data, Pelagic Invertebrates Collection, Scripps Institution of Oceanography LTER site). These average values do not reflect regional differences in abundances, which may be considerable, see text and Figures 6-11.

Species	Regime years	D_0 (indiv. 1000m^{-3})	0.5 D_0 (indiv.1000 m^{-3})
E. pacifica	El Niño (warm)	335	168
E. pacifica	Non-El Niño (cooler)	1,518	759
T. spinifera	El Niño (warm)	4.15	2
T. spinifera	Non-El Niño (cooler)	10.25	5

3.1.3.4 Point Estimates of Unfished Biomass (B_0) and Preliminary Estimates B_{MSY}

Because of the extreme annual, seasonal, and intra-decadal variability in abundances of these species, lack of standardized EEZ-wide surveys, and poorly known distributional differences coast wide, few attempts have been made to estimate unfished biomass of these two species, separately or collectively. The following summarizes various available estimates of krill biomass.

In 1983, a NMFS guide to underutilized fisheries resources (NMFS 1983) estimated the population of *E. pacifica* at "probably over 100 million tons in California," but no supporting data were provided. Furthermore, this number seems unusually high, considering the collective biomass of krill worldwide (~ 85 species) has been estimated at about 300 million tons (Pitcher

1995).

Field et al. (2004) estimated euphausiid mean annual standing biomass (all species, stages) in the northern California Current ecosystem (Cape Mendocino north to Cape Flattery, an area of 70,000 km^2) to be 1,890,000 tons during the early 1960s (a cool, productive regime), compared with 1,450,000 tons in the early-1990s (a warm regime characterized by low productivity). The estimates were based on a top-down estimate of consumption requirements of upper-trophic level predators, calibrated to the extent possible by existing assessments of plankton and nektonic standing stocks and productivity for the two time periods in question. These estimates are dependent on accurate estimates of predator biomass (which are lacking or need updating), and would benefit from a starting estimate of krill standing stock to adjust the model.

Brinton (1976), in his study of the population biology of *E. pacifica* off southern California, described reproduction, growth and development of cohorts, and successions in population structure and biomass over a four year period (1953-56). He estimated *E. pacifica* general densities in the southern California Bight CalCOFI study area (covering approximately 1235 km^2) to be 10-1,000 mg wet weight m^{-2} , which suggests a biomass of from 12,350 to 1.2 million kg (12-1235 mt) for the Bight study area. The minimum average density estimate of 10mg wet weight m^{-2} extrapolated to the Pacific Coast EEZ (812, 201 km^2), would amount to over 8 million kg (8122 mt), but again, such extrapolations mean little without knowledge of relative densities within the extrapolated area. Even less is known of the population biology and status of *T. spinifera*.

W. T. Peterson (pers. commun. ongoing studies, 6/6/2005 and 9/9/05, NMFS,NWFSC, Newport, Oregon) recently made some preliminary first order calculations of adult krill biomass, based on average adult densities of both *E. pacifica* and *T. spinifera* observed at two stations off Newport, Oregon, each sampled monthly since 2001. One station is located just offshore of the shelf break (300m depth) and the other just inshore of the break over the shelf (140 m depth). Overall mean density of adult *E. pacifica* was 10.0 adults m^{-3} and 3.6 adults m^{-3} at the shelf break and shelf stations, respectively, averaging 6.8 adults m^{-3} for both. These stations are sampled at night, when the majority of krill are thought to reside in the sampled upper 20 m, suggesting an area density of 136 *E. pacifica* adults under each m^{-2} (Table 3). Peterson then estimated the area of maximum krill concentration along the U.S. West Coast to be centered around the shelf break, along the length of the EEZ (7.0176×10^{10} m^2). Assuming this reflects the area occupied, and converting average adult length to weight, the observed density extrapolates to a total EEZ B_0= 1,031,584 mt after conversion from preserved to fresh weight (Table 4). Overall mean density of adult *T. spinifera* was 0.8 adults m^{-3} at both shelf break and shelf stations, and extrapolates to B_0 = 189,717 mt of EEZ fresh-weight biomass. Alternately, one could assume a broader habitat is occupied, taking into account higher densities off California that can occur further offshore of the shelf break, as indicated by CalCOFI densities charted for these two species over the past 50 years (E. Brinton, Scripps Institution of Oceanography, La Jolla, CA, 6/6/05, ms. in prep.). Accounting for a broader distribution off central and southern California, the primary area occupied by these two species may be closer to one-quarter of the EEZ area. Based on these estimates and other assumptions, two alternative rough estimates of standing stock (B_0) and B_{MSY} (0.5 B_0) are presented in Tables 3-3 and 3-4.

Table 3-3. Preliminary estimates of standing stock (B_0) and B_{MSY} (0.5 B_0) based on assumption of average adult densities of 136 m^{-2} and 16 m^{-2} for *E. pacifica* and *T. spinifera*, respectively[5], for two habitat area assumptions[6]. Uses length-biomass conversions of Miller (1966) and conversion of combined species totals to fresh wet weight from W.T. Peterson and L. Feinberg (NMFS, NWFSC, Newport Oregon).

Species	Est. avg. density[1], adults m^{-3}	Est. avg. density[1], adults m^{-2}	Est. avg. Adult weight[7] (g)	Kg Km^{-2}	Est. B_0 (mt) Habitat Assumption A[2]	Est. B_0 (mt) Habitat Assumption B[2]	0.5 B_0 (MSY) Habitat Assump. A (mt)	0.5 B_0 (MSY) Habitat Assump. B (mt)
E. pacifica	6.8	136	0.064	8700	610,531	1,766,535	305,266	883,268
T. spinifera	0.8	16	0.100	1600	112,282	324,880	56,141	162,440
Total Metric Tons Preserved Weight (Miller 1966)					722,813	2,091,415	361,407	1,045,708
Total Metric Tons Fresh Weight (Peterson et al[8])					1,221,301	3,533,759	610,651	1,766,880

[5] *E. pacifica* and *T. spinifera* avg. overall mean adult density from W. T. Peterson, NMFS,NWFSC, Newport OR, pers. comm, 9/8/05 (see text).

[6] Habitat assumption A assumes area main krill concentration 70, 176 km^2 (W. Peterson, *ibid*., see text); Assumption B assumes area of main krill concentration within inner quarter EEZ (~203,050 km^2)

[7] Avg. adult *E. pacifica* (11-25 mm TL) from A. Townsend (Scripps Inst. Oceanogr., Invertebrate Collections); avg. adult *T. spinifera* 22 mm TL from Summers (1993); all weights calculated in preserved weight (Miller 1966) and converted to fresh for combined total (see Table 4).

[8] W.T. Peterson and L. Feinberg, NMFS,NWFSC, Newport OR. Carbon weight mg x 2.22=Dry Weight (DW) assuming carbon 45% of DW ; DW x 10 = WW (90% water). Fresh biomass est. approx. 1.7 x preserved biomass.

Table 3-4. Preliminary biomass estimates under two wet weight conversion assumptions presumed to reflect preserved (Miller 1966) and fresh (W.T. Peterson, NMFS, NWFSC, pers. commun., 9/9/05) weights. Provisional MSY estimates given in 'fresh' weight to approximate fresh-landed euphausiids[4].

Species	Est. B_0 Habitat Assumption A Miller 1966 Preserved (mt)	Est. B_0 Habitat Assumption A 90% H_20 Fresh (mt)	Est. B_0 Habitat Assumption B Miller 1966 Preserved (mt)	Est. B_0 Habitat Assumption B 90% H_20 Fresh (mt)	$0.5B_0$ (*MSY*) Habitat Assump. A 90% H_20 Fresh (mt)	$0.5B_0$ (*MSY*) Habitat Assump. B 90% H_20 Fresh (mt)
E. pacifica	610,531	1,031,584	1,766,535	2,984,826	515,792	1,492,413
T. spinifera	112,282	189,717	324,880	548,933	94,859	274,467
TOTALS	722,813	1,221,301	2,091,415	3,533,759	610,651	1,766,880

The above should be used with extreme caution. Among many tentative assumptions, it does not account for ecosystem needs, habitat size differences between the two species, and possible geographic differences in the proportions and densities of adult, juvenile and larval phases. Oregon densities were sampled during 2001-2004, a favorable cool water period, when productivity was presumably high. Thus standing stock and MSY during a less favorable warm water period may be 22% and 40% of the above estimates, for *E. pacifica* and *T. spinifera* respectively, and reduced as much as 90%, judging from the range of densities observed for these species in warm versus cool water periods (Table 3; Brinton and Townsend 2003). Thus a maximum constant yield, the catch estimated to be sustainable with an acceptable level of risk at all possible future levels of biomass, might be as much as 0.9*MSY*. Stochastic population modeling is needed to better define these reference points once agreement is reached on the model parameters or parameter ranges.

Density-to-biomass conversions of the Scripps Institution of Oceanography CalCOFI time series are needed to compare with the Oregon data and adjust EEZ-wide krill biomass estimates accordingly, as appropriate. The SIO data represent an extremely valuable 50+ year record of krill population abundance and variability, data that are seldom available for most managed stocks, yet always so crucial to manage them effectively. Biomass conversions based on size distribution of krill found in the samples and applying allometric conversions of standard length to euphausiid weight still needs to be done. Presumably, working back from the size group composition of each spring collection, proportion of adults could be extracted to approximate estimates of annual adult, or adult and juvenile biomass. Preserved weight to fresh wet weights conversions are also needed, as fresh weight is most appropriate for simulating potential landings. Conversion factors by size group are better known for *E. pacifica*; less known for *T. spinifera*, although limited raw data are available from Summers (1993) on *T. spinifera* sampled off British Columbia, Canada. Work is planned at the NMFS/NWFSC Newport Lab to refine standard length to fresh wet weight conversions for both species, but results are still pending as of this writing.

Most krill sampled by nets are larvae and early juveniles, with the proportion of adults (fishable stock) varying with sampling depth, time, season, year, and geographical area. Brinton and Townsend (2003) reported that off Southern California, decadal averages (1950-2002) of the proportion of adults to the rest of the sampled population (spring nighttime samples) ranged from 1.7-13 % (mean 7; s.d =4). Off Oregon, Peterson and Feinberg[4] report about 3 times the overall average volume densities of *E. pacifica* than off California. The Ohman and Townsend data (Table 2) show an average of 1,518 individuals 1000 m^{-3} off central and southern California in cool water years. Off Oregon, during generally cooler years 2001-2004, the Peterson and Feinberg average was 3,300 individuals 1000 m^{-3}, of which 20-78% were adults. According to Brinton and Townsend (2003), area densities of *E. pacifica* along southern California CalCOFI station lines 77-93 averaged ~1,210 individuals under each square meter of sampled ocean during cool years. This would suggest an average density of roughly 85 adults m^{-2}, given a proportion of 7% adults, which compares with a density of 137 adults m^{-2} off Oregon (Table 3-3). Researchers to the north may be more consistently sampling aggregated adult individuals in shelf-break areas, whereas CalCOFI may be more consistently sampling dispersed individuals (including a greater proportion of calyptopes, furcilia and juveniles) over a wider sampling area. But to some extent, differences could be real, as net California Current surface flow is thought to transport many larvae predominately southward, and southern California Bight circulation patterns favor retainment or accumulation of larvae and juveniles there. Larger juveniles and adults, which undergo vertical migration, can take better advantage of subsurface, northerly-flowing currents during the day.

Finally, and most importantly, because of the great disparity of available estimates regarding biomass, the Council must not use the numbers presented here, especially overall 'average' estimates of biomass and provisional MSY, for specification of MSY as a basis for OY or for setting harvest guidelines or quotas.

3.1.3.5 Need for Standardizing Biomass Assessment Methodology

No coordinated coast wide survey, especially one using the recommended combination of multi-beam acoustics technology and standardized net sampling, has ever been undertaken to assess U.S. Pacific Coast krill. The assessment and measurement of krill abundance presents challenges to both existing sonar and net collecting technology and to mathematical modeling (Brinton and Townsend 1981; Pitcher 1995, Macaulay 1995 and others). Estimating krill biomass cannot be done using standard fisheries acoustics techniques, most of which are designed for larger fin fish and higher target strengths. Krill bioacoustics involves careful selection of equipment, frequencies, target identification, calibration of gear, and consideration of measurement error. Even with scrupulous calibration and accurate information on the reflective properties of individual krill, the acoustic signal can change greatly with the orientation of the animals and condition (i.e., lipid content). Nonetheless, multibeam hydroacoustic surveys appear to offer the best solution for assessing abundance and distribution over large areas.

Net sampling, which has its own set of biases, is usually combined with acoustic sampling to obtain demographic, physiological, and relative density estimates. Obtaining a representative sample can be confounded by the varying net-avoidance abilities of different krill species and life phases, abilities that change with light level, water clarity, net speed and type, and hour of day. Daily day/night vertical migration of krill from the depths to the surface can further confound the interpretation of net sampling data. When simultaneous assessment methods are used, density estimates for a given krill aggregation using direct visual counts, net sampling and hydroacoustics often vary considerably. For accurate determinations to be made, various artificial variables need to be identified and krill estimates subsequently corrected, although a standard for this kind of correction has been difficult to establish. Even in recent times, the mechanisms that affect and determine distribution and density of krill are still under discussion in most cases (Siegel 2000). While estimating density or abundance using nets is prone to bias, standardized net sampling is still very important for obtaining information on species, life phase, and their relative densities which can seldom if ever be obtained from acoustics alone.

Standardization of collecting and processing methods used in surveying California Current krill is needed so that net collection and acoustic data are comparable and can be combined for different geographic areas. This would include:

- A meeting among a team of krill bioacoustic experts to decide on and develop standardized methodology for calibrating, measuring, surveying and interpreting zooplankton acoustic backscatter for the primary purpose of estimating distribution and biomass of both species in the West Coast EEZ, and integrating with net collection data.

- Standardization of krill body length to weight/carbon conversion to wet fresh weight factors by krill species and size group is needed for better and more consistent biomass conversions.

- Expert agreement as to the spatial bounds of primary krill habitat from which density and subsequent biomass conversions can be expanded to obtain initial estimates of biomass of *E. pacifica* and *T. spinifera* standing stocks.

- Analyses (and scientific agreement) to determine which krill life phase of what species might best serve as a proxy of adult abundance in future sampling.

- Lab physiological experiments to refine estimates of productivity, growth and turn-over rates.

Modeling krill population dynamics is also subject to considerable uncertainty, especially with regard to recruitment, individual and population rates of growth, mortality, and the effects of swarming behavior. Krill recruitment and distribution within the California Current system is thought to be strongly influenced by environmental factors - the position of frontal systems, changes in intensity and direction of major currents and ocean forcing - as well as behavioral adaptations by krill themselves, including a strong tendency to aggregate in layers and in schools, swarms and patches. Vertical migration may be a mechanism by which krill effectively shuttle between multidirectional surface and subsurface currents in order to maintain their populations in highly productive core areas (and to separate developmental stages). Offshore Ekman transport via upwelling plumes, jets, and filaments is thought to contribute to large losses from the system (especially larvae), but this transport may also serve as a mechanism to genetically link a substock with another downstream, allowing for greater genetic diversity. Also, in addition to changes in the physical environment, inter-annual variability in abundance may also be affected by changes in predation pressure.

3.1.3.6 Need for Probabilistic and Ecosystem Modeling

Because of the large range of uncertainty concerning input parameters, one option would be to take a probabilistic modeling approach for determining the likelihood of safe harvest occurring. The model would estimate the probability of a highly productive krill year occurring, when a harvest of either or both species might be made with acceptably low risk of harm. Certain very cool, biologically rich oceanographic years might produce adequate surplus production (beyond predator and system needs) to support limited amounts of removals, but presumably these events (with probabilities greater than zero), would be relatively rare. The likelihood of this fishable surplus occurring could be estimated by using probability density functions for biomass, productivity, and predator demand in the following or similar model equation

$$Y = K * (r - M) - P$$

where Y is krill yield, K is krill biomass, r is the instantaneous krill growth rate, P is predation from predators, and M is natural mortality other than predator removals (R. Hewitt, NMFS, SWFSC La Jolla, CA; A. Leising, NMFS, SWFSC Pacific Grove, CA, pers. commun. 6/10/05). For each parameter, instead of a single value being specified (for the most part these values are poorly known), probability distributions would be specified that would allow for uncertainty. At the time of this writing, starting values or suggested bounds for these parameters to initiate computer runs were not yet available. Further work to run Monte Carlo simulations and obtain the probability distributions is still pending assignment of resources. Potential data sources for bounding estimates for this model include: M for *E. pacifica* (Brinton 1976); Siegel and Nicol (2000) citing Jarre-Teichmann and data from Brinton (1976) ; K - M. Ohman, E. Brinton, A. Townsend, SIO, La Jolla, CA; W.T. Peterson NMFS , NWFSC and Leah Feinberg, Oregon State University, Newport, OR; r - *E. pacifica* (Brinton 1976); Ross 1982; P - John

Field, NMFS, Santa Cruz, Ca, krill consumption rates, Don Croll, UC Santa Cruz.

Ecosystem modeling provides another potential management tool for looking at possible harvest impacts on krill and predator stocks. Field et al (2001) constructed a mass balance snapshot of ecosystem consumption and production rates in the Northeast Pacific Ecosystem; krill being an important component of the model. Additional work has been provided by J. Field (NMFS,SWFSC Santa Cruz, CA unpub. pers. commun. 6/2005) in collaboration with Robert Francis, Kerim Aydin, and Sarah Gaichas (doing similar work in the Gulf of Alaska and Bering Sea). The modeling framework uses Ecopath with Ecosim and a static, mass-balance snapshot of energy flow through the system where the production of a prey species is more or less equal to the consumption of that species by predation. Ecosim is a dynamic model that turns these properties into a series of rates that are consumption-based, and the main factors that change abundance are food availability and predation. Top-down estimates of consumption requirements for upper trophic level predators are derived and calibrated to the extent possible using existing assessments of plankton and nektonic standing stocks and productivity.

Field[9] recently described an approach using ecosystem modeling as a tool for evaluating harvest impacts. Preliminary simulations were run of a krill harvest of 300,000 mt/yr (roughly equivalent to the scale of the Pacific hake fishery) and potential impact on krill stocks and krill predators. The response was an average decline of 5% in krill stocks (with a range of roughly 3 to 14%), and an average decline of 2 to 4% (range 1 to 8%) in most commercially important predators of krill (coastal pelagics, hake and rockfish). However, certain adjustments are needed, including a better range of estimates for both predator and krill standing stocks, as well as expansion of the Eastern North Pacific Ecosystem Ecopath/Ecosim Model to include the entire West Coast EEZ. To apply a derivation of this model to estimate effects of various harvest levels off the West Coast, the following items are needed:

- More reliable data on predator abundance (a problem with existing "top-down" models is that the high demand estimated for krill predators often does not agree well with available estimates of krill biomass, and this may be due to overestimates of predator standing stocks);

- 'Bottom-up' runs (based on rough estimates of adult krill biomass from observed krill densities) are to compare with 'top down' runs; and

- Council/NMFS resources (funding, staff time of 6 mo-1 yr) to assemble additional data, run the models, and document the results.

Resulting sustainable yield estimates suitable for use in establishing quotas or total allowable catches through such modeling also would need to be used in conjunction with other management approaches, such as area closures, to ensure adequate protection of species that are dependent on or sensitive to the abundance of krill or which could be directly affected through fishery interactions.

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[9] Presentation, California Current Krill Meeting, June 6, 2005, NOAA, NMFS, Southwest Fisheries Science Center, La Jolla, CA 92037. J. Field, K. Aydin, R. Francis and S. Gaichas. "Modeling Northeast Pacific Ecosystems."

3.2 ROLE OF KRILL IN THE ECOSYSTEM OFF THE U.S. WEST COAST

3.2.1 Importance as Forage

Krill provide a critical link in oceanic food webs between phytoplankton food and upper level predators, many of which are commercially important fish species and ecologically important protected marine mammals and birds. As major California Current herbivores, they act as particularly efficient conduits of nutrients and primary production from the upwelling zone off our coast to the higher trophic levels of the broader marine ecosystem at large, as well as a buffer against the possible development of a degraded ocean system that might result from a buildup of excessive algal blooms in our coastal waters (Bakun and Weeks 2004). Some contend that the removal of apex predators such as large whales in the previous century of whaling is thought to have increased the availability of krill to other consumers in the North Pacific, but whatever 'surplus' that resulted has already been absorbed into the system. Furthermore, the dynamics of this shift are difficult to understand even in hindsight, especially against a backdrop of a host of other changes (environmental and man-induced) that have taken place in the North Pacific over the last 60 years which may have affected the energy flow dynamics within the system. Intensive, direct harvesting of such a pivotal component in the food web would undoubtedly have ecological impacts on the stability of our current trophic system, especially regional systems. Thus the possible extent of these impacts needs to be critically evaluated if large-scale fisheries are contemplated (Pitcher and Chuenpagdee 1995). Possible impacts could include:

- Negative impacts on krill-dependent predators
- Subsequent lower abundance of commercial fish and squid stocks
- Reduced food levels for federally protected marine mammals and birds
- Algal blooms of unharvested phytoplankton, whose growth in nutrient-rich upwelling systems like the California Current may be held in check largely by grazers.
- Degraded ocean conditions caused by unutilized phytoplankton biomass sinking to the sea floor, resulting in thick accumulations of deposited unoxidized organic matter with low or non-existent dissolved oxygen concentrations (Bakun and Weeks 2004) fed by nutrient rich eastern boundary current waters
- Loss of associated goods and services that depend on our regional ecosystem resources and quality.

As with other CPS, California Current krill are eaten by a number of predators, but their importance as forage may vary from predator to predator. Individual consumption rates for even the most krill-dependent species have been difficult to obtain, and almost nothing is known about the extent to which krill predators can switch to other prey.

Within the U.S. Pacific Coast EEZ, *E. pacifica* and/or *T. spinifera* are preyed upon by market squid, *Loligo opalescens*; octopus, *Octopus rubescens* ; Pacific hake, *Merluccius productus*; Pacific herring, *Clupea harengus*; spiny dogfish, *Squalus acanthias*; blue shark, *Prionace glauca*; sablefish, *Anoplopoma fimbria*; myctophids (family: Myctophidae); jack mackerel, *Trachurus symmetricus*; various juvenile and adult rockfishes, *Sebastes spp*., which prey on eggs, larvae and adult krill; various flatfishes (e.g., Pacific sanddab, *Citharichthys sordidus*, slender sole, *Lyopsetta exilis*; Pacific halibut, *Hypoglossus stenolepis*; Pacific salmon *Oncorhynchus* spp.; albacore, *Thunnus alalunga*; humpback whale, *Megaptera novaeangliae*; blue whale, *Balaenoptera musculus*; Grey whale, *Eschrichtius robustus*; and various seabirds, especially Cassin's auklets, *Ptychoramphus aleuticus*; sooty shearwater, *Puffinus griseus*; and common murre, *Uria aalge* (Phillips 1964; Alversen and Larkins 1969; Gotshall 1969; Alton and Nelson 1970; Pinkas et al. 1971; Cailliet 1972; Manuwal 1974; Tyler and Pearcy 1975; Baltz and Morejohn 1977; Jones and Geen 1977; Karpov and Cailliet 1978; Vermeer 1981; Chu 1982; Peterson et al. 1982; Livingston 1983; Lorz et al. 1983; Brodeur and Pearcy 1984; Briggs et al. 1988; Chess et al. 1988; Smith and Adams 1988; Ainley and Boekelheide 1990; Ainley et al. 1990, 1996, 2005; Tanasichuk et al. 1991, 1999; Kiekeffer 1992; Reilly et al. 1992; Laidig et al. 1995; Tanasichuk 1995a,b, 1999; Ware and McFarlane 1995; Robinson 2000; Benson et al. 2002; Hewitt and Lipsky 2002).

Hake and Cassin's auklet appear so dependent on these species for food that the distributions of euphausiids determine those for hake and auklets (Vermeer 1981; Tanasichuk 1995a,b; Ainley et al. 1996; Briggs et al. 1988). Results of diet analyses conducted by Tanasichuk et al (1991) along the southwest coast of Vancouver Island, Canada, showed that euphausiids *E. pacifica* and *T. spinifera* account for 93 and 64% of the daily ration for the dominant pelagic fish species, Pacific hake and spiny dogfish, respectively. Adult Pacific herring are known to feed exclusively on euphausiids. Additionally, *T. spinifera* has persisted as the preferred euphausiid prey of Pacific hake even though numbers of this species declined from representing 60% to 16% of the available population of adult euphausiids (Tanasichuk 1998). Krill of both species are known to comprise >50% of the diet of yellowtail rockfish, 21-50% of the diet of bocaccio and widow rockfish, 98% of the diet of hake in fall, and almost 97% of the diet of market squid (Reilly et al. 1992; Dark et al 1983; Pereyra et al 1969; Livingston 1983). Krill are also important food of salmon, preparatory to their ascending tributaries to spawn. When the rust-colored swarms appear off central California, commercial sport fishing boats, guided by flocks of feeding seabirds, seek krill swarms out in search of salmon, which feed heavily on krill from April to July, especially *T. spinifera* (Smith and Adams 1988; Adams 2001). Blue and humpback whales also converge on krill-rich upwelling centers such as off the Olympic Peninsula, Heceta Bank, around the Farallon Islands, Monterey Bay, and the Point Conception/Channel Islands area to feed on *T. spinfera* and *E. pacifica* during summer and fall, since at least the mid-1980s and early 1990s (Smith and Adams 1988; Schoenherr 1991; Fiedler et al. 1998, Croll et al. 1998).

Ecopath-Ecosim Modeling --- A model of the basic trophic components of the northern California Current ecosystem food web (Fig. 12) has been constructed by Field et al. (2001), with subsequent work by Field et al. 2005[10], using top-down biomass balance estimates of euphausiid production and consumption. Two time periods, representing different oceanographic regimes, were compared. Krill consumption by predators (and production) was estimated to be higher during the early 1960s (a cool, productive regime) when krill total annual production amounted to 207.3 g wet weight m^{-2}. It was lower during the mid-1990s (a warm regime characterized by low productivity) when krill total production amounted to 123.5 g wet weight m^{-2}.

The important role of these two species in the food web was also revealed in Jarre-Teichmann's (1995) trophic flow model of the British Columbia, Canada, shelf area. She found that krill appeared to constitute about 50% of the diet of herring (the dominant predator in that area), followed by hake, with other species being of minor importance (Table 3-5).

Table 3-5. Preliminary assessment of role of krill, *Thysanoessa spinifera* and *Euphausia pacifica* in the food web on the shelf off southern British Columbia, Canada (from Jarre-Teichmann 1995).

Fraction krill total diet (%)		Fraction total predation on krill (%)[11]
51-100	Pacific hake	11
26-50	Herring	88
	Ocean perch	<0.1
0-25	Sablefish	0.2
	Sharks	0.2
	Marine birds	<0.1
	Baleen whales	<0.1

In a more recent modeling exercise, Field et al.[12] estimated krill compose >10% of the diet by volume for 24 species groups and >50% of the diet for 9 species groups in the area between Cape Mendocino and Cape Flattery. Pacific hake and certain groundfishes (e.g., Pacific Ocean perch, canary rockfish, etc.) are particularly krill-dependent in this area. Baleen whales accounted for relatively small portion of total krill consumption in the presented model, but since runs were based on 1960s data, may not reflect current consumption of baleen whales, which are now much more abundant in EEZ and may account for up to 4% of total annual krill consumption (J. Field, NMFS, SWFSC, Santa Cruz, CA, pers. comm. 6/6/05). Model results for total annual consumption in the northern California Current by different forage assemblages are provided in Figure 13. Because the southern California Current area between Cape Mendocino and the

[10] J. Field, K. Aydin, R. Francis, and S. Gaichas. (in prep) "Modeling Northeast Pacific Ecosystems." (Presentation). California Current Krill Meeting, 6 June 2005, NOAA NMFS Southwest Fisheries Science Center, La Jolla, CA 92037

[11] initial estimates as of original publication, 1995.

