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ASSESSMENT OF THE PACIFIC SARDINE RESOURCE IN 2007 FOR U.S. MANAGEMENT IN 2008

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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PACIFIC SARDINE RESOURCE IN 2007
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National Marine Fisheries Service
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ACRONYMS AND ABBREVIATIONS

ADMB	automatic differentiation model builder (programming language)
ASAP	age structured assessment program
BC	British Columbia (Canada)
CA	State of California –or- the California fishing fleet
CANSAR-TAM	catch-at-age analysis for sardine – two area model
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CalVET	California Vertical Egg Tow (ichthyoplankton net)
CDFG	California Department of Fish and Game
CDFO	Canada Department of Fisheries and Oceans
CICIMAR-IPN	Centro Interdisciplinario de Ciencias Marinas – Instituto Politécnico Nacional (La Paz, México)
CONAPESCA	Comisión Nacional de Acuacultura y Pesca
CPS	Coastal Pelagic Species
CPSAS	Coastal Pelagic Species Advisory Subpanel
CPSMT	Coastal Pelagic Species Management Team
CV	coefficient of variation
DEPM	Daily egg production method
EN	Ensenada (México) fishing fleet
FMP	fishery management plan
HG	harvest guideline (or quota), as defined in the CPS-FMP
INP-CRIP	Instituto Nacional de la Pesca – Centro Regional de Investigación Pesquera
MSY	maximum sustainable yield
MX	México
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NW	Pacific northwest fishing fleet (Oregon, Wash., and British Columbia)
NWFSC	Northwest Fisheries Science Center
OR	State of Oregon
PFMC	Pacific Fishery Management Council
SAFE	stock assessment and fishery evaluation
SEMARNAP	Secretaria del Medio Ambiente, Recursos Naturales y Pesca
SS2	Stock Synthesis 2
SSB	spawning stock biomass
SSC	Scientific and Statistical Committee
SST	sea surface temperature
STAR	Stock Assessment Review (Panel)
STAT	Stock Assessment Team
SWFSC	Southwest Fisheries Science Center
TEP	Total egg production
VPA	virtual population analysis
WA	State of Washington

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PREFACE

The Pacific sardine resource is assessed annually in support of the Pacific Fishery Management Council (PFMC) process that, in part, establishes an annual harvest guideline (HG) for the U.S. fishery. In June 2004, the PFMC, in conjunction with NOAA Fisheries Service, 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. At that time, the STAR Panel endorsed use of the 'ASAP' model for conducting the annual assessment updates. Subsequently, sardine assessments were updated using ASAP to provide management advice for the 2005, 2006, and 2007 (Conser et al. 2004; Hill et al., 2006a, b).

The following assessment was conducted using the 'Stock Synthesis 2' (SS2) model, and includes updated data from the fishery and survey sources. The draft assessment was reviewed by a STAR Panel 18-21 September, 2007, in La Jolla, California. Following the STAR, minor modifications to input data and model structure were incorporated in the base model and are included in this report. The present draft will be presented to the PFMC's advisory bodies (SSC, CPSMT, and CPSAS) and the PFMC at their November 2007 meeting (San Diego, CA).

EXECUTIVE SUMMARY

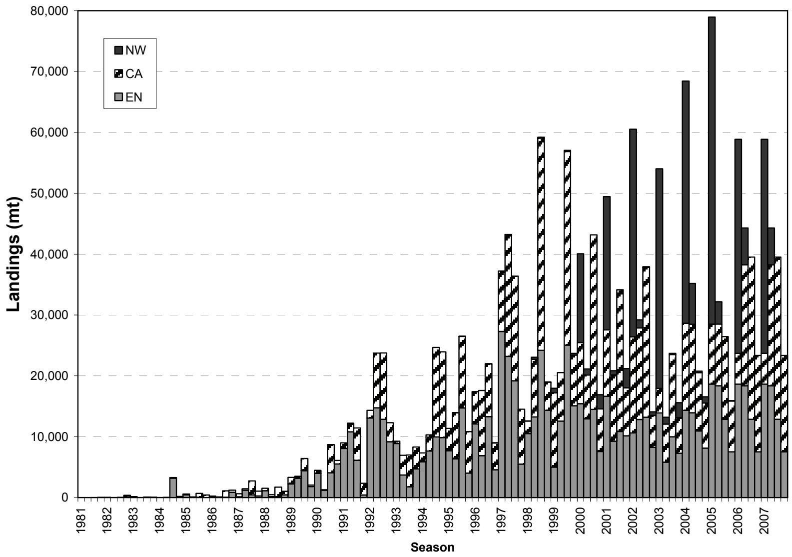
Stock

Pacific sardine (*Sardinops sagax caerulea*) range from southeastern Alaska to the Gulf of California, México, and is thought to comprise three subpopulations. In this assessment, we model the northern subpopulation which ranges from northern Baja California, México, to British Columbia, Canada, and offshore as far as 300 nm. All U.S., Canada, and Ensenada (México) landings are assumed to be taken from a single northern stock. Future modeling efforts should explore a scenario that separates the catches in Ensenada and San Pedro into the respective northern and southern stocks based on some objective criteria.

Catches

Catches in this assessment include commercial sardine landings from three fisheries: Ensenada (México), California (San Pedro and Monterey), and the Pacific Northwest (Oregon, Washington, and British Columbia), from 1981-82 to 2007-08.

Calendar Year	Ensenada (mt)	California (mt)	Pacific Northwest (mt)	Total (mt)
1997	68,439	46,198	71	114,707
1998	47,812	41,055	489	89,357
1999	58,569	56,747	800	116,116
2000	67,845	58,202	16,016	142,063
2001	46,071	54,903	24,883	125,857
2002	46,845	63,444	38,662	148,951
2003	41,342	37,737	37,839	116,918
2004	41,897	47,702	49,349	138,948
2005	56,684	38,193	55,169	150,046
2006	57,438	51,029	41,323	149,789



Data and assessment

The last assessment of Pacific sardine was completed in 2006, for U.S. management in calendar year 2007. The current assessment, conducted using 'Stock Synthesis 2' model (version 2.00i), uses fishery and survey data collected from 1981 to 2007. Fishery data include catch and biological samples for the fisheries off Ensenada, California, and the Pacific Northwest (1981-2007). Two indices of relative abundance are included: Daily Egg Production Method and Total Egg Production estimates of spawning stock biomass (1985-2007) based on annual surveys conducted off California. The model was constructed using an annual time step ('Season'), based on the July-June biological year, and four quarters per season (Jul-Sep, Oct-Nov, Dec-Mar, and Apr-Jun).

Unresolved problems and major uncertainties

The assessment includes indices of spawning biomass based on annual ichthyoplankton and trawl surveys conducted each spring between San Diego and San Francisco ('standard' sampling area). The assessment relies on the assumption that indices of abundance for the 'standard' area are linearly proportional to total spawning biomass. While there is no direct evidence for failure of this assumption, there is some evidence that a portion of the stock is spawning outside of this area. This uncertainty can only be improved by broadening the range of the annual survey to include areas north of San Francisco and south of San Diego.

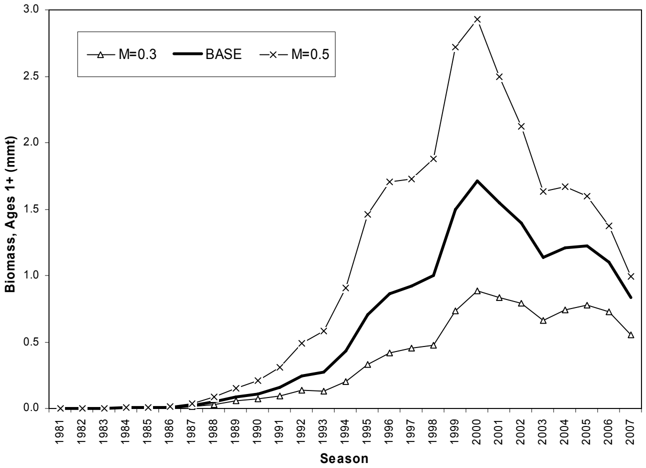
There is uncertainty about sardine stock structure and mixing in the Ensenada and southern California regions. It is possible that some of the catches used in the assessment are from the southern subpopulation, which presumably has different life history parameters (e.g. growth, maturity, natural mortality).

Access to recent Mexican catches and biological data remains a concern. Ensenada catches after 2005 are unknown, so are assumed to be equal to recent levels. The assessment does not include biological data for Ensenada after 2002.

Stock biomass

Stock biomass (ages 1+) estimates from the base model begin at very low levels in 1981, rapidly increase to a peak of over 1.7 million metric tons in 2000, and subsequently trend downward to 832,706 metric tons in 2007.

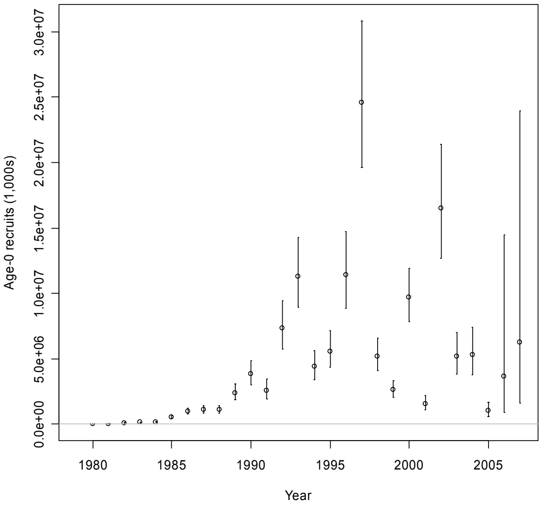
Season	Stock Biomass (mt)
1998	1,002,920
1999	1,495,910
2000	1,713,280
2001	1,548,940
2002	1,397,530
2003	1,137,720
2004	1,211,000
2005	1,219,480
2006	1,101,890
2007	832,706



Recruitment

Recruitment was modeled using the Ricker stock-recruitment relationship. The estimate of steepness was high (*h*=2.5924). Root mean square error for the S-R fit (0.7634) was well matched to the input σ_R (0.7649). Recruitments begin at very low levels in 1981, peak at 24.6 billion fish in 1998, and subsequently decline with the exception of the 2003 year class which was the second highest (16.5 billion fish) in recent history.

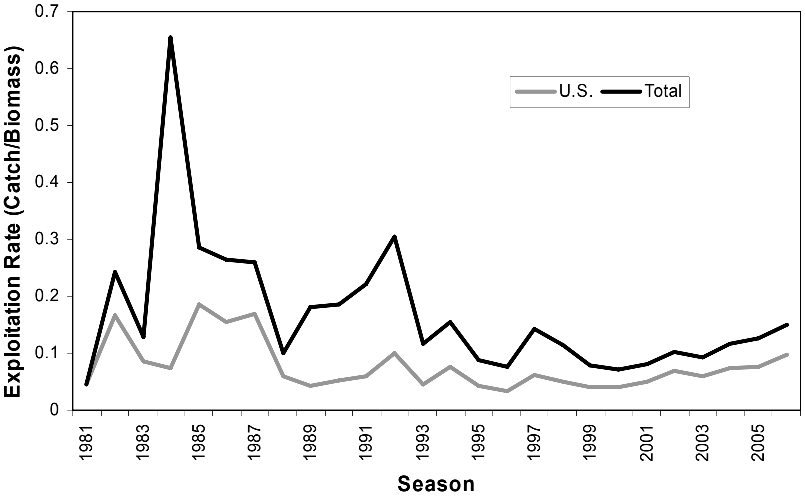
Season	Recruits (age-0, billions)
1998	24.583
1999	5.201
2000	2.603
2001	9.672
2002	1.555
2003	16.469
2004	5.164
2005	5.277
2006	1.010
2007	3.677



Exploitation status

Total exploitation rate (catch/stock biomass) was relatively high during the early period (mid-1980s), but declined as the stock underwent the most rapid period of recovery. Total exploitation was lowest (~7%) in 2000, has since gradually increased to approximately 15%.

Season	U.S. Exploitation Rate	Total Exploitation Rate
1997	0.0612	0.1431
1998	0.0509	0.1136
1999	0.0410	0.0797
2000	0.0404	0.0708
2001	0.0500	0.0811
2002	0.0688	0.1014
2003	0.0601	0.0937
2004	0.0738	0.1164
2005	0.0762	0.1259
2006	0.0972	0.1507



Management performance

The harvest guideline recommended for the U.S. fishery in calendar year 2008 is 89,093 mt. The HG is based on the control rule defined in the CPS-FMP:

$$HG_{2008} = (BIOMASS_{2007} - CUTOFF) \bullet FRACTION \bullet DISTRIBUTION;$$

where HG_{2008} is the total USA (California, Oregon, and Washington) harvest guideline in 2008, $BIOMASS_{2007}$ is the estimated July 1, 2007 stock biomass (ages 1+) from the current assessment (832,706 mt), CUTOFF is the lowest level of estimated biomass at which harvest is allowed (150,000 mt), FRACTION is an environment-based percentage of biomass above the CUTOFF that can be harvested by the fisheries (see below), and DISTRIBUTION (87%) is the percentage of $BIOMASS_{2007}$ assumed in U.S. waters. The following formula is used to determine the appropriate FRACTION value:

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

where T is the running average sea-surface temperature at Scripps Pier, La Jolla, California during the three preceding seasons (July-June). Based on the current (T_{2007}) SST estimate of 18.14 °C, the F_{msy} exploitation fraction should be 15%.

The HG proposed for 2008 (89,093 mt) is substantially lower than the 2007 HG (152,564 mt), but only ~2,000 mt lower than the recent average yield realized by the U.S. fishery. To date, the U.S. fishery has yet to catch all of the HG issued under the federal management.

Year	U.S. HG	U.S. Landings	Total HG	Total Landings
2000	186,791	67,985	214,702	120,876
2001	134,737	75,732	154,870	99,579
2002	118,442	96,888	136,140	141,369
2003	110,908	69,917	127,480	101,425
2004	122,747	92,747	141,089	141,388
2005	136,179	90,024	156,528	149,939
2006	118,937	91,044	136,709	134,043
2007	152,564	---	175,361	---

Research and data needs

High priority research and data needs for Pacific sardine include:

1) gaining better information about Pacific sardine status through annual coastwide surveys that include ichthyoplankton, hydroacoustic, and trawl sampling;
2) standardizing fishery-dependent data collection among agencies, and improving exchange of raw data or monthly summaries for stock assessments;
3) obtaining more fishery-dependent and fishery-independent data from northern Baja California, México;
4) further refinement of ageing methods and improved ageing error estimates through a workshop of all production readers from the respective agencies;
5) further developing methods (e.g. otolith microchemistry, genetic, morphometric, temperature-at-catch analyses) to improve our knowledge of sardine stock structure. If sardine captured in Ensenada and San Pedro represent a mixture of the southern and northern stocks, then objective criteria should be applied to the catch and biological data from these areas;
6) exploring environmental covariates (e.g. SST, wind stress) to inform the assessment model.

INTRODUCTION

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 México).

Sardines 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 Agulhas, 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 (outer coastal Baja California to southern California), and a Gulf of California subpopulation were distinguished on the basis of serological techniques (Vrooman 1964) and, more recently, a study of temperature-at capture (Felix-Uraga et al., 2004; 2005). A recent electrophoretic study (Hedgecock et al. 1989) showed, however, no genetic variation among sardine from central and southern California, the Pacific coast of Baja California, or the Gulf of California. Although the ranges of the northern and southern subpopulations overlap, the stocks may move north and south at similar times and not overlap significantly. The northern stock is exploited by fisheries off Canada, the U.S., and northern Baja California and is included in the Coast Pelagic Species Fishery Management Plan (CPS-FMP; PFMC 1998).

Pacific sardine probably migrated extensively during historical periods when abundance was high, moving north as far as British Columbia in the summer and returning to southern California and northern Baja California in the fall. Tagging studies indicate that the older and larger fish moved farther north (Janssen 1938, Clark and Janssen 1945; Figure 1). 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 15 years, but individuals in historical (pre-1965) and current California commercial catches are usually younger than five years. In contrast, the most common ages in the historical Canadian sardine fishery were six years to eight years. There is a good deal of regional variation in size-at-age, with size increasing from south to north and from inshore to offshore (Phillips 1948, Hill 1999). Size- and age-at-maturity may decline with a decrease in biomass, but latitude and temperature are likely also important (Butler 1987). At relatively low biomass levels, sardine appear to be fully mature at age one, whereas at very high biomass levels only some of the two-year-olds are mature (MacCall 1979).

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

Pacific sardine spawn in loosely aggregated schools in the upper 50 meters of the water column. Spawning occurs year-round in the southern stock and peaks April through August between San Francisco and Magdalena Bay, and January through April in the Gulf of California (Allen et al. 1990). Off California, sardine eggs are most abundant at sea surface temperatures of 13°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.

Sardine are oviparous multiple-batch spawners with annual fecundity that is indeterminate and age- or size-dependent (Macewicz et al. 1996). Butler et al. (1993) estimated that two-year-old sardine spawn on average six times per year whereas the oldest sardine spawn up to 40 times per year. Both eggs and larvae are found near the surface. Sardine eggs are spheroid, have a large perivitelline space, and require about three days to hatching at 15^{o}C.

Sardine are planktivores that consume both phytoplankton and zooplankton. When biomass is high, Pacific sardine may consume a considerable proportion of total organic production in the California Current system.

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 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 such as 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 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% per annum in the early 1980s (Barnes et al. 1992). Recent estimates (Hill et al. 2006a, b) 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 are highly dependent upon environmental conditions associated with sea surface temperature.

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% per annum 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 was been used in recent assessments employing CANSAR and CANSAR-TAM (Deriso et al. 1996, Hill et al. 1999, Conser et al. 2003).