[12] Field, J., K. Aydin, R. Francis, and S. Gaichas. Modeling Northeast Pacific Ecosystems. Presentation California Current Krill Meeting, June 6,2005, La Jolla, CA)

Mexican border differs considerably to the northern area, this model or models need to be expanded for the entire EEZ, or constructed similarly for the area south of Cape Mendocino to the Mexico border.

One problem with existing top-down models is that the high demand estimated for krill predators often does not agree well with available estimates of krill biomass, and it is unclear as to whether this is due to an overestimate of predator biomass or underestimate of krill biomass or both. Better predator biomass estimates are needed.

3.2.2. Assessing Predator Requirements

In addition to Field et al's (2001, 2005) top-down estimates of consumption of major krill consumers mentioned above, Croll and Kudela (In press) recently compiled allometric estimates of daily metabolic have recently assessed current and pre-exploitation prey biomass requirements (kg individual^{-1} day^{-1}) for North Pacific large whale populations, obtaining a mean of estimates from five different prey requirement models. The mean estimates for the two major krill consumers, the blue and humpback whale, were 1120 (S.D.= 359, CV=0.32) and 532 kg (S.D.= 123, CV=0.23) individual^{-1} day^{-1}, respectively.

3.2.3 Krill Predator Harvest and Effects

Selective fishing pressure on krill predators may also have a dramatic but not easily predictable effect on the ecosystem. The Bering Sea ecosystem was thought to have been drastically changed by whaling, sealing and fishing efforts over the last 40 years (D. Bowen cited in Head (1997). Between the 1950s and 1970s, some 300,000 sperm and baleen whales were taken by whalers, together with large numbers of fur seals. Subsequently Pacific Ocean perch were fished to negligible levels, followed by herring and saith. When the "natural" fish species had gone, the area was taken over by pollock, and its levels increased from 2 million metric tons in the 70s to 16 million metric tons in the 80s, when it was 80% of the fish biomass. During this period the Stellar sea lion and harbor seal populations declined, perhaps in response to decreases in the abundance of capelin and sand lance, the latter being forage for the pollock. The suggestion is that the removal of the baleen whales may have led to an increase in zooplankton (and krill) levels, which in turn may have led to the proliferation of species that competed for forage with the sea lions and harbor seals.

3.2.4 Other Ecosystem Roles

In addition to the considerable importance as prey, largely unknown are the ecosystem needs for the huge detritus and effluvia contributed by krill populations. Krill casts, which contain nitrogen, carbon, Vitamin A and other materials, as well as associated chitinoclastic bacteria, form an important food source for other organisms (Ackman et al. 1970). Molting once every five days, krill can produce weight equal to seven times the dry weight produced in one year. Krill are also important contributors to the Vitamin A cycle in the sea, and can synthesize and store Vitamin A in high concentrations in their bodies, especially in the eyes. As major consumers of phytoplankton and other microplankton, krill also remove and recycle vast quantities of primary production from coastal waters. To what extent this grazing helps to hold algal and dinoflagellate blooms in check and aid in maintaining stability and health of the system is not known. This function may become increasingly important as harmful blooms increase along our coast with the increased fertilization from urban run-off. Euphausiids are also thought to influence carbon flux and food availability to pelagic and benthic organisms in the sea by physically fragmenting sinking organic particles called "marine snow," with the collective rapid beating of their appendages. Marine snow can comprise as much as 60% of water column particulate organic carbon, which would otherwise sink out of reach of the upper ocean where light is available for photosynthesis, and before bacteria could break down the organic matter into dissolved nutrients to sustain phytoplankton. The krill in their massive swarm numbers, especially in upwelling zones such as off the U.S. West Coast, are thus able to fragment much larger organic particles into smaller particles (which sink more slowly), a process thought to increase the residence time of carbon in the upper water column, enhancing attached bacterial production and helping to enrich the upper ocean zone (Goldthwait et al 2004).

3.3 EXISTING AND POTENTIAL FOR EXPANSION OF KRILL FISHERIES

3.3.1 Existing Krill Fisheries: Global Perspective

There are at least six commercial fisheries that now harvest (or have harvested in the recent past) six different species of euphausiid. These are the fisheries for Antarctic krill (*E. superba*) fished in the Antarctic; for North Pacific krill (*E. pacifica*) fished off Japan and off western Canada; for E. nana, fished off the coast of Japan; for Thysanoessa inermis fished off the coast of Japan and off eastern Canada; and for *T. raschii* and *Meganyctiphanes norvegica*, which have been experimentally harvested off eastern Canada (Nicol and Endo 1999). The largest quantities of krill are harvested off Antarctica and Japan. The current world catch of all species of krill is over 150, 000 tons per annum, although few fisheries are being exploited to their maximum theoretical potential. The size of the world krill harvest is currently limited by lack of demand, although some fisheries are being deliberately managed at low levels because of ecological concerns or to control prices (Nicol and Endo 1999).

3.3.2 Krill Product Uses and Markets

The products of the krill industry have been variously reviewed by Budzinski et al (1985), Eddie (1977), Everson (1977), Grantham (1977), Suzuki (1981), Suzuki and Shibata (1990), Nicol and Endo (1997, 1999), and most recently by Nicol et al. (2000) and Nicol and Foster (2003). Krill products are mostly used for the aquaculture and sport fishing bait market but considerable effort has also been put into developing products for human consumption, particularly from Antarctic krill. Krill products are also currently being promoted for pharmaceutical, industrial and the so-called 'nutraceutical' industry as a nutritional/health supplement.

The Japanese Antarctic krill fishery, which takes most of the current catch, produces four types of product: Fresh frozen (34%), boiled frozen (11%), peeled krill meat (23%) and meal (32%). Yields in the manufacture of these products are 80-90% for fresh frozen and boiled frozen, 8-17% for peeled krill and 10-15% for meal in 1995 (T. Ichi, cited by Nicol and Endo 1997).

3.3.2.1 Human Consumption

The use of krill for human consumption has been reviewed and the nutritional value of krill has been assessed (Suzuki and Shibata 1990; Nicol and Endo 1997). The Japanese Antarctic fishery produced boiled, frozen krill and peeled tail meat for human consumption and 43% of the catch is used for this market. All of the peeled tail meat is now frozen in blocks on board. Information on other nations' Antarctic krill fisheries is not generally available. A small amount of *E. pacifica* caught off Japan is also used for human consumption. Although much effort in the past has gone into producing krill products for human consumption, there have been few recent developments in this area. (Nicol and Endo 1997).

3.3.2.2 Bait for Recreational Fisheries.

Approximately 70 % of the fresh frozen portion of the Japanese Antarctic krill catch is sold whole as bait, and 10% of this is used as chum for sport fishing. Nicol and Endo (1997) citing Kuroda and Kotani, report there is little competition between Antarctic krill, *E. superba*, and *E. pacifica* used for sport fishing, because the smaller *E. pacifica* is used as chum (about 50% of the total catch), whereas the larger *E. superba* is mostly used as bait.

3.3.2.3 Aquarium food.

A small quantity of Antarctic krill is freeze dried for the home aquarium market. An estimated 50% of the catch of *E. pacifica* from the British Columbia fishery is used as aquarium food (Nicol and Endo 1997).

3.3.2.4 Aquaculture

Currently most krill caught in all commercial fisheries is used for aquaculture feed. For Antarctic krill, 34% of the Japanese catch is fresh frozen, of which 20% is used for aquaculture and 32% is used to produce meal which is used in fish culture; 50% of the Japanese *E. pacifica* catch and much of the Canadian catch of this species is used as an ingredient in feed for fish culture (Nicol and Endo 1997). Krill provide a nutritious diet and can be used successfully as a source of protein, energy and flesh pigmenting carotenoids. Carotenoids are found in krill at around 30 ug g^{-1} and can deteriorate rapidly during storage if not refrigerated below 0º C . The Japanese *E. pacifica* catch destined for aquaculture is used in feed to add reddish color to the skin and meat of fishes such as bream, salmon, trout, yellowtail and others, since *E. pacifica* contains large amounts of carotenoid pigments, especially astaxanthin. Extracts from Antarctic krill have also been used as pigmenting agents for yellowtail (*Seriola quinqueradiata*) and coho salmon (*Oncorhynchus kisutch*). Japanese people love red color as an indication of good luck, and they often choose red fish and shellfish for celebrations and holidays. Krill amino acids are thought to have growth-promoting properties (Storbakken 1988) and krill are known to stimulate both feeding and growth in some fish (Shimizu et al 1990) . Diets supplemented with krill meal stimulated feeding behavior in sea bream (Pagurus major), an effect probably due to the presence of the amino acids proline, glycine and glucosamine. The growth promoting factors seem to be steroids located in the cephalothorax region, thus are available in non-muscle meal. The use of *E. pacifica* as a food source has also contributed to increased disease resistance in hatchery reared salmon smolts (Haig-Brown 1994). This has been attributed to the early development of the immune system when using krill as a food source. Krill-fed salmon were also found to have a superior taste and did not significantly accumulate fluoride from the krill exoskeletons in their flesh. krill products are also thought to be a good source of minerals for aquatic animals. Rainbow trout feeds contain krill as the principal protein source has significantly less dorsal fin erosion than did those fed the fish meal based control food (Nicol at al 2000).

3.3.2.5 Autoproteolytic precipitates

Krill precipitate is produced using autoproteolysis, making use of krill's high level of proteolytic enzymes to produce a high yield (80% protein recovery) krill concentrate or precipitate. The final product has a very low fluoride content (< 29 mg F kg^{-1}), a protein content of 18-22%, fat less than 7% and a high level of carotenoid pigments. This product is used mainly as a colorant and flavourant additive to fish feeds and other products for human consumption.

3.3.2.6 Biochemical use/ food additive/ health supplement

A freeze-dried krill concentrate is prepared from peeled tail meat and marketed as a food additive and health food supplement. It is promoted as having a major revitalizing effect on the body, with a high n-3 fatty acid content, moderate caloric content, high nutritional value, and easy to digest. It is advertised by the manufacturers to be an important source of antioxidants and minerals required to prevent dental cavities and osteoporosis and have anti-aging properties. It is promoted as being 100% natural and free of any side effects, even when taken at higher doses, and low in contaminants such as PCBs. Krill oil, sold in gel caps, is also sold and marketed as a clean, pure source of special antioxidants not found in other products and having a higher content of Omega-3 fatty acids than other fish oils. It purportedly maintains healthy heart, joints and even regulates symptoms of premenstral syndrome (Aquasource Products 2005).

It is anticipated that this market, while probably expanding, requires relatively low volumes of high quality krill product compared to the aquaculture feed and supplement market (S. Nicol, Australian Antarctic Division, Tasmania, Australia, pers. commun, 21 Mar 2005, La Jolla, CA.) In addition, a Chilean company recently announced (Aquafeed.com, 5/17/05) that it has launched a patent for assisting in calcuim intake and depostion on bones for helping osteoporosis prevention and cure through a combination of krill and salmon byproducts with other specific ingredients. It is not known if this product has in fact cleared all regulatory hurdles for sale. The claim is that this new dietary nutraceutical organic supplement is a rich source of calcium and fluorine. It would be available in a pate form for direct human consumption. As with other additives, it is unlikely that this product would etablish a very large market for krill or krill products in the near term.

3.3.3 Potential for Market Expansion

Nicol and Foster (2003) reviewed recent trends in the fishery for Antarctic krill, and also speculated on possible expansion of krill fisheries worldwide, examining records of krill patents lodged by year and country of origin. Fisheries for krill have shown much potential for expansion, yet have not reached anticipated levels. The slow development of fishing for krill over the years has allowed environmental considerations to be taken into account when developing management strategies. The fishery for Antarctic krill has been relatively stable for a decade at 100,000 tons per year; the Japanese coastal krill fisheries are probably near capacity at ~ 70,000 tonnes/ year (Endo 2000); and the British Columbia fishery has been essentially capped at 500 tons. Nonetheless, commercial focus on products derived from krill has continued to develop, with interest in aquaculture, pharmaceutical and medical products apparently overtaking those for human consumption. Following a recent trend, most new growth in terms of volume is likely to come from the aquaculture industry, which has been increasingly pursuing natural food additive sources to enhance flesh color as well as promote rapid and healthy growth of cultured fish and invertebrates (Nicol 1989). Secondarily, krill oils are likely to be the subject of expanding markets in the nutraceutical, cosmetic and pharmaceutical industries, which focus on a high quality, high value, and relatively low volume product. Nicol and Foster (2003) propose that only in the Antarctic does there appear to be great scope for expansion of a krill fishery, considering that environmental and political considerations in recent years have prevented development or expansion of most Northern Hemisphere krill stocks (off Alaska, U.S. Pacific coast state waters, the east Coast of Canada). Even so, with the growth of aquaculture and increasing demand for new and improved aquaculture feeds and supplements, it is reasonable to assume that demand for krill sources closer to aquaculture operations within the tri-state area may continue to persist.

3.4 EXISTING STATE MANAGEMENT OF KRILL FISHERIES ALONG THE U.S. WEST COAST

3.4.1 California

California imposed a ban on landing and krill fishing in state waters in 2000.

3.4.2 Oregon

Oregon imposed a ban on landing of krill and krill fishing in state waters in 2003. Fishing beyond state waters may not be feasible because of rough ocean fishing conditions which constrain krill fishing operations.

3.4.3 Washington

Currently, no krill fishery takes place in Washington, and there has been no interest expressed in harvesting krill in state waters. Washington law prohibits the landing and sale of commercial quantities of krill, which is designated an unclassified species with very limited take options. Given recent discussions relating to krill harvest in other Pacific coast areas, the state may consider additional modifications that might make future commercial harvest of krill in Washington even more unlikely.

3.5 KRILL FISHERIES AND MANAGEMENT IN OTHER AREAS—LESSONS LEARNED

Krill was little known until the middle of the nineteenth century, and then mainly as a food item found in the stomachs of whales. The first krill fishing was likely been done by Mediterranean fishermen who harvested daytime surface swarms of krill for use as bait in the mid to late 1800s. Krill was promoted as a food alternative during World War II by the British (Haig-Brown 1994), and in the late 1960s and early 1970s, commercial fishing began in Antarctic waters and in the North Pacific off Japan and British Columbia, Canada. Exploratory and scientific permit fishing also began in the early 1970s off eastern Canada in the Gulf of St. Lawrence.

The following is a brief description of each species:

Euphausia superba (Antarctic krill) is one of the bigger species, growing to a maximum size of 6.5cm and weighing up to 2g. Antarctic krill grow to their maximum size over a period of approximately 3-5 years. The fishery concentrates on the larger adults in the 40-65mm size range. Antarctic krill occurs throughout most of the waters south of the Antarctic Convergence but is most abundant closer to the Antarctic continent and around some of the Antarctic and sub Antarctic islands. It has been commercially harvested all around the Antarctic although the current fishery concentrates in the South Atlantic with summer fisheries along the Antarctic Peninsula and winter fisheries around South Georgia Island (Miller 1991).

E. pacifica is commercially harvested off the coast of Japan (Odate 1979; Odate 1991) and off the coast of British Columbia, Canada (Haig-Brown 1994).

Euphausia nana, closely related to *E. pacifica*, is only found in the waters off southern Japan and in the East China Sea. *E. nana* reaches a total length of 12mm and is harvested commercially off the Japanese coast (Hirota and Kohno 1992).

Thysanoessa inermis is found in the North Pacific and in the North Atlantic, particularly in the colder waters but does not breed north of 65-70°N. It reaches a length of 30mm. It has been commercially harvested in the Japanese coastal zone (Kotori 1994) and in the Gulf of St. Lawrence, Canada (Runge and Joly 1995).

Thysanoessa raschii is found in the North Pacific and in the North Atlantic, particularly in the colder waters and in Arctic regions. It was commercially harvested on an experimental basis in the Gulf of St. Lawrence, Canada (Runge and Joly 1995). It reaches a length of 25mm.

Meganyctiphanes norvegica is found over a large climatic range, from the subarctic in the waters surrounding Greenland, Iceland and Norway to the warmer waters of Cape Hatteras in the West and the Mediterranean in the East (Mauchline 1969). It has been commercially harvested in the Gulf of St. Lawrence and there was a proposal to fish for this species on the Scotian Shelf, Eastern Canada in 1995 (Runge and Joly 1995). Small scale harvesting of *M. norvegica* has also occurred in the Mediterranean (Fisher et al. 1953). *M. norvegica* is a medium-sized krill reaching a total length of over 40mm.

3.5.1 Antarctic Krill (*Euphausia superba)* and the CCAMLR Management Approach

Nicol (1995), Nicol and Endo (1997), Kock (2000) and others have summarized the development of the Antarctic krill fishing industry. Krill fishing on a commercial scale started in the 1972/73 season. Results of scientific exploration revealed the size of the krill resource, and interest grew in exploiting the so-called "surplus" krill left remaining after removal of their chief predators— baleen whales— by commercial exploitation. Another important factor in the development of the fishery was the declaration of 2000 mile Exclusive Economic Zones in the late 1970s, which prompted distant water fishing nations to turn to international waters for new fishing grounds. The fishery soon concentrated in localized areas in the Atlantic Ocean, with the main fishing grounds to the east of South Georgia, around the South Orkney Islands and off the north coast of the South Shetland Islands. After peaking at more than 500,000 t in 1981/82, catches dropped substantially because of problems in processing krill and more effort being diverted to finfishing. From 1986/87 to 1990/91, annual catches stabilized at between 350 000 and 400 000 t, which was about 13% of the world catch of crustaceans. When economic factors forced the Russian fleet to stop fishing, catches declined dramatically after 1991/92 to about 80 000 tonnes per annum. Since then, Chile has also stopped fishing for krill. The current krill catch is in the range of 90,000–100,000 t per year. The South Orkney Islands and the Antarctic Peninsula region are usually fished in summer, while the South Georgia fishing grounds are mainly fished in winter, when the more southerly grounds are covered by ice. The amount of krill harvested to date totals slightly more than 5.74 million t, of which the former Soviet Union and two of its succeeding states (Russia and Ukraine) took almost 84% and Japan 14.5%. More than 90% of the catch was from the western part of the Atlantic Ocean area.

In the first 10 years of krill fishing, catches, in particular those made by vessels from countries of the former Soviet Union, were largely used for animal feed. In the mid-1980s, difficulties in processing krill were overcome. Today, most krill is processed for aquaculture feed, bait and human consumption. Its use in aquaculture and its potential in biochemical products is increasing interest in krill fisheries.

CCAMLR (Commission for the Conservation for the Conservation of Antarctic Marine Living Resources) manages the Antarctic krill fishery; the system is considered the most sophisticated and comprehensive of krill management schemes. It addresses CCAMLR's Article II objectives to 1) manage fisheries so harvested stocks maintain stable recruitment, 2) maintain ecological links between harvested and dependent species, and 3) prevent changes that cannot be reversed within 20-30 years.

In managing krill, it was concluded that an MSY model was inappropriate to set adequate catch levels of krill, since it assumes stability in natural systems, considers the exploited stock as coming from a single species, and relies on a predictable relationship between stock size/growth and fishing effort. Furthermore, MSY does not account for interactions between exploited stocks and other species, which is crucial to address the CCAMLR objectives.

In 1990, CCAMLR's Scientific Committee identified general operational management principles for setting catch limits for krill that were subsequently endorsed by the Commission. These were to 1) aim at keeping krill biomass at a level higher than would be the case for single-species harvesting considerations, and, in so doing, to ensure sufficient escapement of krill to meet the reasonable requirements of predators; 2) focus on the lowest biomass that might occur over a future period, rather on the average biomass at the end of the period, as might be the case with a single-species context; and 3) ensure that any reduction of food to predators which may result from krill harvesting does not disproportionately affect land-breeding predators with restricted foraging ranges as compared to predators in pelagic habitats (CCAMLR 2004).

CCAMLR has approached krill management using a model that enables calculation of a precautionary catch limit, and a program to monitor the health of dependent species. The approach uses three primary elements described below:

- The Krill Yield Model--A single species model is used to assess the potential yield available for the krill stock that has the lowest risk to the stock itself (Agnew 1997). Based on the approach of Beddington and Cooke (1983), the model projects the dynamics of a krill population over a period of time with random recruitment to establish the probability distribution of risk of population decline for a number of fixed harvesting strategies. The approach calculates the proportional value of γ in the formula

  $$\text{Yield} = \gamma B_0 \quad 1$$

  where B_0 is the estimated pre-exploitation biomass of the krill population. The modeling exercise can proceed in the absence of an estimate of B_0 , since this is taken to be 1.0, and will yield a value of γ. But to be applied in management so that a precautionary total allowable catch (TAC) can be set, an estimate of B_0 is required, which has been estimated from acoustic surveys, the most recent being carried out in 2000. Subsequent biomass assessments are not needed on a regular basis, because the model uses the pre-exploitation biomass estimate, plus various parameters (variation in population age structure, recruitment, mortality, etc), which can be refined over time. The higher level of uncertainty in any parameter, the more conservative the estimate of TAC.

- Decision rule requirements--These involve straightforward decision rules for defining acceptable long-term catch from the yield model calculations.

  - Rule 1: Choose $\gamma 1$ where probability of spawning stock biomass dropping below 20% of its median level in the absence of fishing, over a 20 year simulation, is <10%.

  - Rule 2: Choose $\gamma 2$ where the median spawning stock biomass after 20 years is 75% of its median level in the absence of fishing.

  - Rule 3: Select the lower of $\gamma 1$ and $\gamma 2$ for the calculation of krill yield.

- Ecosystem monitoring--CCAMLR's Ecosystem Monitoring Program (CEMP) monitors predator species, and uses the information to differentiate between changes due to krill harvest, and due to environmental change. This monitoring provides ongoing feedback on trends in the ecosystem, so that management adjustments can be made in light of changes and needs of dependent species.

The yield model and its decision rules offer a method of setting precautionary catch limits which consider both the harvested species and its predators, when there is some uncertainty in the assessment of the stock. The system was developed in consultation with Convention members and arrived at by consensus. In general, the higher the level of uncertainty in any parameter, the more conservative will be the estimate of Total Allowable Catch (TAC). One of its advantages is that it sets a fixed catch for a 20-year period. Agnew (1997) reports that the choice of limits, especially the limit of 75% of unexploited biomass of Rule 2, is somewhat arbitrary, but Rule 1 limits are becoming accepted internationally as appropriate for a precautionary approach. And Rule 2 limits, along with the continued ecosystem monitoring, are considered by CCAMLR to be a pragmatic interim solution to the problem of estimating the escapement from the fishery required to maintain predator populations where data are lacking.

In addition to the model and decision rules, catch "triggers" have been established to enable managers to respond quickly to any rapid increases in the fishery, especially in areas that support dependent species. Currently, Antarctic krill catch limits amount to about 9% of the estimated biomass in two major statistical areas. These two areas, which together cover just over 51% of the CCAMLR Area, consist of the Atlantic sector of the Southern Ocean (Area 48 and its subareas,) and in the South East Indian Ocean sector (area 58.4.1). In Atlantic Area 48, the overall precautionary catch limit has been set at 4 million tons; subdivided into regional limits of 0.832 million, 1.104 million, 1.056 million and 1.08 million tons for South Sandwich Islands (48.4), South Georgia (48.3), South Orkneys (48.2), and Antarctic Peninsula (48.1) subareas, respectively. These subareas, especially the Antarctic Peninsula and South Georgia, include large colonies and breeding sites of land-based krill predators, so that catch limits are also augmented by the provision that if the total catch in Area 48 in any fishing season exceeds a "trigger" level of 620,000 t (catches over the past decade have been relatively stable at around 100, 000 t^{-yr}), the precautionary limits could be subdivided into even smaller management units following the advice from the Scientific Committee. This would allow the Commission to partition the overall limit into even smaller areas, for more effective management and protection of predator populations, in the event a rapid expansion of the fishery should occur. In the South

Indian Ocean statistical area, the overall limit is set at 440,000 subdivided into 277,000 t west of 115ºE, and 163 000 t east of 115ºE, respectively.

3.5.2 Japan

The Japanese commercial fishery, which began in the mid 1940s , concentrates on highly visible daytime surface swarms in coastal waters. It operates without quotas to fulfill the needs of local aquiculture operations, and amounts to some 100,000 tons (Nicol 1997). There is external regulation by the number of licenses, the size of boats, and the duration of fishing effort and self-regulation, to keep the prices up. Of the three species commercially exploited in Japanese waters (*E. pacifica*, *E. nana,* and *T. inermis*), the catch of "Isada," or *E. pacifica*, is much larger than the other two and more important. The average annual catch of *E. pacifica* was 60,427 t in the late 1980s and 1990s with a value of 1.5 to 3.6 billion yen. It is especially abundant in Sanriku waters, the sea area off northeastern Japan, where many endemic and migrant predators including pelagic and demersal fishes, marine mammals, seabirds and benthic organisms also depend on this species for food (Nicol and Endo 1997). Early in the fishery, a sand lance dip net fishing method (using a bow-mounted trawl with a small mesh size) was used when fishing conditions for sand lance were poor. In the late 1960s, increasing demand for food for sea bream culture and sportfishing bait caused the fishery to expand to the northern and southern coasts of Miyagi Prefecture, and in 1972 expanded to Ibaraki Prefecture and to the south. Thus the fishery which began in Miyagi Prefecture developed into an important fishery in the Sanriku and Joban coastal waters.

The fishery requires a license from a prefectural governor. Small boats (less than 20 t) are predominantly engaged in the fishery. One or two-boat seines are used in all prefectures except Miyagi, where both one-boat seines and bow-mounted trawls have been used. A bow-mounted trawl can only catch swarms with 8m of the surface, while the seines can catch subsurface swarms as deep as 150 m by using echo sounders to detect swarms. The fishing grounds are over the continental shelf (< 200m) within 10-20 m from shore.

The total annual catch of *E. pacifica* has increased steadily over the last 20 years, exceeding 40,000 t in 1978, 80,000t in 1987, and 100, 000 t in 1992. This increase followed the introduction of plastic containers in about 1975 and by the use of fish pumps in the 1980s. In 1993 the total catch decreased to 60,881 t, when catch regulations were imposed in certain prefectures to obviate price declines (Nicol and Endo 1997).

For fishermen, the most important factor related to the fishery is the ability to predict the length of the fishing season and the area of occurrence of the fishery. The fishing ground is formed near the front between the coastal branch of the Oyashio Current and the coastal waters with optimal surface water temperatures of 7-9° C. Various researchers have classified various types of oceanographic conditions that influence optimum catches in the fishery.

E. pacifica fishery regulations are set separately for each prefecture. The license of the prefecture governor decides the fishing period, the time limit to come back to port, operation time, fishing area, boat size and other factors. Other regulations include total catch limit per season, and maximum number of plastic storage containers per boat per day. Fishermen regulate

catches in order to keep the price high, collaborating with their counterparts in adjacent prefectures.

Thysanoessa inermis and *Euphausia nana* are two other species harvested in Japanese waters. *T. inermis* has been fished since the early 1970s along the western coats of Hokkaido. Reproductive surface swarms of this species are fished during the day, usually from early March to early April. A spoon net, with a 1-m diameter and 3-4 m handle is used to catch the swarms. The price varies from 75 to more than 3,000 yen per kg. The yearly catch varies from several tons to 200 t. The neritic species *E. nana* has been commercially fished also since the 1970s in Uwajima Bay, Ehime Prefecture, Shikoku. The yearly catch varies from 2,000 to 5,000 t from 1981-1991, and two fishing methods are used. One is nighttime purse seining from March through July using a netting boat, a transport boat, and up to three light boats equipped with attracting lamps. The other method is a daytime seining operation during spring through early summer that uses two netting vessels, a boat with hydroacoustics to locate swarms, and a transport vessel. Landed *E. nana* are used as feed for red sea bream and the price is about 50 yen per kg (Nicol and Endo 1997).

3.5.3 British Columbia, Canada

The only krill fishery along the U.S.-Canada Pacific Coast exists in the Strait of Georgia, British Columbia (Fulton and Le Brasseur 1984; Nicol and Endo 1997). *E. pacifica* is typically one of the dominant species, accounting for over 70% of the euphausiid biomass where the commercial fishery occurs (Nicol and Endo 1997). Fishers deploy fine mesh plankton trawl nets that are towed several meters below the surface after dusk. The catch is either frozen at sea on board the catcher vessel, or placed in totes and iced for transport to a land-based facility for further processing and freezing. Most of the product is used as a feed supplement in fish food for the fin fish aquaculture industry and for aquarium needs. There are also limited and developing markets for uses of euphausiids as a human food product in Canada and abroad. The Department of Fisheries and Oceans Canada conducts biomass surveys annually in the Strait of Georgia in the area of greatest harvest to monitor abundance and to ensure that the impact of the commercial harvest is negligible.

Two types of vessels participate: smaller freezer vessels whose catches are limited due to freezing capacity (5-6 t of krill a day) and larger vessels that land large quantities of krill for onshore processing and freezing (Nicol and Endo 1997). The catch must be frozen within 24 hrs to avoid a significant deterioration of product quality. The fishing season can be as short as 20 days (actual fishing days) and individual vessels may land as little as 32 t in a season. Nets used have mouth areas of around 80 m^2, the trawl mouth is kept open by means of a beam and is buoyed to keep it from flipping when the ship turns. There are weights on the footline to maintain the net's shape. Fishing is carried out close to the surface - often less than 20 m deep and on moonless nights when the krill rise to the surface forming layers less than 10 m in vertical extent. The krill are located by echosounders. The larger vessels use a seine net and are usually out-of-season salmon fishing boats with no onboard freezing capacity. The presence of these vessels in the fishery is usually dependent on the success of the salmon fishery. If there has been a bad salmon catch, then krill are fished to increase revenues

Information on the history of the British Columbia fishery has been summarized by Nicol and Endo (1997). It began on an experimental basis in 1972, confined to the Strait of Georgia and the east coast of Vancouver Island. Quotas were established in 1976 in response to concerns about harvesting an important forage species upon which salmon and other commercially important finfish depend. The annual catch was set at 500 t with an open season from November to March to minimize the incidental catch of larval and juvenile fish and shrimp. This quota was reportedly derived from an estimate of the annual consumption of euphausiids by all predator species in the Strait of Georgia, and is 3% of this estimate. In 1983, participation in this fishery was restricted to those individuals who had applied for, and held, a certain category license, which was not subject to limited entry. Until 1985, annual landings were less than 200 t, with fishing concentrated initially in Saanich Inlet, then Howe Sound and most recently in Jervis Inlet. Due to continued concentration of fishing effort in Jervis Inlet rather than the adjacent waters in the Strait of Georgia, separate inlet quotas were introduced in 1989. The annual TAC increased to 785 t; 500 t for the Strait of Georgia and 20 to 75 t for each of the major mainland inlets.

In 1990, due to concerns of local stock overfishing, the overall annual quota was reduced again to 500 t; 285 t for the mainland inlets and 215 t for the Strait of Georgia. That year, 56 licenses were issued, of which 17 reported landings of 530 t for a landed value of Can $415,000. This was the first year since the beginning of this fishery that the annual quota had been reached. Only 53 t of euphausiids were reported landed in 1993 with a total landed value of Can $41,000. This decline in landings from 381 t reported in 1992 was a function of market conditions rather than any decline in krill stocks. Preliminary landings of euphausiids reported for 1994 were in excess of 300 t, with a value of Can$ 259,000, as markets stabilized somewhat from the previous year. The number of licenses issued for this fishery increased annually from 7 in 1983 to 56 in 1990, then declined to 45 in 1991. In 1993, licenses were limited to 25 vessels upon the advice of industry and because the annual quota was being taken by the current fleet. Only one vessel during 1993 and three vessels during 1994 reported euphausiid landings. Bycatch consists of larval and juvenile fish and myctophids (Lee 1995).

In late 1995, a workshop was held at the University of British Columbia on "Harvesting Krill: Ecological Impact, Assessment, Products and Markets " (Pitcher and Chuenpagdee 1995). The workshop dealt in some detail with the British Columbia euphausiid fishery, the importance of euphausiids to the coastal marine ecosystem, and improvements in assessments methods of the potential yield of British Columbia krill stocks. The Regional Executive Committee of the Canadian Department of Fisheries and Oceans has stated that as a matter of policy the region is not prepared to support additional developmental fisheries on forage species such as krill, and the 500 t quota for the Strait of Georgia and mainland inlets is expected to remain fixed for the foreseeable future (Morrison 1995).

3.5.4. Atlantic Coast of Canada (Gulf of St. Lawrence Fishery and Scotian Shelf Permit Request)

Exploratory scientific fishing was started on the Atlantic coast of Canada in 1972 to locate large harvestable concentrations of krill(*Meganyctiphanes norvegica, Thysanoessa raschii* and *T. inermis*) in the Gulf of St. Lawrence (Nicol and Endo 1997). The estimated biomass of krill in two areas of the Gulf where the krill were most concentrated was 75,000 t and an estimated catch rate for trawlers fishing a 100 m^2 mouth opening trawl was estimated to be 379 kg h^{-1} based on a biomass estimate of 1 g m^{-3}. The estimated potential for exploitation of all three krill species in the Gulf, based on an exploitation rate of 50% of the biomass, was 37 500 t estimated in 1975 to be worth Can$3.75 million (Sameoto 1975).

The first experimental, pre-commercial fishery to harvest krill was permitted in the Gulf of St. Lawrence in 1991. New acoustic studies determine the abundance of krill in the Gulf ranged from 400 000t to 1 million t (Nicol and Endo 1997). It was determined that the allowable catch level of 300t would have a negligible effect on the krill populations and on the populations of natural predators on krill, but there was concern about the possible impacts of taking the whole of the catch from a restricted area, the effect on the populations of whales that feed in that area, and concern over the incidental bycatch, particularly of juvenile fishes. The Gulf fishery produced frozen krill and freeze dried krill for ornamental fishes and for public aquaria and freeze dried krill as an ingredient in salmon feed and as a flavourant for food for human consumption. But interest in this fishery declined and catches were quite low, and the fishery became inactive after 1998.

Another permit request was received in 1995 to fish 1,000t of krill (primarily *M. norvegica)* on the Scotian Shelf and Gulf of Maine, off Nova Scotia, Canada. The krill was to be used to produce a product to coat fish pellets to be fed to young salmon in fish farming. Concerns were voiced about effects on krill-dependent fish species of the region that have a major portion of krill in their diet. There was also concern over the significant by-catch of larval and juvenile forms of other commercial species that could be taken with the krill catch and possible interactions with populations of the endangered right whale. In 1998, Canada's Minister of Fisheries and Oceans announced that he would not consider authorizing a fishery for krill (or any other untapped forage species) on the Atlantic Coast of Canada until more information was known about the effects on the food chain for harvesting forage species, and before an ecosystem approach and plan was developed.

3.6 POTENTIAL BYCATCH ISSUES

As krill fisheries have developed in places such as the Antarctic and Canadian waters, in addition to concern about krill-dependent predators, concern has been expressed over bycatch of non-target fish and invertebrates, particularly larval and juvenile fishes (Everson et al. 1991; Moreno 1995, Runge and Joly 1995). Nonetheless, it is still unclear whether fish and/or invertebrate bycatch is a major or minor problem to the stocks involved, and this will have to be addressed before any fishery is considered. Nicol and Endo (1997) report that bycatch (particularly that of larval fishes) has been a significant issue in the Antarctic krill fishery, particularly because of the severe depletion of some of the fish stocks in the South Atlantic. But operators reportedly avoid areas where there is likely to be a contaminating catch of fish, and large Antarctic krill aggregations tend to be monospecific. In the British Columbia krill fishery, bycatch has also been a concern, and for this reason, the season was restricted to November through March to minimize the incidental catch of larval and juvenile fish and shellfish (e.g., young salmon and shrimp).

In coastal areas off Oregon, Washington and California, juvenile salmonids (including endangered stocks), pelagic juveniles of *Sebastes* spp., herring and other juvenile and larval fishes, squid, pelagic invertebrates, and night-feeding seabirds would likely be vulnerable to small-mesh krill trawls fished at night. The extent to which the fishery would impact these potential bycatch species is not known without a description of fishing methods, areas, times and gear, and the amount of effort expended.

3.7 POTENTIAL PROTECTED SPECIES INTERACTIONS AND IMPACTS IN THE MANAGEMENT AREA

This section provides a short summary of potential effects of krill removal on species listed under the ESA and MMPA that are known to feed on one or both of the California Current species *Thysanoessa spinfera* and *Euphausia pacifica*. A more detailed description of each species is provided in Appendix B of this document.

3.7.1 Marine Mammals

3.7.1.1 Southern Sea Otter (*Enhydra lutris nereis*).

The southern (California) sea otter was listed as threatened in 1977 under the Endangered Species Act of 1973, as amended. This species generally forages over rocky or soft-sediment ocean bottom, primarily in water depths 82 ft deep or less within 1.2 miles of shore. It is possible that krill fishing operations could take this species, but this may depend on the method employed, and would have to be carefully reviewed if any fishery should develop.

3.7.1.2 Humpback whale (*Megaptera novaeangliae*).

The humpback whale has been listed as an endangered species under the United States Endangered Species Act (ESA) since 1970. It obtains food by straining krill and schools of small fish with its baleen, and is one of the major predator species seen in association with krill swarms off California. Since these whales congregate for feeding in krill swarming areas, the potential for interaction with any potential krill fishing operation exists, but the extent to which these interactions will have adverse impacts is not known at this time, but should be considered in fashioning any krill fishery controls for a future fishery.

3.7.1.3 Blue whale (*Balaenoptera musculus*).

The blue whale has been listed as endangered under the ESA since 1970. The majority of the eastern north Pacific population spends the summer on feeding grounds between central California, the Gulf of Alaska and the Aleutian Islands. Blues have been observed feeding on dense swarms of euphausiids (dominated by either *Thysanoessa spinifera* or *Euphausia pacifica*) near Monterey and the Farallones between July and October, and over deep submarine canyons in southern California and around the Santa Barbara Channel Islands. Since these whales congregate in krill swarming areas, the potential for interaction with any potential krill fishing operation exists, but the extent to which these interactions would occur or have adverse impacts is not known at this time, but should be considered should a krill fishing activity be developed or authorized in the future.

3.7.1.4. Fin whale (*Balaenoptera physalus*)

This species has been listed as endangered under the ESA since 1970. The estimated biomass requirement in the North Pacific is 901 kg day $^{-1}$ (Croll et al in press). There is some indication that fin whales have increased in abundance in California coastal waters, but the trends are not statistically significant. Though not as frequently observed in association with inshore krill swarms as humpback and blue whales, the potential for interaction with any proposed krill fishing activity exists, but the extent to which these interactions will have adverse impacts is not known at this time.

3.7.1.5 Sperm whale (*Physeter macrocephalus*).

The sperm whale has been listed as an endangered species under the ESA since 1970. It is widely distributed across the entire North Pacific, occurring off all three Pacific Coast states, and is found year-round in California waters. Unlike the other large whales, the sperm whale does not feed with baleen (and on krill), but is a toothed whale. This species may be least likely of the large whales to be affected by any potential krill fishing operation unless perhaps drawn to squid and other larger prey attracted by krill swarms.

3.7.1.6. Northern Right Whale (*Eubalaena glacialis*).

Right whales are listed as endangered under the ESA. Off the coasts of Oregon, Washington and California, there have been extremely few sightings of this species since the mid 1950s. Data are scant for fisheries interactions with North Pacific right whales. Although there are two fishery-related mortalities reported from Russian waters, fishery-related interactions are not known to be a problem in the eastern North Pacific. In the Atlantic, gillnets, lobster pots, seines, longlines and fish weirs are reportedly the main gear types that are known to entangle right whales, so it is possible that seine net krill fishing operations might entangle an animal.

3.7.1.7 Sei Whale (*Balaenoptera borealis*).

These baleen whales are distributed far out to sea in temperate regions and do not appear to be associated with coastal features. The sei whale is listed as endangered under the ESA and rare in West Coast EEZ waters. Sei whales have a diverse diet, including many species of fish species and squid, although the primary prey appears to be copepods. Like the right whale, it is possible that seine net krill fishing operations might entangle an animal, but this species is generally not attracted to coastal krill swarms off our coast and thus is not as likely as the blue and humpback whale to interact with or compete with krill fishing operations in pursuit of euphausiid swarms.

3.7.1.8 Guadalupe fur seal (*Arctocephalus townsendi*).

This seal is a protected species in California and is listed as a threatened species. These seals now primarily breed and pup at Isla Guadalupe, Mexico. In the West Coast region, a few Guadalupe fur seals are known to inhabit southern California sea lion rookeries in the Channel Islands. It is possible that krill fishing operations could cause incidental mortality or injury to Guadalupe fur seals, but there have been no documented reports of mortalities or injuries of pinnipeds in krill net fisheries elsewhere.

3.7.1.9. Steller Sea Lion (*Eumetopias jubatus*).

This species, listed as endangered, ranges along the North Pacific Ocean rim, from northern Japan, to a centered abundance and distribution in the Gulf of Alaska and the Aleutian Islands, south to California, with the southernmost rookery being Año Nuevo Island (37ºN latitude). Steller sea lions prey primarily upon schooling fishes, such as pollock and herring, as well as invertebrates, such as squid and octopus. Like other pinnipeds, this species has been vulnerable to set net and drift gillnet fishery in the past and may possibly be vulnerable to krill seine operations, especially if drawn to krill swarms in pursuit of herring or other fish prey feeding on euphausiid aggregations outside its protected zones.

3.7.2 Salmonids

Pacific salmonids in their oceanic habitat (including juvenile stages) are known to depend heavily on *T. spinifera* and *E. pacifica* for food and to seek out dense swarms of these species.

They would likely compete with, as well as be vulnerable to incidental catch in, any net fishery targeting dense krill swarms within the U.S. West Coast EEZ.

3.7.2.1 Coho Salmon (*Oncorhynchus kisutch*).

Three Evolutionarily Significant Units (ESUs) of coho are listed as threatened--the Southern Oregon/Northern California Coasts, Oregon Coast, and Central California ESUs. While juvenile and maturing coho are found in the open north Pacific, the highest concentrations appear to be found in more productive waters of the continental shelf within 60 km of the coast. Coho salmon have been occasionally reported off the coast of southern California near the Mexican border

3.7.2.2 Chinook Salmon (*O. tshawytscha*).

Nine chinook salmon ESUs are identified as either endangered or threatened. These include Sacramento River Winter-run (Endangered), Snake River Fall-run (Threatened), Snake River Spring/Summer-run (Threatened), Central Valley Spring-run (Threatened), California Coastal (Threatened), Puget Sound (Threatened), Lower Columbia River (Threatened), Upper Willamette River (Threatened), and Upper Columbia River Spring-run (Endangered). Catch data and interviews with commercial fishers indicate that maturing chinook salmon are found in highest concentrations along the continental shelf within 60 km of the Washington, Oregon, and California coast lines. Recently listed populations of chinook salmon also feed in the Gulf of the Farallones as adults before returning to the Sacramento River drainage to complete their life cycle.

3.7.2.3 Chum Salmon (*O. keta*).

Two ESUs of chum are listed, the Hood Canal (Threatened) and Columbia River (Threatened) ESUs. Maturing chum salmon in the North Pacific begin to move coastward in May and June and enter coastal waters from June to November. No region-specific information on chum salmon migrations to Washington and Oregon has been reported.

3.7.2.4 Sockeye Salmon (*O. nerka*).

The Ozette Lake ESU (Threatened) and Snake River (Endangered) ESU of sockeye salmon are protected under the ESA. Initially, sockeye salmon juveniles travel northward from Washington and British Columbia to the Gulf of Alaska staying in a migratory band relatively close to the coast. British Columbian and Washington populations of sockeye salmon utilize the area east and south of Kodiak Island in concert with Alaskan stocks, but tend to be distributed further to the south than the Alaskan stocks (down to 46º N latitude).

3.7.2.5 Steelhead (*O. mykiss*).

Ten ESUs of steelhead are listed on the ESA including Upper Willamette River (Threatened), Middle Columbia River (Threatened), Southern California (Endangered), South-Central California Coast (Threatened), Central California Coast (Threatened), Upper Columbia River (Endangered), Snake River Basin (Threatened), Lower Columbia River, (Threatened), Central Valley, California (Threatened), and Northern California (Threatened). Steelhead habitat requirements change as they go through different life phases, but the most critical are thought to be related to watershed habitat (rivers, bays, estuaries throughout Washington, Oregon, California and Idaho. Adult steelhead in their oceanic existence also need adequate forage and productive environmental conditions in order to grow and survive and return to natal rivers and streams to spawn.

3.7.3 Seabirds

Over seventy species of pelagic birds occur in the pelagic environment offshore Washington, Oregon and California. These include Northern Fulmar, Brown Pelican, albatrosses, shearwaters, loons, grebes, murres, auklets, murrelets, storm petrels, phalaropes, skuas, gulls, terns, puffins, and guillemots. Some, like the albatrosses, cover vast expanses of the ocean in search of food. Others have more restricted foraging ranges, taking their prey (e.g., small fishes and/or invertebrates like euphausiids) from at or near the sea surface by dabbing or making shallow dives. Still others (e.g., murres, loons) dive to depths greater than 300 feet in pursuit of prey. Often birds seek areas where ocean processes concentrate their prey along fronts and areas of convergence, or near the shelf break where large aggregations of krill and other prey converge and rise to near the surface. Seabird distribution at sea and breeding success is often heavily influenced by the changing physical oceanography of the area that affects the distribution of prey. Seabird populations have a number of characteristics in common which make them susceptible to harm caused by environmental and human-induced changes in their habitat. Resident seabirds concentrate their nesting efforts over several months at small areas, and they traditionally use the same nesting areas year after year, where they can be susceptible to predation and other coastal disturbances. Some birds (e.g., pelican, cormorants, gulls) also concentrate in roosts or resting sites when not at sea. Many seabirds depend on concentrated food supplies, where food and game fish also concentrate and where the birds may compete or interact with fishers or anglers and their operations. Seabirds also tend to be closely dependent on prey resources such as euphausiids that are highly affected by oceanic regime shifts. The most krill-dependent seabirds are thought to be the Cassin's auklet, *Ptychoramphus aleuticus,* which suspends breeding when available krill levels diminish, and the sooty shearwater, *Puffinus griseus*. The common murre, *Uria aalge*, is also known to feed on krill.

Only a few seabirds are listed under the ESA, under the jurisdiction of the U.S. Fish and Wildlife Service. They are as follows:

3.7.3.1 Short-tailed Albatross (*Phoebustria albatrus*).

This species is listed as endangered. Short-tails breed on Torishima, an island owned and administered by Japan. They have also been observed (non-breeding behavior) on Minami-Kojima in the Senkaku Islands of Southern Ryukyu Islands, also owned and administered by Japan. The species is a surface feeder and the diet consists of flying fish eggs, shrimp, squid, and crustaceans. Birds feed primarily during daybreak and twilight hours and have been known to forage as far as 3,200 km (1,988 miles) from their breeding grounds. Like other albatrosses, their surface feeding, scavenging habits may make them vulnerable to fishing operations. The possibility of krill fishing gear interaction with this species, though remote, does exist and may warrant further examination.

3.7.3.2 Bald Eagle (*Haliaeetus leucocephalus*).

Bald eagles, listed as threatened under the ESA, range from Alaska south to Baja California, Mexico, living near large bodies of open water such as lakes, marshes, seacoasts and rivers. They feed on fishes (usually freshwater or nearshore salt water or anadromous species) and carrion. Off Washington, Oregon and California, eagles are generally not known to feed outside enclosed bays and nearshore areas beyond three miles from shore. Thus krill fishing operations, would not be considered a significant threat to this species.

3.7.3.3 Marbled Murrelet (*Brachyramphus marmoratus marmoratus*).

The Marbled Murrelet, listed as threatened under the ESA, is a small seabird found in coastal areas of the eastern Pacific Ocean from Alaska to central California. It feeds on small ocean fish such as sand lance and herring, and invertebrates such as decapods and cephalopods. It is thought that any potential krill fishing will likely take place outside Marbled Murrelet feeding areas, but the possibility of fishery interactions do exit where krill-rich submarine canyons areas approach the coast.

Of the other murrelets, only Xantus' (*Synthliboramphus hypoleucus)* is most likely to range into potential krill fishing areas. It may be vulnerable to small mesh krill fishing gear, as it is to small mesh drift gillnets and set nets, especially near colonies. This murrelet is not listed, but is under consideration for threatened status. The species persists in very low numbers with an estimated population of less than 10,000 breeding individuals. A significant portion of this small population nests on the southern California Channel Islands, while the remainder nests on islands along the northwest coast of Baja California, Mexico.

3.7.3.4 California Least Tern (*Sterna antillarium (=albifrons) browni*).

This species is listed as endangered. These terns traditionally nest on open, sandy, ocean-fronting beaches that are often near the mouths of estuaries; they seldom occur far out to sea, away from their lagoon or estuary with its dependable food supply. Least terns are opportunistic feeders known to capture more than 50 species of fish, however, these birds feed predominately on small schooling fishes near the surface in relatively shallow, nearshore waters and coastal brackish/ freshwater ponds, channels, and lakes, so are unlikely to interact with any potential krill fishing operations.

3.7.3.5 Snowy Plover (*Charadrius alexandrinus nivosus*).

Western Snowy Plovers, listed as threatened, are small shorebirds that breed along the Pacific coast of the United States and northern Mexico, and interior sites in several western states. Snowy Plovers are not known to feed in or traverse the marine pelagic environment except in areas immediately adjacent to the coast, therefore they are not likely to be affected by krill fishing practices or proposed actions, being primarily affected by disturbance of shore beach/dune habitat and by predation.

3.7.3.6 Brown Pelican (*Pelecanus occidentalis*).

This species, listed as endangered, occurs along the coast in Oregon and Washington in summer and in California year round, especially south of Point Conception, CA. Adults continue to feed young for some time after they leave colony. It is possible that an inshore krill fishery could have incidental interactions with this species, but this species is generally thought to occur in areas closer to shore that the primary krill swarming areas or potential harvest areas beyond 3 nautical miles from shore.

3.7.4. Sea Turtles

3.7.4.1 Green Turtle (*Chelonia mydas*).

This species is listed as threatened except for breeding populations found in Florida and the Pacific coast of Mexico, which are listed as endangered. Green turtles are declining virtually throughout the Pacific Ocean, with the possible exception of Hawaii. This species is more likely to occur in the U.S. EEZ during warm water El Niño events, at a time when euphausiid production would likely be greatly diminished, as would commercially profitable krill densities and interest in krill fishing.

3.7.4.2 Leatherback Turtle (*Dermochelys coriacea*).

This species is listed as endangered throughout its range. Leatherbacks are the most frequently sighted marine turtle off the northern and central California coastline, and take of this species in drift net and longline fisheries is of considerable concern and are the proximate cause of strict regulation of those fisheries. Though not generally known to occur in association with inshore krill swarms (as they feed on gelatinous organisms), they occur over slope and shelf water areas off California in August when krill swarms are often observed. Therefore, there would be a potential for interaction with any proposed krill fishing activity in the same areas. The extent to which these interactions would occur and/or would have adverse impacts is not known at this time.

3.7.4.3 Loggerhead Turtle (*Caretta caretta*).

The loggerhead is a circumglobal species and is listed as threatened under the ESA. In the eastern Pacific, loggerheads are reported as far north as Alaska, and as far south as Chile. Occasional sightings are also reported from the coast of Washington, but most records are of juveniles off the coast of California. Takes of this species have been of concern in the drift gillnet and high seas longline fisheries, especially during warm water El Niño years. As with the green turtle, this species is more likely to occur in the EEZ in extreme warm water years at a time when euphausiid production would likely be greatly diminished, as would commercially profitable krill densities.

3.7.4.4 Olive Ridley Turtle (*Lepidochelys olivacea*).

This is the smallest living sea turtle with populations nesting on the Pacific coast of Mexico listed as endangered under the ESA (all other populations are listed as threatened). Its range is essentially tropical. Olive ridleys feed on tunicates, salps, crustaceans, other invertebrates and small fish. Stranding records from 1990-99 indicate that olive ridleys are rarely found off the U.S. West Coast (off California). For this species, the potential for interaction with any proposed krill fishing activity exists, but the probability of encounters and the extent to which these interactions will have adverse impacts is not known at this time.

3.8 ESSENTIAL FISH HABITAT FOR KRILL

3.8.1 Introduction and Need for Action

Section 303(a)(7) of the M-SA requires that fishery management plans (FMPs) describe and identify essential fish habitat, minimize to the extent practicable adverse effects on such habitat caused by fishing and identify other actions to encourage the conservation and enhancement of such habitat. The M-SA provides the following definition:

> "The term 'essential fish habitat' means those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." (16 U.S.C. § 1802 (10)).

NMFS has published regulations for implementation of the EFH requirements. These regulations (at 50 C.F.R. 600 Subpart J) provide additional interpretation of the definition of essential fish habitat:

> "'Waters' include aquatic areas and their associated physical, chemical, and biological properties that are used by fish, and may include aquatic areas historically used by fish where appropriate; 'substrate' includes sediment, hard bottom, structures underlying the waters, and associated biological communities; 'necessary' means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and 'spawning, breeding, feeding, or growth to maturity' covers a species' full life cycle."

The NMFS guidelines intended to assist councils in implementing the EFH provision of the M-SAset forth the following four broad tasks:

- Identify and describe EFH for all species managed under an FMP;
- Describe adverse impacts to EFH from fishing activities;
- Describe adverse impacts to EFH from non-fishing activities; and
- Recommend conservation and enhancement measures to minimize and mitigate the adverse impacts to EFH resulting from fishing and non-fishing related activities.