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 in 1936. 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 México. 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 Pacific 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, substantial Pacific sardine landings are now made in the Pacific northwest and in Baja California, México. Sardine landed in México 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., México, and Canada have been developed.

Early 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 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.

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 Performance Under the CPS-FMP (2000-present)

In January 2000, management authority for the U.S. Pacific sardine fishery was transferred to the Pacific Fishery Management Council. Pacific sardine was one of five species included in the federal CPS-FMP (PFMC 1998). The CPS-FMP includes a maximum sustainable yield (MSY) control rule intended to prevent Pacific sardine from being overfished and to 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 ('Harvest Guideline for 2008' section**)**. A thorough description of PFMC management actions for sardine, including harvest guidelines, may be found in the most recent CPS SAFE document (PFMC 2007). U.S. harvest guidelines and resultant landings since calendar year 2000 are displayed in Table 1 and Figure 2a. Coast-wide harvests (Ensenada to British Columbia) and implied HGs since 2000 are provided in Figure 2b. Pacific sardine landings for all major fishing regions off the West Coast of North America may be found in Table 2.

ASSESSMENT

Biological Data

Stock Structure

For purposes of this assessment, we assume to model the northern subpopulation ('cold stock') that extends from northern Baja California, México to British Columbia, Canada and extends well offshore, perhaps 300 nm or more (Macewicz and Abramenkoff 1993). 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, México 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. Future modeling scenarios will include a case that separates the catches in Ensenada and San Pedro into the respective northern ('cold') and southern ('temperate') stocks using temperature-at-catch criteria proposed by Felix-Uraga et al. (2004, 2005). Subpopulation differences in growth and natural mortality would also be taken into account.

Weight-at-length

The weight-length relationship for Pacific sardine (combined sexes) was modeled using fishery samples collected from 1981 to 2006, using the standard power function:

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

where W is weight (kg) at length L (cm), and a and b are the estimated regression coefficients.

The estimated coefficients were a = 0.821879E-05 and b = 3.19405 (corrected R^2 = 0.941; n = 86,495). Coefficients a and b were set as fixed parameters in all SS2 models (Figure 3).

Age and Growth

The largest recorded Pacific sardine was 41.0 cm long (Eschmeyer et al. 1983), but the largest Pacific sardine taken by commercial fishing since 1983 was 28.8 cm and 0.323 kg. The oldest recorded age is 15 years, but commercially-caught sardine are typically less than five years old.

Sardine otolith ageing methods were first described by Walford and Mosher (1943) and further clarified by Yaremko (1996). Pacific sardine are routinely aged by fishery biologists in México, California, and the Pacific Northwest, using annuli in whole sagittae. A birth date of July 1 is assumed when assigning year class to California, Oregon, and Washington samples. Ensenada sample raw ages were adjusted *post-hoc* to match this assumption by subtracting one year of age from fish caught during the first semester of the calendar year. Lab-specific ageing errors were calculated as described in 'Conditional age-at-length compositions'.

Sardine growth was initially estimated outside the SS2 model to provide initial parameter values and CVs for the length at Age_{min} (0.5 yrs), the length at Age_{max} (15 yrs), and the growth coefficient K. Growth parameters were directly estimated in the SS2 model (see Baseline Results section).

Maturity

Maturity-at-length was estimated using from sardine during from survey trawls between 1986 and 2006 (n=3,591). Reproductive state was established through histological examination. Parameters for the logistic function were fixed in SS2 (Figure 4a), where the length-at-inflexion (i.e. 50% maturity) = 16.0 cm and the slope = -0.7571, where:

$$\text{Maturity} = 1/(1+\exp(slope*\text{Length}(inflexion)))$$

Resultant maturity and fecundity-at-age during the spawning season is presented in Figure 4b.

Natural Mortality

Adult natural mortality rates have been estimated to be M=0.4 yr^{-1} (Murphy 1966; MacCall 1979) and 0.51 yr^{-1} (Clark and Marr 1955). A natural mortality rate of M=0.4 yr^{-1} means that 33% of the sardine stock would die of natural causes each year if there were no fishery. Consistent with previous assessments, the base-case value for 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 include commercial landings and biological samples for three regional fisheries: 1) California (San Pedro and Monterey; or 'CA'); 2) northern Baja California (Ensenada; or 'EN'); and 3) the Pacific Northwest (Oregon, Washington, and British Columbia; or 'NW'). Biological data includes individual weight (kg), standard length (cm), sex, maturity, and otoliths for age determination. CDFG currently collects 12 random port samples (25 fish per sample) per month to determine age-composition and weights-at-age for the directed fishery. Mexican port samples, collected by INP-Ensenada 1989-2002, were aged and made available for this assessment by coauthor Felix-Uraga. ODFW and WDFW have collected port samples since 1999. Sample sizes by fishery for the 1981 to 2006 seasons are provided in Table 3.

All fishery data were compiled based on the biological year (July 1-June 30; hereafter referred to as ‘Season’) as opposed to a calendar year time step. Further, each model ‘season’ was assigned approximate ‘quarterly’ time steps, where: ‘Qtr-1’=Jul-Sep; ‘Qtr-2’=Oct-Nov; ‘Qtr-3’=Dec-Mar; and ‘Qtr-4’=Apr-Jun. Quarters 2 and 3 have an unequal number of months, but this design is intended to more appropriately assign fishing mortality (Pope’s approximation) during the peak of California’s fall fishery (Qtr-2). Moreover, this design will accommodate future models exploring stock structure scenarios based on temperature-at-catch criteria – the transition to colder temperatures off southern California and northern Baja occurs between November and December.

<u>Landings</u>

California commercial landings were obtained from a variety of sources based on dealer landing receipts (CDFG), which in some cases were augmented with special sampling for mixed load portions. During California’s incidental sardine fishery (1981-82 through 1990-91), many processors reported sardine as mixed with jack or Pacific mackerel, but in some cases sardine were not accurately reported on landing receipts. For these years, sardine landings data were augmented with shore-side ‘bucket’ sampling of mixed loads to estimate portions of each species. CDFG reports these data in monthly ‘Wetfish Tables’, which are still distributed by the Department. These tables are considered more accurate than PacFIN or other landing receipt-based statistics for California CPS, so were used for this assessment. Projected landings for the final time step (2006-07) were based on 2005-06 landings.

Ensenada (northern Baja California) landings from July 1982 through December 1999 were compiled using monthly landings from the ‘Boletín Anual’ series published by the Instituto Nacional de la Pesca’s (INP) Ensenada office (e.g. see Garcia and Sánchez, 2003). Monthly catch data from January 2000 through June 2005 were provided by Dr. Tim Baumgartner (CICESE-Ensenada, Pers. Comm.), who obtained the data electronically from Sr. Jesús Garcia Esquivel (Department of Fisheries Promotion and Statistics, SEMARNAP-Ensenada). These new catch data for 2000 to mid-2005 incorporate estimates of sardine delivered directly to tuna rearing pens off northern Baja California, and are overall 37% higher than the landings used in the previous assessment. Ensenada landings for calendar year 2005 were reported to be 56,684 mt (Cota-V. et al. 2006). Projected landings for 2005-06 and 2006-07 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. □ardi.).

The SS2 model includes commercial sardine landings in California, northern Baja California and the Pacific Northwest from 1981-82 through 2007-08. Landings for 2007-08 are unknown, so were projected to be the same as 2006-07. Landings were aggregated by season, quarter, and fishery as presented in Table 4 and Figure 5.

Length-composition

Length-compositions were compiled by season, quarter, and fishery for SS2 input. Length-compositions comprised of 0.5 cm bins, ranging from 9.5 cm to 25 cm standard length (32 bins total). The 25 cm bin accumulates fish whose sizes are equal to or greater than 25 cm. Total numbers of lengths observed in each bin was divided by 25, the average number of fish collected per sampled load, and was input as effective sample size. Length-compositions were input to SS2 as proportions. A summary of the data sources by season, quarter, and fishery is provided in Table 3. Length-compositions by fishery are displayed in Figures 6-11.

In response to a STAR Panel request (Item A), the length-composition data for the California fishery were re-compiled using month and port area (southern California and central California) as the sampling unit and re-weighting observations based on landings within each stratum. The data re-weighting had a negligible effect on the appearance of the input data and outcome. The STAT and STAR panel did, however, agree that the re-weighted length compositions should form the basis for the final base model (Figures 6 and 7). It was also agreed that data re-weighting should be performed as a standard practice on all fishery inputs in future assessments.

Conditional age-at-length

Conditional age-at-length compositions were constructed from the same fishery samples described above. Age bins included 0, 1, 2, 3, 4, 5, 6, 7, 8-10, 11-14, and 15-20 (11 bins total). No fish older than 14 were observed in the fishery samples, so the 15-20 bin serves as an accumulator that allows growth to approach L_∞. Age-compositions were input as proportions of fish in 1-cm length bins. As per the length-compositions, the number of individuals comprising each bin was divided by 25 (fish per sample) to set the initial effective sample size. Age data were available for every length observation. Conditional age-at-length compositions for each fishery are presented in Figures 12-14.

Ageing error vectors (std. dev by age) were calculated and linked to fishery-specific age-compositions. Error estimates were on based on paired readings by two or more individuals within each ageing laboratory (CICIMAR-IPN for EN samples; CDFG for CA samples; WDFW for NW samples) for a range of ages typically observed within each sampled region. Standard deviations were regressed when double-reads were unavailable for a given age.

At the request of the STAR Panel (Item D), 'implied' age-compositions were compiled based on the cross-product of observed length-frequencies and corresponding conditional age-at-length information. The implied age-compositions were included as model inputs with effective sample sizes set close to zero (Figures 15-20). Inclusion of these input data facilitated comparison of model predictions of age-composition to the inferred values through examination of residual patterns.

Fishery-Independent Data

Overview

Two sources of fishery-independent data have been used in previous Pacific sardine assessments: a) daily egg production method (DEPM) estimates of spawning stock biomass, and b) relative abundance of sardine schools sighted by aerial spotter pilots. For the current assessment, the traditional DEPM time series has been split into two separate series: DEPM (Index 1) and TEP (total egg production; Index 2), based upon the availability of adult daily-specific fecundity data for each survey. Further, for reasons cited below, the aerial spotter index (3) was not included in the final base model.

Daily Egg Production Method (DEPM)

Daily egg production method (DEPM) spawning biomass estimates were available for calendar years 1986-1988 and 1994-2007 (Table 5, Figure 21). Methods employed for the DEPM-SSB point estimates are published in Wolf and Smith (1986), Wolf et al. (1987), Wolf (1988^{a},b), Lo et al. (1996, 2005), Lo and Macewicz (2006), and Lo et al. (2007). The latest DEPM estimate, based on eggs and adults collected from March 27 to May 1, 2007, was 392,492 mt (Table 5, Figure 21 and 22). In SS2, the DEPM index was taken to represent sardine SSB (length selectivity option '30') in April (Qtr-4) of each season.

Total Egg Production (TEP)

Adult sardine samples are needed to calculate daily specific fecundity (eggs per population weight (g) per day) for a true DEPM estimate. Adult sardine were not always available from the egg production surveys (e.g. 1995, 1996, 1998-2001, and 2003 survey years; see Lo et al. 2007). In past assessments, this was dealt with by averaging values for adult reproductive parameters (spawning fraction, batch fecundity, female weight, sex ratio) borrowed from other survey years. This practice violates the assumption of independent observations among years and should be discontinued for purposes of population modeling. As an alternative, we chose to include these data as a Total Egg Production (TEP) series, which is simply the product of egg density (P_0) and spawning area (km^2). Values for the TEP series are provided in Table 5 and displayed in Figure 21. Like DEPM, TEP was also taken to represent sardine SSB, but the model is now able estimate separate catchability coefficients (Q) for the two observation types.

TEP values were assumed to be linearly related to SSB as measured by the DEPM. At the request of the STAR Panel (Item C), TEP estimates were calculated for years for which DEPM estimates were available, and the corresponding values were compared. The relationship of TEP to DEPM was linear (slope=0.79) and highly correlated ($R^2 = 0.9178$; Figure 23).

The STAR Panel raised the question as to whether DEPM and TEP estimates based on the standard sampling area (San Diego to San Francisco) were proportional to total spawning biomass, or if systematic bias (resulting in changes to q) has occurred over time. In response to this request (Item E), charts of egg distributions were provided and reviewed for systematic sampling trends. Upon review, the panel agreed that there does not appear to be any consistent sampling bias (i.e. there is no evidence that the surveys consistently missed spawning to the north, south, or west of the standard survey area). The complete series of charts are not reproduced for this report, but can be found in the following publications: Wolf and Smith

(1986); Wolf et al. (1987); and Lo et al. (1996, 2005, 2007), Lo and Macewicz (2006).

Egg distribution charts were also provided for two years in which sampling occurred outside of the standard area: 1) in April 2004 off Baja California (IMECOCAL program) and 2) in April 2006 from San Francisco to British Columbia (SWFSC 'coastwide' survey). The April 2004 survey map indicates small areas of low egg densities off Baja California relative to the standard area (Figure 24). The 2006 survey resulted in DEPM estimates for the standard (San Diego-San Francisco) and northern (San Francisco-British Columbia) areas. The biomass estimate north of San Francisco comprised approximately 10% of the total (Figure 25; Lo et al. 2007).

Aerial Spotter Index

Pilots employed by the fishing fleet to locate pelagic fish schools report data for each flight on standardized logbooks and provide them to the SWFSC. Delta-GLM models were used to standardize the data and calculate indices of relative abundance (Appendix I). Two indices were calculated – one based on traditional spotter logbook data (1985-2001) and the other based on a combination of spotter logbooks supplemented with data from surveys contracted by the SWFSC (Table 5, Figure 26, and Appendix I). Complete details regarding the survey data and statistical methods are provided in Lo et al. (1992) and Appendix I of this report.

The spotter index chosen for sensitivity analyses in this assessment was based on logbook data only (1985-2001). Size selectivity for the spotter index is unknown. Recent assessments have assumed the data to be an index of young fish (ages 0-2) biomass (e.g. Conser et al. 2004, Hill et al. 2006a,b). This assumption may not be valid for the 1980s and early 1990s when much of the total population was concentrated in the Southern California Bight. We therefore set the index to mirror selectivity of the California fishery, accommodating a shift from larger fish in the early period to smaller fish in the recent period. Timing of the survey was set to the beginning of Qtr 2, at approximately 50% of the July-June effort.

The aerial spotter index has shown a marked downward trend since the mid-1990s, in stark contrast to the trend in DEPM/TEP estimates. A scatterplot of paired observations illustrates the contradictory nature of these two data sources (Figure 27). All attempts to include the aerial spotter data in SS2 model runs resulted in extremely poor fits to the spotter series and unrealistically high population sizes (See the 'Model Diagnostic Examinations and Uncertainty' section).

The aerial spotter logbook program has undergone marked change over the past decade. Fewer fisheries utilize spotter pilots to locate fish schools, and the remaining pilots are now primarily hired to locate tuna for the net pen industry off Baja California or for the sport fishing fleet. As a result, the total number of experienced pilots and logbook returns has declined significantly. Total effort (day and night) has dropped from a peak of 339 flights in 1994 down to three flights in 2003. Night flights peaked at 224 in 1994, dropping to zero by 2001 (Appendix I, Table 1). Spotter pilots can identify sardine schools during day or night. However, sardine schools are more likely to be near the surface at night, and iridescence generated by the school aids in identification of species and school size. Another important change has been a shift in effort distribution southward to offshore areas of Baja California (Figure 28). The use of spotter data has been further confounded by the concurrent northward and offshore expansion of the Pacific sardine population. In an attempt to address the decrease and redistribution in effort, the SWFSC implemented contracts to supplement collection of the logbook data off California (Appendix I). These supplemental data have been used to extend the aerial spotter index through 2007 (Appendix I), however, the STAR Panel reviewing the Pacific mackerel assessment (May 2007) did not endorse the joining of these two data series. For the above reasons, and given the overall lack of fit to the time series, the aerial spotter index was excluded from the final base model (J14).

Other Sardine Surveys

Other surveys for Pacific sardine have been conducted off Baja California and the Pacific Northwest in recent years. In many cases, the design and preliminary results have been summarized in a series of reports to the Trinational Sardine Forum (e.g. Lo et al. 2006). The surveys, and their potential use in future sardine assessments, are summarized here.

The IMECOCAL surveys, initiated in late 1997, are conducted two to four times per year off Baja California. Like CalCOFI, IMECOCAL surveys include ichthyoplankton collection using bongo net tows and CUFES. Standard stations have identical positions to those of the early CalCOFI pattern (1951-1984), but the sampling pattern is somewhat more constricted. Unlike CalCOFI, raw ichthyoplankton data from IMECOCAL surveys are not freely available to the broader scientific community for analysis and assessment. Development of relative-abundance time series for stock assessment (e.g. DEPM, TEP, or larval census) is entirely dependent upon the willingness of individual researchers (i.e. the responsible data custodians) to share their portion of data, as well as the availability of funds to expedite sample processing. To date, two types of estimates have been made available through the Trinational Sardine Forum (Lo et al. 2006): 1) sardine larval census values for 1997, 1998, and 1999; and 2) DEPM estimates from CUFES samples taken in 2002 and 2003. Neither of these series will be potentially useful for assessment modeling until more observations are made available.

Since the mid-1990s, the NWFSC has conducted a variety of surveys off Oregon and Washington that include collection of sardine ichthyoplankton or adults. Emmett et al. (2005) and Lo et al. (2006) provide a thorough description and summary of these surveys. Ichthyoplankton surveys were conducted off Oregon each July during 1994 to 1998, and sardine eggs collected by CalVET net allowed for SSB estimation via the DEPM. Results from the ichthyoplankton surveys were published by Bentley et al. (1996) and Emmett et al. (2005). Adult sardine were not collected during the egg surveys, so DEPM estimates were based on an average daily specific fecundity value from California samples (i.e. TEP estimates would be more appropriate). NWFSC egg production surveys were discontinued after 1998, negating use of this series for assessment modeling.