In sum, the EFH regulations require that EFH be described and identified within the U.S. EEZ for all life stages of each species in a fishery management unit if they occur within that zone. FMPs must describe EFH in text and/or tables and figures which provide information on the biological requirements for each life history stage of the species. An initial inventory of available environmental and fisheries data sources should be taken to compile information necessary to describe and identify EFH and to identify major species-specific habitat data gaps. The EFH regulations also suggest that where possible, FMPs should identify Habitat Areas of Particular Concern (HAPCs) within EFH for habitats which satisfy the criteria of being 1) sensitive or vulnerable to environmental stress, 2) are rare, or are 3) particularly important ecologically.

3.8.2 Methods and Data Sources

Data and information to describe krill EFH were obtained primarily from the scientific literature, as well as through consultation with krill researchers (Appendix A) and examination of data on geographic catch densities off California for the years 1950-2002 provided by E. Brinton and A. Townsend, Scripps Institution of Oceanography (SIO), Pelagic Invertebrates Collection (pers. commun., La Jolla, CA 6/6/2005). The majority of these data are level 1 data, where all that is known is where a species occurs based on distribution data for all or part of the geographic range of the species (presence/absence). Some preliminary data are also available on areal densities of relative abundance (Level 2, see SIO reference above). Little is known of growth, reproduction or survival rates within habitats (Level 3); or habitat-dependent production rates quantified by habitat quantities, qualities and specific locations (Level 4).

3.8.3 Description and Analysis of EFH Alternatives: Proposed Options and Analysis

Option 1. Status Quo. Do not designate EFH.

If krill are incorporated as a MUS in the CPS or other FMP, this is not an option, since the M-SA requires designation of essential fish habitat for all MUS in FMPs.

Option 2. Adopt EFH as described in section 3.8.6.

No biological, social or economic impacts are expected beyond administrative costs of reviewing federally regulated projects for potential impacts on this habitat, where krill and krill predators concentrate.

Option 3: Designate the full EEZ as EFH

There is little statistical basis for designating EFH beyond the areas identified in 3.8.6. However, it is conceivable that krill exist throughout the EEZ even if not in concentrations that support a forage role or that support reproduction or other life stages.

3.8.4 Habitat Areas of Particular Concern (HAPCs)

In the process of reviewing the literature and available data on habitat use and preferences of krill, an effort was made to determine specific areas within U.S. West Coast EEZ EFH that satisfied the criteria of being 1) sensitive or vulnerable to environmental stress, 2) rare, or 3) particularly important ecologically.

A review of the literature and available data on krill aggregating areas and reproductive swarms, with high densities of predators such as salmon, seabirds and large baleen whales, revealed certain krill-rich upwelling areas to be especially important. Dense krill swarms and predator aggregations are reported most consistently within the ocean boundaries of the following NOAA Marine Sanctuaries: Olympic Coast NMS off Washington (Calambokidis 2004) and Cordell Bank NMS, Gulf of the Farallones NMS (Chess et al 1988; Smith and Adams 1988; Kieckhefer 1992; Schoenherr 1991; Adams 2001; Howard 2001) and Channel Islands NMS in California (Armsrong and Smith 1997; Fiedler et al. 1998; Croll et al 1998). (Fig. 14). Additionally, the following other high-density krill and krill predator areas have been reported: Heceta Bank and Cape Blanco areas, Oregon (Ainley et al. 2005; Ressler 2005; Tynan et al 2005) and Bodega Canyon (Howard 2001). A confluence within these areas of rich, upwelled unstratified water and topological features such as submarine canyons, banks, and island shelves may not only provide rich feeding areas for krill, but may also contain features necessary for krill patches to be exploited by baleen whales, fish and seabirds, by concentrating and trapping krill over the shelf as they attempt to descend to the depths during the day (Chess et al. 1988; Fieldler et al. 1998; Ressler et al. 2005)

The following HAPC options are proposed:

HAPC Option 1. Status Quo–Do not designate HAPCs

HAPC Option 2. Designate for krill and feeding baleen whales and other krill predators the ocean area within the boundaries of Cordell Bank, Gulf of the Farallones, Monterey Bay, Channel Islands, and Olympic Coast NOAA Marine Sanctuaries as HAPCs. These sanctuaries encompass the most important consistently krill-rich, predator feeding areas around California islands as well as important submarine canyons, bank, shelf and slope areas (e.g., Gulf of the Farallones, Pescadero Canyon, Ascension Canyon, Monterey Bay Canyon area, Channel Islands)

HAPC Option 3. Designate for krill and feeding baleen whales and other krill predators the ocean area within the boundaries of Cordell Bank, Gulf of the Farallones, Monterey Bay, Channel Islands and Olympic Coast NOAA Marine Sanctuaries, and Heceta Bank area (east of longitude 125˚ 30' W Long, between 43˚50' and 44˚ 50' Lat), off Cape Blanco (east of longitude 125˚ 30' between 42˚20' and 43˚ 000' Lat), and the Bodega Canyon area as HAPCs. This is similar to Option 3, but also includes three additional known important krill areas outside of Sanctuary boundaries.

HAPC Option 4. Designate for krill and feeding baleen whales and other krill predators the ocean area within the boundaries of Cordell Bank, Gulf of the Farallones, Monterey Bay, Channel Islands and Olympic Coast NOAA Marine Sanctuaries as HAPCs and all other waters of the EEZ federal coastal and island waters off Washington, Oregon and California out to 60 nautical miles from shore. This would cover all the areas Option 1, the highest krill density areas in Option 2, and additionally other inshore island, shelf, bank and slope areas along the coast suspected of supporting high densities of krill and krill predators within the EEZ.

3.8.5 Affected Environments

3.8.5.1 Biological Environment

The California Current marine ecosystem offshore Washington, Oregon and California is home to vast variety of fishery, seabird, marine mammal, and sea turtle resources, many of which depend on krill directly or indirectly to sustain their populations. These include groundfish species (shelf and slope rockfishes, Pacific whiting, flatfishes, sablefish, lingcod, greenlings, sturgeon; sharks; skates, rays); four species of Pacific salmon; steelhead; highly migratory pelagic species (tunas, marlin, swordfish, pelagic sharks, dorado); other relatively large pelagic fishes (louvar, oarfish, lancet fishes, escolar, oilfish, opah, saury, common mola, spearfish, sailfish, blue marlin, wahoo, bonito, black skipjack and others); small coastal pelagic species (sardines, herring, anchovy, mackerels, smelts, and squid); marine mammals (California sea otter and various whales, porpoises and dolphins, sea lions, and seals); pelagic seabirds (including northern fulmar, brown pelican, albatrosses, shearwaters, loons, murres, auklets, storm petrels and others) (Leet et al. 2001).

The California Current system is particularly rich in microscopic organisms (diatoms, tintinnids and dinoflagellates) which form the base of the food chain, especially in areas where consistent ocean upwelling occurs, enhancing primary production. The California Current area is an eastern boundary current ecosystem, one of the most productive regions of the world. As with other eastern boundary current systems, primary production is not nutrient- limited except in extreme El Niño years because of a relatively constant supply of nutrients upwelled from the depths and supplemented by nutrients from estuarine and urban runoff. This rich supply of diatoms and other small plankters provides food for euphausiids and many other zooplanktonic organisms such as shrimps, copepods, ctenophores, chaetognaths, oceanic squids, salps, siphonophores, amphipods, heteropods, and various larval stages of invertebrates and fishes. Grazers like small coastal pelagic fishes and squid depend on this planktonic food supply, which in turn provide forage for larger species nearer the apex of the food chain. Certain seabirds and turtles and also baleen whales also depend on the euphausiid food supply, and many fishes, seabirds and toothed cetaceans feed on fishes that are plankton feeders.

Episodic oceanographic events such as El Niño (warm water incursion) and La Niña (cooler water incursion) may affect the occurrence and distribution of organisms and productivity of the system. Longer periods of certain ocean temperature regimes that persist for decades can also affect reproduction and recruitment of marine species (e.g., sardine, rockfish) for several generations and result in substantial changes in abundance over time (Leet et al. 2001). During episodic or persistent warm periods when cold water euphausiids decline or shift north, the more tropical species may become more abundant within the EEZ, along with some of the more tropical prey species upon which they feed. For example, The pelagic red crab, and the neritic warm-water euphausiid, *Nyctiphanes simplex,* may shift northward from Mexico waters, displacing *T. spinifera* from its usual habitat over the continental shelf off California and Oregon to the more northerly parts of its range.

3.8.6 Description of Designated Essential Krill Habitat in the U.S. West Coast EEZ

The following sections describe essential habitat for the two species. It was not possible at this time to discern consistent differences in distribution of the various life stages, other than coastwide, the larvae of both species tend to occur closer to shore, often over the shelf. It is recommended that these designations be updated on final analysis and publication of the Scripps Institution of Oceanography 50-year time series of maps showing spatial densities of these and other euphausiid species in the CalCOFI sampling area (E. Brinton, SIO, unpub. data, personal commun. 6/8/05).

Isobaths (depth contours) are used below as outer boundaries of EFH, but only because they roughly approximate the outer bounds of reported densest concentrations of the populations, and because static boundaries are preferred for the legal definition of EFH. These contours also roughly form the outer boundaries of some of the major upwelling areas (though perhaps not some of the larger offshore jets), within which consistently high concentrations of phytoplankton occur (Fig. 15). The boundaries are not meant to imply the strict association of these highly dynamic macroplanktonic species with fixed bottom topography, other than that discussed under section 3.1.2.2. Horizontal Distribution EEZ.

3.8.6.1 *Euphausia pacifica* EFH (Fig. 16)

Larvae, juveniles and adults: From the inner boundary of the U.S. West Coast EEZ (beyond 3 nm) seaward to the 1000 fm (1,829 m) isobath, from the U.S.- Mexico north to the U.S.-Canada border, from the surface to 400 m deep, from the U.S.- Mexico north to the U.S.-Canada border (Fig. 16). Highest concentrations occur within the inner third of the EEZ, but can be advected into offshore waters in phytoplankton-rich upwelling jets (Fig. 15) that are known to occur seaward to the outer boundary of the EEZ and beyond.

3.8.6.2 *Thysanoessa spinifera* EFH (Fig. 17)

Larvae, juveniles and adults: From the inner boundary of the U.S. West Coast EEZ (beyond 3 nm) seaward to the 500 fm (914 m) isobath, from the U.S.- Mexico north to the U.S.-Canada border, from the surface to 100 m deep. Largest concentrations in waters less than 200 m deep, although individuals, especially larvae and juveniles, can be found far seaward of the shelf, probably advected there by upwelling jets (Figs. 15, 17).

3.8.7 Possible Adverse Impacts to EFH from Fishing Activities

At this time it is not known what types of gear might be chosen for harvesting krill off the U.S. West Coast, since various types of methods have been used world fisheries - beam trawl, small midwater trawl, bow scoop net, purse seines, etc. But because gear would likely be deployed in midwater to the surface, physical damage to the water column habitat is not anticipated at this time.

3.8.8 Possible Adverse Impacts to EFH from non-fishing activities

Little is known of the effects of non-fishing activities on krill habitat. The only known study was conducted in 1996 and 1997, when NOAA/NMFS investigated for the U.S. Army Corps of Engineers the effects of disposal of dredged materials at the San Francisco Deep Ocean Disposal

Site on midwater organisms (Roberts et al 1997; Roberts et al 1998) at a site off the San Francisco peninsula. In year one of the study, the effects of dumping were studied by comparing the abundance of selected zooplankton and micronekton taxa (including euphausiids as a group) at the dump site, with collections taken at a reference area (Pioneer Canyon) and in the area bordering the dump site (buffer zone). Tests comparing the buffer zone abundances with the dump site abundances did not show significant differences between the disposal and buffer areas, and in 13 of these cases there were actually more organisms found in the disposal area than in the buffer area. Thus the findings did not show an adverse dump effect, and suggested that some other factors may have influenced differences in the observed locations. In year two, dump site abundances, with euphausiids broken down to species, were compared with abundances at seven peripheral stations 11 miles to the north and 10-14 miles to the south. Results and analyses failed to show any striking impacts at the dump site that could be attributed to the disposal of dredged materials. Nonetheless, sampling took place during a highly variable small window of time and during a period of low euphausiid productivity, whereas effects during more productive, non-El Niño years may differ.

3.9 SUMMARY OF POTENTIAL IMPACTS TO KRILL AND AFFECTED ENVIRONMENT

Based on the information presented, there are several impact factors the Council will need to consider in determining the necessary and appropriate controls on krill fishing. These include:

- Possible negative impacts on food supply of krill-dependent predators (whales, seabirds,important commercial and recreational fishes such as groundfishes, salmon, squid, etc), with subsequent lower abundance of commercial fish and squid stocks, and reduced food levels for federally protected marine mammals and birds.

- Potential negative impacts with other commercial stocks and protected species due to gear interactions with certain krill-dependent predators that co-occur in the same high-density krill swarm areas.

- Potential bycatch of juvenile salmon, squid and other CPS and other commercially important larval and juvenile fish and invertebrates.

- Possible increase in algal blooms of phytoplankton, whose growth in nutrient-rich upwelling systems like the California Current is held in check largely by grazers (would depend on the amount of harvest removals).

- Degraded ocean conditions caused by unutilized phytoplankton biomass sinking to the sea floor resulting in thick accumulations of deposited unoxidized organic matter with low or non-existent dissolved oxygen concentrations (Bakun and Weeks 2004) fed by nutrient rich eastern boundary current waters.

- Possible localized disruption of carbon, nitrogen and Vitamin A cycling in the sea through removals of significant numbers of krill. Disruption of carbon flux and food availability to small pelagic and benthic organisms dependant on the fragmentation of sinking organic particles ("Marine snow") created by the collective rapid beating of krill appendages in the water column. Marine snow can comprise as much as 60% of water column particulate organic carbon.

- Potential negative fishing gear/user group interactions between krill vessels and commercial and recreational vessels and whale and bird watching vessels.

- Loss of associated goods and services that depend on our regional ecosystem resources and quality.

3.10 RESEARCH NEEDS

The following research needs were identified after a review of the literature and available data, and individual consultation with California Current euphausiid researchers.

3.10.1 MSY-OY Specification Needs

To reduce uncertainties in the specification of MSY (and thus improve the basis for specification of OY) and meet the requirements of the M-SA, the following research analyses are needed:

1. Construction of a single-species probabilistic yield model to determine the likelihood of a fishable krill surplus occurring, using probability density functions for biomass, productivity, and predator demand and a yield equation incorporating krill yield, krill biomass, instantaneous krill growth rate, consumption needs of predators, and natural mortality other than predator removals. Bounding estimates are needed for the model input parameters for Monte Carlo simulations to determine the likelihood of a harvestable krill surplus production occurring (i.e., production beyond predator needs and population stability). This means that funding, staff and support must be committed to coordinate and run model simulations.

2. Construction of a multispecies ecosystem model(s) to estimate effects of various harvest levels. This would involve 1) expanding the existing Eastern North Pacific Ecosystem Ecopath/Ecosim Model (Field et al. 2001; Field and Francis In press; Field et al in press) to include the entire West Coast EEZ, and 2) running a perturbation version of this model (i.e., a model in which fishery removals of krill would be the change in the ecosystem). This is expected to take 6 months to one year after assignment of work and allocation of resources.

3.10.2 Standing Biomass Estimation and Survey Needs

Standardization of collecting and processing methods is required before net density and acoustic data from different geographic regions can be combined and converted to coast-wide, or even regional, biomass estimates. The following are needed:

1. A meeting among a team of krill bioacoustic experts to decide on and develop standardized methodology for calibrating, measuring, surveying and interpreting zooplankton acoustic backscatter for the primary purpose of estimating distribution and biomass of both species in the West Coast EEZ, and integrating with net collection data.

2. Standardization of krill body length to weight/carbon conversion factors by krill size group. *E. pacifica* length-carbon relationships are available from SIO especially for *E. pacifica* and some data are available for *T. spinifera* from Patricia Summers' 1993 Master's thesis, Univ. Victoria, B.C. Canada.

3. Expert agreement as to the spatial bounds of primary krill habitat from which density and subsequent biomass conversions can be expanded to obtain initial estimates of biomass of *E. pacifica* and *T. spinifera* standing stocks.

4. Analyses (and scientific agreement) to determine which krill life stage of what species might best serve as a proxy of adult abundance in future sampling.

5. Laboratory metabolic experiments to refine estimates of productivity, growth and turn-over rates.

4.0 ENVIRONMENTAL CONSEQUENCES OF ALTERNATIVES CONSIDERED

4.1 Impacts of Strategic Alternatives

4.1.1 No Action

4.1.1.1 Effects on Krill

This alternative will have no predictable impacts on krill resources. It is not known if a krill fishery would develop within the West Coast EEZ in the absence of new management controls.

If a fishery were to develop, it would be by non-West Coast vessels that are not registered under any West Coast state laws and are not subject to state restrictions when operating in the EEZ or beyond. Such a fishery (assuming the use of trawl and not purse seine) would not be dependent on clearance through the 90-day review period provided by the List of Fisheries regulation. There would be no limit on the catch of krill or on the time or area in which fishing occurs, and krill fishing could occur within portions of the EEZ that are within national marine sanctuaries off the West Coast. There would be no permit or reporting requirement and there would be no requirement for observers, and thus no information would be collected for any fishing that occurred. The potential for decreasing the spawning biomass to levels that threaten successful reproduction would depend on the level of harvest and the times and areas at which harvest was conducted. The risk of stock declines may be greater for *T. spinifera*, which has a 3-year cycle and limited spawning periods. If the fishery were relatively small and/or limited to areas which have no major importance to the long-term survival of krill, the risk to the krill stocks could be low.

4.1.1.2 Effects on Other Fish Species

This alternative would have the highest probability of adverse impacts on other fish species. If a fishery developed without controls, it could harvest krill at levels that could reduce the availability of krill to other fish species. As indicated in Chapter 3, some Council-managed (hake, spiny dogfish, rockfishes) species are fairly dependent on krill, either year round or on a seasonal basis, and these species would be more at risk than species for which krill is not important or for which there might be adequate substitutes for krill in their diet. In the absence of good information on the fishing activities (where, when and how much), there would be great difficulty relating declines in other species to the removal of krill by a fishery.

4.1.1.3 Effects on Other Living Marine Resources

It is not known though it is likely that, at some level, krill harvest would become an issue in terms of adverse effects on species of special concern, such as species listed under the ESA or MMPA or species of seabirds. It is possible that a large harvest, especially in times or areas in which whales actively feed on krill masses, would result in stress to those whale populations and possibly in decreased growth or reproductive success or feeding of juveniles. The risk of such impacts increases in relation to the level of harvest and the coincidence of harvest of krill with times and areas in which krill are most important to such other species. If krill fishing is not controlled and monitored, the ability to relate a krill fishery with changes in abundance, distribution, reproductive success, or other factors related to major predators is very limited or non-existent. This may be especially important in areas such as the marine sanctuaries in which krill concentrations and whale concentrations appear to coincide.

Krill also appear to be important forage for some marine bird species such as Cassin's auklet. The availability of krill in prime hatchling feeding periods would be most important. This availability is probably greatest in the spring and summer, and those periods of krill concentrations would probably coincide with periods when fishing would be most likely. An uncontrolled krill fishery could result in high risk to such bird species.

4.1.1.4 Effects on Other Fisheries

It is not known though it is likely that, at some level, krill harvest would become an issue in terms of adverse effects on at least some fish species under Council management such as hake or some other groundfish. It is especially noteworthy that some groundfish species that are overfished (e.g., canary rockfish) appear to be significant feeders on krill. It is possible that a large harvest, especially in times or areas in which these fish species actively feed on krill, would result in stress to those fish populations and possibly in decreased growth or reproductive success or survival of juveniles. The risk of such impacts increases in relation to the level of harvest and the coincidence of harvest of krill with times and areas in which krill are most important to such other fish species. If krill fishing is not controlled and monitored, the ability to relate a krill fishery with changes in abundance, distribution, reproductive success, or other factors related to these other fish species is very limited or non-existent, though it is possible that food habit studies in conjunction with existing survey work (e.g., CalCOFI) would provide some insight into the relationship (if any). Unlimited krill fishing would pose a high risk of adverse effects.

4.1.1.5 Economic Effects

This alternative would have the greatest potential to result in a krill fishery with attendant economic benefits and potential economic costs. As noted, there is some (though unknown) potential for a krill fishery off the West Coast. The price of krill at this time appears not to offer a substantial enough reward to warrant an investment in a new fishery. However, with the increasing potential for offshore aquaculture (the Administration is supporting legislation that could promote such activity in the EEZ on a broader level), there would be increasing potential for a krill fishery.

It is not clear if a krill fishery in the EEZ alone by a factory/processing vessel that does not deliver its product to a West Coast state would be subject to landings laws and taxes.

4.1.1.6 Effects on Data Collection

This alternative would be unlikely to generate useful data assuming that state landing laws and reporting requirements would not apply if the active operated in the EEZ and did not land any products into West Coast ports..

4.1.1.7 Effects on Bycatch

It is not known if a krill fishery would have any bycatch, as there has been no krill fishing and thus there are no data at this time to indicate if bycatch would be a significant issue.

4.1.1.8 Effects on Habitat

Krill fishing (especially with midwater trawl) would not likely have any significant impacts on non-living components of habitat. There would be no predictable impacts on EFH for any Council-managed species under current designations of EFH for those species.

4.1.1.9 Effects on Protected Species

As noted above, this alternative has the potential to adversely affect protected species by reducing the availability of important prey. This is most pronounced for certain whale species and bird species. Large harvests would be possible under this alternative. Such harvests, especially if they coincided in times and areas when krill were most important to other living marine resources, could adversely affect other species by reducing food availability, perhaps in turn adversely affecting reproductive success and growth or even juvenile survival. There could also be direct impacts through fishery interactions with krill fishing gear.

4.1.1.10 Administrative Considerations

This would be the least costly alternative. There would be no need for further Council consideration of action or regulatory action by the U.S. Government.

SUMMARY: This alternative is not responsive to the request from the NOAA Sanctuary Managers, and it would leave a high risk of adverse effects on krill and on resources dependent on or sensitive to the abundance and availability of krill. While it is not predictable that a krill fishery will develop, it is predictable that, if a party were interested in krill fishing, then fishing would occur first in waters where krill tend to concentrate. These are the same waters in which such species as whales and seabirds would be most dependent on krill. Thus, any fishery would have a high probability of adversely affecting a wide variety of resources.

4.1.2 Include Krill in CPS FMP (Preferred Alternative)

4.1.2.1 Effects on Krill

The effects on krill would depend on the nature of the controls (e.g., amount of harvest allowed, times and places in which harvest is allowed, etc.) placed on krill fishing. If a conservative harvest strategy (especially an initial strategy prohibiting harvest until more is known) were adopted, the risk of serious short- or long-term harm to krill stocks would be minimal. On the other hand, allowing large harvests of krill without restrictions on times or areas would have a higher risk of long-term adverse effects on krill stocks. Inclusion of krill in the CPS FMP provides a basis for a managed fishery that adapts controls over time as more information becomes available, just as the Council approaches management of many other species. Also, the information that would be collected if permits, reporting and observer requirements were applied (as with other FMP fishery components) to krill fishing could greatly improve the understanding of krill as a species and as a component of the ecosystem if a fishery were to occur. This would further reduce the risk of harm to the krill stocks from incorrect management decisions.

4.1.2.2 Effects on Other Fish Species

Depending on the controls placed on the fishery, this alternative would control the risk of adverse effects on other fisheries from krill removals in a fishery. The greater the control and the greater the collection of information, the less the risk of long-term damage to any fish species from a krill fishery.

4.1.2.3 Effects on Other Living Marine Resources

Depending on the controls placed on the fishery, this alternative would control the risk of adverse effects on other living marine resources from krill removals in a fishery. The greater the control and the greater the collection of information, the less the risk of long-term damage to any other living marine resource species from a krill fishery.

4.1.2.4 Effects on Other Fisheries

To the extent other fish stocks are protected from harm, this alternative would protect fisheries on these other species from harm. This may be especially important in the sense that the relationship between krill and other species could be better understood by collecting data from a controlled fishery that is closely monitored over time.

4.1.2.5 Economic Effects

This alternative would appear most likely to result in optimum economic effects. A fishery management program could be constructed that might allow controlled and observed fishing, thus prospectively benefiting fishers, while ensuring that fishing only occurs in a manner (gear, time, place, amounts) that provides substantial assurance that the productivity and values of krill and other living marine resources are fully protected from long-term harm.

4.1.2.6 Effects on Data Collection

This alternative would be most likely to generate data needed to better understand the productivity of krill, the role of krill in the ecosystem, and the relationship between krill and the productivity and yield of other fisheries. Again, a controlled and closely observed fishery will result in better information to support improved management decisions in the future than an uncontrolled and unobserved fishery.

4.1.2.7 Effects on Bycatch

This alternative would be more likely to result in good data about bycatch (if any) in a krill fishery.

4.1.2.8 Effects on Habitat

Krill fishing would not be expected to have any effects on marine habitat or any components of essential fish habitat for any managed species.

4.1.2.9 Effects on Protected Species

This alternative would be less likely to result in adverse impacts on any protected species than would be likely with an uncontrolled fishery, but the likelihood of impacts would depend in large part on the types of controls placed on the fishery. A management program that controls the fishery in time and space to prevent fishing in association with marine mammals and/or sea birds would be less likely

4.1.2.10 Administrative Considerations

This alternative requires the completion of an FMP amendment and associated rulemaking by NMFS, assuming approval of the Council proposal. This entails completion of the necessary documentation, including environmental analysis, completion of economic and regulatory analyses, and potentially consultation under the ESA. A final Council decision would require approximately six months (allowing for Council adoption of a preferred alternative in November, publication and distribution for public review of a proposed amendment over the winter, and

Council approval of a proposed FMP amendment in March 2006). Once in place, the krill management program would be subject to annual review and adjustment as more information becomes available. The cost of this alternative is low to moderate, depending on the nature and complexity of management controls ultimately adopted.

SUMMARY: This alternative would provide a basis for actions to reduce the risk of adverse effects from an uncontrolled krill fishery. It would integrate krill fishery management into the management framework of the CPS fisheries, from which any West Coast krill fishers would likely originate. The basic management principle of the CPS FMP would be followed, that is, that fishing would be permitted only after the stock is demonstrated to be sufficiently large to support stock maintenance and forage for fish and other species and to achieve other important ecosystem functions (e.g., contributing to the Vitamin A cycle, detrital mixing). This alternative would also establish a framework for rapid adjustments in management as well as for permits and reporting to support monitoring and future management of the resources. A krill fishery management program can effectively manage to reduce the risk of adverse impacts on krill, dependent resources, habitat and bycatch. The cost of this approach is low to moderate but the reduction of risk to krill and dependent or sensitive species could be substantial. Depending on the specific controls implemented, this alternative could be consistent with or even go beyond the request of NOAA Sanctuary managers.

4.1.3 Designate Krill as Component of Groundfish Essential Fish Habitat

4.1.3.1 Effects on Krill

This alternative would provide some protection for krill depending on the nature of the specification of krill as groundfish EFH. To the extent the specification includes krill over a large area and not just in waters near the bottom where krill may be more critical for groundfish, the protection for krill would be greater.

4.1.3.2 Effects on Other Fish Species

To the extent that krill protection as a component of groundfish EFH helps maintain krill populations throughout the marine environment, other fish species that are dependent on or sensitive to krill abundance will be protected indirectly by this alternative.