The NWFSC has conducted two different surface trawl surveys in the nearshore region of northern Oregon and southern Washington since 1999 (Emmett et al. 2005, Lo et al. 2006): the 'Plume' surveys and the 'Predator/Forage Fish' surveys. The 'Plume' surveys sample a larger section of coast, but are conducted in September and during daylight hours, so are less likely to capture adult sardine. The 'Predator/Forage Fish' surveys are conducted around July during nighttime hours, so occur during a month of peak local abundance and when the fish are more likely oriented near the surface. The 'Predator/Forage Fish' trawls sample a relatively small area of the OR-WA coast (approximately 7,600 km^2, Figure 29), and swept area biomass estimates are highly variable both among survey weeks and among survey years (Emmett et al. 2005, Lo et al. 2006). Due to the patchy nature of sardine distribution and the relatively small area sampled, the 'Predator/Forage Fish' survey may not provide a representative index of relative abundance for the Pacific Northwest region.

Since 1997, DFO-Canada has conducted swept area trawl surveys along the western coast of British Columbia, primarily during summer months (McFarlane et al. 2005, Lo et al. 2006). McFarlane et al. (2005) provide swept area biomass estimates for the 1997, 1999, and 2001 surveys. Biomass estimates have not been published for other survey years, and the raw data have not been made available for analysis and time series development.

History of Modeling Approaches

The Pacific sardine population (pre-collapse) was first modeled by Murphy (1966), who used VPA methods and adjusted fishing mortality according to trends in fishery CPUE. MacCall (1979) further refined Murphy's analysis using additional data and prorated portions of Mexican landings to exclude catches from the southern subpopulation. Deriso et al. (1996) modeled the recovering population (1982 onward) using CANSAR, a modification of Deriso's (1985) CAGEAN model. CANSAR was subsequently modified into a quasi-two area model 'CANSAR-TAM' (Hill et al. 1999) to account for net losses from the core model area during the peak of the population's expansion. Both versions of CANSAR modeled the population with two semesters per year and incorporated a modified Ricker spawner-recruit function. The modified Ricker function included an environmental covariate (SST at SIO Pier) to adjust recruitments according to change in prevailing ocean climate (Jacobson and MacCall 1995; Deriso et al. 1996). CANSAR and CANSAR-TAM were used for annual stock assessments and management advice (CDFG and later PFMC) from 1996 through 2004. In 2004, a STAR Panel endorsed use of the ASAP model for routine assessments. ASAP was used for sardine assessment and management advice for calendar years 2005 to 2007 (Conser et al. 2004, Hill et al. 2006a, b).

SS2 Model Description

Stock Synthesis 2 (SS2, Methot 2005, 2007) is based on the AD Model Builder software environment, which is essentially a C++ library of automatic differentiation code for nonlinear statistical optimization (Otter Research 2001). The SS2 model framework allows the integration of both size and age structure (Methot 2005). The general estimation approach used in the SS2 model accounts for most relevant sources of variability and expresses goodness of fit in terms of the original data, potentially allowing that final estimates of model precision to capture most relevant sources of uncertainties (see Methot 2005).

The SS2 model comprises three sub-models: 1) A population dynamics sub-model, where abundance, mortality and growth patterns are incorporated to create a synthetic representation of the true population; 2) An observation sub-model that defines various processes and filters to derive expected values for the different type of data; 3) A statistical sub-model that quantifies the difference between observed data and their expected values and implement algorithms to search for the set of parameters that maximizes the goodness of fit. Another layer of the model is the estimation of management quantities, such as short term-forecast of the catch level given a specified fishing mortality policy. Finally, these sub-models and layer are fully integrated and the SS2 model use forward-algorithms, which begin estimation prior or in the first year of available data and continues forward up to the last year of data (see Methot (2005) for additional details).

Assessment Program with Last Revision Date

SS2 Version 2.00i, compiled 7 August 2007, was used in this assessment. The reader is referred to Methot (2005, 2007) for a complete description of the SS2 model.

Likelihood Components, Constraints on Parameters, Selectivity Assumptions

The objective function for the base model included contributions from the DEPM and TEP indices, contributions from the length-compositions and conditional age-at-length data for the three fisheries, a contribution from the deviations about the spawner-recruit model and, in some cases, a contribution from a light harvest rate penalty.

Data from all three fisheries were modeled using length-based selectivity functions. The CA and EN fisheries were modeled using the double-normal function (6 parameters, 3 time blocks) and the NW fishery was modeled using a logistic function (2 parameters, 2 time blocks). Pronounced shifts in length-composition were observed to occur over time in both the CA and EN fisheries (Figures 30 and 31). We assumed this change was related to changes in sardine density and changes to the distribution (i.e. local availability) of sardine throughout phases of the population's recovery and expansion to offshore and northern feeding and spawning habitat. To capture this dynamic, we broke CA and EN selectivity pattern into three time blocks: 1981-1991, 1992-1999, and 1999-2007. During the 1981-1991 period, sardine abundance was low and larger sardine were primarily caught incidentally in round hauls for Pacific mackerel (then in high abundance). Sardine abundance had substantially increased by the 1992-1998 period, pure schools were common off southern California and northern Baja California, large spawning events were observed off central California, and sardine were encountered 300 nm off the California coast (Macewicz and Abramenkoff 1993) and as far north as British Columbia. By the third period (1999-2007), substantial fisheries for larger sardine had developed in the Pacific Northwest, and the CA and EN fisheries typically caught only smaller, younger fish (0-2 years of age).

Initial modeling runs resulted in logistic-like selectivity patterns for the CA and EN fisheries during the first time block even though selectivity was governed by the double-normal function. Moreover, we suspect that the CA and EN fisheries would have fully selected larger sardine during the 1981-1991 period due to the coastal distribution of both the population and the fishery. Since SS2 will not allow different selectivity functions for a given fishery to be applied in different time blocks, we fixed most of the double-normal parameters (all but the ascending width) to force a simple-logistic shape during the first period (Figures 30 and 31). This resulted in better fits to the size-composition and survey index data, and prevented the estimates of the initial population size from scaling to unrealistically high levels. All selectivity parameters for the second and third time blocks were freely estimated.

During the course of STAR Panel review, examination of Pearson residuals for fits to the NW fishery length- and age-compositions revealed marked patterns after 2003. An industry member present noted that the NW fishery has found new markets for the smaller fish in recent years. In response, the STAR Panel requested an additional run with the NW fishery modeled using two selectivity time blocks, with a break between the 2003 and 2004 seasons (STAR Item H). Based on an improvement to the total likelihood and slight improvement to the index fits, the STAR Panel and STAT agreed that this change should be included in the base model.

To start the population in a depleted state, the recruitment R_0 offset parameter 'R_1' was freely estimated. Recruitment deviations were estimated from 1975 to 2006, so the initial age composition is based on observations from at least six cohorts in the initial fishery data.

Stock-recruitment

Pacific sardine are believed to have a broad spawning season, starting in January off northern Baja California and ending by July off the Pacific Northwest. The SWFSC's annual egg production surveys are timed to capture (as best is possible) the peak of spawning activity of the central and southern California coast during April. In our SS2 models, we calculated SSB at the beginning of Qtr-4 (i.e. April). Recruitment was assumed to occur in Qtr-1 of the following season (consistent with the July-1 birth date assumption).

To be consistent with past assessments in ASAP, initial modeling efforts used the Beverton-Holt (B-H) stock-recruitment function. However, all B-H runs resulted in very high estimates of steepness ($h \approx 0.95$), higher than expected estimates for R_0 and R_1, upward trends in the recruitment deviations over time, and high σ_R estimates (1.1-1.2). Attempts to fine-tune σ_R in B-H cases resulted in a progressively higher recruitment RMSE and unrealistically high estimates of population size (Table 6). For these reasons, the decision was made to use the Ricker stock-recruitment function. Model runs based on the Ricker relationship were ultimately more stable and improved the trend in recruitment deviations (Figures 61, 68). Jacobson and MacCall (1995) found that Pacific sardine were best modeled using Ricker assumptions, and past assessments using CANSAR and CANSAR-TAM included a modified Ricker S-R function (e.g. Deriso et al. 1996, Hill et al. 1999, Conser et al. 2003). Sardine recruitment can theoretically be limited under high population sizes due to egg predation by planktivores (including adult sardine), limitations to spawning or feeding habitat, or shifts in habitat size related to environmental change.

Convergence Criteria

The iterative process for determining numerical solutions in the model was continued until the difference between successive likelihood estimates was <0.0001.

Model Selection and Evaluation

Parameter estimates for the base model (J14) are provided in Table 7. The base model, reviewed and endorsed by the STAR Panel, had the following specifications:

1. Year ("season") based on a July 1 birth date (assessment years 1981-82 to 2006-07);
2. Four quarters per "season" (July-Sept, Oct-Nov, Dec-March, April-June);
3. Use of conditional age-at-length and length-frequency data for México, California and the Pacific Northwest (re-weighted based on revised strata);

4. M = 0.4yr^{-1}; Time-invariant growth (estimated);
5. Length-specific selectivity with time-blocking:
    a. México: 1981-91, 1992-98, and 1999-2007 (double normal function, fixed to simple logistic shape in first period);
    b. California: 1981-91, 1992-98, and 1999-2007 (double normal function, fixed to simple logistic shape in first period);
    c. Pacific Northwest: 1981-2003, and 2004-2007 (simple logistic function, both periods);
6. Ricker stock-recruitment relationship; $\sigma_R = 0.765$; Steepness estimated;
7. Initial recruitment estimated; recruitment residuals estimated from 1975 to 2006.

Base Model 'J14' Results

Growth

The growth parameters (the size at age 0.5, the size at age 15, the von Bertalanffy growth rate parameter *K*, and the CVs for size at the minimum and maximum ages) were estimated within the model. Sardine were estimated to grow to 9.5 cm SL by age 0.5 (CV = 0.206) and 23.7 cm SL (CV = 0.038) by age 15. Growth rate (*K*) was estimated to be 0.5986 yr^{-1}. Estimated sardine growth is displayed in Figure 32.

Indices of abundance

Fits to the DEPM and TEP series are displayed in Figures 33-36. Input CVs for each index were iteratively adjusted to match the model estimates of variance. Model fits to both series fell within the CVs for each survey observation.

Selectivity estimates

Length selectivity patterns estimated for each fishery are displayed in Figure 30. For comparative purposes, the selectivity patterns by time block are displayed in Figure 31. Both the CA and EN fisheries caught progressively smaller fish by time block, but the shift was more pronounced for the CA fishery. Selectivity for the NW fishery, estimated in two time periods, displayed a pronounced shift toward smaller fish after 2003 (Figure 30). Model fits to length frequencies are shown in Figures 37-39, and Pearson residuals to the fits are shown in Figures 40-42. Model fits to implied age-compositions are shown in Figures 43-45, and Pearson residuals to the fits are shown in Figures 46-48. Observed and effective sample sizes for the length frequency data are displayed in Figures 49-51. Observed and effective sample sizes for conditional age-at-length compositions are displayed in Figures 52-54.

Harvest rate

The estimated harvest rates by fishery are displayed in Figure 55. A relatively high harvest rate of 84% was estimated for the Ensenada fishery in Qtr-3 of 1984. The catch for this quarter was high relative the vulnerable biomass (based on selectivity), so the selectivity peak for the EN fishery was shifted slightly lower to avoid any harvest rate penalty and to match observed and expected catch for that quarter.

Spawning stock biomass

Base model estimates of SSB since 1981 are presented in Figure 56. Unexploited SSB (B_0) was estimated to be 928,165 mt.

Recruitment

The time series of recruitment estimates and confidence intervals is provided in Table 8 and Figure 57. Virgin recruitment (R_0) was estimated at 5.01 billion age-0 fish. Initial recruitment (R_1) was approximately 10.2 million fish. Recruitment increased rapidly through the mid-1990s, peaking at 24.6 billion age-0 fish in 1998. Recruitments have been relatively low since the late 1990s, with the exception of the 2003 year class, which was the second highest in the series (16.5 billion fish).

Stock-recruitment

The estimated (Ricker) stock-recruitment relationship is displayed in Figure 58. The estimate of steepness was high (h=2.5924). The fit of the Ricker model to the estimates of recruitment are shown in Figure 59. Recruitment deviations and their asymptotic standard errors are shown in Figures 60 and 61. Root mean square error for the S-R fit (0.7634) was well matched to the input σ_R (0.7649). The base model was run using input σ_R values ranging from 0.5 to 1. Model RMSE values were stable, ranging about 0.76 to 0.79 (Figure 62).

Stock biomass (ages 1+) for PFMC management

The stock biomass for management purposes is defined as the sum of the biomass for fish aged 1 and older. Base model estimates of stock biomass are shown in Figure 63 and Table 8. Stock biomass increased rapidly through the 1980s and 1990s, peaking at 1.71 million mt in 2000, but has trended downward to the present (July 1, 2007) level of 832,706 mt.

Uncertainty and Sensitivity Analyses

Sensitivity to indices

Model runs were conducted to examine sensitivity to using only one of the survey indices at a time. Likelihood estimates and some derived quantities of interest are provided in Table 6. Models including only the DEPM or TEP indices had fits to the data and derived quantities that were very similar to those for the base model, which included both of these indices. Models which included the aerial spotter index, either alone or in combination with the two egg production series, had poor fits to the spotter data (Figure 64) and unrealistically high population estimates (Table 6).

Sensitivity to ageing error assumptions

A sensitivity run was conducted to examine the implications of allowing for ageing error in the base model when fitting conditional age-at-length data (STAR Item J). The base model was run with ageing error standard deviations set at 0.001. As expected, the model ignoring ageing error tended to weaken the large year classes and strengthen the small ones (Figure 65), and the 2007 age 1+ biomass decreased to 695,918 mt (Table 6). The STAR Panel agreed to continue to allow for ageing error in the base model.

Sensitivity to early catch data from Ensenada

The base model estimated a very high harvest rate (84%) for the Ensenada fishery in Qtr-3 of the 1984 season. Landings for that quarter (3,174.2 mt) were caught during one month (January

1985), with no landings for the preceding 16 months or the following 5 months. Since this anomalous catch followed a pronounced El Niño event, it is possible that these sardines originated from southern Baja California and were not part of the recovering northern stock. The STAR Panel requested (Item N) a model run omitting this catch to assess whether this catch would have noticeable impact on management-related quantities. Basic results from this run are presented in Table 6. As expected, the model estimated a lower initial population size and scaled down the entire recruitment and biomass time-series. Ending year age 1+ biomass was 689,203 mt. While the origin of this single anomalous catch remains uncertain, both the STAT and STAR Panel noted the need for objective criteria for systematically removing catches based on stock source.

Sensitivity to stock-recruitment assumptions

A model was summarized to demonstrate sensitivity to the Beverton-Holt spawner-recruitment relationship. The base model was rerun using the B-H function, and σ_R was tuned to match the model RMSE for recruitment deviations Likelihoods and derived quantities are shown in Table 6. The peak stock biomass (age 1+) for the B-H case was more than 2.7 million mt (Table 6). Moreover, B-H estimates were poorly matched to the recruitment series throughout the 1980s (Figures 66 and 67). A comparison of recruitment deviations for the Ricker and Beverton-Holt cases indicates a trend in residuals for the B-H model (Figure 68).

Likelihood profiles

At the request of the STAR Panel (Item S), likelihood profiles were constructed for steepness (*h*), natural mortality (*M*), and σ_R. Results for σ_R are presented in Figure 62 and discussed in the '*Stock-recruitment*' section above. Steepness (*h*) was profiled using values ranging from 1.4 to 3.6 (Figure 69). The profile was bowl-shaped, with the lowest total likelihood centered on the value estimated for the converged model ($h = 2.59$).

Natural mortality (*M*) was profiled using values ranging from 0.1 to 0.8 yr^{-1} (Figure 70). The lowest value for the likelihood function occurred at $M = 0.7\ \text{yr}^{-1}$, much higher than the value fixed for the base model ($M = 0.4\ \text{yr}^{-1}$). There was, however, a conflict between better fits to the indices at lower *M* and better fits to composition data at higher *M* (Figure 70). Given this, and the fact that the harvest control rule was derived based on an assumption of $M = 0.4\ \text{yr}^{-1}$, the STAT and STAR Panel agreed that *M* should remain fixed at 0.4 yr^{-1} in the base model.

The STAR Panel also requested that uncertainty around base model biomass be bracketed using a range of plausible *M* values (0.3 and 0.5). Results from these runs are presented in Figure 71.

Prospective analysis

To further examine the properties of the base model and provide another basis for bracketing uncertainty, a series of prospective runs were conducted in which the start year of the model was incrementally advanced from 1981 to 1985 (STAR request Item U). Increasing the model start year resulted in an upward scaling of the biomass and recruitment estimates (Figures 72 and 73), particularly when the model was begun in 1984 and 1985. The 1984 model increased overall recruitments by 5.6%, overall biomass by 2.4%, and ending year biomass was 17.5% higher than the base model. The 1985 model increased overall recruitments by 10.4%, overall biomass by 14.3%, and ending year biomass was 19.7% higher than the base model. Therefore, the choice of the model start year is important because the stock is postulated to have increased from a highly depleted state, rather than being fished down from unexploited conditions.

Retrospective analysis

The STAR Panel requested (Item T) a retrospective analysis of the base model, where data are incrementally removed from the end year back to 2002. Like the prospective analysis, the retrospective provides an additional means of examining properties of the model and further characterizing uncertainty. Results of these analyses are displayed in Figures 74 and 75. The assessment exhibits a retrospective pattern in that it tends to underestimate recent recruitments (Figure 75) and hence ending year biomass (Figure 74).