4.1.3.3 Effects on Other Living Marine Resources

To the extent that krill protection as a component of groundfish EFH helps maintain krill populations at healthy levels throughout the marine environment, other living marine resources (e.g., cetaceans, seabirds) that may be dependent on or sensitive to krill abundance will be protected indirectly by this alternative.

4.1.3.4 Effects on Other Fisheries

Designation of krill as a component of groundfish EFH should provide some benefits to the groundfish fishery by reducing the risk that krill harvest would adversely affect groundfish stocks by removing a key food source. To the extent that this benefits other fish stocks as well, the fisheries on those stocks will receive some benefit.

4.1.3.5 Economic Effects

This alternative would generally have some positive benefits by reducing the risk of stock declines in any fish stocks dependent on or sensitive to krill abundance in waters off the West Coast. Further, to the extent protection of krill under this alternative benefits cetaceans and seabirds, especially in important wildlife viewing areas (e.g., National Marine Sanctuaries), there could be benefits for businesses that support wildlife watching tours in those areas. There would be no direct adverse impacts on existing fisheries or other economic users of krill as there are no such activities now. However, this alternative might preclude development of any krill fishery in the future or make such fishing less productive by designating certain areas as not available for krill fishing.

4.1.3.6 Effects on Data Collection

This alternative might result in increased research on krill off the West Coast, as it would be important to have a better understanding of the role of krill as a component of groundfish EFH. However, this might be limited to the role of krill relative to groundfish and not to a broader community of resources for which krill might be important.

4.1.3.7 Effects on Bycatch

This alternative would not be expected to have significant impacts on bycatch of any species.

4.1.3.8 Effects on Habitat

This alternative would provide some protection for habitat for groundfish and for any other resources that are dependent on the habitat shared with groundfish.

4.1.3.9 Effects on Protected Species

This alternative would provide some benefits to protected species to the extent that the alternative would protect krill populations in areas important to those species.

4.1.3.10 Administrative Considerations

This alternative would require amendment of the groundfish FMP and associated rulemaking by NMFS. It would require two Council meetings (including the November meeting). Protection for krill would be limited to those geographic areas covered by the groundfish EFH designation. Protection beyond those waters would be dependent on other actions (e.g., designation as an EFH component for other species or amendment of the CPS FMP).

SUMMARY: This alternative, at least as it might pertain to groundfish fisheries, has been rejected by the Council through its decisions dealing with actions for Groundfish EFH designation. The Council has not indicated an interest in designating krill as a component of EFH for any other managed fish species. The Council has concluded that this approach is not necessary and appropriate for krill conservation and management at this time. It could be administratively difficult and complex and would raise the prospect that other living marine resources should also be designated as components of EFH for managed fish species. The degree to which this approach could reduce the risk of adverse effects on krill and associated resources from a fishery is not known as it has not been tested.

4.1.4 Designate Krill as a Forage Species

4.1.4.1 Effects on Status of Krill

This alternative could but is not assured of maintaining the krill stock at healthy levels. The problem is that this approach would have to be carried out on a FMP-by-FMP basis. If krill were identified as forage for groundfish through a Groundfish FMP amendment, then only vessels fishing for groundfish would likely be affected by any harvest controls that maintain or protect that forage value. The Groundfish FMP amendment could not control directed harvest of krill by vessels not subject to the Groundfish FMP. If all relevant FMPs were amended, then substantially complete control would be achieved, assuming that only a vessel already on the West Coast and engaged in another fishery under management would be interested in development of a krill fishery. On the other hand, if a non-West Coast vessel were to engage in krill fishing and not be engaged in any non-managed fisheries off the West Coast, then this alternative would likely not achieve conservation benefits for the krill stock.

4.1.4.2 Effects on Other Fish Species

To the extent that this alternative is effective in controlling krill harvest, the stocks of fish dependent on or sensitive to krill abundance will likely benefit.

4.1.4.3 Effects on Other Living Marine Resources

To the extent that this alternative is effective in maintaining the krill population at levels that provide sufficient forage for dependent or sensitive species, this alternative will have beneficial effects on other living marine resources.

4.1.4.4 Effects on Other Fisheries

To the extent that this alternative is effective in maintaining the krill population at levels that provide sufficient forage for fish species that are the target of fisheries, this alternative will provide benefits to (or at least not adversely affect) other fisheries.

4.1.4.5 Economic Effects

To the extent that this alternative is effective in maintaining the krill population at levels that meet forage needs of dependent or sensitive fish stocks, this alternative will likely have positive economic effects. Also, such activities as wildlife viewing (whale watching, bird watching) will likely be enhanced (or at least not harmed) by this alternative if it results in healthy krill populations that support non-fish resources.

4.1.4.6 Effects on Data Collection

This alternative is not expected to result in substantial increases in data collection or research.

4.1.4.7 Effects on Bycatch

This alternative would not be expected to have significant effects on bycatch. To the extent bycatch might occur if krill fishing were permitted, the restriction of krill fishing to maintain forage values would likely reduce or prevent such bycatch.

4.1.4.8 Effects on Habitat

This alternative would likely have minor but beneficial impacts on habitat.

4.1.4.9 Effects on Protected Species

To the extent that this alternative maintains and protects the stock of krill at high levels, it would likely benefit protected species.

4.1.4.10 Administrative Considerations

This alternative may be more difficult and complex than the other action alternatives because of the issues involved. First, to achieve full protection of forage values through this approach, it may be necessary to amend all Pacific Council FMPs. To understand this problem, it is important to note that the legal and factual context was somewhat different for the North Pacific Fishery Management Council when it decided to designate krill as forage in its groundfish FMPs. That is, the MSA provides much broader authority for State management in the EEZ off Alaska in the absence of Federal regulations under the MSA. The State of Alaska has authority to manage fisheries in the EEZ, even if by non-Alaska registered vessels, that are not managed under North Pacific Fishery Management Council FMPs. West Coast States do not have similar authority. Therefore, the Pacific Council would likely have to designate krill as forage under several FMPs to extend control of krill fishing across the range of managed fisheries off the West Coast; and even this would not address the potential for a fishery by vessels not currently under any FMP management program.

Second, there is the issue of which species to include in the "forage" category. In the North Pacific Council case, there was broad agreement as to the mix of species to include in the forage category; this does not appear to be the case on the West Coast. At this point, there has been no suggestion that other species be formally included as "forage" for any managed species, though there is no question that other species (including sardines and mackerel) fill a forage role for other species (and each other to some extent). However, designation of krill alone as forage could raise the question of whether the Council is being consistent and reasonable. Therefore, this alternative is likely to take more time and resources to achieve krill conservation than the other alternatives discussed above.

SUMMARY: This alternative is more complex than it initially appeared. The legal and administrative context is different from the North Pacific Council situation. It would likely be necessary to engage in a more complex assessment of all prospective forage species, some of which may be targets of existing fisheries. This approach could reduce the risk of adverse effects from krill fishing, but at the same time would seem to both preclude krill fishing and put at risk losses from closing other forage species. Much would depend on the management controls that were ultimately chosen by the Council for regulating fishing for krill and other forage species (note that CPS are already regulated but other forage candidates are not in the Council FMPs).

4.2 Impacts of Alternative Conservation Measures

This section assesses the potential impacts of different types and levels of control through fishery conservation and management measures imposed on krill fishing. Some of these conservation and management measures could be implemented under any of the strategic alternatives described above but most if not all are generally considered in the context of the alternative to manage krill fishing under the CPS FMP. As indicated above, it is presumed that if any fishing is to be allowed, there would be permit and reporting requirements as well as authority for NMFS to place observers on board krill fishing vessels.

4.2.1 Prohibit Krill Fishing in the EEZ

4.2.1.1 Effects on Status of Krill

This would provide maximum protection for krill in the EEZ. The future productivity of krill would be affected only by events other than fishing.

4.2.1.2 Effects on Other Fish Species

This would likely provide benefits to, or at least prevent adverse effects on, other fish species by ensuring that fishing would not cause a decline in the availability of krill to other fish species at historic levels.

4.2.1.3 Effects on Other Living Marine Resources

This alternative would likely provide benefits to, or at least prevent adverse effects on, other living marine resources by ensuring that fishing would not cause a decline in the availability of krill to these resources as well as preventing any direct interaction between krill fishing and these other living marine resources.

4.2.1.4 Effects on Other Fisheries

This alternative would likely provide benefits to other fisheries to the extent that the prohibition of fishing for krill prevents any adverse effects of krill stock reduction on any other targeted fish species.

4.2.1.5 Economic Effects

This alternative would provide benefits to existing fisheries and to businesses and entities involved in such activities as whale watching. However, it would preclude fishing for krill and thus any potential economic benefits from such fishing.

4.2.1.6 Effects on Data Collection

This alternative would have no benefits in terms of added data collection and research.

4.2.1.7 Effects on Bycatch

This alternative would preclude any problem of bycatch in krill fishing in the EEZ.

4.2.1.8 Effects on Habita

This alternative would prevent any adverse impacts on habitat from fishing in the EEZ.

4.2.1.9 Effects on Protected Species

This alternative would provide benefits to, or at least prevent adverse effects of krill fishing on, protected species.

4.2.1.10 Administrative Considerations

This alternative would be relatively simple to carry out. It is consistent with existing West Coast states' laws. It is "precautionary" in that it would prevent rise of a fishery when there is little or no information about the likely risk of stock depletion from fishing and about the consequences of such a condition. It would go beyond the request of the National Marine Sanctuaries Program. While a complete prohibition of fishing might raise some concern, it is noted that there is now no krill fishing and thus no party is directly prohibited from engaging in an activity already underway. This should reduce the likelihood of objections on economic grounds. A prohibition of krill fishing is also relatively easily enforced. This alternative could be more attractive if there were a provision promoting the use of EFPs to allow very tightly controlled and monitored fishing at times and/or in places in which the risk of adverse impacts on important resources (e.g., protected species, overfished species) would be very low. There is no krill fishing now that would be eliminated so there would not be adverse social impacts that would raise concerns.

4.2.2 Prohibit Krill Fishing in EEZ Waters of National Marine Sanctuaries

This alternative would be consistent with the request of the NOAA National Marine Sanctuary officials from central California but would also include EEZ waters within the Channel Islands National Marine Sanctuary (off California) and the Olympic Coast National Marine Sanctuary (off Washington). Note that krill fishing would be prohibited under State laws in any State waters of these Sanctuaries. Krill fishing in other EEZ waters would not be prohibited but would be subject to permit, reporting and possible observer coverage requirements.

4.2.2.1 Effects on Status of Krill

This alternative would provide substantial protection to krill off the West Coast. Waters within the National Marine Sanctuaries are among the waters in which krill concentrations for spawning are most likely and in which krill concentrations supporting feeding by whales and seabirds are most critical.

4.2.2.2 Effects on Other Fish Species

Species of fish that occur in Sanctuary waters and that are dependent on or sensitive to the abundance and availability of krill in those waters will benefit from this alternative. Species that are not dependent on or sensitive to krill abundance and availability may benefit to the extent that krill fishing would not adversely affect habitat or result in bycatch of those species. There could be some indirect benefits if, by preventing fishing, this alternative ensures that the habitat enhancing role of krill (see 3.2.4) is maintained within Sanctuary waters at the least, which should benefit all resources in those waters.

4.2.2.3 Effects on Other Living Marine Resources

Other living marine resources in Sanctuary waters would benefit to the extent the protection of krill is important to these resources. This may be especially important to some seabirds.

4.2.2.4 Effects on Other Fisheries

Participants in other fisheries would benefit to the extent that the protection of krill in Sanctuaries helped maintain the stocks of the target species and the prohibition of krill fishing ensured that there would be no bycatch of those target species.

4.2.2.5 Economic Effects

This alternative would prevent adverse effects of krill fishing on other fisheries. This alternative also could have positive economic benefits if the protection of krill in Sanctuaries provided a basis for continued non-consumptive acctivities such as whale watching trips in or near Sanctuaries. It is likely that krill fishing in Sanctuary waters at some level would reduce concentrations of krill and thereby reduce krill feeding by whales. Whether this would reduce whale migrations into or through Sanctuaries is not known.

4.2.2.6 Effects on Data Collection

This alternative would have minor impacts on data collection. To the extent this alternative resulted in less krill fishing with attendant data collection/reporting, there would be less information for use in future management. To the extent this alternative ensures the continued migration of whales into or through Sanctuaries and thus enhances whale watching, it also would likely result in improved data collection.

4.2.2.7 Effects on Bycatch

This alternative would prevent any bycatch in krill fishing in Sanctuary waters. Whether there would be any bycatch in the first place is not known.

4.2.2.8 Effects on Habitat

This alternative would prevent any adverse effects of krill fishing on habitat in the Sanctuaries. This could include preventing indirect adverse effects that krill fishing might have on the habitat enhancing role of krill (see 3.2.4). It would not prevent adverse effects of krill fishing (if any) on habitat outside the Sanctuaries.

4.2.2.9 Effects on Protected Species

This alternative would prevent any adverse effects on protected species from krill fishing in the Sanctuaries. This could include the indirect effects that krill fishing could have through the reduction of krill abundance and availability for whales and seabirds within the Sanctuaries.

4.2.2.10 Administrative Considerations

This alternative would be fairly simple to implement through the amendment of the regulations for the CPS FMP. It would be responsive to the request of the NOAA National Marine Sanctuary officials from central California but would go beyond that request to include EEZ waters within the Channel Islands National Marine Sanctuary (off California) and the Olympic Coast National Marine Sanctuary (off Washington). It would provide substantial certainty of protection to krill and krill-dependent resources in the Sanctuaries, though there could be some remaining risk in adjacent waters. Whether it would be consistent with the ESA would be determined through consultations on the proposal. There is no krill fishing now that would be eliminated so there would not be adverse social impacts that would raise concerns.

4.2.3 Prohibit Krill Fishing in EEZ Waters in All National Marine Sanctuaries and in Selected Other Predator-dependent Krill Waters (e.g., off Cape Blanco; inshore of Heceta Bank and Bodega Canyon)

4.2.3.1 Effects on Status of Krill

This alternative would even more protection to krill off the West Coast. Waters within the National Marine Sanctuaries are among the waters in which krill concentrations for spawning are most likely and in which krill concentrations supporting feeding by whales and seabirds are most critical. Waters off Cape Blanco and inshore of Heceta Bank and Bodega Canyon are also known as areas of intense congregations of krill from time to time. Thus this alternative would prevent krill fishing and stock declines in more of the areas in which spawning concentrations are known to occur regularly and therefore would prevent adverse effects of fishing on spawning and reproduction in these waters. It appears this would provide very substantial protection for krill though there are other areas that may also be important for krill.

4.2.3.2 Effects on Other Fish Species

To the extent these area closures assure krill availability to other fish species dependent on or sensitive to krill abundnace and availability, they will support and protect those other species. There are no doubt other areas in which species that feed on krill could be adversely affected if krill fishing were to occur.

4.2.3.3 Effects on Other Living Marine Resources

To the extent these area closures assure krill availability to other living marine resources, fish species dependent on or sensitive to krill abundance and availability, they will support and protect those other species. There are no doubt other areas in which species that feed on krill could be adversely affected if krill fishing were to occur.

4.2.3.4 Effects on Other Fisheries

This alternative could benefit other fisheries to the extent that the target species benefit from either greater abundance and availability of krill or from any reduction in bycatch in krill fishing.

4.2.3.5 Economic Effects

This alternative would benefit existing fisheries but would preclude benefits from a krill fishery in the waters that would be closed. It is not known if krill fishing would occur if these known areas of kril concentration were closed to fishing. To the extent these closures benefit other living marine resources such as whales, they could result in benefits to activities that are oriented to those resources, such as whale watching.

4.2.3.6 Effects on Data Collection

This alternative would be less likely to result in krill fishing and associated data collection and reporting.

4.2.3.7 Effects on Bycatch

This alternative would prevent any bycatch in the closed areas.

4.2.3.8 Effects on Habitat

This alternative would preven any adverse effects on habitat from krill fishing in the closed areas. To the extent this maintains the idirect habitat enhancing effects of krill, the habitat will gain from this alternative.

4.2.3.9 Effects on Protected Species

This alternative will provide additional protection for protected species from adverse effects of krill fishing, both direct and indirect.

4.2.3.10 Administrative Considerations

This alternative would be fairly simple to implement through amendment of the regulations for the CPS FMP. It would go beyond the request from the NOAA National Marine Sanctuary officials and would almost cover the full prohibition of krill fishing in West Coast States' laws. It would provide substantial certainty of protection for krill and other living marine resources dependent on or sensitive to the abundance and availability of krill in the closed waters. Whether it is consistent with the ESA would be determined through consultations. There is no krill fishing now that would be eliminated so there would not be adverse social impacts that would raise concerns.

4.2.4 Allow Unlimited Krill Fishing Beyond 60 Miles from the Inner Boundary of the EEZ

This alternative would allow krill fishing only in waters 60 miles or more from the inner boundary of the EEZ would be permissible, but krill fishing would not be allowed shoreward of that boundary. This would encompass virtually all waters within National Marine Sanctuaries, the other areas listed in 4.3.3, and waters at or inshore of the shelf break. Thus all waters in which there are or have been observed krill concentrations would be off limits to fishing. This would go beyond the request from the sanctuary managers and would provide a larger area in which the non-consumptive values of krill would be fully protected.

4.2.4.1 Effects on Status of Krill

At this time, this alternative would not be expected to result in a substantial krill fishery. The available information from resource surveys and research suggests that krill are more likely found in concentrations in waters closer to shore, i.e., on the shelf break and around islands. There may be areas and times, however, when krill are present and concentrated in offshore waters, and this alternative would allow vessels to engage in directed and unlimited harvest of krill in those waters. It is conceivable this could provide a seasonal opportunity for large trawl vessels when not active in hake or pollock fisheries. It is not believed that this would affect the status of the krill resources closer to the West Coast, though this is not certain.

4.2.4.2 Effects on Other Fish Species

This alternative would be expected to maintain the benefits that other fish species in the closed areas gain from continued abundance and availability of krill. It would not be expected to result in significant effects on other fish species more than 60 miles from shore off the West Coast.

Krill may be one of many food sources for open ocean fish, but there is no information suggesting a dependence on or sensitivity to the abundance and availability of krill by such species as tuna and swordfish, though their role in the diet of such species as squid is not known.

4.2.4.3 Effects on Other Living Marine Resources

This alternative would not be expected to result in significant effects on other living marine resources more than 60 miles from the West Coast. However, this is somewhat uncertain. It may be that cetaceans feed on krill on the open ocean at least opportunistically. Also, some species of seabirds may feed on krill as they make more extensive at sea migrations.

4.2.4.4 Effects on Other Fisheries

This alternative would not be expected to affect other fisheries; to the extent these fisheries rely on species for which krill are important, there should be some benefit from prevention of adverse effects on target stocks due to krill fishing.

4.2.4.5 Economic Effects

This alternative is not expected to have significant economic impacts on existing fisheries. It would likely preclude establishment of a new krill fishery. This alternative could have positive benefits for activities associated with such species as whales that are dependent on krill and that are the target of non-consumptive uses (e.g., whale watching). To the extent this alternative maintains the continued availability of krill that attract whales, whale watching will be enhanced.

4.2.4.6 Effects on Data Collection

This alternative is not expected to result in any significant increase in data collection as it is not expected that a significant fishery will develop.

4.2.4.7 Effects on Bycatch

This alternative would preclude bycatch from krill fishing in the closed areas. If it results in no krill fishing anywhere, then clearly there will be no bycatch at all.

4.2.4.8 Effects on Habitat

This alternative would prevent adverse impacts on habitat from a krill fishery in the closed areas. To the extent this alternative results in continued abundance of krill, the habitat enhancing role of krill will be maintained.

4.2.4.9 Effects on Protected Species

This alternative would be expected to prevent any adverse effects (direct and indirect) of krill fishing on protected resources in the closed areas. Since the closures encompass most if not all waters in which these protected species occur and have involvement with krill, this protection could be significant

4.2.4.10 Administrative Considerations

This alternative would be relatively simple to implement. It would go beyond the limit requested by the National Marine Sanctuary Program and therefore would likely be approvable on policy grounds. It would be consistent with the prohibition on krill fishing in states' waters and thus consistent with states' coastal zone management plans. Whether it is consistent with ESA requirements would be determined through consultations in NMFS. There is no krill fishing now that would be eliminated so there would not be adverse social impacts that would raise concerns.

4.3 Alternative Controls on Krill Fishing

While area closures appear to be the most administatively simple management control for krill fishing, the Council should also consider the potentials of other controls that could provide some opportunity for fishing without serious risk to krill and associated resources.

4.3.1 Catch Limits (Quotas)

4.3.1.1 Effects on Status of Krill

The probability of any effects on krill would depend on the quota level set. A low quota would not likely have significant long-term effects on krill stocks; a large quota would have a higher probability of adverse effects. The risk of adverse effects may also vary depending on the quota level in relation to oceanic conditions. If krill are sensitive to ocean temperatures, it may be important to have a low or zero quota in warm water years, while allowing for greater harvests in cold water years. To the extent krill abundance is linked to oceanographic conditions, it could be difficult to establish a quota system that is sufficiently robust to deal with all oceanographic scenarios.

4.3.1.2 Effects on Other Fish Species

Other fish species are more or less likely to be affected in correlation with impacts on krill. To the extent a quota ensures that krill stocks will be maintained at or above some minimal level (sufficient to meet forage requirements), fishing at that quota level will presumably not result in adverse impacts on these other fish species.

4.3.1.3 Effects on Other Living Marine Resources

Other living marine resources are more or less likely to be affected in correlation with impacts on krill. To the extent a quota ensures that krill stocks will be maintained at or above levels that meet the forage requirements of these other living marine resources, fishing at that quota level would not likely result in adverse effects on those resources.

4.3.1.4 Effects on Other Fisheries

This alternative would not likely affect other fisheries so long as the quota is set at a level that ensures that forage requirements for targeted fishery stocks are met.

4.3.1.5 Economic Effects

This alternative (assuming the quota level were set to maintain krill stocks at healthy levels) would likely have positive economic impacts in terms of maintaining the values of existing fisheries and non-consumptive activities related to other resources dependent on or sensitive to the abundance and availability of krill in the EEZ. This alternative would likely preclude any significant krill fishery, thus, the economic activity that could be associated with such a fishery will not occur.

4.3.1.6 Effects on Data Collection

This alternative, if it resulted in a small fishery, would make minor contributions to the data base for a better understanding of the productivity of krill and its role in the environment. Assumikng a low quota, however, this alternative would likely not result in a fishery that would demonstrate the impacts of reduced populations of krill in the environment.

4.3.1.7 Effects on Bycatch

This alternative would not likely result in substantial bycatch as any fishery would be expected to be fairly small. However, there would likely be observers documenting whatever bycatch occurred; this would be beneficial information.

4.3.1.8 Effects on Habita

This alternative would not be expected to result in any impacts on habitat from krill fishing. If the quota were set at a low level, then any habitat-enhancing role of krill would not likely be affected.

4.3.1.9 Effects on Protected Species

This alternative would not be expected to impact protected species. However, this is not certain. A quota alone might not be sufficient to fully protect some species. Even a fishery for a low quota level could be detrimental to protected species if fishing were permitted in times and/or areas where protected species would most likely be dependent on krill abundance and availability. For example, if seabirds have a limited foraging range during nesting, it might be important to ensure that no fishing (even for a low quota) be permitted within that foraging range during the nesting period.

4.3.1.10 Administrative Considerations

This alternative would be somewhat complex to carry out. First, there would need to be a decision on the quota itself; there is a limited information base for setting a quota that would ensure that no long-term harm to krill stocks would result from fishing at that level. In addition, there are two krill stocks involved; the Council could have to decide a quota level for each or possibly for the two in combination. Third, the Council would have to consider the need for other measures to be implemented with the quota. As noted above, time or area constraints may also be critical. Finally, the rationale for the quota(s) and associated controls would have to be set forth with such factual information as exists, and there would have to be environmental and economic analysis of the alternatives. On the other hand, the Council has considerable history using quotas or other catch limits so this would not be a dramatically new management measure.

4.3.2 Limits by Season

It may be possible to identify specific times in which krill fishing (at some level) would be possible with low risk of adverse effects on krill.

4.3.2.1 Effects on Status of Krill

If krill aggregations are critical to successful spawning and reproduction or other critical life history stages, and aggregations are linked to time of year, this alternative could have protective benefits for krill by preventing harvest activities that might disrupt or adversely affect these processes. As noted above, krill congregations for spawning tend to be seasonal,though seasonality varies by species and area along the coast.

4.3.2.2 Effects on Other Fish Species

To the extent this alternative helps ensure the long-term abundance and availability of krill, other fish species that are dependent on or are sensitive to the abundance and availability of krill will benefit.

4.3.2.3 Effects on Other Living Marine Resources

To the extent this alternative helps ensure the long-term abundance and availability of krill, other living marine resources that are dependent on or are sensitive to the abundance and availability of krill will benefit.

4.3.2.4 Effects on Other Fisheries

To the extent this alternative helps ensure the long-term abundance and availability of krill and thus the abundance and availability of targeted fish species, fisheries for those targeted species will benefit.

4.3.2.5 Economic Effects

This alternative is likely to help maintain the economic values associated with fisheries and non-consumptive resource uses that are tied to the abundance and availability of krill. To the extent this alternative prevents a krill fishery that would otherwise occur, there would be a reduction in economic activity. However, it is not clear that there would be any economic losses.

4.3.2.6 Effects on Data Collection

This alternative is not likely to substantially affect the future collection of data, except that there would be no data collected to provide a basis for determining if disruption of aggregations would affect the stock in any way.

4.3.2.7 Effects on Bycatch

This alternative would not be expected to affect bycatch except to the extent that bycatch might be greater during aggregating periods than other periods in which krill might be harvested.

4.3.2.8 Effects on Habitat

This alternative would not be expected to have any impact on habitat.

4.3.2.9 Effects on Protected Species

To the extent this alternative protects the long-term abundance and availability of krill, this alternative is likely to benefit protected resources that are dependent on or sensitive to the abundance and availability of krill.

4.3.2.10 Administrative Considerations

This alternative would be somewhat difficult given the variability of spawning times and the fact that spawning times vary between species and areas of the coast. It would be necessary to establish a scientific basis for the selected closed or open seasons and to evaluate the benefits and costs of alternative closed and open seasons. This documentation would be difficult but not impossible. However, to the extent seasonal aggregations are driven as much by calendar as by oceanic conditions, it could be difficult to establish open and closed seasons that work well under all oceanographic scenarios. This alternative would not provide as much certainty of effective control as other alternatives such as area closures and low quotas.

4.3.3 Exempted Fishing Permits

4.3.3.1 Effects on Status of Krill

This measure could have long-term benefits for krill conservation if (a) EFPs are well structured and controlled, with limited size and scope and (b) activities under EFPs are well monitored such that the information base is improved for a better understanding of the krill resource and its role in the marine environment. In the short term, there should be little impact on the krill resource assuming control over the size, timing, and areas of operations under an EFP.

4.3.3.2 Effects on Other Fish Species

This alternative should have little or no impact on other fish species provided that activities under EFPs are sufficiently controlled and observed. The risk of adverse effects could be reduced by some sort of trigger condition that would curtail or terminate the EFP if certain impacts on other fish species were observed (e.g., takes of salmonids or overfished groundfish above a certain level).

4.3.3.3 Effects on Other Living Marine Resources

This alternative should have little or no impact on other living marine resources provided that activities under EFPs are sufficiently controlled and observed. It would be important to ensure that krill fishing would be precluded or at least very limited in times and areas in which cetaceans or seabirds might be especially dependent on krill abundance for forage. The risk of adverse effects could be reduced by some sort of condition that would curtail or terminate the EFP if certain impacts on other living marine resources were observed (e.g., interactions with cetaceans or a take of seabirds).

4.3.3.4 Effects on Other Fisheries

This alternative should have little or no impact on other fisheries provided that the activities under EFPs are sufficiently controlled and observed.

4.3.3.5 Economic Effects

This alternative is not likely to have direct economic effects. The long-term effects will depend on whether EFPs or other controls result in fishing and future management changes that then control fishing activities.

4.3.3.6 Effects on Data Collection

This alternative will make contributions to data collection to the extent that fishing under EFPs occurs with good observations, reporting and analysis of data generated by the fishing.

4.3.3.7 Effects on Bycatch

This alternative could be beneficial in terms of documenting potential bycatch levels if a krill fishery were to be allowed.

4.3.3.8 Effects on Habitat

This alternative would not be expected to have substantial impacts on habitat.

4.3.3.9 Effects on Protected Species

This alternative would not be expected to have direct effects on protected species, but it could result in better data on the relationship and co-occurrence of krill and protected species.

4.3.3.10 Administrative Considerations

This alternative is not especially complex. The Council has substantial experience with EFPs, and has established protocols for soliciting and processing EFP applications. Further, NMFS has delegated responsibility for EFP processing to the Regional Administrators, simplifying the decision process. EFPs have proven to be an effective tool for promoting research-oriented fishing by interested parties with little risk to the resources involved or to the resource users involved. As with most other measures, however, there remains a requirement for adequate documentation of the likely benefits and costs of the EFP and the impacts of EFP fishing on the variety of resources of concern.

4.3.4 Prohibit Krill Fishing in the EEZ Initially but Establish Process for Future Permitting

Under this alternative, the Council would adopt a conservative stance with the expectation that, through resource surveys and research cruises and with the addition of results of EFPs and other activities, there would ultimately be a sound, scientific basis for determination of conditions under which krill fishing could be reasonably permitted. At that time, the Council would amend its management strategy as necessary and appropriate so that fishing could occur if there were times, places, amounts, or other limits on that fishing to ensure that there would be no subtantial harm or excessive risk of harm to the marine resources that the Council has responsibility for. This alternative would have the same effects as alternative 1 for the present time. Future effects would depend on future management changes.

4.3.5 Combinations of Measures

The Council could conclude that a combination of measures could be adopted at this time that would allow krill fishing without excessive risk of substantial harm to the marine resources for which the Council has responsibility. It is conceivable a mix of time and area controls and harvest limits, with attendant permit, reporting and observer requirements, would allow fishing, provide sufficient protection for krill, provide sufficient protection for other living marine resources, and generate needed data for future management decisions. Unfortunately, there are dozens of possible scenarios and it is not possible to develop and evaluate them at this time. The Council would have to provide more guidance as to the range of combinations to be evaluated and possibly priorities among the objectives of the management program. This could be a very complex undertaking, and the resources required could be substantial. This alternative is not considered further at this time.

4.4 Environmental Justice Concerns

There do not appear at this time to be any environmental justice concerns associated with the prospective action to conserve and manage krill resources off the West Coast. After Council action on this document, this issue will be revisited for confirmation.

4.5 Coastal Zone Management Act Concerns

Upon selection of preferred alternatives, a request for consistency determination under the CZMA will be sent to each coastal state.

4.6 American Indian Religious Freedom Act

None of the alternatives are expected to have any effects related to this Act.

4.7 Cumulative Impacts

Generally, in combination with existing fishery controls and existing measures to protect other marine resource components, all of the action alternatives considered would likely add to the

overall conservation of important living marine resources (and associated users) along the West Coast.

5.0 MITIGATION AND UNAVOIDABLE ADVERSE IMPACTS (To be completed after Council decisions)

5.1 Mitigating Measures

5.2 Unavoidable Adverse Impacts

5.3 Irreversible and Irretrievable Commitment of Resources

6.0 CONSIDERATION OF NOAA AND CEQ SIGNIFICANT IMPACT CRITERIA

NOAA Administrative Order 216-6 (NAO 216-6) identifies nine criteria, in addition to the Council on Environmental Quality's (CEQ) regulations at 40 C.F.R. § 1508.27, for determining the significance of the impacts of an action for purposes of NEPA. For the alternatives presented in this document, the NAO 216-6 and CEQ criteria are addressed as follows:

1. Can the action be reasonably expected to jeopardize the sustainability of any targeted fish species? None of the alternatives would be expected to directly and significantly affect any targeted fish species in the area of the management action. However, the No Action alternative and the "uncontrolled fishing for krill" alternative could both result in adverse impacts on targeted fish stocks through the reduction of necessary forage.

2. Can the action be reasonably expected to jeopardize the sustainability of any non-target species? None of the alternatives would be reasonably expected to jeopardize the sustainability of any non-target species, though the risk of adverse impacts on such species as cetaceans and seabirds that are dependent on krill would be greater under the No Action and uncontrolled krill fishing alternatives. Whether these would jeopardize

the continued existence of any species listed under the Endangered Species Act (ESA) would be assessed for a consultation under that act prior to approval or implementation of any such alternative.

3. Can the action be reasonably expected to allow substantial damage to the ocean and coastal habitats and/or essential fish habitat (EFH) as defined under the Magnuson-Stevens Act and identified in FMPs? None of the alternatives would be expect to alter the expected impacts to ocean and coastal habitats and/or essential fish habitat (EFH) as defined under the Magnuson-Stevens Act for currently targeted species as designated in existing FMPs for West Coast fisheries, except that one alternative would expand the EFH designation for West Coast groundfish to include krill. There also would be no effect on any property or place listed in or eligible for listing in the National Register of Historic Places, nor would it cause loss/destruction of significant scientific, cultural, or historic resources.

4. Can the action be reasonably expected to have a substantial adverse impact on public health and safety? None of the alternatives would be expected to affect public health and safety. U.S. vessels are subject to U.S. Coast Guard safety requirements and those would not be affected by this rule.

5. Can the action be reasonably expected to have an adverse impact on endangered or threatened species, marine mammals, or critical habitat of these species? All of the alternatives except the No Action alternative and the uncontrolled fishing" alternative would be expected to contribute to protection and conservation of endangered or threatened species, marine mammals, and critical habitat of these species. A formal consultation is expected to be conducted under the ESA once the Council has decided on a proposed course of action. It is anticipated that an informal consultation addressing the potential impacts of krill fishing (if any) allowed under that proposed action will conclude that there is no need for further consultations.

6. Can the action be reasonably expected to result in cumulative adverse effects that could have a substantial effect on the target species or non-target species? None of the alternatives except the No Action alternative and the unrestricted fishing alternative would be expected to result in cumulative adverse effects that could have a substantial effect on the target species or non-target species.

7. Can the action be reasonably expected to have a substantial impact on biodiversity and ecosystem function within the affected area (e.g., benthic productivity, predator-prey relationships, etc.)? None of the alternatives except perhaps the No Action and unrestricted fishing alternatives could reasonably be expected to have a substantial impact on biodiversity and ecosystem function within the affected area (e.g., benthic productivity, predator-prey relationships). No effects in terms of introduction/spread of nonindigenous species would be expected under any alternatives.

8. Are significant social or economic impacts interrelated with significant natural or physical environmental effects? There are no identifiable significant adverse individual

or cumulative social or economic impacts associated with any of the alternatives.

9. To what degree are the effects on the quality of the human environment expected to be highly controversial? There are no known highly controversial effects on the quality of the human environment. To the extent krill fishing were to occur with little or no control, there would be more uncertain effects or a higher risk of effects that involve unique or unknown risks. Depending on the Council's final choice of action, there could be a new precedence set and possibly some impact on State or local regulations outside the EEZ.

7.0 LIST OF PREPARERS

Svein Fougner

Susan Smith

8.0 LIST OF AGENCIES AND PERSONS CONSULTED

National Ocean Services, NOAA
West Coast National Marine Sanctuaries Managers
National Marine Fisheries Service
U.S. Fish and Wildlife Service
U.S. Coast Guard
West Coast Treaty Tribes

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10.0 FIGURES

Decadal variability in abundances of the dominant euphausiid species in southern sectors of the California Current. Deep-Sea Res. II-Topical Studies in Oceanography 50(14-16): 2449-2472. Courtesy Pelagic Invertebrates Collection, Scripps Institution of Oceanography.

Figure 8. Antilogged mean and frequency distribution of abundance, *E. pacifica*, CalCOFI southern California (M. Ohman and A. Townsend, 8/6/05, Pelagic Invertebrates Collection, Scripps Institution of Oceanography LTER site, after Brinton and Townsend 2003).

Figure 9. Antilogged mean and frequency distribution of abundance, *E. pacifica*, CalCOFI central California (M. Ohman and A. Townsend, 8/6/05, Pelagic Invertebrates Collection, Scripps Institution of Oceanography LTER site, after Brinton and Townsend 2003).

Figure 10. Antilogged mean and frequency distribution of springtime abundance, *T.spinifera* CalCOFI southern California. (M. Ohman and A. Townsend, 8/6/05, Pelagic Invertebrates Collection, Scripps Institution of Oceanography LTER site, after Brinton and Townsend 2003).

Figure 11. Antilogged mean and frequency distribution of springtime abundance, *T.spinifera* CalCOFI central California (M. Ohman and A. Townsend, 8/6/05, Pelagic Invertebrates Collection, Scripps Institution of Oceanography LTER site, after Brinton and Townsend 2003).

Figure 12. Estimated annual consumption of principal northern California Current forage assemblages (benthic fauna, euphausiids, forage fish and other nekton such as cephalopods and mesopelagics) by generalized predator guilds (commercially important crustaceans, pelagics-including salmon, Pacific hake, groundfish and seabirds/marine mammals). Credit: John C. Field, Groundfish Analysis Team, NMFS SWFSC, Santa Cruz, CA.

Figure 13. Dispersal of energy from euphausiids with respect to other intermediate energy sources in the Northern California Current. The size of the boxes and the width of the bars connecting various boxes are scaled to the log of the standing biomass (within maximum and minimum levels) and biomass flow respectively. The estimated trophic level is along the y axis, and colors representing the alternative energy pathways such that energy derived from euphausiid production is blue and energy from other sources is red. Credit: John C. Field, Groundfish Analysis Team, NMFS SWFSC, Santa Cruz, CA, pers. comm 4/19/05.

Figure 14. U.S. West Coast National Marine Sanctuaries (Courtesy Pam van der Leeden and Dan Howard, NOAA Cordell Bank National Marine Sanctuary)

Figure 15. Chlorophyll along the California, Oregon, and Washington coasts, September 21, 2004, detected by Sea-viewing Wide Field-of-view Sensor (SeaWiFS), indicating coastal upwelling was strong that day. High concentrations of phytoplankton have colored the ocean waters dark green in the natural color image shown on the left; on right panel highest concentrations (dark red) are shown near the shore, especially in the northern part of the EEZ. (NASA images courtesy the SeaWiFS Project, Goddard Space Flight Center, and ORBIMAGE)

Figure 16. Essential habitat *Euphausia pacifica,* indicated in grey shading.

Figure 17. Essential habitat *Thysanoessa spinifera,*indicated in grey shading..

ATTACHMENTS

Appendix A Summary of a Meeting on California Current Krill off the U.S. West Coast, June 6, 2005

Appendix B Information on ESA Listed Species Which May Be Affected By Potential Krill Fisheries in the U.S. West Coast EEZ

Pacific Coast Krill Biology and Status

Oct-Nov 2005

From Chap.3 , Briefing Document Agenda Item D.2.a Attachment 1- Alternatives Analysis – Management of Krill off the U.S. West Coast

NMFS Southwest Region/Southwest Fisheries Science, 8604 La Jolla Shores Drive, La Jolla, CA

Krill Species of Concern

- Only 2 species likely to be targeted by a fishery because of their swarming characteristics:
  - *Euphausia pacifica*
  - *Thysanoessa spinifera*

Why Bother If There's No Harvest?

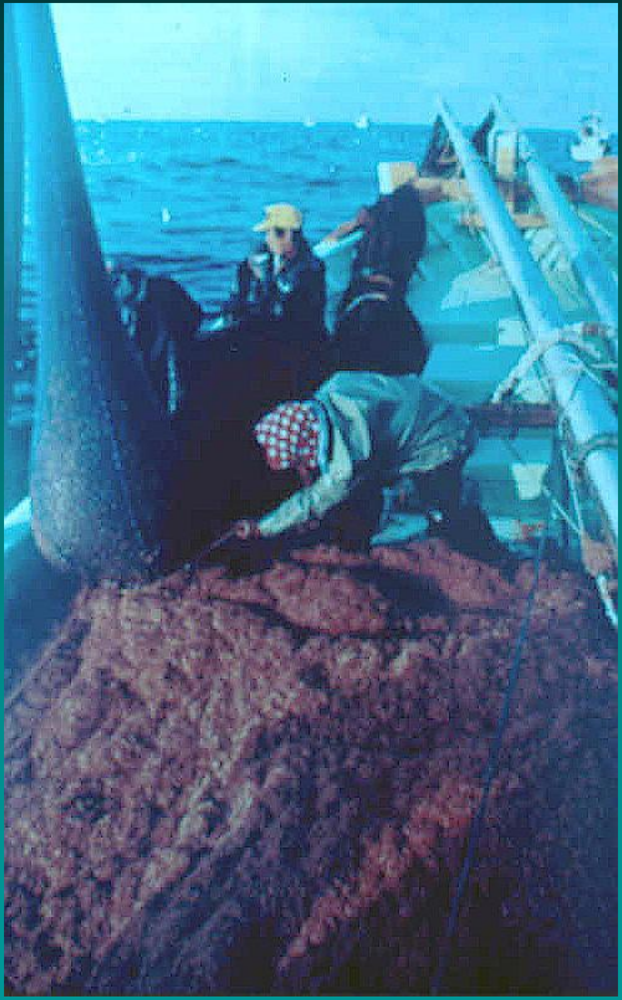
- Tho banned in state waters, out-of-state vessels could fish >3 nm and land elsewhere. Freezer vessels self-contained, do not need nearby landing ports.

- Sanctuaries concerned over potential krill fishing in their waters, where krill-dependant predators converge.

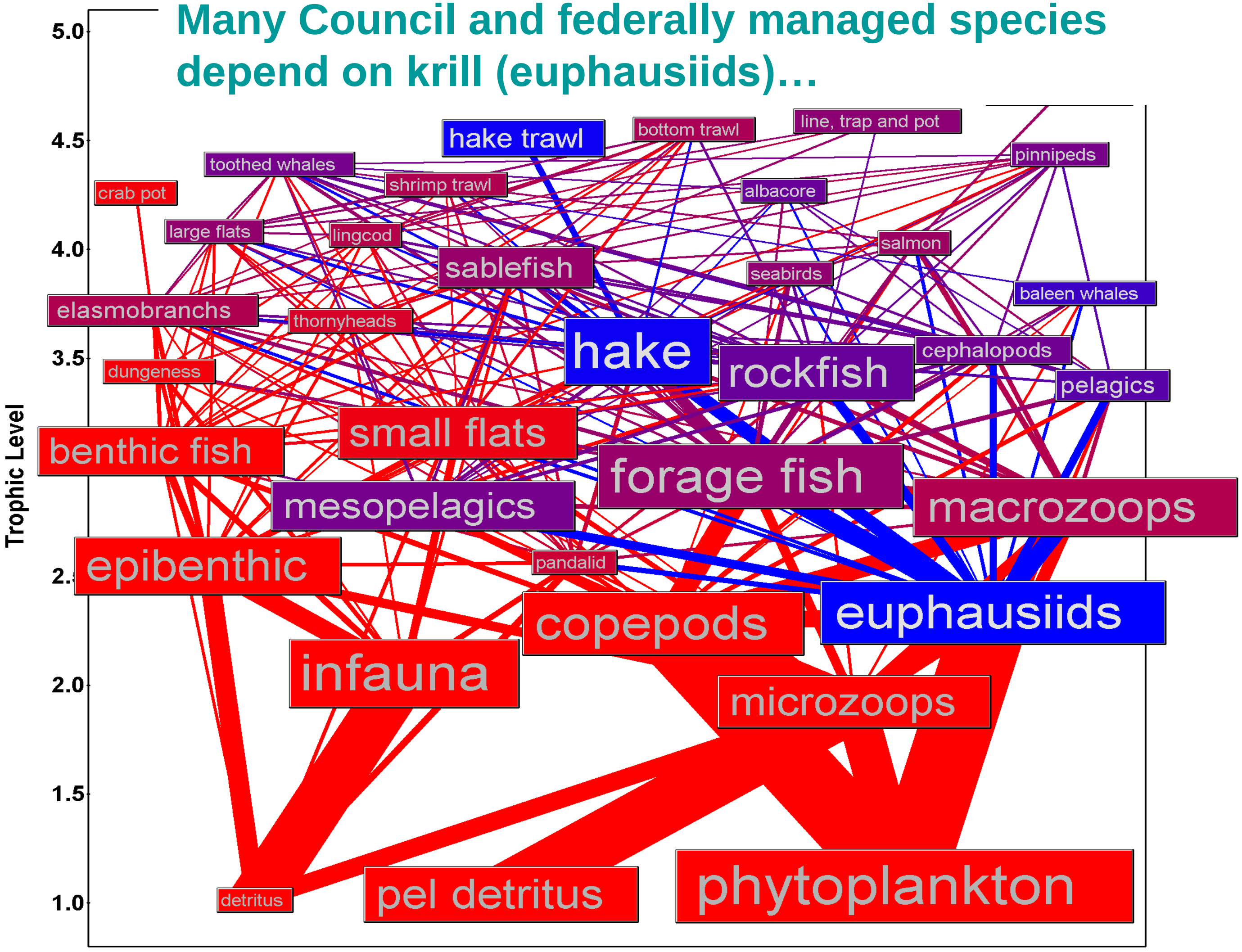
- Increased interest in krill as aquaculture feed and for various biochemical products (krill oil etc, high in Omega 3 fatty acids, antioxidants, phospholipids)

And fisheries for *E. pacifica* already exist in Japan and British Columbia, Canada.

- Japan fishery (~100,000 t yr^{-1}) self-regulated mainly to keep prices up.
- British Columbia regulated by quota and closed season--annual catch set at 500 t.



Vital link in the California Current Food Web- Many Council and federally managed species depend on krill (euphausiids)…



Energy dispersal from euphausiids with respect to other intermediate energy sources in the Northern California Current. Box size and connecting bar width scaled to log of standing biomass (within max-min levels) and biomass flow, respectively. Energy from euphausiids production in blue; from other sources, red.

From John C. Field, Groundfish Analysis Team, NMFS, Santa Cruz, CA.

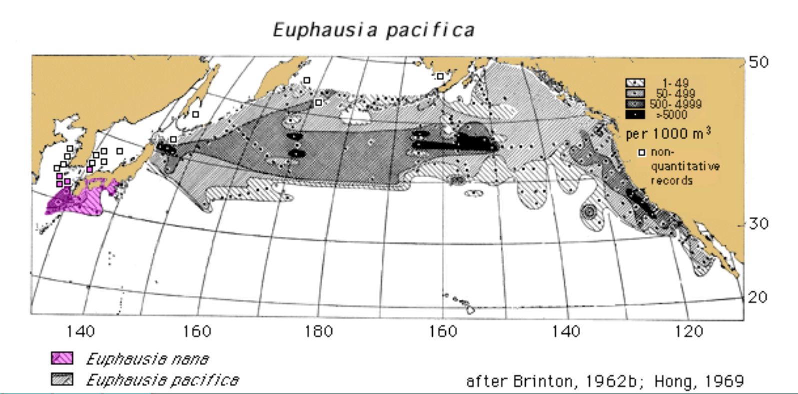
Ecosystem Importance

Not Only

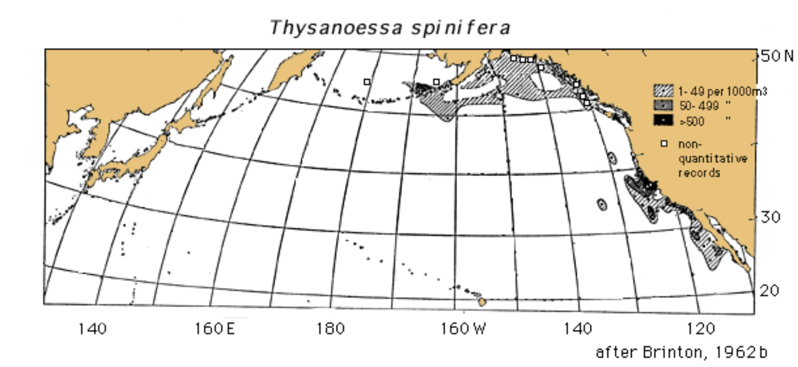
- Important forage for fish, marine mammals and birds….

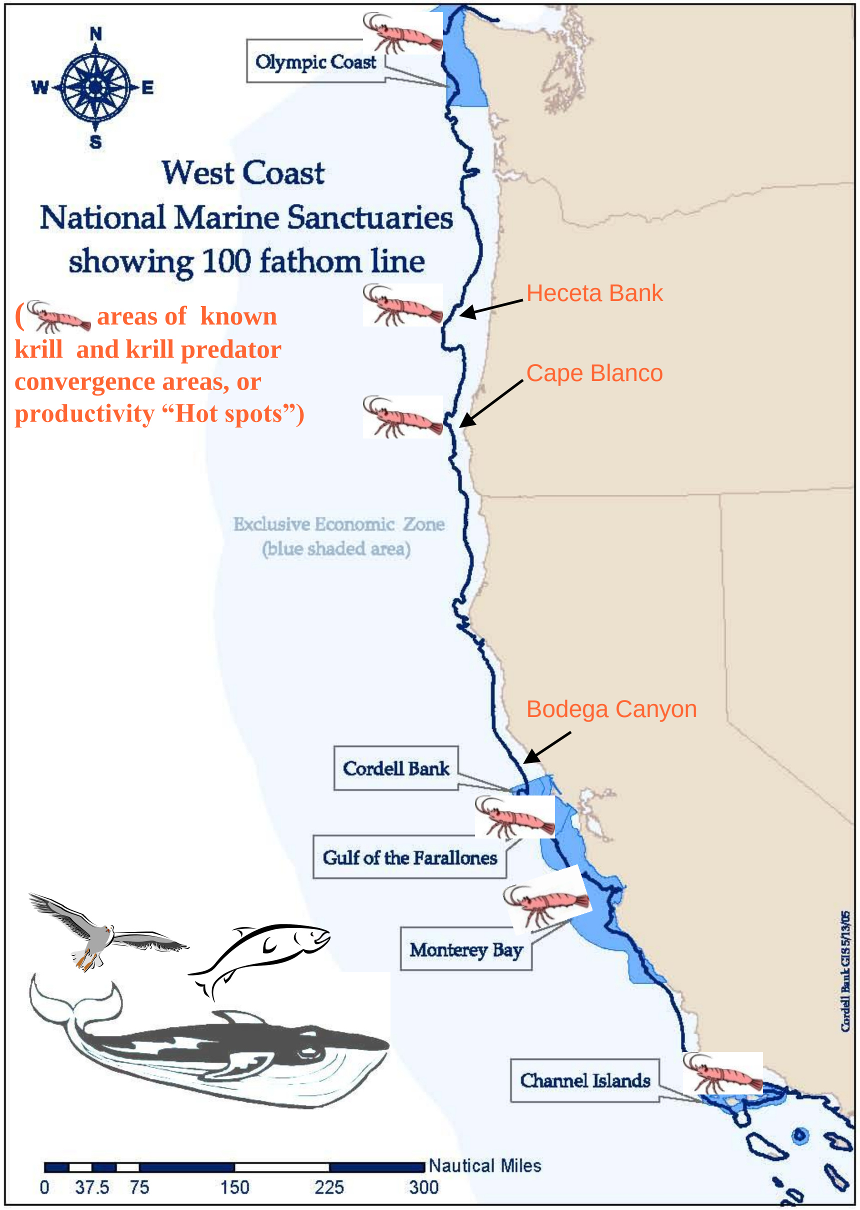
Other ecosystem roles as well….

- Krill casts (high in N, C, Vit A and chitinoclastic bacteria) are an important food source for other organisms (molt once every 5 days; produce 7x dry weight production in one year)
- Important in Vit A cycle in sea—can synthesize and store it in high concentrations-esp. in eyes.
- Krill remove and recycle vast amounts of primary production from coastal waters and may hold algal and dinoflagellate blooms in check.
- Swarms of krill influence carbon flux by physically fragmenting sinking organic particles, or "marine snow" with the collective beating of their appendages—thought to increase residence of carbon in upper water column, helping enrich the upper ocean.



Both species occur coastwide and beyond the EEZ- but krill and krill predators also known to converge in certain "hot spots", associated with major upwelling areas…….candidates for HAPCs?

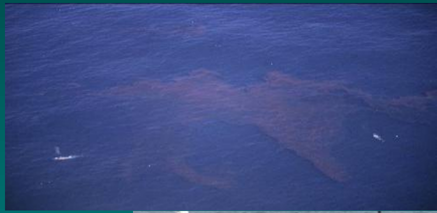




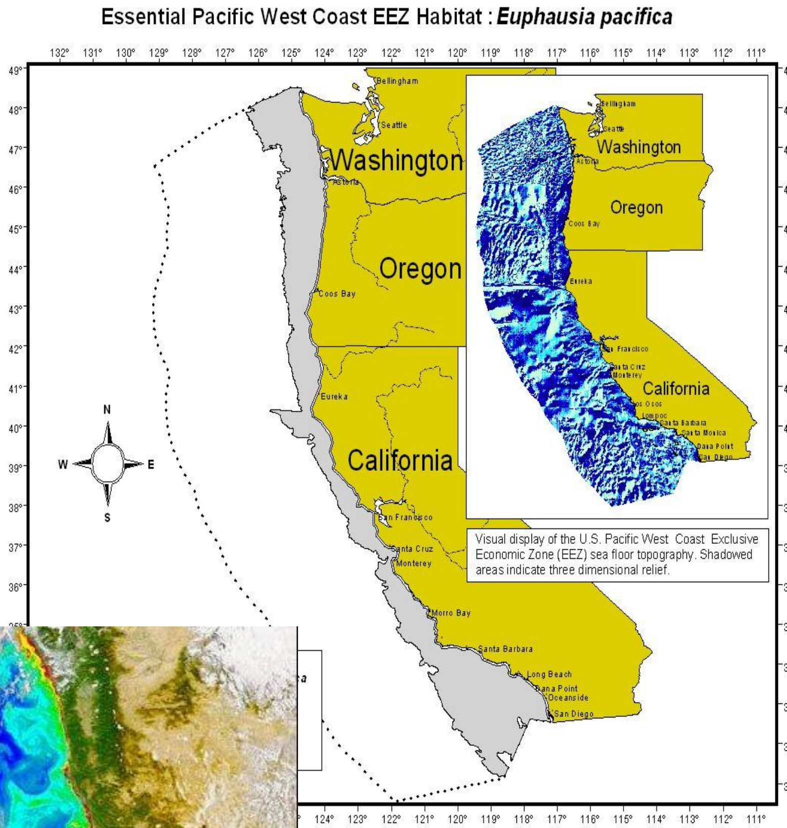
“Hot Spot” Convergence Areas Part of the Problem..