Comparison to previous assessments

Stock biomass (age 1+) and recruitment estimates from the base model were compared to final values from all previous assessments used for PFMC management. Results are displayed in Figures 76 and 77. Stock biomass and recruitment estimates for base model are within the same general range as previous assessments, but displayed different trends with respect to peak and end point estimates. Recruitments from the base model followed the same general pattern of high and low values, but with a greater magnitude of variability (i.e. higher highs and lower lows)(Figure 77). One marked difference between the SS2 and ASAP results was each models estimate of the 1997 and 1998 year class sizes (SS2 being high, and ASAP relatively low). Previous CANSAR assessments provided relatively high estimates of these two year classes, more within the range of SS2 values (Figure 77). This is likely due to fundamental structural differences between ASAP and the SS2 and CANSAR models.

Biomass (age 1+) from the base SS2 model was initially lower than past ASAP and CANSAR models, until the mid- to late-1990s when SS2 and CANSAR provided comparable estimates (Figure 76). SS2 estimates of peak and recent biomass tended to be higher than those from CANSAR and ASAP, with the single exception of the 2006-ASAP model. The 2006-ASAP, used for the current management cycle, had higher biomass estimates than SS2 in the final few years.

HARVEST GUIDELINE FOR 2008

The Pacific sardine harvest guideline recommended for the U.S. fishery in calendar year 2008 is 89,093 mt. Statistics used to determine this harvest guideline are discussed below and presented in Table 9. To calculate the proposed harvest guideline for 2008, 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 the long-term. The Amendment 8 harvest formula for sardine is:

$$HG_{2008} = (BIOMASS_{2007} - CUTOFF) \bullet FRACTION \bullet DISTRIBUTION;$$

where HG_{2008} is the total USA (California, Oregon, and Washington) harvest guideline in 2008, $BIOMASS_{2007}$ is the estimated July 1, 2007 stock biomass (ages 1+) from the current assessment

(832,706 mt), CUTOFF is the lowest level of estimated biomass at which harvest is allowed (150,000 mt), FRACTION is an environment-based percentage of biomass above the CUTOFF that can be harvested by the fisheries (see below), and DISTRIBUTION (87%) is the percentage of BIOMASS_{2007} 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:

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

where T is the running average sea-surface temperature at Scripps Pier, La Jolla, California during the three preceding 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 (1981-2007; Table 5, Figure 78), the appropriate F_{msy} exploitation fraction has consistently been 15%; and this remains the case under current oceanic conditions ($T_{2007} = 18.14$ °C).

The HG proposed for 2008 (89,093 mt) is substantially lower than the 2007 HG (152,564 mt), but only ~2,000 mt lower than the recent average yield realized by the U.S. fishery. To date, the U.S. fishery has yet to catch all of the HG issued under the federal management.

RESEARCH AND DATA NEEDS

High priority research and data needs for Pacific sardine include:

1) gaining better information about Pacific sardine status through annual coastwide surveys that include ichthyoplankton, hydroacoustic, and trawl sampling;
2) standardizing fishery-dependent data collection among agencies, and improving exchange of raw data or monthly summaries for stock assessments;
3) obtaining more fishery-dependent and fishery-independent data from northern Baja California, México;
4) further refinement of ageing methods and improved ageing error estimates through a workshop of all production readers from the respective agencies;
5) further developing methods (e.g. otolith microchemistry, genetic, morphometric, temperature-at-catch analyses) to improve our knowledge of sardine stock structure. If sardine captured in Ensenada and San Pedro represent a mixture of the southern and northern stocks, then objective criteria should be applied to the catch and biological data from these areas;
6) exploring environmental covariates (e.g. SST, wind stress) to inform the assessment model.

Additional research recommendations for Pacific sardine may be found in the 2007 STAR Panel report, the 2007 CPS-SAFE document (PFMC 2007), and in the PFMC's Research and Data Needs document for 2006-2008 (PFMC 2006).

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Table 1. Fishery performance since onset of federal management in 2000.

Year	U.S. HG	U.S. Landings	Total HG	Total Landings
2000	186,791	67,985	214,702	120,876
2001	134,737	75,732	154,870	99,579
2002	118,442	96,888	136,140	141,369
2003	110,908	69,917	127,480	101,425
2004	122,747	92,747	141,089	141,388
2005	136,179	90,024	156,528	149,939
2006	118,937	91,044	136,709	134,043
2007	152,564	---	175,361	---

Table 2. Pacific sardine landings for major fishing regions off the West Coast of North America, 1981-2006. The stock assessment only includes catches from Ensenada, México to British Columbia, Canada.

	MÉXICO					UNITED STATES					CANADA	
Calendar Year	Gulf of California*	Magdalena Bay	Cedros Island	Ensenada	México Total	So. Calif.	Cen. Calif.	Oregon	Wash.	U.S. Total	British Columbia	GRAND TOTAL
1981	93,989	10,557	1,705	0	106,251	15	0	0	0	15	0	106,265
1982	71,425	9,392	2,362	0	83,179	131	0	0	0	131	0	83,310
1983	111,526	2,386	1,580	274	115,766	352	0	0	0	352	0	116,119
1984	146,467	2,454	1,044	0	149,965	171	64	0	0	235	0	150,199
1985	160,391	10,979	1,429	3,722	176,521	559	34	0	0	593	0	177,114
1986	240,226	14,203	2,808	243	257,480	1,051	113	0	0	1,164	0	258,644
1987	272,574	8,599	2,856	2,432	286,461	2,056	39	0	0	2,095	0	288,556
1988	261,363	12,081	846	2,035	276,325	3,775	10	0	0	3,785	0	280,109
1989	294,095	7,746	2,344	6,224	310,410	3,443	238	0	0	3,681	0	314,091
1990	109,942	16,975	2,086	11,375	140,378	2,508	307	0	0	2,815	0	143,193
1991	113,631	15,893	551	31,392	161,468	6,774	976	0	0	7,750	0	169,217
1992	6,858	5,026	348	34,568	46,801	16,061	3,128	4	0	19,193	0	65,993
1993	7,594	7,671	1,505	32,045	48,814	15,488	705	0	0	16,192	0	65,007
1994	127,486	33,787	1,685	20,877	183,835	10,346	2,359	0	0	12,705	0	196,540
1995	174,951	34,541	0	35,396	244,888	36,561	4,928	0	0	41,489	23	286,400
1996	200,870	25,795	0	39,065	265,730	25,171	8,885	0	0	34,056	0	299,786
1997	203,529	14,656	0	68,439	286,624	32,837	13,361	0	0	46,198	71	332,893
1998	59,400	2,493	0	47,812	109,705	31,975	9,081	1	0	41,056	488	151,249
1999	51,266	11,795	0	58,569	121,630	42,863	13,884	775	1	57,523	24	179,178
2000	65,593	42,276	0	67,845	175,715	46,835	11,367	9,529	4,765	72,496	1,722	249,933
2001	190,862	40,572	0	46,071	277,505	47,662	7,241	12,780	10,837	78,520	1,266	357,292
2002	220,360	50,969	0	46,845	318,174	49,366	14,078	22,711	15,212	101,367	739	420,280
2003	198,757	53,862	0	41,342	293,961	30,289	7,448	25,258	11,604	74,599	977	369,537
2004	102,034	47,173	0	41,897	191,104	32,393	15,308	36,112	8,799	92,613	4,438	288,155
2005	94,341	40,000	0	56,684	191,025	30,253	7,940	45,008	6,929	90,130	3,232	284,387
2006	126,392	no data	0	57,438	183,830	33,286	17,743	35,648	4,099	90,776	1,575	276,181

*Gulf of California catch statistics are compiled by an Oct-Sep fishing season, e.g. the 2006 value represents landings made between Oct. 2005 and Sep. 2006.

Table 3. Raw numbers of Pacific sardine sampled for size and age by model season, quarter, and fishery.

Model Season	Qtr	CA	EN	NW	Total
1981	1	0	0	0	0
	2	0	0	0	0
	3	79	0	0	79
	4	125	0	0	125
1982	1	221	0	0	221
	2	100	0	0	100
	3	441	0	0	441
	4	179	0	0	179
1983	1	133	0	0	133
	2	244	0	0	244
	3	130	0	0	130
	4	92	0	0	92
1984	1	0	0	0	0
	2	0	0	0	0
	3	69	0	0	69
	4	145	0	0	145
1985	1	142	0	0	142
	2	39	0	0	39
	3	607	0	0	607
	4	362	0	0	362
1986	1	178	0	0	178
	2	226	0	0	226
	3	966	0	0	966
	4	147	0	0	147
1987	1	324	0	0	324
	2	222	0	0	222
	3	1,555	0	0	1,555
	4	753	0	0	753
1988	1	338	0	0	338
	2	224	0	0	224
	3	764	0	0	764
	4	305	34	0	339
1989	1	397	21	0	418
	2	0	76	0	76
	3	1,059	69	0	1,128
	4	25	4	0	29
1990	1	47	213	0	260
	2	123	23	0	146
	3	1,956	121	0	2,077
	4	221	544	0	765
1991	1	511	533	0	1,044
	2	398	418	0	816
	3	749	1,012	0	1,761
	4	385	216	0	601
1992	1	197	326	0	523
	2	1,821	146	0	1,967
	3	1,281	132	0	1,413
	4	384	115	0	499
1993	1	19	124	0	143
	2	276	0	0	276
	3	522	37	0	559
	4	331	185	0	516
1994	1	64	126	0	190
	2	487	114	0	601
	3	1,795	111	0	1,906
	4	1,322	143	0	1,465
1995	1	312	181	0	493
	2	432	120	0	552
	3	1,051	152	0	1,203
	4	831	47	0	878
1996	1	1,800	192	0	1,992
	2	1,194	93	0	1,287
	3	860	117	0	977
	4	655	76	0	731
1997	1	1,289	210	0	1,499
	2	1,011	134	0	1,145
	3	1,363	111	0	1,474
	4	642	30	0	672
1998	1	744	53	0	797
	2	1,238	136	0	1,374
	3	1,836	205	0	2,041
	4	645	143	31	819
1999	1	694	90	74	858
	2	347	128	0	475
	3	1,083	213	0	1,296
	4	542	122	104	768
2000	1	666	165	1,686	2,517
	2	471	98	24	593
	3	1,197	90	0	1,287
	4	862	159	264	1,285
2001	1	862	32	2,083	2,977
	2	1,107	113	50	1,270
	3	1,557	78	0	1,635
	4	757	139	448	1,344
2002	1	492	11	2,389	2,892
	2	490	0	272	762
	3	1,340	0	0	1,340
	4	894	0	124	1,018
2003	1	865	0	2,116	2,981
	2	567	0	99	666
	3	1,238	0	0	1,238
	4	902	0	273	1,175
2004	1	1,155	0	1,389	2,544
	2	848	0	273	1,121
	3	1,138	0	75	1,213
	4	916	0	125	1,041
2005	1	1,162	0	970	2,132
	2	916	0	50	966
	3	1,360	0	0	1,360
	4	1,385	0	0	1,385
2006	1	1,618	0	249	1,867
	2	1,147	0	50	1,197
	3	2,080	0	0	2,080
	4	1,422	0	0	1,422
Grand Total		71,463	8,281	13,218	92,962

Table 4 . Pacific sardine landings (mt) by model season, quarter, and fleet for the base model. EN landings for 2006-07 were assumed identical to 2005-06. All fishery landings 2007-08 were assumed identical to 2006-07.

Model Season	Qtr	CA	EN	NW	Total
1981	1	4.3	0.0	0.0	4.3
	2	1.5	0.0	0.0	1.5
	3	14.1	0.0	0.0	14.1
	4	43.1	0.0	0.0	43.1
1982	1	42.2	0.0	0.0	42.2
	2	31.0	0.0	0.0	31.0
	3	40.5	0.0	0.0	40.5
	4	223.5	149.5	0.0	373.0
1983	1	48.3	124.1	0.0	172.4
	2	36.8	0.0	0.0	36.8
	3	89.1	0.0	0.0	89.1
	4	74.0	0.0	0.0	74.0
1984	1	22.0	0.0	0.0	22.0
	2	51.3	0.0	0.0	51.3
	3	138.3	3,174.2	0.0	3,312.5
	4	185.5	0.0	0.0	185.5
1985	1	112.1	474.7	0.0	586.8
	2	43.2	73.4	0.0	116.6
	3	614.3	85.9	0.0	700.2
	4	421.6	13.3	0.0	434.9
1986	1	121.5	115.6	0.0	237.1
	2	83.4	27.8	0.0	111.2
	3	1,032.1	74.6	0.0	1,106.7
	4	311.3	900.4	0.0	1,211.7
1987	1	489.1	149.0	0.0	638.1
	2	245.4	1,205.7	0.0	1,451.1
	3	2,280.9	458.0	0.0	2,738.9
	4	794.9	264.1	0.0	1,059.0
1988	1	387.8	1,138.8	0.0	1,526.6
	2	311.6	179.7	0.0	491.3
	3	1,639.8	96.2	0.0	1,736.0
	4	579.7	461.0	0.0	1,040.7
1989	1	1,075.7	2,249.9	0.0	3,325.6
	2	355.1	3,162.7	0.0	3,517.8
	3	1,992.4	4,422.6	0.0	6,415.0
	4	235.5	1,828.0	0.0	2,063.5
1990	1	489.0	3,972.3	0.0	4,461.3
	2	131.1	1,186.7	0.0	1,317.8
	3	4,656.0	4,066.5	0.0	8,722.5
	4	579.5	5,520.8	0.0	6,100.3
1991	1	926.2	8,069.4	0.0	8,995.6
	2	1,419.4	10,814.0	0.0	12,233.4
	3	5,319.4	6,131.5	0.0	11,450.9
	4	1,909.2	432.4	0.0	2,341.6
1992	1	1,289.5	13,056.6	3.7	14,349.8
	2	8,968.2	14,780.7	0.2	23,749.1
	3	10,907.5	12,873.7	0.0	23,781.2
	4	3,154.7	9,178.8	0.2	12,333.7
1993	1	371.7	8,882.2	0.0	9,253.9
	2	3,199.2	3,741.7	0.0	6,940.9
	3	5,258.3	1,766.2	0.0	7,024.5
	4	3,602.0	4,718.3	0.0	8,320.3
1994	1	1,443.3	5,880.8	0.0	7,324.1
	2	2,671.7	7,655.0	0.0	10,326.7
	3	14,698.3	9,985.1	0.0	24,683.4
	4	14,089.1	9,871.8	0.0	23,960.9
1995	1	3,641.5	7,711.2	0.0	11,352.7
	2	7,603.8	6,371.3	0.0	13,975.1
	3	11,756.6	14,730.3	22.7	26,509.6
	4	6,817.8	4,022.0	0.0	10,839.8
1996	1	5,312.8	12,103.6	0.0	17,416.4
	2	10,680.3	6,901.0	0.0	17,581.3
	3	8,643.0	13,305.3	40.8	21,989.1
	4	4,390.6	4,587.4	2.7	8,980.7
1997	1	9,956.2	27,281.4	0.0	37,237.6
	2	20,020.9	23,183.5	27.2	43,231.7
	3	17,184.9	19,200.3	0.0	36,385.1
	4	9,010.4	5,514.2	0.8	14,525.4
1998	1	2,068.8	10,511.8	22.7	12,603.3
	2	9,463.0	13,269.6	336.7	23,069.3
	3	34,839.5	24,207.0	153.3	59,199.8
	4	4,634.0	14,344.8	50.1	19,028.9
1999	1	12,217.9	5,023.8	725.0	17,966.7
	2	7,966.4	12,582.1	0.0	20,548.5
	3	31,852.1	25,036.0	162.4	57,050.6
	4	8,324.0	15,101.0	267.2	23,692.3
2000	1	10,036.4	15,441.9	14,575.6	40,054.0
	2	7,200.2	12,943.4	1,008.8	21,152.3
	3	28,682.6	14,487.2	2.0	43,171.7
	4	6,996.5	7,584.3	2,336.5	16,917.4
2001	1	10,909.9	16,644.1	21,888.1	49,442.1
	2	10,903.9	9,272.8	658.5	20,835.2
	3	23,274.9	10,872.3	0.0	34,147.2
	4	7,892.0	10,158.9	3,136.3	21,187.3
2002	1	15,810.6	10,611.8	34,098.8	60,521.2
	2	15,040.8	12,841.8	1,326.5	29,209.0
	3	24,631.4	13,209.3	100.8	37,941.5
	4	5,230.8	8,275.0	596.9	14,102.7
2003	1	3,995.4	13,926.1	36,115.5	54,037.0
	2	6,267.7	5,819.4	1,126.7	13,213.8
	3	13,505.0	10,004.8	179.6	23,689.4
	4	5,881.8	7,290.0	2,438.8	15,610.6
2004	1	14,290.6	14,350.8	39,799.3	68,440.6
	2	14,521.1	13,959.4	6,718.5	35,199.0
	3	9,605.9	10,950.1	213.4	20,769.4
	4	7,440.9	8,119.1	1,015.9	16,575.9
2005	1	9,839.6	18,653.2	50,477.1	78,969.9
	2	10,124.3	18,377.9	3,675.5	32,177.7
	3	13,567.8	12,873.8	0.0	26,441.6
	4	8,317.0	7,532.7	101.7	15,951.4
2006	1	5,040.2	18,653.2	35,164.2	58,857.6
	2	19,879.1	18,377.9	6,056.7	44,313.7
	3	26,653.5	12,873.8	0.0	39,527.3
	4	15,839.7	7,532.7	0.0	23,372.4

Table 5. Fishery-independent indices of Pacific sardine abundance and the SST at Scripps Pier (three-year running average).

Season	DEPM	CV	TEP	CV	Spotter Logbook	CV	Spotter Logbook +Survey	CV	SST at SIO Pier °C
1981	---	---	---	---	---	---	---	---	16.98
1982	---	---	---	---	---	---	---	---	17.05
1983	---	---	---	---	---	---	---	---	17.25
1984	---	---	---	---	---	---	---	---	17.58
1985	6,948	0.51	---	---	15,461	0.34	15,686	0.34	17.80
1986	---	---	---	---	8,409	0.32	8,342	0.32	17.87
1987	15,685	0.91	---	---	14,340	0.24	14,259	0.24	17.71
1988	13,514	0.60	---	---	8,402	0.29	8,395	0.29	17.55
1989	---	---	---	---	3,410	0.24	3,365	0.24	17.24
1990	---	---	---	---	17,696	0.16	17,443	0.16	17.19
1991	---	---	---	---	18,372	0.15	18,156	0.15	17.35
1992	---	---	---	---	98,045	0.15	96,464	0.15	17.61
1993	127,102	0.32	---	---	143,092	0.11	140,327	0.11	17.84
1994	---	---	93,947	0.50	65,408	0.14	64,240	0.14	17.97
1995	---	---	97,923	0.42	21,554	0.14	21,111	0.14	18.04
1996	371,725	0.31	---	---	28,093	0.20	27,443	0.20	18.07
1997	---	---	369,775	0.34	51,300	0.17	51,498	0.17	18.08
1998	---	---	332,177	0.35	20,323	0.17	19,904	0.17	18.47
1999	---	---	1,252,539	0.40	6,567	0.19	6,425	0.18	18.08
2000	---	---	931,377	0.39	1,789	0.37	789	0.37	17.75
2001	206,333	0.35	---	---	7,031	0.53	940	0.52	17.24
2002			556,177	0.18	---	---	10,061	0.47	17.31
2003	281,639	0.30	---	---	---	---	10,560	0.11	17.46
2004	621,657	0.54	---	---	---	---	1,736	0.21	17.60
2005	836,960	0.46	---	---	---	---	---	---	18.03
2006	392,492	0.45	---	---	---	---	1,972	0.62	18.11
2007	---	---	---	---	---	---	---	---	18.14

Table 6. Likelihood components for base model J14 and various sensitivity cases.

Likelihood Component	Base Model	*M*=0.3	*M*=0.5	Beverton-Holt S-R	DEPM only	TEP only	AERIAL only*	Include All Indices*	No Ageing Error	Omit Ensenada Catch in 1984-3
Indices										
DEPM	-0.180976	-0.97438	0.48560	2.372820	-0.256107	-----	-----	0.972400	- 0.509683	-0.349317
TEP	-0.958496	-1.34928	0.03383	-1.378530	-----	- 1.045350	-----	4.249490	0.140555	-0.947293
AERIAL	-----	-----	-----	-----	-----	-----	204.872	210.317	-----	-----
Subtotal	**-1.139470**	**-2.32366**	**0.51943**	**0.994286**	**-0.256107**	**- 1.045350**	**204.872**	**215.539**	**- 0.369128**	**-1.296610**
Length Comp										
CA	2,122.54	2147.30	2107.64	2,104.82	2,122.75	2,124.01	2,086.96	2,086.27	2,367.49	2,109.44
EN	842.57	848.31	846.13	843.06	842.01	842.68	808.78	809.29	928.38	849.82
NW	436.06	439.79	427.99	435.82	436.81	436.53	499.72	495.96	526.87	432.42
Subtotal	**3,401.17**	**3435.39**	**3381.75**	**3,383.70**	**3,401.57**	**3,403.21**	**3,395.45**	**3,391.53**	**3,822.74**	**3,391.68**
Age Comp										
CA	2,939.34	3005.80	2898.24	2,891.38	2,939.16	2,935.99	3,076.20	3,076.12	2,731.24	2,918.46
EN	684.19	684.68	685.31	688.40	684.39	683.70	697.69	697.13	761.82	688.62
NW	279.92	281.83	280.38	276.30	279.85	279.55	290.36	289.62	271.08	279.38
Subtotal	**3,903.44**	3972.30	3863.93	**3,856.08**	**3,903.41**	**3,899.24**	**4,064.24**	**4,062.87**	**3,764.14**	**3,886.47**
TOTAL LIKELIHOOD	**7,445.72**	**7611.76**	**7354.31**	**7,362.99**	**7,446.63**	**7,445.72**	**7,781.16**	**7,786.84**	**7,728.25**	**7,450.44**

Derived Quantities of Interest	Base Model	*M*=0.3	*M*=0.5	Beverton-Holt S-R	DEPM only	TEP only	AERIAL only*	Include All Indices*	No Ageing Error	Omit Ensenada Catch in 1984-3
SSB-virgin (mt)	928,165	551,271	1,408,790	1,162,750	918,893	990,191	13,700,300,000	13,698,600,000	984,525	791,231
R-virgin (billions)	5.01	1.79	11.78	6.27	4.96	5.34	72,003.60	72,003.50	5.48	4.29
R-peak (billions)	24.58	11.83	50.02	36.69	24.26	26.06	192,350.00	198,316.00	15.63	21.86
B-1+ peak (mt)	1,713,280	887,321	2,931,180	2,708,420	1,694,460	1,834,430	23,394,500,000	23,017,400,000	1,690,060	1,465,110
B-1+ 2007 (mt)	832,706	555,940	993,128	1,507,650	815,731	906,919	10,740,200,000	11,362,900,000	695,918	689,203

Φιγυρε 8. Recruitment and biomass scaled unrealistically high when aerial spotter data were included (i.e. not decimal error).

Table 7. Parameter estimates and standard deviations for final base model (J14).

Parameter	Estimated / Fixed / Derived	Value	Std_Dev
NatMort_young	Fixed	4.0000E-01	---
NatMort_old	Fixed	4.0000E-01	---
Length_Amin	Estimated	9.7494E+00	1.0008E-01
Length_Amax	Estimated	2.3849E+01	7.8671E-02
VonBert_K	Estimated	5.7169E-01	1.1127E-02
CV_young	Estimated	2.0010E-01	4.3523E-03
CV_old	Estimated	3.6374E-02	1.5739E-03
Log_R0	Estimated	1.5426E+01	1.4034E-01
Steepness	Estimated	2.5924E+00	1.5002E-01
ΣR	Fixed	7.6490E-01	---
Env_Link	Fixed	0.0000E+00	---
R1_(R0 offset)	Estimated	-6.1965E+00	2.2649E-01
Rdev-1975	Estimated	-1.6340E+00	4.9069E-01
Rdev-1976	Estimated	-1.7009E+00	4.8111E-01
Rdev-1977	Estimated	-1.5090E+00	4.8058E-01
Rdev-1978	Estimated	-8.1181E-01	3.9489E-01
Rdev-1979	Estimated	-1.6452E-01	2.6632E-01
Rdev-1980	Estimated	1.0363E+00	1.8328E-01
Rdev-1981	Estimated	-4.1102E-01	2.5701E-01
Rdev-1982	Estimated	-4.6993E-02	2.2716E-01
Rdev-1983	Estimated	-2.7403E-01	1.8716E-01
Rdev-1984	Estimated	-1.2725E-01	1.9220E-01
Rdev-1985	Estimated	5.7563E-01	1.7760E-01
Rdev-1986	Estimated	5.9523E-01	1.8401E-01
Rdev-1987	Estimated	-5.6757E-03	1.8360E-01
Rdev-1988	Estimated	-7.2804E-01	1.6612E-01
Rdev-1989	Estimated	-3.2336E-01	1.5692E-01
Rdev-1990	Estimated	-6.8974E-02	1.5054E-01
Rdev-1991	Estimated	-6.7340E-01	1.5862E-01
Rdev-1992	Estimated	1.9326E-01	1.2686E-01
Rdev-1993	Estimated	5.1489E-01	1.0951E-01
Rdev-1994	Estimated	-4.6972E-01	1.0239E-01
Rdev-1995	Estimated	-1.3676E-02	1.1756E-01
Rdev-1996	Estimated	8.5104E-01	1.2604E-01
Rdev-1997	Estimated	1.5903E+00	1.0184E-01
Rdev-1998	Estimated	2.9081E-01	1.4648E-01
Rdev-1999	Estimated	4.8054E-01	2.5373E-01
Rdev-2000	Estimated	1.9882E+00	2.6696E-01
Rdev-2001	Estimated	-2.7354E-01	2.3827E-01
Rdev-2002	Estimated	1.7707E+00	1.7704E-01
Rdev-2003	Estimated	2.9797E-01	1.6179E-01
Rdev-2004	Estimated	4.6640E-01	2.1805E-01
Rdev-2005	Estimated	-1.2316E+00	3.1878E-01
Rdev-2006	Estimated	-1.8373E-01	7.5321E-01
Q_DEPM	Estimated	-7.5671E-01	2.2377E-01
Q_TEP	Estimated	-8.3102E-01	2.5515E-01

Table 7 cont. Parameter estimates and standard deviations for final base model (J14).

Parameter	Estimated / Fixed / Derived	Value	Std_Dev
CA_selex_P1_Block1	Fixed	2.2000E+01	---
CA_selex_P1_Block2	Estimated	1.7138E+01	1.2858E-01
CA_selex_P1_Block3	Estimated	1.5376E+01	9.0839E-02
CA_selex_P2_Block1	Fixed	0.0000E+00	---
CA_selex_P2_Block2	Estimated	-2.0464E+01	5.8066E+03
CA_selex_P2_Block3	Estimated	-2.4301E+01	1.5386E+04
CA_selex_P3_Block1	Estimated	2.0592E+00	4.9910E-02
CA_selex_P3_Block2	Estimated	2.1564E+00	7.2335E-02
CA_selex_P3_Block3	Estimated	1.8245E+00	7.1723E-02
CA_selex_P4_Block1	Fixed	2.6000E+00	---
CA_selex_P4_Block2	Estimated	1.7677E+00	1.2579E-01
CA_selex_P4_Block3	Estimated	1.7173E+00	7.1798E-02
CA_selex_P5_Block1	Fixed	-1.0000E+01	---
CA_selex_P5_Block2	Estimated	-7.4826E+00	1.1059E+00
CA_selex_P5_Block3	Estimated	-6.6076E+00	7.4054E-01
CA_selex_P6_Block1	Fixed	1.0000E+01	---
CA_selex_P6_Block2	Estimated	-3.3958E+00	3.4516E-01
CA_selex_P6_Block3	Estimated	-4.4777E+00	2.0009E-01
EN_selex_P1_Block1	Fixed	2.1000E+01	---
EN_selex_P1_Block2	Estimated	1.6260E+01	2.2032E-01
EN_selex_P1_Block3	Estimated	1.7064E+01	4.1827E-01
EN_selex_P2_Block1	Fixed	0.0000E+00	---
EN_selex_P2_Block2	Estimated	6.0103E-02	1.2344E-01
EN_selex_P2_Block3	Estimated	-1.4582E+00	4.6536E-01
EN_selex_P3_Block1	Estimated	2.2486E+00	5.7489E-02
EN_selex_P3_Block2	Estimated	8.4911E-01	2.1881E-01
EN_selex_P3_Block3	Estimated	1.5837E+00	3.2041E-01
EN_selex_P4_Block1	Fixed	2.6000E+00	---
EN_selex_P4_Block2	Estimated	2.1156E-01	4.5100E-01
EN_selex_P4_Block3	Estimated	9.6276E-01	3.5397E-01
EN_selex_P5_Block1	Fixed	-1.0000E+01	---
EN_selex_P5_Block2	Estimated	-8.6952E+00	3.7684E+00
EN_selex_P5_Block3	Estimated	-6.4733E+00	2.7438E+00
EN_selex_P6_Block1	Fixed	1.0000E+01	---
EN_selex_P6_Block2	Estimated	-2.9173E+00	6.7802E-01
EN_selex_P6_Block3	Estimated	-5.5498E+00	2.0389E+00
NW_selex_P1_Block1	Estimated	1.9260E+01	1.3164E-01
NW_selex_P1_Block2	Estimated	1.5972E+01	1.9719E-01
NW_selex_P2_Block1	Estimated	2.2110E+00	1.7153E-01
NW_selex_P2_Block2	Estimated	2.2979E+00	2.2688E-01

Table 7 cont. Parameter estimates and standard deviations for final base model (J14).

Parameter	Estimated / Fixed / Derived	Value	Std_Dev
B0	Derived	9.2817E+05	1.3157E+05
Binit	Derived	1.8903E+03	3.9016E+02
SSB-1981	Derived	1.3530E+03	2.1950E+02
SSB-1982	Derived	1.9481E+03	2.9999E+02
SSB-1983	Derived	2.8585E+03	2.6045E+02
SSB-1984	Derived	3.1376E+03	2.9651E+02
SSB-1985	Derived	5.8813E+03	5.6265E+02
SSB-1986	Derived	1.0305E+04	9.7969E+02
SSB-1987	Derived	2.2315E+04	2.3876E+03
SSB-1988	Derived	4.9601E+04	4.8144E+03
SSB-1989	Derived	7.5769E+04	7.9958E+03
SSB-1990	Derived	1.0088E+05	1.2010E+04
SSB-1991	Derived	1.3765E+05	1.9684E+04
SSB-1992	Derived	1.9391E+05	3.1154E+04
SSB-1993	Derived	2.5733E+05	4.1510E+04
SSB-1994	Derived	4.1367E+05	6.2048E+04
SSB-1995	Derived	6.5504E+05	9.4419E+04
SSB-1996	Derived	7.6150E+05	1.1009E+05
SSB-1997	Derived	7.4377E+05	1.1511E+05
SSB-1998	Derived	9.0469E+05	1.3850E+05
SSB-1999	Derived	1.3688E+06	1.9556E+05
SSB-2000	Derived	1.4622E+06	2.1232E+05
SSB-2001	Derived	1.2511E+06	1.8914E+05
SSB-2002	Derived	1.0879E+06	1.6988E+05
SSB-2003	Derived	9.1319E+05	1.4997E+05
SSB-2004	Derived	9.9730E+05	1.6616E+05
SSB-2005	Derived	9.7230E+05	1.7705E+05
SSB-2006	Derived	8.2666E+05	1.7188E+05
SSB-2007	Derived	5.6622E+05	1.4836E+05

Table 7 cont. Parameter estimates and standard deviations for final base model (J14).

Parameter	Estimated / Fixed / Derived	Value	Std_Dev
R0	Derived	5.0063E+06	7.0257E+05
Rinit	Derived	1.0196E+04	2.0968E+03
R-1981	Derived	4.8069E+04	6.1103E+03
R-1982	Derived	9.9439E+04	1.0749E+04
R-1983	Derived	1.1598E+05	1.2627E+04
R-1984	Derived	1.4731E+05	1.7742E+04
R-1985	Derived	5.5341E+05	5.9312E+04
R-1986	Derived	9.7674E+05	1.0600E+05
R-1987	Derived	1.1214E+06	1.4225E+05
R-1988	Derived	1.1216E+06	1.4763E+05
R-1989	Derived	2.3871E+06	3.2126E+05
R-1990	Derived	3.8213E+06	4.7404E+05
R-1991	Derived	2.5708E+06	3.8721E+05
R-1992	Derived	7.3627E+06	9.2874E+05
R-1993	Derived	1.1290E+07	1.3431E+06
R-1994	Derived	4.3812E+06	5.6329E+05
R-1995	Derived	5.5780E+06	6.9731E+05
R-1996	Derived	1.1436E+07	1.4856E+06
R-1997	Derived	2.4583E+07	2.8491E+06
R-1998	Derived	5.2014E+06	6.3419E+05
R-1999	Derived	2.6026E+06	3.3226E+05
R-2000	Derived	9.6719E+06	1.0414E+06
R-2001	Derived	1.5546E+06	2.7098E+05
R-2002	Derived	1.6469E+07	2.1976E+06
R-2003	Derived	5.1640E+06	8.0160E+05
R-2004	Derived	5.2768E+06	9.1197E+05
R-2005	Derived	1.0098E+06	2.6794E+05
R-2006	Derived	3.6771E+06	2.9166E+06
R-2007	Derived	6.2643E+06	4.8342E+06

Table 8. Pacific sardine recruitment (age-0, billions), spawning stock biomass (SSB, mt), age 1+ biomass (mt), and exploitation rate (catch/biomass), 1981 to 2007, from base model J14.

Season	Recruits (age-0)	SSB	Stock Biomass (ages 1+)	U.S. Harvest Rate	Total Harvest Rate
1981	0.022	1,353	1,404	0.045	0.045
1982	0.048	1,948	2,013	0.168	0.242
1983	0.099	2,859	2,891	0.086	0.129
1984	0.116	3,138	5,445	0.073	0.656
1985	0.147	5,881	6,420	0.186	0.286
1986	0.553	10,305	10,053	0.154	0.265
1987	0.977	22,315	22,622	0.168	0.260
1988	1.121	49,601	48,341	0.060	0.099
1989	1.122	75,769	84,604	0.043	0.181
1990	2.387	100,884	111,509	0.053	0.185
1991	3.821	137,650	158,755	0.060	0.221
1992	2.571	193,912	243,062	0.100	0.305
1993	7.363	257,332	272,461	0.046	0.116
1994	11.290	413,667	430,463	0.076	0.154
1995	4.381	655,038	702,406	0.042	0.089
1996	5.578	761,499	864,060	0.034	0.076
1997	11.436	743,771	917,855	0.061	0.143
1998	24.583	904,689	1,002,920	0.051	0.114
1999	5.201	1,368,780	1,495,910	0.041	0.080
2000	2.603	1,462,240	1,713,280	0.040	0.071
2001	9.672	1,251,100	1,548,940	0.050	0.081
2002	1.555	1,087,930	1,397,530	0.069	0.101
2003	16.469	913,186	1,137,720	0.060	0.094
2004	5.164	997,300	1,211,000	0.074	0.116
2005	5.277	972,299	1,219,480	0.076	0.126
2006	1.010	826,656	1,101,890	0.097	0.151
2007	3.677	566,222	832,706	---	---

Table 9. Proposed harvest guideline for Pacific sardine for the 2008 management year. See 'Harvest Guideline' section for methods used to derive the harvest guideline.