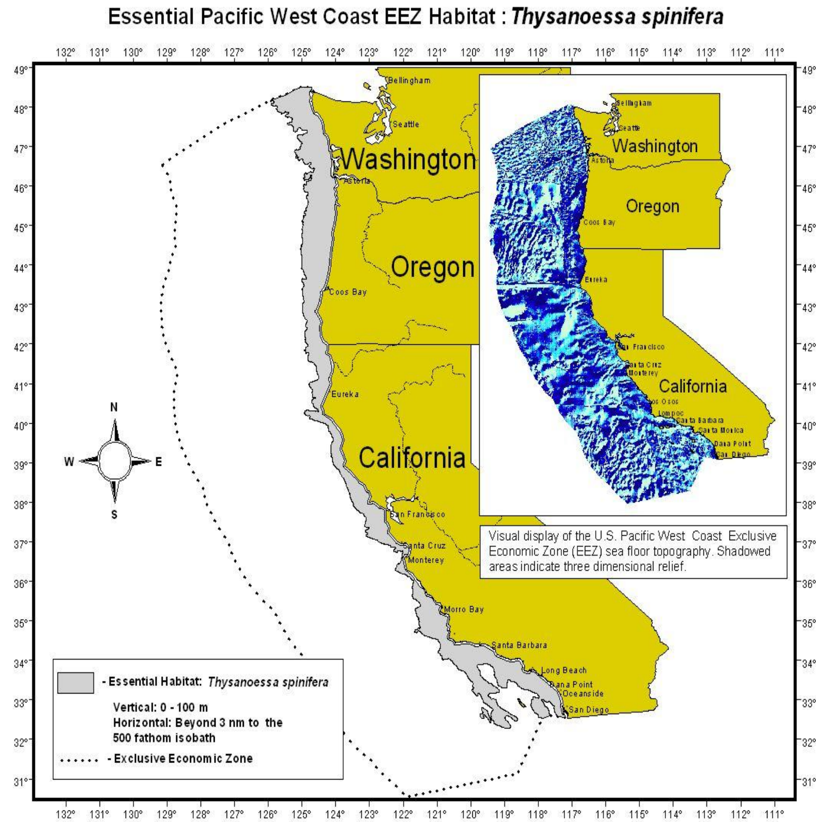
- Krill vessels will likely be highly efficient at locating these ‘hot spots’ in search of commercial densities of krill (~ > 3 g wet weight/m^3)

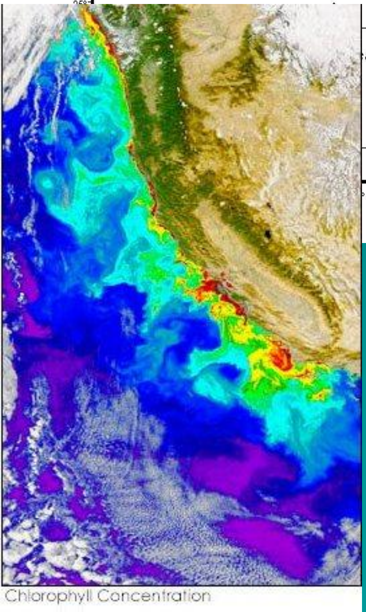
- Raises likelihood of bycatch and/or protected species interactions, with marine life of all types drawn to the same areas to feed on krill or krill predators.

Krill Essential Habitat





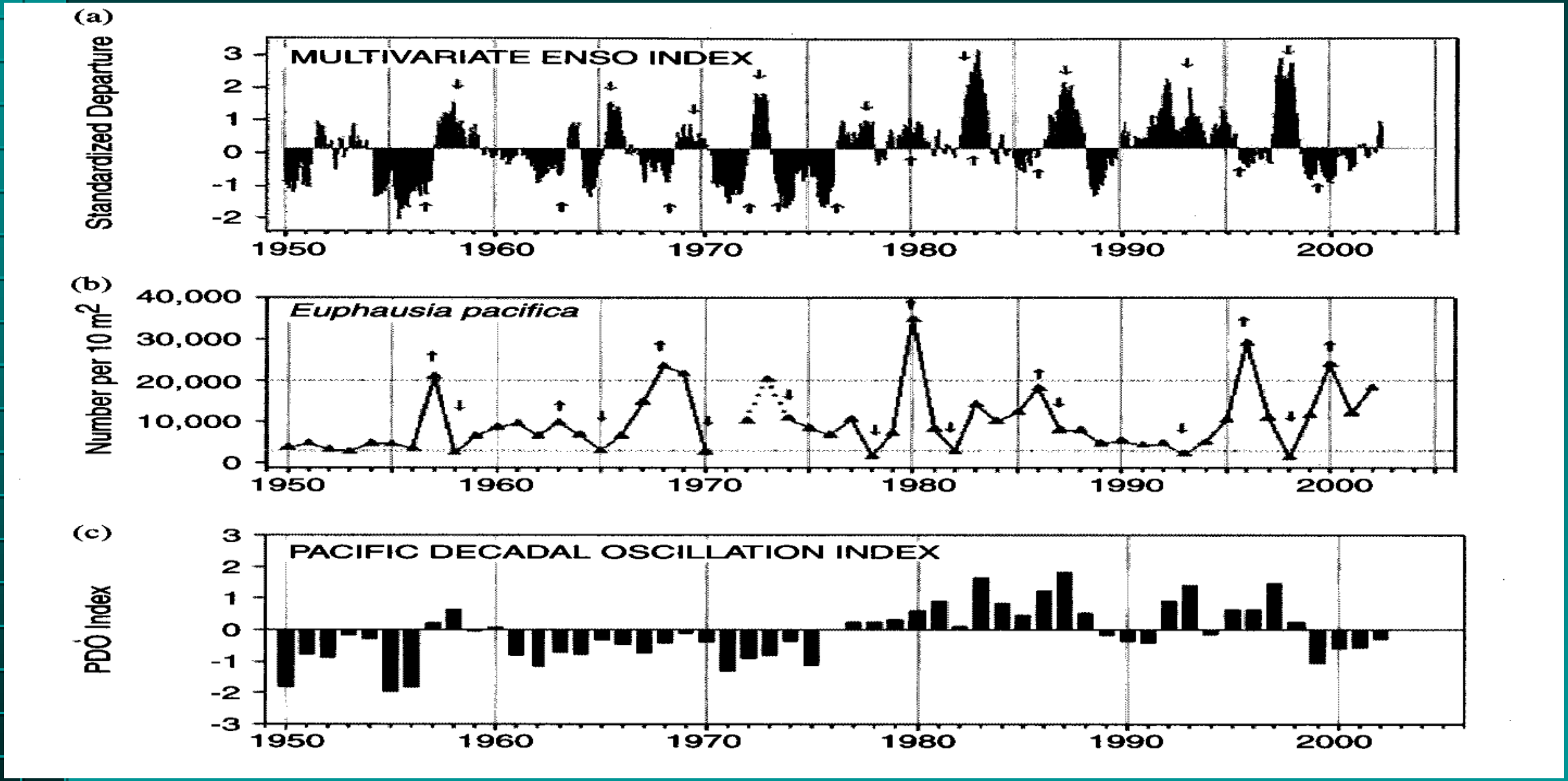


Sampling data show the bulk of krill occur in the inner quarter of the EEZ (EFH Option 2), where upwelling and primary productivity is richest…BUT offshore areas are under sampled…and upwelling jets do carry enriched waters far offshore.

Both are …

- Cool-water sub arctic species.
- Biomass can plummet in extreme warm water years; times of reduced upwelling and primary production.
- But resilient, can rebound from extreme El Niño lows (Brinton &Townsend (2003).

50-year CalCOFI time series shows extreme abundance fluctuations that can change rapidly with oceanographic conditions…



- **From Brinton &Townsend (2003).** Scripps Institution of Oceanography

June 2005 Meeting Krill Experts

- **To discuss ‘best available science’ on krill (sponsored by NMFS SWR)**
  - Krill status, distribution, best available data and stock assessment methods, also research needs.

(Summary of meeting is Appendix A of Krill Alternatives Doc.)

- **Major points were :**
  - Our review of what is known to date seems accurate,
- **BUT**
  - Still no reliable estimates of standing stock exist for either species, only very rough ‘first cut’ numbers.
  - No EEZ-wide estimates of predator/ecosystem needs
  - Estimates of distribution and abundance need to be improved

Krill Meeting Points, cont….

- **2 modeling exercises suggested to improve stock assessment in short-term**
  - Expansion of an existing ecosystem model to better gauge the ecosystem impacts of krill harvest
  - Single-species probabilistic yield model to determine the likelihood of a fishable krill surplus occurring beyond ecosystem needs.

But krill experts point out…

  - Even if more reliable yield estimate could be calculated, setting an allowable catch based on MSY may not be practical or appropriate, as krill fluctuate rapidly and extremely from year to year and even season to season depending on oceanographic conditions.

- **To improve stock assessment survey methods in both short and longer term need to --**
  - Standardize/agree upon measurement methodology (conversion factors, net density and acoustic data to convert to coast-wide, or even regional biomass estimates).
  - Convene meeting of krill bioacoustic experts to develop best survey techniques.
  - Reach agreement on spatial bounds of primary krill habitat.

Provisional B_o and *MSY* Estimates

- -- Caveats
  - Numbers based on densities observed in one area off Oregon, extrapolated to EEZ-wide area(s) presumed to represent the area(s) occupied by krill, on which experts still disagree
  - Numbers in Table 3-3 presented in way to imply precision—not our intent. Range of uncertainty varies greatly—
  - Standing stock may be reduced as much as 90% in extreme El Nino years, as observed from stock variability.
  - Predator/Ecosystem needs not specified
  - SSC consulted concerning better assessment approaches.

-

Provisional EEZ Biomass Estimates (W.T. Peterson, NMFS, Newport, OR)

Table 3-3. Preliminary estimates of standing stock (B_O) and B_{MSY} (0.5 B_O) based on assumption of average adult densities of 136 m $^{-2}$ and 16 m $^{-2}$ for *E. pacifica* and *T. spinifera*, respectively[1], for two habitat area assumptions[2]. Uses length-biomass conversions of Miller (1966) and conversion of combined species totals to fresh wet weight from W.T. Peterson and L. Feinberg (NMFS, NWFSC, Newport Oregon).

Species	Est. avg. density[1] adults m^{-3}	Est. avg. density[1] adults m^{-2}	Est. avg. Adult weight[3] (g)	Kg Km^{-2}	Est. B_O (mt) Habitat Assumption A[2]	Est. B_O (mt) Habitat Assumption B[2]	0.5 B_O (MSY) Habitat Assump. A (mt)	0.5 B_O (MSY) Habitat Assump. B (mt)
E. pacifica	6.8	136	0.064	8700	610,531	1,766,535	305,266	883,268
T. spinifera	0.8	16	0.100	1600	112,282	324,880	56,141	162,440
Total Metric Tons Preserved Weight (Miller 1966)					722,813	2,091,415	361,407	1,045,708
Total Metric Tons Fresh Weight (Peterson et al[4])					1,221,301	3,533,759	610,651	1,766,880

Total EEZ Krill B_o = 1.2 -3.5 million mt, *MSY*= 0.6-1. 8 million mt

Habitat Assumption A: Main krill densities extend 20nm on either side of shelf break, continuously length of EEZ.

Habitat Assumption B: Main krill densities extend throughout inner quarter of EEZ (approx 3x Habitat Assumption A).

[1] *E. pacifica* and *T. spinifera* avg. overall mean adult density from W. T. Peterson, NMFS,NWFSC, Newport OR, pers. comm. 9/8/05 (see text).

[2] Habitat assumption A assumes area main krill concentration 70, 176 km^2 (W. Peterson, *ibid.*, see text); Assumption B assumes area of main krill concentration within inner quarter EEZ (~203,050 km^2)

[3] Avg. adult *E. pacifica* (11-25 mm TL) from A. Townsend (Scripps Inst. Oceanogr., Invertebrate Collections); avg. adult *T. spinifera* 22 mm TL from Summers (1993); all weights calculated in preserved weight (Miller 1966) and converted to fresh for combined total (see Table 4).

[4] W.T. Peterson and L. Feinberg, NMFS,NWFSC, Newport OR. Carbon weight mg x 2.22=Dry Weight (DW) assuming carbon 45% of DW ; DW x 10 = WW (90% water). Fresh biomass est. approx. 1.7 x preserved biomass.

Summary

- Krill stocks are important in the California Current food web and have other ecosystem roles as well.
- Both stocks exhibit extreme and rapid fluctuations with environmental conditions.
- Much is known about relative abundance and long and short term variability—but little work has been done to calculate absolute abundance in the EEZ (much less stock-wide).
- Very provisional EEZ B_o and *MSY* estimates* have been assembled (W.T. Peterson) — but they do not include ecosystem needs and require further refinement, esp. agreement among researchers on methods and krill habitat occupied.
- A modest amount of additional effort –expansion of an existing regional California Current ecosystem model, and development of a probabilistic yield model is recommended. (Would help measure ecosystem effects of various harvest levels and determine the likelihood of a harvestable krill surplus occurring, respectively).
- Longer term needs include standardizing survey techniques and effort.

* B_{o} = 1.2 -3.5 million mt, *MSY*= 0.6-1.8 million mt

Acknowledgements

LIST OF AGENCIES AND PERSONS CONSULTED, INCLUDING KRILL MEETING ATTENDEES)

- NOAA Marine Sanctuaries: Dan Howard, Pam van der Leeden (Cordell Bank NMS); Barbara Blackie (Olympic Coast NMS)
- NMFS: (SWFSC): John Field, Andrew Leising, Lisa Ballace, Paul Fiedler, Kevin Hill, Roger Hewitt, Christian Reiss; Rand Rasmussen
- (NWFSC) Bill Peterson
- PRBO -Point Reyes Bird Observatory: Bill Sydeman, Jaime Jahncke, Ben Saenz
- Oregon State University: Leah Feinberg
- U.C. San Diego, SIO-Scripps Institution of Oceanography: Mark Ohman, Ed Brinton, Annie Townsend
- U.C. Santa Cruz: Don Croll, Baldo Marinovic
- California Dept. Fish Game: Dale Sweetnam
- Coastal Pelagic Species Mgt Team
- Washington Dept. Fish and Wildlife: Michele K. Culver
- Oregon Dept. Fish and Wildlife: Jean McCrae
- National Ocean Services, NOAA

EFH OPTIONS

- Option 1. Status Quo. Do not designate EFH.

- Option 2. Adopt EFH as described in section 3.8.6.

- Option 3: Designate the full EEZ as EFH

Habitat Areas of Particular Concern (HAPCs)

- **HAPC Option 1**. Status Quo–Do not designate HAPCs
- **HAPC Option 2**. Designate for krill and feeding baleen whales and other krill predators the ocean area within the boundaries of Cordell Bank, Gulf of the Farallones, Monterey Bay, Channel Islands, and Olympic Coast NOAA Marine Sanctuaries as HAPCs. These sanctuaries encompass the most important consistently krill-rich, predator feeding areas around California islands as well as important submarine canyons, bank, shelf and slope areas (e.g., Gulf of the Farallones, Pescadero Canyon, Ascension Canyon, Monterey Bay Canyon area, Channel Islands)
- **HAPC Option 3**. Designate for krill and feeding baleen whales and other krill predators the ocean area within the boundaries of Cordell Bank, Gulf of the Farallones, Monterey Bay, Channel Islands and Olympic Coast NOAA Marine Sanctuaries, and Heceta Bank area (east of longitude 125˚ 30' W Long, between 43˚50' and 44˚ 50' Lat), off Cape Blanco (east of longitude 125˚ 30' between 42˚20' and 43˚ 000' Lat), and the Bodega Canyon area as HAPCs.
- **HAPC Option 4.** Designate for krill and feeding baleen whales and other krill predators the ocean area within the boundaries of Cordell Bank, Gulf of the Farallones, Monterey Bay, Channel Islands and Olympic Coast NOAA Marine Sanctuaries as HAPCs and all other waters of the EEZ federal coastal and island waters off Washington, Oregon and California out to 60 nautical miles from shore.

Krill Management in the EEZ

- Background

  NOAA Sanctuaries Request

  Initial Alternatives Report from NMFS/GCNW

  SWR Commitment

  Decision to Use CPS FMP

  Preparation of Alternatives Analysis – NOT a NEPA document at this stage

Decisions for the Council

Select Preferred Alternatives for Public Review

- Objectives for Krill Management
- Principal Species
- Managed or Monitored Species
- Essential Fish Habitat
- Habitat Areas of Particular Concern
- Conservation and Management Measures

Alternatives Considered for Management Mechanism

- CPS FMP Amendment (preferred)
- EFH Designation (rejected)
- Forage Designation (rejected)

Draft Objectives

- Maintenance of krill stocks
- Ensure timely recovery in case of decline below critical level
- Data collection for any fishing
- Foundation for research
- Protect key foraging areas for dependent and associated predators

Managed vs. Monitored Stock

- CPS FMP has both categories
- Managed has firm MSY control rules
- Monitored has default MSY control rules
- Managed generally include quota formula
- Monitored has no catch limits but can have gear, time, area or other controls

Conservation and Management Measures Considered

- Prohibit Krill Fishing (absolute)
- Area closures
- Seasonal closures
- Quotas/Harvest Guidelines
- Limits Based on Water Temperatures
- EFPs

Management Considerations

- Magnuson-Stevens Act requirements
- Uncertainty
- Complexity
- Responsiveness
- Risk to Krill
- Economic Potentials

Summarize
Select Preferred Alternatives

- Objectives
- Species
- To categorize as active or monitored
- To select conservation and management measures
- To select EFH and HAPC

Document Adjustments

- Clarify Council decision on mechanism to be used
- Add info about managed vs. monitored stocks under CPS FMP
- Delete material suggesting FONSI until final decisions are made
- Delete material suggesting consistency with MSFCMA law until final decisions are made

Next Steps

- Complete draft EA with FMP/Reg Amendment for public distribution and review
- Public hearings? Optional
- Complete review and analysis of public comments for Council consideration 2006
- Prepare draft “final” amendment and proposed regulations following Council action

COASTAL PELAGIC SPECIES ADVISORY SUBPANEL REPORT ON ALTERNATIVES ANALYSIS FOR KRILL MANAGEMENT

The Coastal Pelagic Species Advisory Subpanel (CPSAS) met October 6, 2005 in La Jolla, California and heard a review of the alternatives analysis for controlling krill fishing by Mr. Svein Fougner.

The CPSAS agrees that krill is critically important to the ecosystem as forage fish for many species. In order to protect krill from the possibility of overharvest as well as to prevent potential detremental side effects to other fish stocks, the CPSAS agrees that the Council should explore management measures for regulating development of krill fisheries within the West Coast Exclusive Economic Zone.

However, a complete ban on krill fishing is not appropriate; more information is needed to assess the possibility of fisheries being allowed.

The CPSAS is concerned about diverting funding and resourses to krill management at the present time when considerable work and research on other coastal pelagic species (CPS) matters has been repeatedly requested and is currently underfunded and not completed.

The CPSAS believes there could be some benefit to including krill within the CPS fishery management plan, especially with regard to research opportunities on the complex of species including sardine. However, the CPSAS would recommend that krill be managed under a third category of management rather then as an “active” or “monitored” species. This third category would need to be created. The CPSAS understands that NMFS is investigating fishery management plans around the country for examples of alternate management categories or strategies that may have utility for krill management on the West Coast.

PFMC
10/17/05

COASTAL PELAGIC SPECIES MANAGEMENT TEAM REPORT ON ALTERNATIVES ANALYSIS FOR KRILL MANAGEMENT

The Coastal Pelagic Species Management Team (CPSMT) heard a presentation from Mr. Svein Fougner regarding the alternatives analysis for the management of krill prepared by the National Marine Fisheries Service (NMFS), Southwest Regional Office. Given the lack of baseline scientific information on abundance and stock structure, and the recognized importance of krill to many marine predators, the CPSMT agrees that management measures to prevent development of directed krill fisheries would be prudent. The CPSMT reviewed the Council's November 2004 preliminary preferred alternative to incorporate krill into in the Coastal Pelagic Species (CPS) Fishery Management Plan (FMP) to achieve conservation and management objectives.

The CPSMT agrees that incorporation of krill into the CPS FMP would provide a means to regulate potential krill fisheries. The CPSMT was concerned about the potential addition of considerable workload to achieve this goal, particularly when there is a great deal of work yet to be completed with regard to sardine conservation and management. The CPSMT urges NMFS to continue to take the lead in the development of an amendment. It is unclear at this time exactly how krill would be incorporated into the FMP, especially biological reference points such as unfished biomass, maximum sustainable yield, harvest control rules, and overfishing definitions would be required. The CPSMT recommends that the Council and NMFS investigate simplified management strategies under the CPS FMP which minimize the need for intensive analyses.

PFMC
10/17/05

Agenda Item D.2.c
Supplemental HC Report
November 2005

HABITAT COMMITTEE REPORT ON ALTERNATIVES ANALYSIS FOR KRILL MANAGEMENT

The Habitat Committee (HC) supports the preferred alternative to designate krill under the Coastal Pelagic Fisheries (CPS) Fishery Management Plan (FMP) and to prohibit krill fishing in the Exclusive Economic Zone (Alternative 2.3.1). By including krill in the CPS FMP, we can preclude directed harvest.

Additionally, it should be noted that the Council may also address nonfishing impacts to krill as essential fish habitat (EFH). Because krill is an important prey item, it is identified as EFH under the groundfish FMP and could be identified as EFH under other FMPs as well.

Whatever management measure the Council chooses, it should be mindful of the fact that three states already have prohibitions on krill fishing. The Council may wish to consider the implications of possible inconsistency with state regulations if limited krill fishing is allowed to occur. The HC commends the states for having taken action on prohibiting a krill fishery, and recommends the Council make management measures consistent with existing state regulations.

The proposed description of essential krill habitat does not include water shoreward of the three nautical mile boundary. The HC recommends that essential krill habitat also be considered within state waters.

PFMC
10/26/05

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON ALTERNATIVES ANALYSIS FOR KRILL MANAGEMENT

Ms. Susan Smith and Mr. Svein Fougner met with the Scientific and Statistical Committee (SSC), and summarized the data and analyses used in the "Draft alternatives analysis for the management of krill fishing off the U.S. West Coast" (Agenda Item D.2.a., Attachment 1). Information in this document will be used in the Council's process of determining how krill may be managed off the U.S. West Coast.

Two species of krill are included in the proposed action, *Euphausia pacifica* and *Thysanoessa spinifera*. Although both species may range throughout the Exclusive Economic Zone, the distribution is patchy and varies annually. Areas of high krill abundance with the presence of predators have been proposed as defining "hot spots" for the purposes of management. However, the underlying data for those area determinations was not presented. The SSC suggests that maps of krill abundance be included in the document so that an objective approach to the designation of "hot spots" can be better understood. Also, the geographic inter-annual variability of krill should be provided for the discussion of "hot spots".

Abundance data were assembled for the document from several sources, based on different sample designs and survey methods. Issues such as avoidance of sample gear during daylight surveys, and the possibility that samples may not have been taken randomly may affect the interpretation of survey data, but the influence of these effects on the analyses was not clear. The question of abundance would benefit from standardized survey methods applied coast-wide, including hydroacoustic (multi-beam) and random survey design for plankton-net sampling.

Estimates of the krill standing stock that are provided in the document appear to be reasonable based on the available data, and may serve as a provisional range of values for B_0. However, the range for B_0 provided in the document (Table 3-3) only captures the uncertainty associated with habitat assumptions used to derive the values. The SSC notes that the range would be considerably broader if the CVs from the underlying density estimates were brought into the calculations.

If the Council desires to develop a control rule for West Coast krill stocks, the concept of maximum sustainable yield (MSY) does not appear to be practical or appropriate. As in the case of market squid and sardine, the SSC suggests that explicit dependence on MSY be avoided in developing a krill control rule. The technical review for market squid (Amendment 10) determined that attempts to estimate MSY were not scientifically supportable, and it is reasonable to expect that a more thorough review for krill would reach the same conclusion. The SSC recommends that an F-based approach to developing a krill control rule be explored as an alternative, if the Council decides to manage the stock and provide for a fishery. This approach may not be dependent on unreliable estimates of biomass, and could provide an advisable level of precaution for a resource that is ecologically important as forage for other species that are managed by the Council. The approach of adding krill to the CPS FMP would appear to be a reasonable way to provide management oversight for the krill resource, while also providing an opportunity to support research into the significant data gaps that exist. However, the SSC cautions that additional work on krill may divert or dilute research resources that are important for ongoing management of other Council-managed species.

Considerable research on krill populations and harvest rates has previously been done for Antarctic krill stocks, and existing literature could provide additional insights into modeling a possible West Coast krill fishery. Also, estimates of fishable krill harvest may be possible using existing ecosystem models.

PFMC
10/31/05

OCEANA

175 SOUTH FRANKLIN STREET, SUITE 418 JUNEAU, ALASKA 99801 907.586.4050 WWW.OCEANA.ORG

September 13, 2005

Mr. D. Robert Lohn
NOAA Fisheries Regional Administrator
7600 Sand Point Way NE
BIN C15700, Bldg. 1
Seattle, WA 98115-0700

Mr. Donald Hansen, Chairman
Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 200
Portland, OR 97220-1384

Delivered via first-class mail, email: pfmc.comments@noaa.gov and facsimile (503)820-2299

RE: Krill management

Dear Mr. Lohn and Mr. Hansen:

Oceana and many others appreciate your attention to the importance of the forage fish, krill. We urge NOAA and the Pacific Fishery Management Council to take the necessary action to ban the commercial harvest of krill. As you know, **krill form the base of the marine food web**. Krill are a keystone forage species for much of the life in the California Current Large Marine Ecosystem, a significant portion of which falls within the Exclusive Economic Zone of the coasts of Washington, Oregon and California. By consuming phytoplankton, krill provide an essential link between primary production and higher trophic levels. These small crustaceans are a crucial food source for juvenile and adult salmonids, spiny dogfish, rockfish, Pacific hake, seabirds, sardine, herring, squid, baleen whales, and many other species.

Removing krill through commercial harvest would upset this balance and have significant and wide-ranging adverse effects. Krill occur in "patchy" distributions associated with upwelling zones. Patchily distributed populations are susceptible to localized depletion, as would occur with a commercial harvest. In addition, bycatch problems in a commercial krill fishery would occur on a micro-scale with macro-level effects. The fine mesh nets needed to sieve krill from the ocean will capture even the smallest larval fish. Additional strain on already taxed populations of overfished groundfish species is risky and unnecessary. The cumulative impacts of a commercial krill fishery would be severe. Pressure on overfished groundfish species, endangered seabirds, and endangered marine mammals would be exacerbated.

We've seen what can happen when krill disappear. Earlier this summer, upwelling currents failed to materialize off the California coast and subsequently so did the life-sustaining swarms of krill. Seabird die-offs were the most immediate reported result, and other ecosystem effects will undoubtedly be discovered. While this particular krill event was environmental in nature, it serves as an example of the cascading environmental effects fluctuations in krill biomass can cause and underscores the unnecessary risk a commercial catch would pose.