Stock biomass (age 1+, mt)	Cutoff (mt)	Fraction	Distribution	Harvest guideline for 2008 (mt)
832,706	150,000	15%	87%	89,093

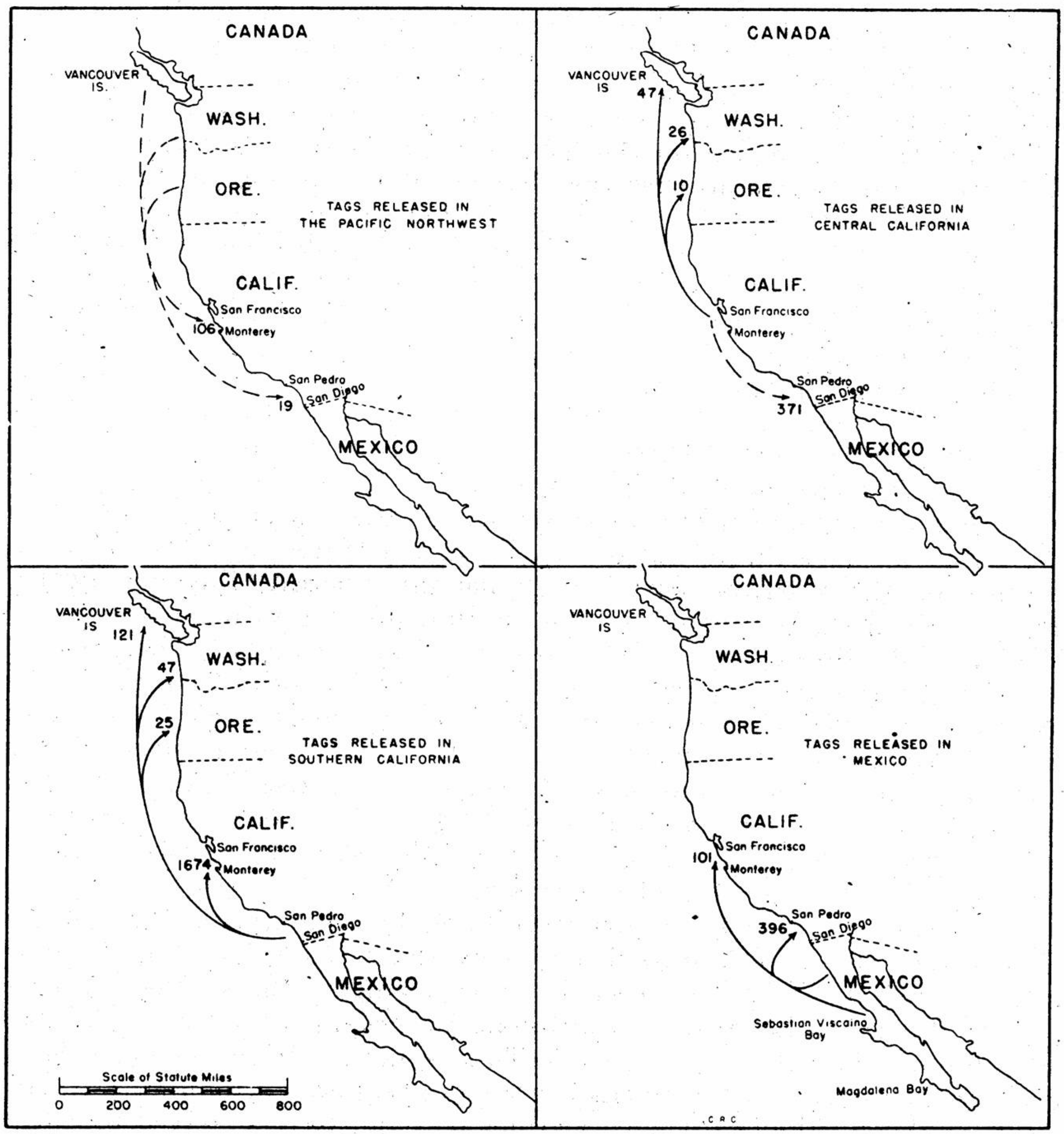


Figure 1. Sections of the Pacific Coast of North America showing the major movements of tagged sardines as indicated by recoveries from June 1935 to May, 1944 (reproduced from Clark and Janssen, 1945).

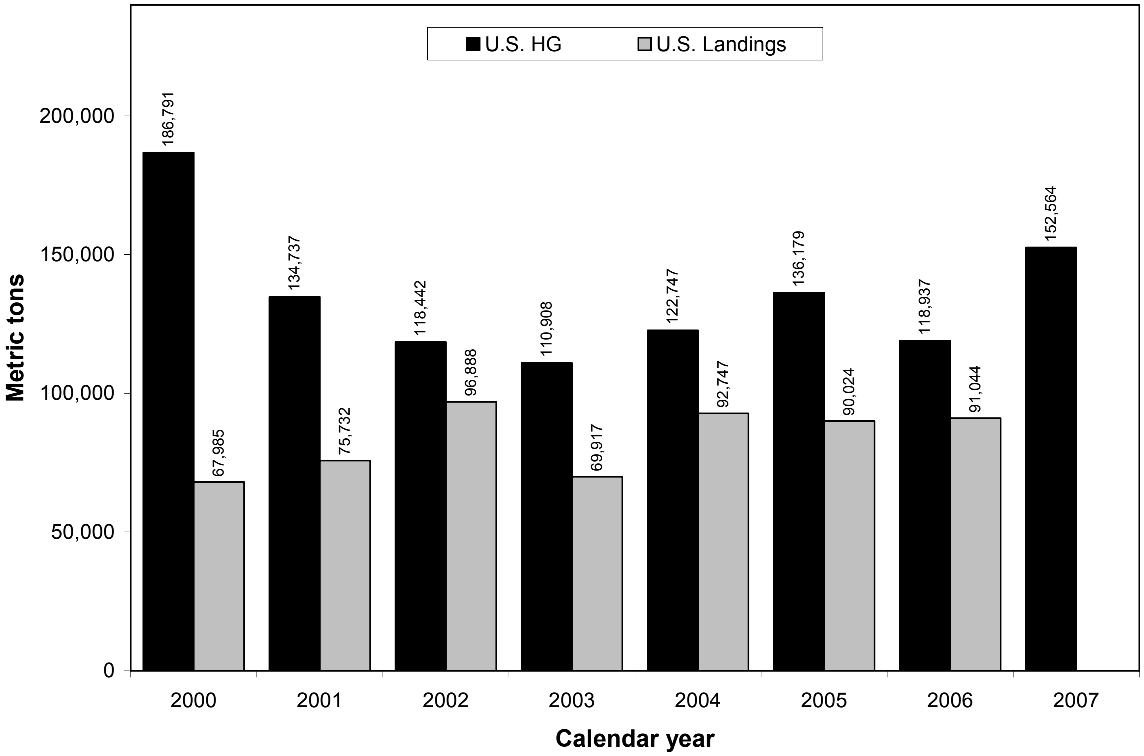


Figure 2a. Performance of the U.S. Pacific sardine fishery since calendar year 2000.

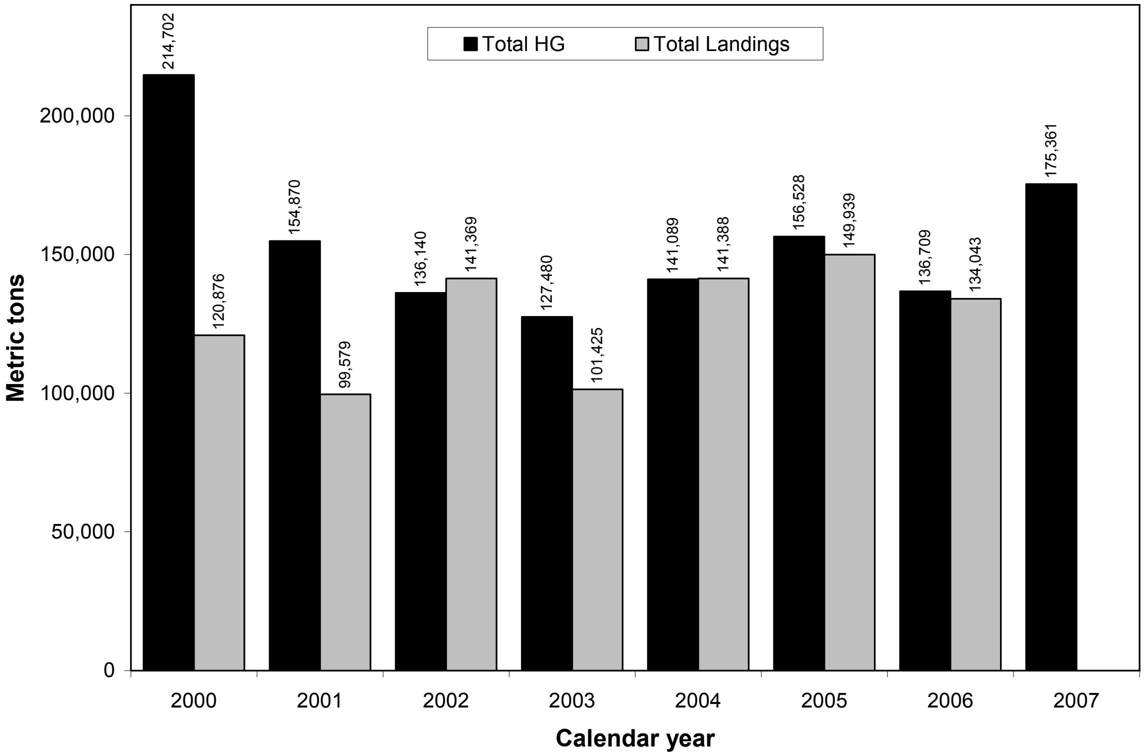


Figure 2b. Coast-wide harvest (Ensenada to British Columbia) and HGs since 2000.

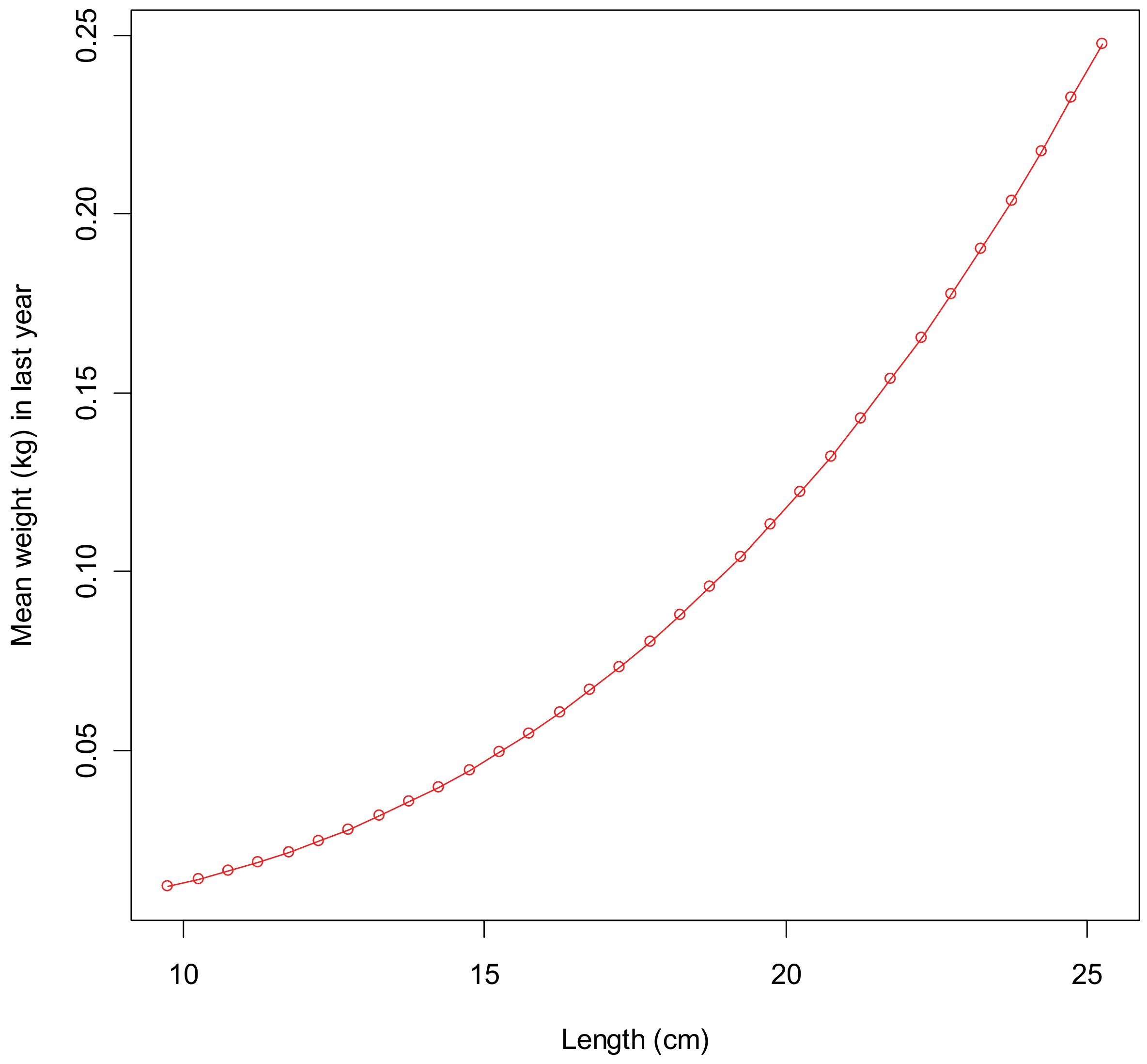


Figure 3. Weight-at-length as applied in base model J14.

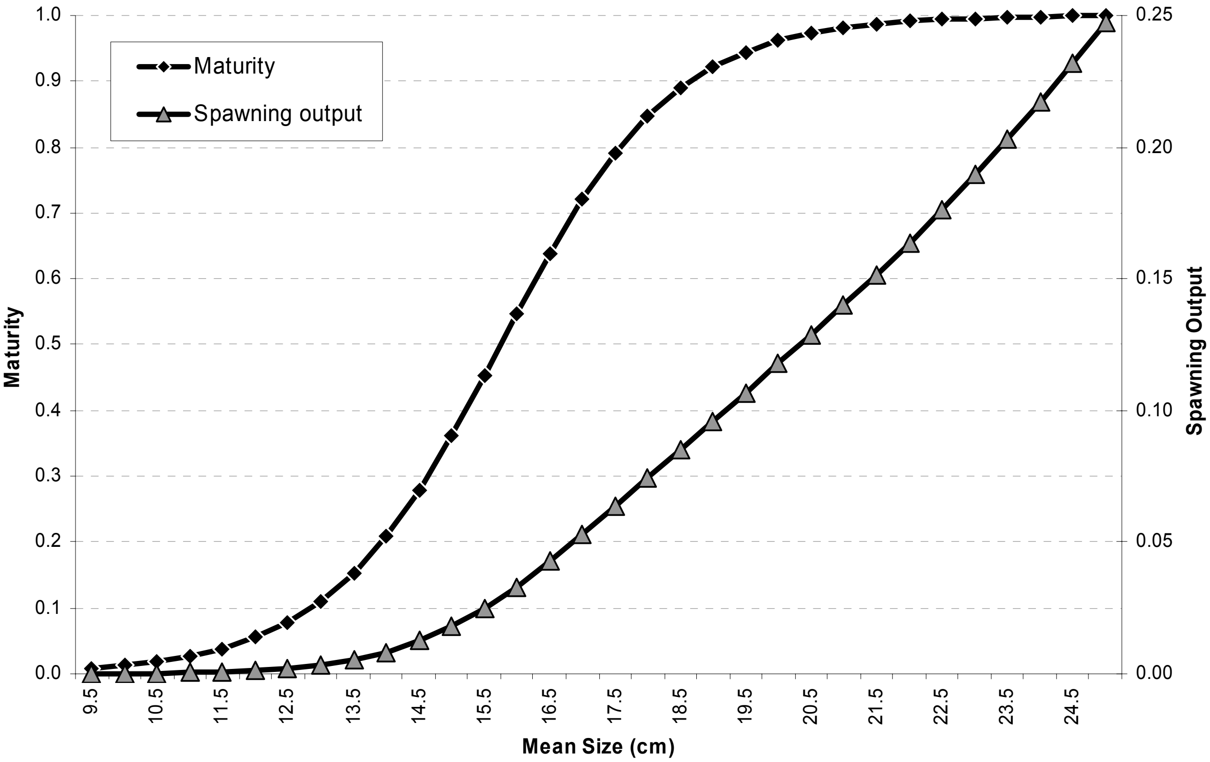


Figure 4a. Maturity and spawning output as a function of length in base model J14.

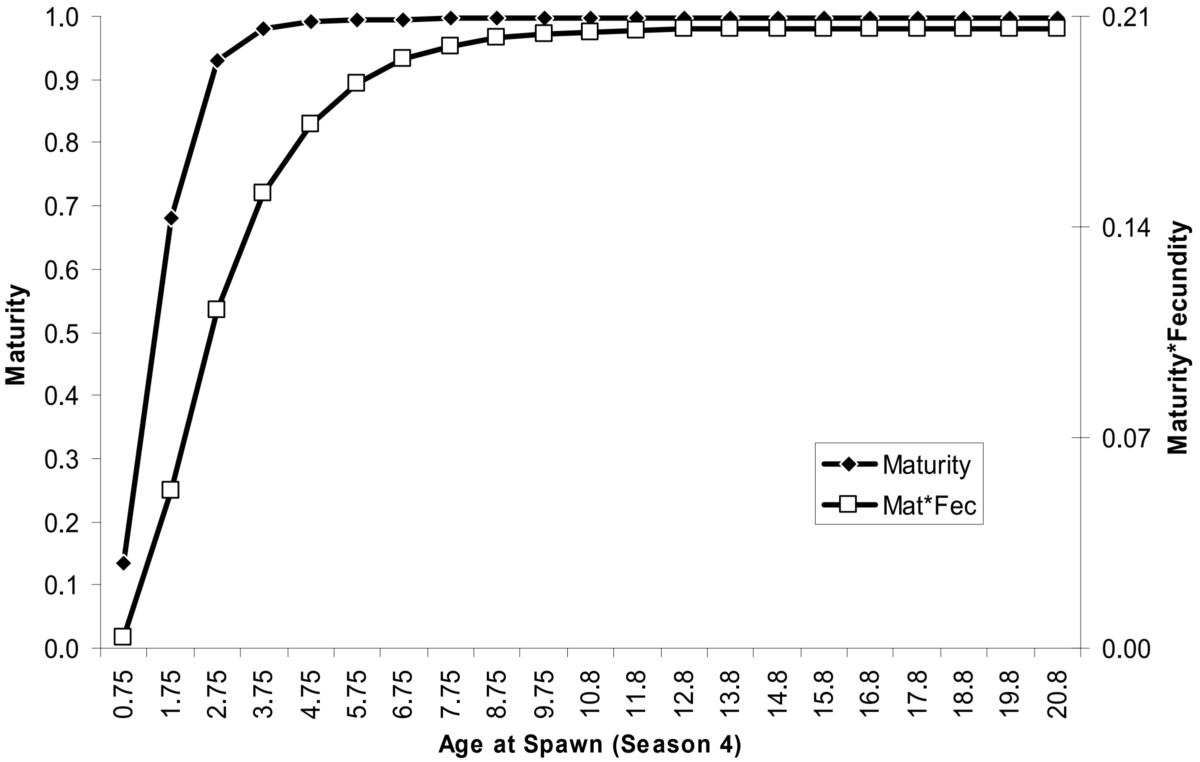


Figure 4b. Maturity and fecundity as a function of age in base model J14.

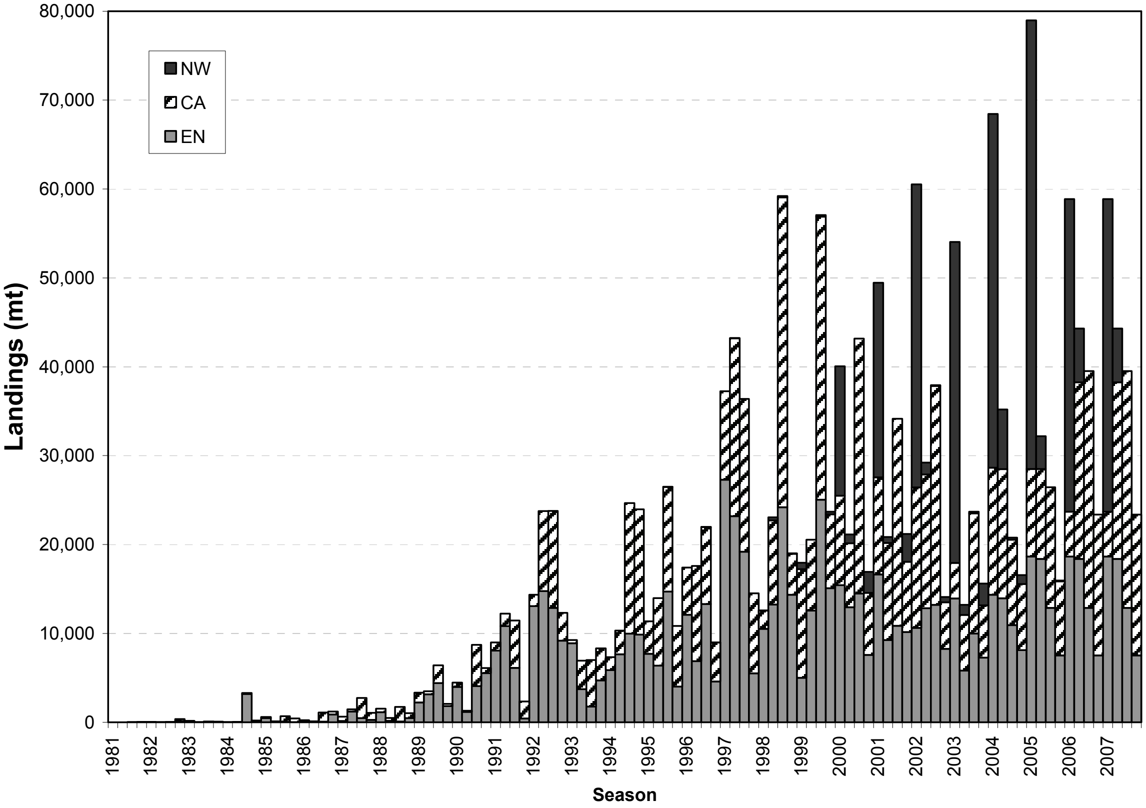


Figure 5. Pacific sardine landings (mt) by fishery and season as used in base model J14.

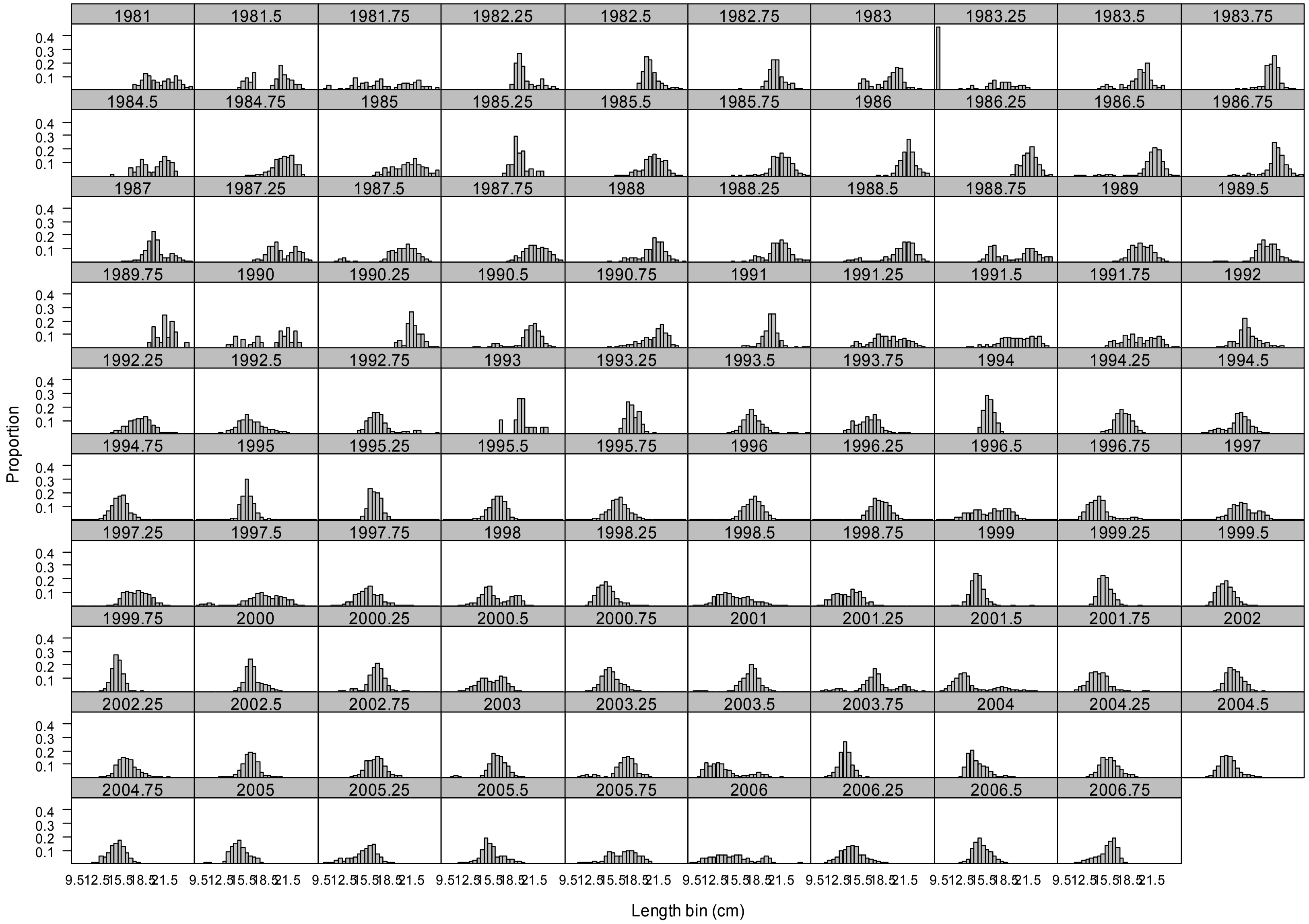


Figure 6. Length-composition data for the California fishery, 1981-2006.

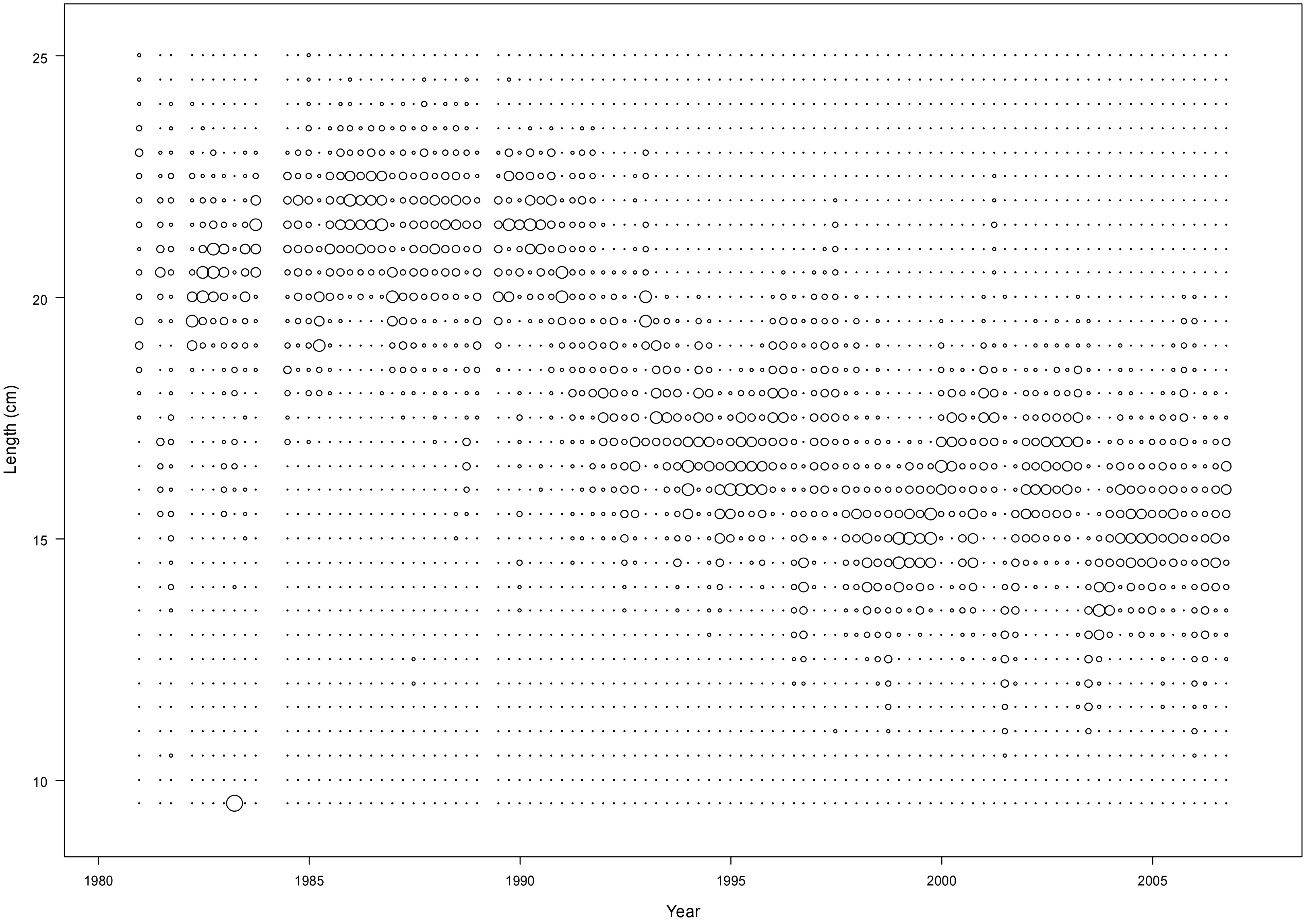


Figure 7. Length-composition data for the California fishery, 1981-2006.

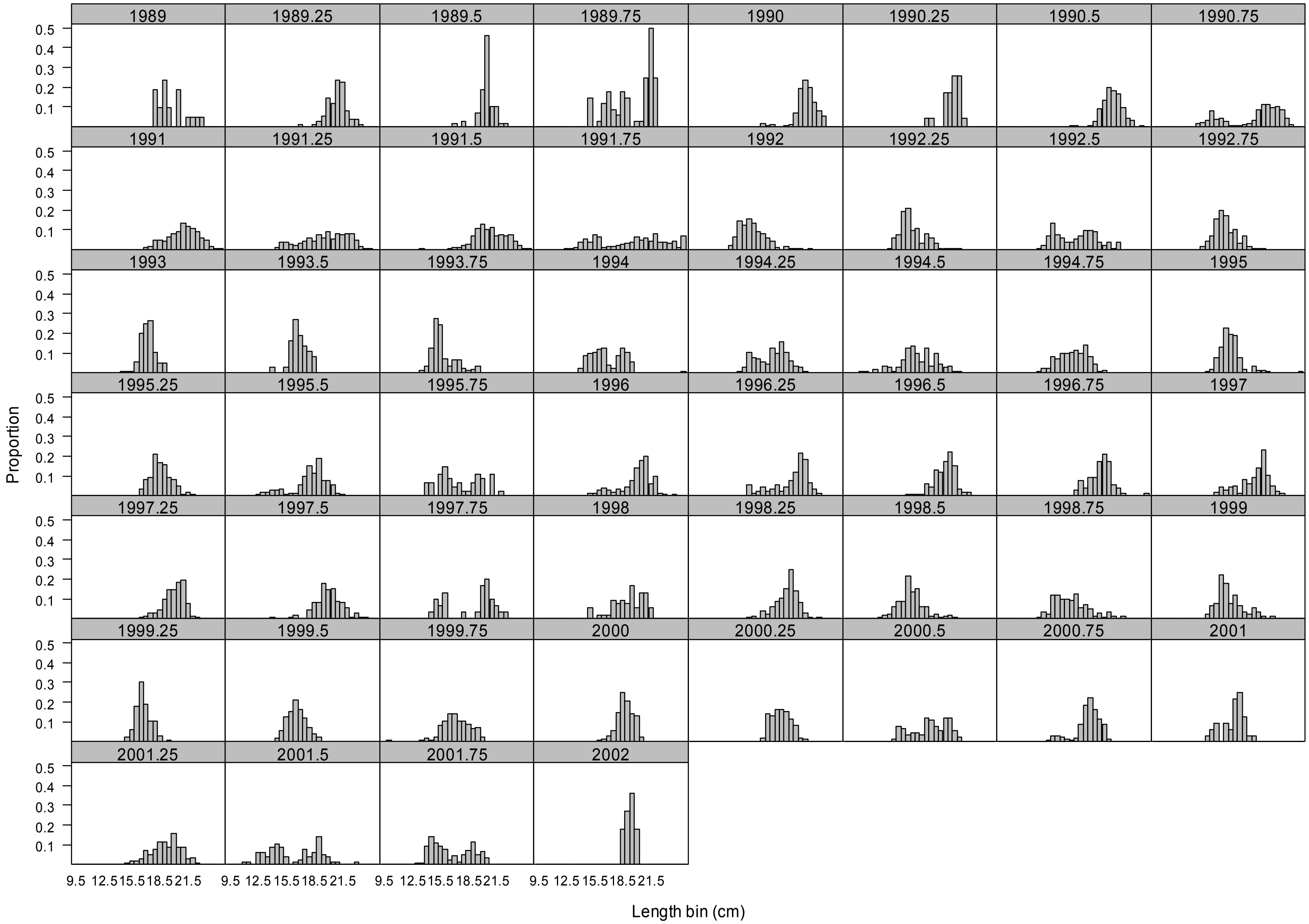


Figure 8. Length-composition data for the Ensenada fishery, 1989-2002.