The Regional Fishery Management Councils have an opportunity to take a holistic ecosystem approach and provide protection for krill throughout U.S. waters. One of the Councils has taken such action. The North Pacific Fishery Management Council has taken action to protect krill and other forage fish in the North Pacific by creating a forage fish species category and banning the directed commercial harvest of krill.

The Pacific Fishery Management Council is discussing several options for krill management. We strongly urge the Pacific Fishery Management Council to take action to ban the development of a commercial directed fishery for krill. We support the adoption of a rule that specifically prohibits directed fishing for the forage fish krill at all times in federal waters of the Pacific. This action is necessary to conserve and manage the forage fish, krill, of the Pacific and further the goals and objectives of the Fishery Management Plans. We look forward to working with you on this issue.

Sincerely,

Jim Ayers
Director, Pacific Region

cc: PFMC members
Mr. Leonard Scardino
Dr. Donald McIsaac

Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 200
Portland, OR 97220-1384

RECEIVED
SEP 27 2005
PFMC

Re: Request to Protect Krill as a Forage Species

Dear Pacific Fishery Management Council Members,

The West coast of the United States supports some of the world's most important commercial fisheries. These fisheries are made possible by the extremely productive waters of the California Current System off the coast of Washington, Oregon, and California and the Alaska Current in the Gulf of Alaska. Euphausiids, or krill, play a central role in these marine ecosystems. **Krill form a key link between phytoplankton and commercial and recreationally important fish, marine mammals, and seabirds. Most species (including humans) are only one or two feeding levels away from krill, and it is the primary prey of most of the commercial fish, marine mammal, and seabird species of Alaska, Washington, Oregon, and California.** Commercially important species that directly or indirectly depend upon krill include salmon, pollock, rockfish, hake, flatfish, squid, mackerel, sardine, and herring. The combined economic value of these resources exceeds $5 billion annually.

Krill production in these waters support some of the most diverse fish, marine mammal and seabird communities in the world including 6 species of threatened or endangered marine mammals and 1 species of endangered seabird – all of which either directly or indirectly depend upon krill resources. As a group of fishermen, marine biologists, and conservationists we believe that krill is a trophic key for Pacific Coast ecosystems – for both fished and protected species. In order to effectively protect these important marine resources and the ecosystem upon which they depend, it is critical to protect the integrity and health of krill off the West coast of the United States. **Commercial and recreational fisheries can only recover if the ecosystems upon which they depend are intact.**

In recognition of its importance in marine food webs, krill fishing has been banned in the state waters of Washington, Oregon, and California. Recently the PFMC was asked to consider a similar ban for Federal waters. Based primarily on the advice of NMFS, at the November 2004 meeting, the Council

"directed staff to begin development of management measures to regulate directed fisheries for krill within Council-managed waters. These measures would be incorporated into an amendment to the CPS FMP as described in Option 2 of Options for Controlling Fishing for Krill (Agenda Item H.4.b, November 2004)." *PFMC decisions, November 2004, PFMC website.*

If formally adopted, this option (amending the CPS FMP for krill) could open the door for directed commercial krill fishing in Federal waters. It is not clear why the Council is tentatively adopting option 2 rather than option 3 – designating krill as forage under one or more FMPs and thereby prohibiting fishing for krill. This would a) protect this important forage species for commercially important and protected resources, b) be consistent with ecosystem management goals for the Pacific fisheries, and c) be consistent with the ban established by state regulatory authorities in Washington, Oregon, and California.

The Presidentially-appointed US Commission on Ocean Policy recommended that marine resources should managed on an ecosystem basis "to reflect the relationships among all ecosystem components, including humans and nonhuman species and the environments in which they live." (US Oceans Commission Report – Executive Summary, September 2004). Protecting krill resources is the most direct means to achieve such a policy. While fully protecting krill will have no economic impact on existing commercial or recreational marine resources, the initiation of a fishery may have severe impacts. While not particularly controversial, fully protecting krill will help preserve and maintain the health of the marine ecosystem upon which commercial and recreational users depend.

In its April 2005 meeting the Council:

"reviewed a progress update from National Marine Fisheries Service (NMFS) Southwest Region (SWR) on a proposed course of action for management of krill in the West Coast Exclusive Economic Zone and National Marine Sanctuaries under the auspices of the Coastal Pelagic Species FMP. The Council approved a draft outline for an alternatives analysis. The Council will provide guidance on a preferred schedule at the April meeting following a progress update from NMFS SWR on the alternatives analysis." *PFMC decisions, March 2005, PFMC website.*

This decision resulted in the issuing of a Statement of Work for the development of a NEPA-consistent Alternatives Analysis for krill management (Agenda Item F.1.a NMFS Report 2 April 2005). It is not at all clear to us how the Council has decided to tentatively move forward with Option 2 of the Options for Controlling Fishing for Krill (Agenda Item H.4.b, November 2004) before the Alternatives Analysis that should provide the information upon which to base any management decision has been completed. This concern was underlined by PFMC and NMFS moving forward with a meeting that was held on June 6, 2005 at the Southwest Fisheries Science Center to:

"discuss the status, distribution, existing data sets and potential stock assessment methods, and management research needs for these two species in the EEZ. The Pacific Fisheries Management Council hopes to develop a program to regulate potential krill fishing in federal waters under the Magnuson-Stevens Act." *Summary of a Meeting on California Current Krill off the U.S. West Coast, June 6, 2005. NMFS Southwest Fisheries Science Center, Large Conference Room.*

We strongly feel that Option 3 is the better management approach, and believe that any actions to develop a stock assessment analyses – tentative or otherwise – for krill management should not be made until the Alternatives Analysis described in Agenda Item F.1.a NMFS Report 2 April 2005 has been completed.

Specifically, as a group of researchers, commercial stakeholders, and non-government organizations, we would like to urge the PFMC to fully consider and adopt Option 3 (protect krill as a forage species) as the approach that a) protects coastal pelagic ecosystems, b) insures the long-term sustainability of coastal pelagic commercial fisheries, c) assures the protection and recovery of threatened or endangered marine species, d) is consistent with management policies already adopted by Washington, Oregon and California State regulatory authorities, and e) is a comparatively painless way for the Council to proactively enact an ecosystem-based management approach to marine resources . Thank you for your consideration.

Sincerely,

Donald A. Croll
Associate Professor
University of California, Santa Cruz

Leon Panetta
Director
Panetta Institute

Zeke Grader
Executive Director
Pacific Coast Federation of Fishermen's Associations

Susan Williams
Director, Bodega Marine Laboratory
University of California

Tim Eichenberg
Acting Director
Pacific Regional Office
The Ocean Conservancy

Jennifer Bloesser
Science Director
Pacific Marine Conservation Council

Rod Fujita
Scientist
Environmental Defense

Caroline Karp
Chair
Sierra Club Marine Wildlife and Habitat Committee

Gary Griggs
Director, Institute of Marine Sciences
University of California Santa Cruz

William Sydeman
Research Director
Point Reyes Bird Observatory

Baldo Marinovic
Research Biologist
University of California Santa Cruz

Bernie Tershy
Executive Director
Island Conservation

James Ayers
Pacific Director
Oceana

Brendan Cummings
Marine Biodiversity Program Director
Center for Biological Diversity

James Harvey
Professor
Moss Landing Marine Laboratories

John Calambokidis
Director
Cascadia Research

Kenneth Coale
Director
Moss Landing Marine Laboratories, California State University

Roy Thomas
President
Carmel River Steelhead Association

Darus Peake
Chairman
Oregon Salmon Commission
And
Commissioner President
Port of Garibalidi, Oregon

Mike McCorkle
President
Southern California Trawler's Association

Steph Dutton and Heidi Tiura
Captains
Sanctuary Cruises

Jan Hodder
Professor
University of Oregon Institute of Marine Biology

Ernie Koepf
President
California Herring Fishermen's Association

Dan Wolford
Science Director
Coastside Fishing Club

Coastside Fishing Club
666 Brighton Road, Pacifica, CA 94044

Agenda Item D.2.d
Supplemental Public Comment 2
November 2005

7 October 2005

Dr. Donald McIsaac
Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 200
Portland, OR 97220-1384

Krill Harvest Ban Option 3 Endorsed

At the November 2004 meeting the Council initiated action to protect krill: "Based primarily on the advice of NMFS, the Council directed staff to begin development of management measures to regulate directed fisheries for krill within Council-managed waters. These measures would be incorporated into an amendment to the CPS FMP as described in Option 2 of *Options for Controlling Fishing for Krill* (http://www.pcouncil.org/bb/2004/1104/nmfsrpt_h4b.pdf). The Council also included a specific alternative for analysis that would prohibit directed krill fisheries within waters of West Coast National Marine Sanctuaries." http://www.pcouncil.org/decisions/1104decisions.html. We appreciate and applaud the Council's intent to protect krill.

However we strongly disagree with the Council's choice of Option 2 as the means to achieve that protection. Option 2 in fact creates the legal structure leading to the establishment of a krill fishery. It will lead to the removal of krill from the ecosystem, and will threaten the viability of many recreationally important fisheries. Rather than protect krill, it likely will have exactly the opposite effect. We must reject Option 2 as a viable option.

Option 3 ((http://www.pcouncil.org/bb/2004/1104/nmfsrpt_h4b.pdf)) is much more likely to achieve the desired protection, by designating krill as forage under one or more FMPs and prohibit, outright, fishing for krill. This designation would protect this important forage species for recreationally important fisheries. This option is much more direct and specific (than Option 2) in its intent and in its actions. Rather than encourage and then attempt to regulate an emergent krill fishery (as in Option 2) this Option would ban development of a krill fishery altogether. This is a much stronger and much preferred approach; consistent with the intent, desires, and actions of each of the three Pacific States, and with the principles of ecosystem management.

The Coastside Fishing Club is greatly concerned about the negative impacts of possible emergent krill fisheries inside the Pacific EEZ. We cannot state strongly enough that krill are an important forage species for our recreational fisheries, and deserving of the highest measures of protection. Any action that threatens to reduce the availability of krill, by any amount, is a direct threat to recreationally important fisheries, including salmon and rockfish. In an era where so few Klamath River salmon constrain an entire fishery, removal of forage fish will only exacerbate the problem.

Coastside Fishing Club
666 Brighton Road, Pacifica, CA 94044

In an era where a few critical rockfish stocks constrain millions of recreational fishermen, an emergent krill fishery will have devastating impacts.

The ecosystem implications of an emergent krill fishery are immense. These animals serve as an essential food source for fish, many marine mammals including whales and seals, and seabirds. Specifically they are an essential food source for Canary Rockfish and Bocaccio, two fish stocks that control nearly all Pacific Coasts recreational rockfishing, and for dozens of other rockfish species. (Love, et al, The Rockfishes of the Northeast Pacific, 1989) Krill occupy a unique niche in the ocean's ecology. "Feeding on phytoplankton and small zooplankton, krill populations expand and become a critical link in many marine systems. Krill convert energy from the primary producer level into a form that is useable by animals in the upper levels of the marine food web. Krill often are referred to as "keystone" species because they ... are a major food source for salmon... rockfish, seabirds, and a myriad of lesser known species .... The main reason humpback and blue whales visit the (Cordell) Bank in the summer is to fatten up on krill to prepare for the rigors of the coming year.... Krill are a critical source of energy for seabirds, penguins, seals, sharks, octopus, and many species of whales." (Dan Howard, *Krill in Cordell Bank National Marine Sanctuary.*) Removal of any amount of such a critical element at the base of the food chain will likely have impacts on the entire health of the ocean.

An emergent krill fishery cannot be managed as a single species, whereby an MSY can be computed on the basis of the survivability of the species; rather this fundamental element of the food chain must be viewed as a critical element of the entire ocean ecosystem. Ecosystem management is not a catch phrase for krill, but an absolute necessity. While a management error relating to the top predators (most commercial and recreational fishes) may have dire implications for that fishery, the effects may largely be confined to that fishery. However a management error relative to krill may have dire effects relative to the health of the entire ocean ecosystem and to all of the commercial and recreational fisheries. We cannot afford to take that risk.

The lack of data on the present and historical biomass of krill, on its overall role in the ecosystem, on its significance to specific recreational fisheries, and on the likely impacts of an emergent krill fishery, create an situation in which attempts to manage an emergent Krill fishery are certain to lead to disaster: a disaster that is likely to have immense and negative impacts to the entire ecosystem of the Pacific fisheries. "Scientific management of the krill fishery requires that we know a great deal about the biology of krill. To date it has proved extremely difficult to study these oceanic animals since they will not adapt well to laboratory conditions" (Dr. Stephen Nicol, *Time to Krill.*) Management requires data, and an ability to react to, and to control potential outcomes. In the absence of data, control is not possible. In today's data poor environment, the only appropriate action is to create an outright ban on a krill fishery, not to encourage an emergent fishery and then attempt to manage it.

Specifically, as a faction of the recreational fishing community, the Coastside Fishing Club urges the PFMC to fully consider and adopt Option 3 (protect krill as a forage species within an existing FMP – such as Salmon and/or Groundfish) as the approach to protect oceanic ecosystems, ensure

Coastside Fishing Club
666 Brighton Road, Pacifica, CA 94044

the long-term sustainability of coastal fisheries, assure the protection and recovery of threatened or endangered marine species, maintain consistency with management policies already adopted by Washington, Oregon and California, and lead the Council towards adoption of an ecosystem-based management approach to marine resources.

The Coastside Fishing Club is an all volunteer, California non profit organization with more than 10,000 members, dedicated to improving the recreational fishing experience for all Californians.

Dan Wolford

Orig /s/ Dan L Wolford

Science Director
Coastside Fishing Club

Copies to

Mike Burner
John DeVore
Chuck Tracy
Carolyn Porter
Sandra Krause
Bob Franko
Darrell Ticehurst
Chris Hall
Mike Giraudo
Ben Sleeter
John Vietor

CALIFORNIA WETFISH PRODUCERS ASSOCIATION

Representing California's Historic Fishery

October 24, 2005

Dr. Don McIsaac, Executive Director
Mr. Don Hansen, Chair
Members of the Pacific Fishery Management Council
7700 NE Ambassador Place #200
Portland, OR 97220-1384

RE: Agenda Items D.1.d SARDINE STOCK ASSESSMENT and HARVEST GUIDELINE and D.2.d ALTERNATIVES FOR KRILL MANAGEMENT

Dear Dr. McIsaac, Chairman Hansen and Council members,

These comments are submitted on behalf of the California Wetfish Producers Association, which represents the majority of wetfish processors and fishermen in Monterey and southern California. We appreciate this opportunity to present our views and concerns regarding the CPS agenda items noted above.

Re: D.1.d – Pacific Sardine Stock Assessment and Harvest Guideline, we fully support the statement of the CPS Advisory Subpanel, with emphasis on the underlined portions:

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). However, the CPSAS voiced unanimous and strong concern that research on Pacific Northwest (PNW) sardine has not been adequately incorporated in the model to date. Furthermore, additional research is needed to evaluate the migration rates, spawning contribution, and relationship of PNW sardine to the spawning biomass as a whole.
The CPSAS is encouraged about plans for a synoptic survey of the sardine resource in April 2006. The CPSAS recommends that data collected during research surveys in the PNW be analyzed and included in the assessment model for the next year's stock assessment.
And:
The CPSAS recommends the Council encourage National Marine Fisheries Service to continue to fund comprehensive annual CPS research, including the survey off the PNW and explore a possibility to encourage similar surveys in Canada and Mexico.

PO Box 1951 Buellton, CA 93427 Telephone 805-693-5430 Fax 805-686-9312
Email <dplesch@earthlink.net>

<u>The CPSAS continues to strongly believe that coordinated international management of CPS fisheries is essential to avoid the potential for coastwide overfishing</u>. Moreover, the CPSAS also agrees that inclusion of complete Mexican catch statistics is vital to the CPS assessment process.

We would greatly appreciate the Council's continued appeals to the NMFS and the State Department, stressing the critical importance of trinational sardine research and transboundary cooperative management to avoid overfishing the Pacific sardine resource.

Re: D.2.d. – Alternatives for Krill Management

As a member of the Coastal Pelagic Species Advisory Subpanel, I supported the CPSAS statement presented to the Council on this issue. However, because I'm unable to attend the November Council meeting in person, I appreciate this opportunity to offer the following clarification of the CPSAS statement from the perspective of CWPA and California's wetfish industry.

First, CWPA members agree that krill is critically important to the ecosystem as forage for other marine life, and in order to avoid potentially negative effects to other species, the Council should explore measures to protect krill from overharvest. However, we're concerned that implementing a ban on krill fishing through the CPS Fishery Management Plan, with scant information on the resource, could set a potentially damaging precedent for other CPS fisheries.

We understand that, to date, the Council has received no proposals to begin a krill fishery off the west coast. We further understand that all three west coast states have longstanding prohibitions against landing krill in any west coast port. Thus the recent interest in regulating krill is driven by a fear that a fishery could develop at some future time, through a loophole in the "national" list of fisheries at 50 CFR 600.725 that provides a general category of "fishing with trawl gear" for unspecified species among the fisheries listed by NMFS for waters under the jurisdiction of the PFMC. Thus, someone wanting to engage in fishing for krill with trawl gear (the principal gear used in other krill fisheries) off the West Coast would not need any permits from NMFS and, as with a factory-trawl catcher-processor vessel, could avoid landing the catch on the west coast.

We understand and support the Council's interest in acting to protect krill from the unintended consequence of unregulated fishing. However, we also agree with and support the concern expressed by the CPSAS re: diverting funding and resources to krill management at a time when considerable work and research on other CPS, specifically sardine, have been repeatedly requested and are currently under-funded and incomplete.

If there could be some benefit to including krill within the CPS FMP, especially with regard to providing additional resources to enhance research on the complex of species including sardine, we could support the proposal to amend the CPS FMP to include krill. However, we also agree with and reiterate the CPSAS recommendation that krill be included under a third category of management rather then as an "active" or "monitored" species. This third category, such as a research category, would need to be created.

Our first preference, however, is to investigate other examples of alternative categories or strategies that may have utility for krill management on the West Coast.

Perhaps the most direct and immediate action would be to close the existing loophole by amending the list of fisheries to clarify that the general category of "fishing with trawl gear" for unspecified species does not include krill. Then anyone wanting to engage in krill fishing with any other gear (e.g., purse seine) would be required to notify the Council 90 days in advance. The Council would have opportunity at that time, based on real, rather than hypothetical, interest, to advise NMFS on how to control the activity.

We have read with interest the public comment submitted in support of prohibiting fishing on krill by listing it as forage in other FMP-managed fisheries. While we appreciate the concern expressed for krill's importance in the ecosystem, we also agree with the conclusion reached in the alternatives analysis that many species could be so categorized – in fact, virtually every organism in the marine environment is forage for something else. We suggest that perhaps the most direct and immediate approach is to clarify the list of fisheries, which would buy additional time to further investigate the best solution to regulate krill.

Thank you very much for your consideration of these comments.

Best regards,

Diane Pleschner-Steele
Executive Director

OCEANA
175 SOUTH FRANKLIN STREET, SUITE 418 JUNEAU, ALASKA 99801 907.586.4050 WWW.OCEANA.ORG

October 25, 2005

Delivered via facsimile: (503) 820-2299 / (206) 526-6426 and email: pfmc.comments@noaa.gov

Mr. D. Robert Lohn, Regional Administrator
NOAA Fisheries
7600 Sand Point Way NE
BIN C15700, Bldg. 1
Seattle, WA 98115-0700

Mr. Donald Hansen, Chairman
Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 200
Portland, OR 97220-1384

RE: Agenda Item D-2: Alternatives Analysis For Krill Management

Dear Mr. Lohn and Mr. Hansen:

Oceana urges the Pacific Fishery Management Council and NOAA Fisheries to continue to pursue the goal of protecting the health of the ecosystem by prohibiting directed fishing for all krill in the Pacific EEZ. The PFMC has demonstrated their commitment, authority and responsibility to take this important conservation action. Prohibiting directed fishing for all krill in the Pacific EEZ would be consistent with the principles of ecosystem-based management, as well as actions taken by West Coast member states and the Alaska region.

In June 2004, the PFMC acknowledged the role of krill in the marine environment, "initiated consideration of prohibiting [emphasis added] directed fisheries for krill" and directed Council staff to "develop information on the procedural mechanisms for prohibiting fishing for krill and other forage species within the Pacific coast EEZ."[1] The draft alternatives analysis does include an alternative that would meet the Council's requested analysis of prohibiting directed fishing for krill species in the Pacific EEZ. The other management options leave the door open to directed krill fisheries and are fraught with peril. Selection of any alternative that permits the pioneering of a new fishery on a keystone species would require a full-blown Environmental Impact Statement, a more

[1] McIsaac, D.O. December 16, 2004. Letter to Mr. McInnis and Mr. Fox, NMFS. RE: The process for developing restrictions on the directed harvest of krill within the Pacific coast Exclusive Economic Zone. Pacific Fishery Management Council. Agenda Item G.2.a. March 2005.

time-consuming, complex, and expensive path than the one the Council is currently on to act precautionarily to preclude a fishery.

As you are aware, krill act as "keystone species" in the California Current Large Marine Ecosystem because of the essential role they play as prey for a wide diversity of marine life. Krill are a major food source for many fishes including rockfish, hake, herring, threatened and endangered salmon, plus seabirds and endangered baleen whales. Krill populations exhibit great natural variability in abundance and areas of high krill density are patchily distributed. This increases the potential for any directed fishery to cause localized depletions of krill and krill-dependent marine life. When krill disappear, as they did last summer when upwelling currents failed to materialize, there are serious and direct consequences. Seabird die-offs were the most immediately reported result, and other ecosystem effects will undoubtedly be discovered.

The only responsive management approach in the alternatives analysis is outlined in section 2.3.1, which would amend prohibit directed fishing for two krill species throughout the Pacific EEZ. The alternatives analysis finds this approach would provide the maximum protection for krill and krill-dependent predators, ensuring natural levels of prey for endangered marine life such as whales and commercially important fish. The analysis states that this alternative would be "relatively simple to carry out," and that it is "precautionary" and "consistent with West Coast states' laws."[2] Additional approaches to accomplish the same objective worthy of consideration would be revision of the list of fisheries (50 C.F.R. § 600.725), or preparation of a generic amendment to designate all krill as a "prohibited species."

The alternatives analysis highlights the many difficulties associated with managing a krill fishery. The analysis notes the extreme variability in abundance of krill, the lack of standardized surveys and the poor available information on krill distribution coast wide. Further, the analysis highlights the critical link krill provide in the food web and the certain negative impacts a fishery would have on krill-dependent predators, commercial fish and squid and federally protected marine mammals and birds. Recognizing these facts, the Coastal Pelagic Species Management Team stated: "Given the lack of baseline scientific information on abundance and stock structure, and the recognized importance of krill to many marine predators, the CPSMT agrees that management measures to prevent development of directed krill fisheries would be prudent."[3]

[2] NMFS 2005. Alternatives Analysis. Management of Krill Fishing off the U.S. West Coast, at 76.
[3] CPSMT Report. October 17, 2005. Pacific Fishery Management Council. Agenda Item D.2.c. November 2005.

While the alternatives analysis looks at several options for managing krill, the only responsive and responsible option is to prohibit directed krill fishing throughout the federal waters of the Pacific EEZ. We urge the Council to select the alternative that prohibits fishing for all krill in the Pacific EEZ as the preferred management approach.

Sincerely,

Jim Ayers
Director, Pacific Region

The Ocean Conservancy

NRDC
THE EARTH'S BEST DEFENSE

October 25, 2005

Mr. Donald K. Hansen
Chair, Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 200
Portland, OR 97220

Dear Chairman Hansen and Council Members:

On behalf of the Natural Resources Defense Council and The Ocean Conservancy and our more than one million members and activists, we write to continue our support a prohibition on krill harvesting in the EEZ off of California, Oregon & Washington. We ask the Council to adopt a ban by designating krill as a biological component of EFH or by developing a forage fish amendment.

We see absolutely no justification for developing a krill fishery, particularly when so many state and federal resources are focused on rebuilding species which feed on krill. We strongly disagree with the Council's approach of designating krill as a management unit species under the Coastal Pelagic Species Fishery Management Plan (CPS FMP). Any action the Council takes on krill should be done with the sole goal of prohibiting krill fishing. Placing krill into a category generally reserved for target species sends the wrong message and forces the Council into the convoluted path of designing measures to ensure a species produces maximum sustainable yield, when in reality krill should yield no landings at all.

The November 2004 NMFS report to the Council on krill states that amending the CPS FMP (then Option 2) "would be relatively straightforward, though it also would take some dedication of Council resources". We recognize that any FMP amendment takes time and resources, but in reviewing the current Alternatives Analysis it would appear that this is an understatement. Pursuing a krill ban through EFH amendments, or a forage fish amendment, do not appear to require any more time or resources than will need to be dedicated to figuring out measurable overfishing criteria or EFH for krill.

More importantly, EFH or a forage fish amendment approach are more appropriate tools for the task at hand. Krill truly is an essential biological component of the ecosystem and an important forage species. We urge the Council to recognize this by rejecting the proposal to make krill a management unit species under the CPS FMP.

Sincerely,

Kate Wing
NRDC

Kaitilin Gaffney
The Ocean Conservancy

ALTERNATIVES ANALYSIS FOR KRILL MANAGEMENT

The Council has initiated development of regulatory protection for krill and is working with the National Marine Fisheries Service (NMFS) to develop management measures to regulate directed fisheries for krill within Council-managed waters. At the November 2004 meeting, the Council passed a motion that krill protection would be considered under the auspices of the Coastal Pelagic Species (CPS) Fishery Management Plan (FMP).

This proposed action is in recognition of the importance of krill as a fundamental food source for much of the marine life along the West Coast. Moreover, state laws prohibit krill landings by state-licensed fishing vessels into California, Oregon, and Washington, respectively. Thus, the action could provide for consistent federal and state management. There are currently no directed krill fisheries in Council-managed waters.

The NMFS Southwest Region, has taken the lead on this proposed krill amendment and has drafted an alternatives analysis which explores various management alternatives for regulating krill fishing in the Exclusive Economic Zone off the West Coast. The Coastal Pelagic Species Management Team (CPSMT) and the Coastal Pelagic Species Advisory Subpanel (CPSAS) have met and reviewed the alternatives analysis and have provided statements. After hearing reports from NMFS, the advisory bodies, and the public, the Council is scheduled to adopt a range of management measures for public review. The Council may elect to adopt a preliminary preferred management alternative at this time. It is anticipated that NMFS Southwest Region will prepare an environmental assessment analyzing the Council’s recommendations in time for final Council action on a preferred alternative for the management of krill fishing at the March 2006 Council meeting.

Council Action:

Adopt Public Review Draft of the Range of Management Alternatives and Preferred Management Strategy.

Reference Materials:

1. Agenda Item D.2.a, Attachment 1: Alternatives Analysis for the Management of Krill Fishing Off the U.S. West Coast.
2. Agenda Item D.2.c, CPSAS Report.
3. Agenda Item D.2.c, CPSMT Report.
4. Agenda Item D.2.d, Public Comment.

Agenda Order:

a. Agenda Item Overview — Mike Burner
b. NMFS Report — Mark Helvey
c. Reports and Comments of Advisory Bodies
d. Public Comment
e. **Council Action**: Adopt Public Review Draft of the Range of Management Alternatives and Preferred Management Strategy