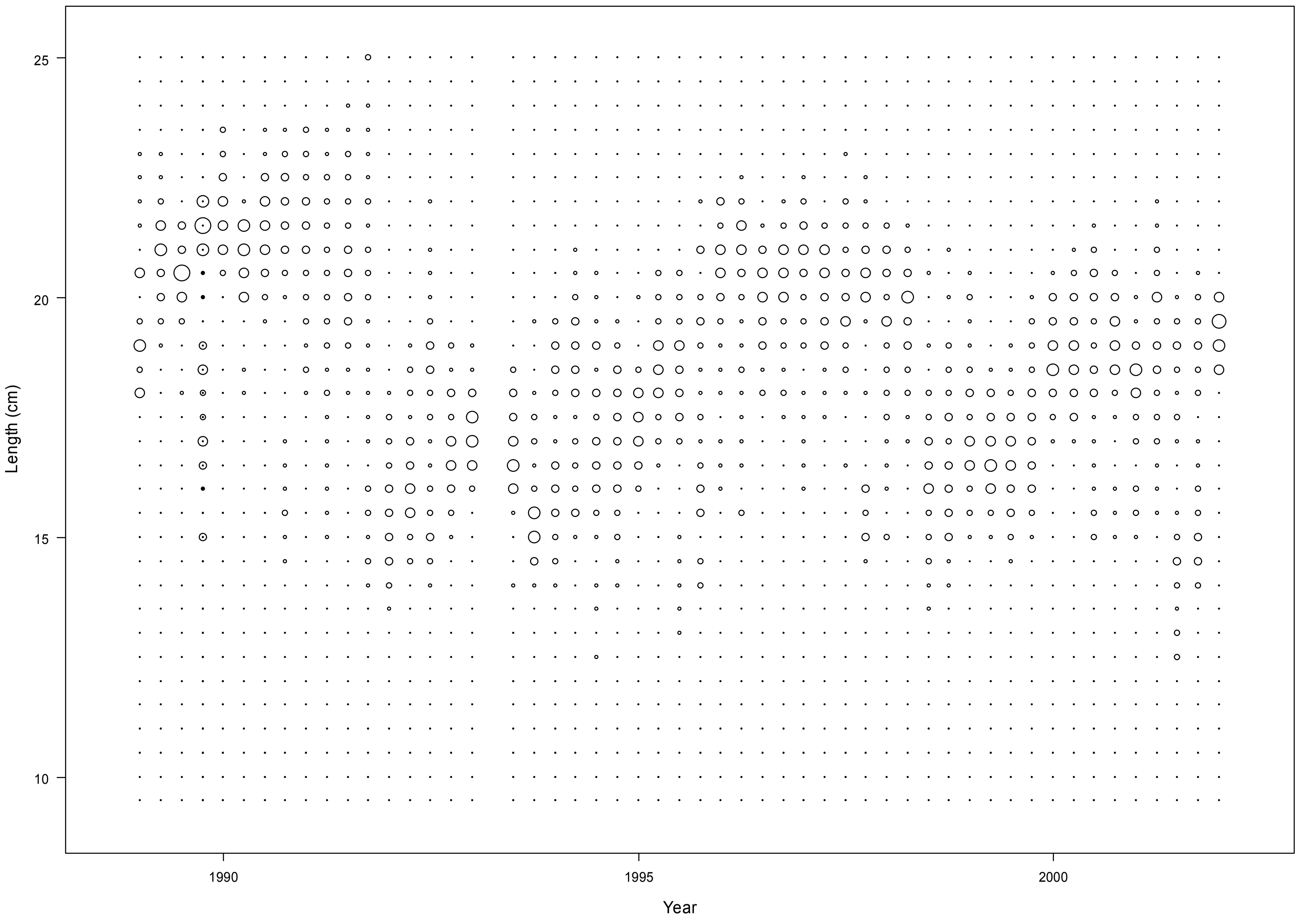


Figure 9. Length-composition data for the Ensenada fishery, 1989-2002.

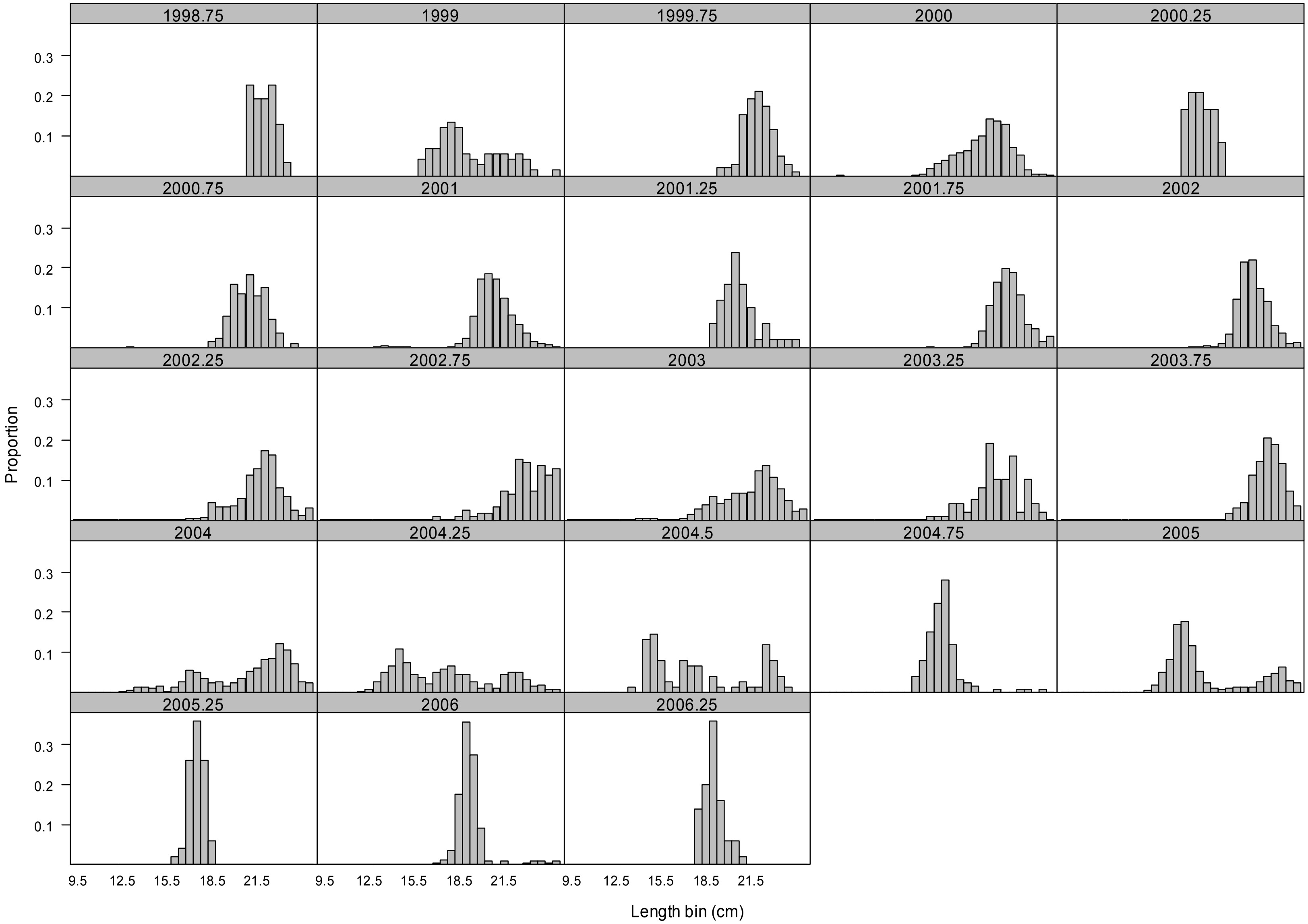


Figure 10. Length-composition data for the Pacific Northwest fishery, 1998-2006.

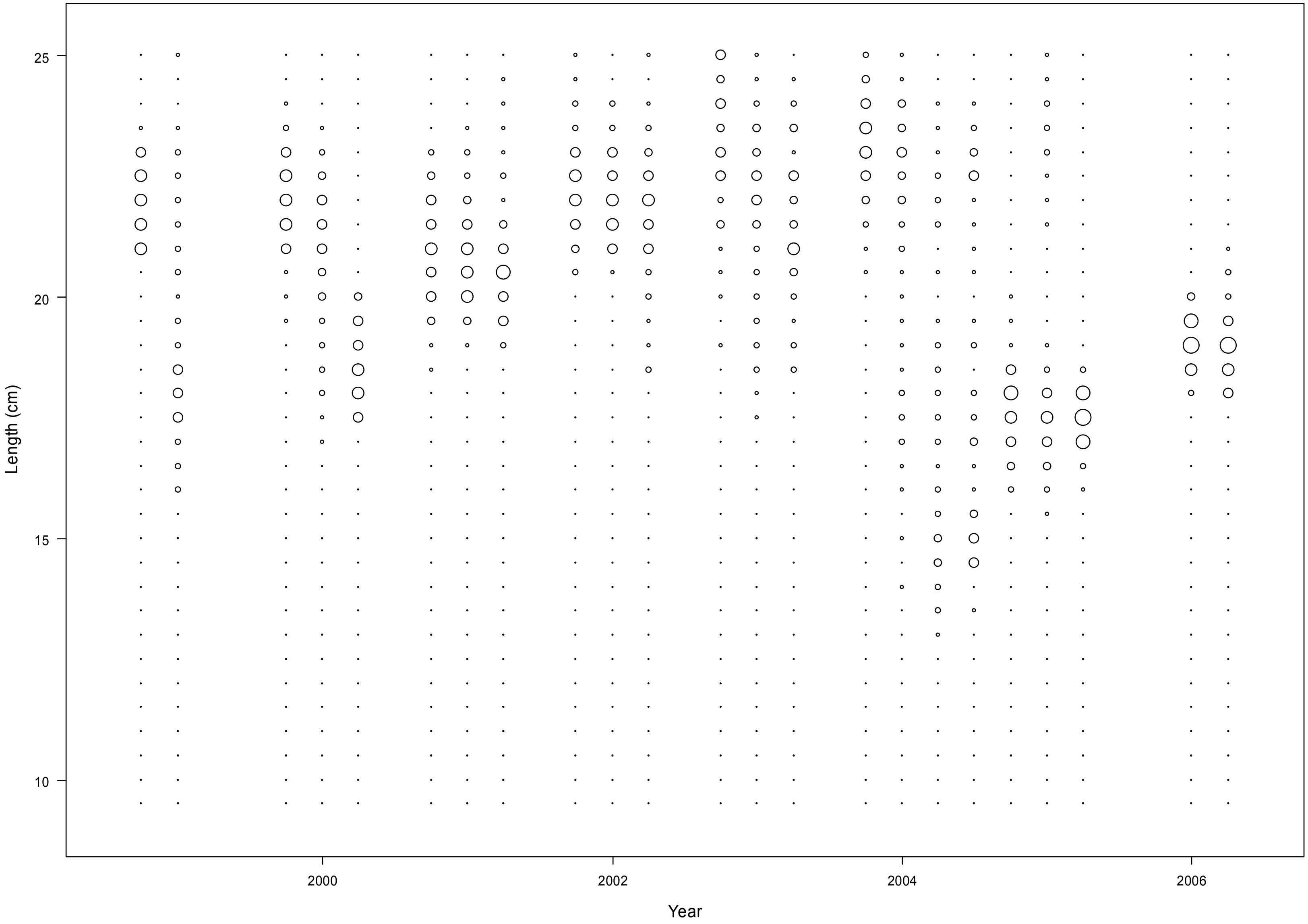


Figure 11. Length-composition data for the Pacific Northwest fishery, 1999-2006.

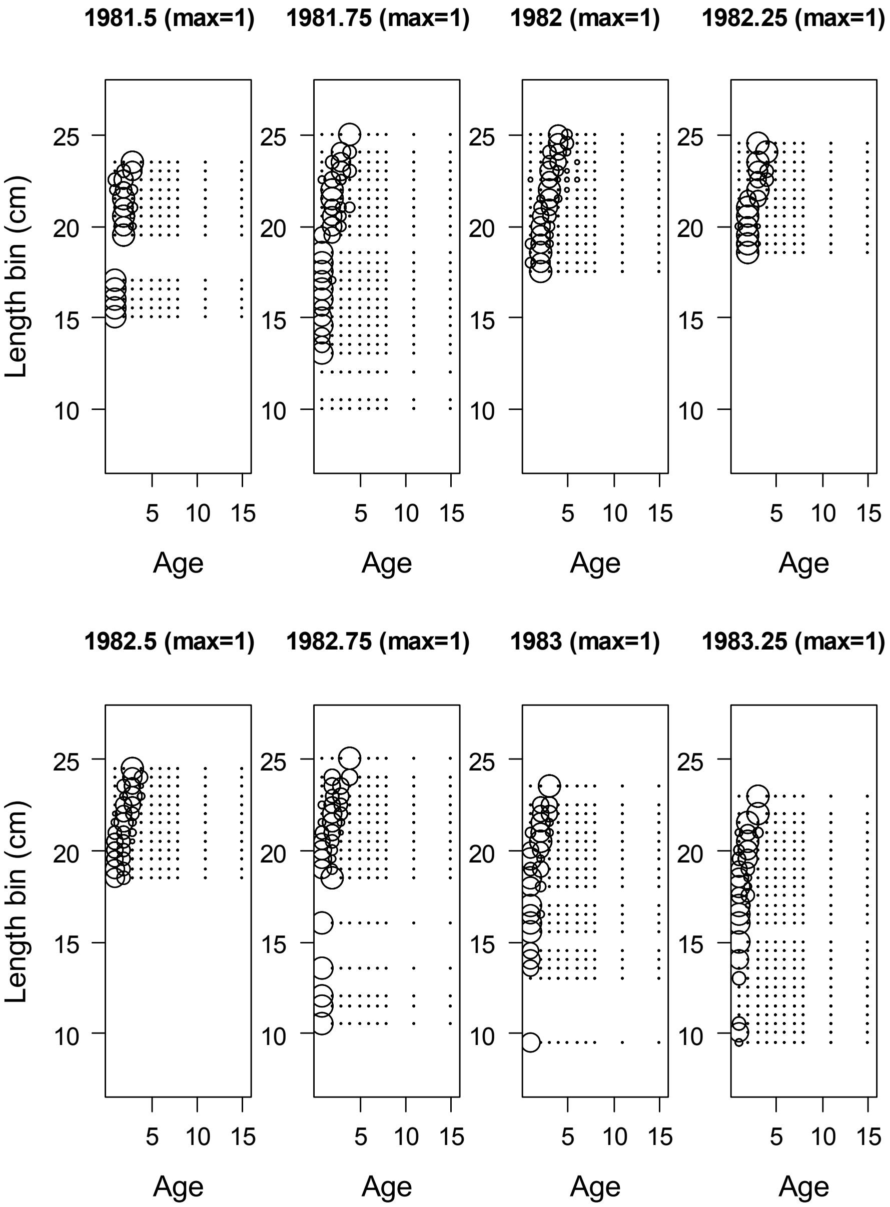


Figure 12. Conditional age-at-length data for the California fishery.

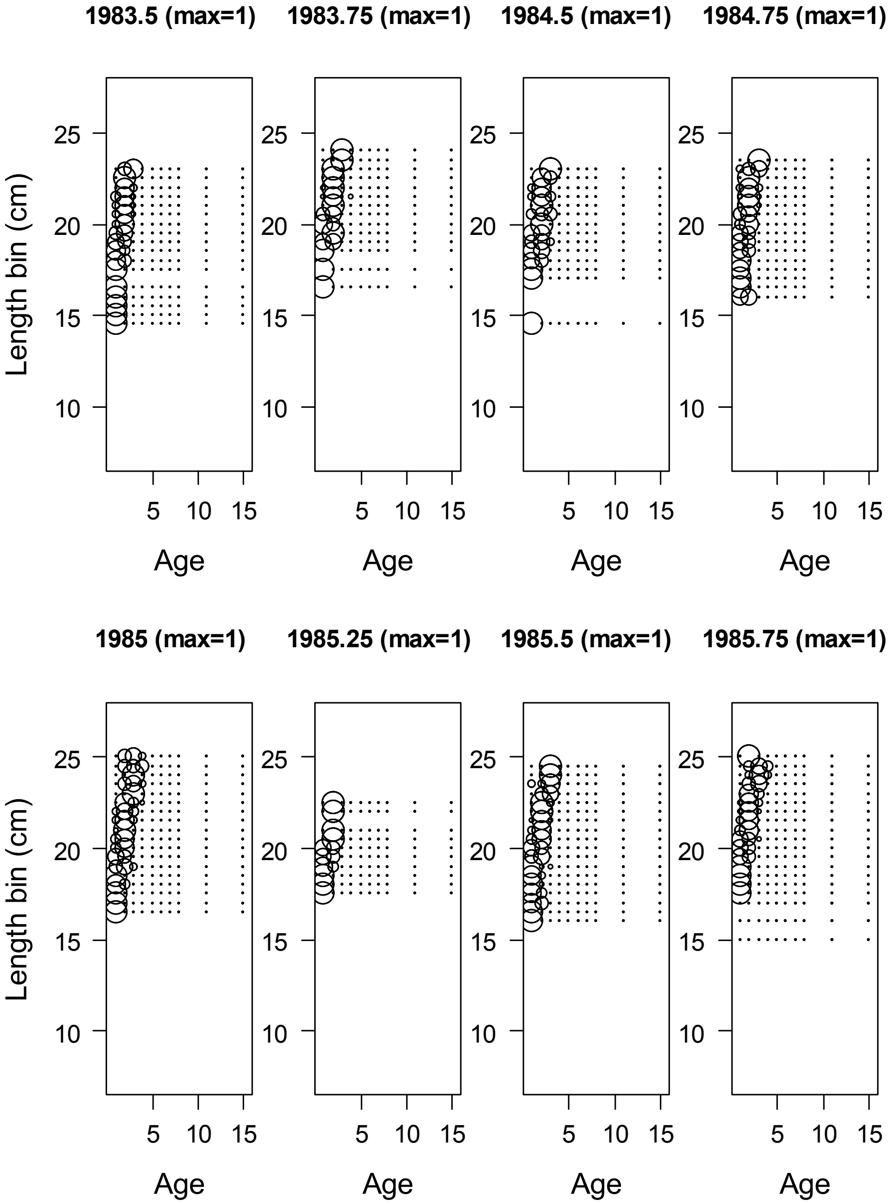


Figure12 cont. Conditional age-at-length data for the California fishery.

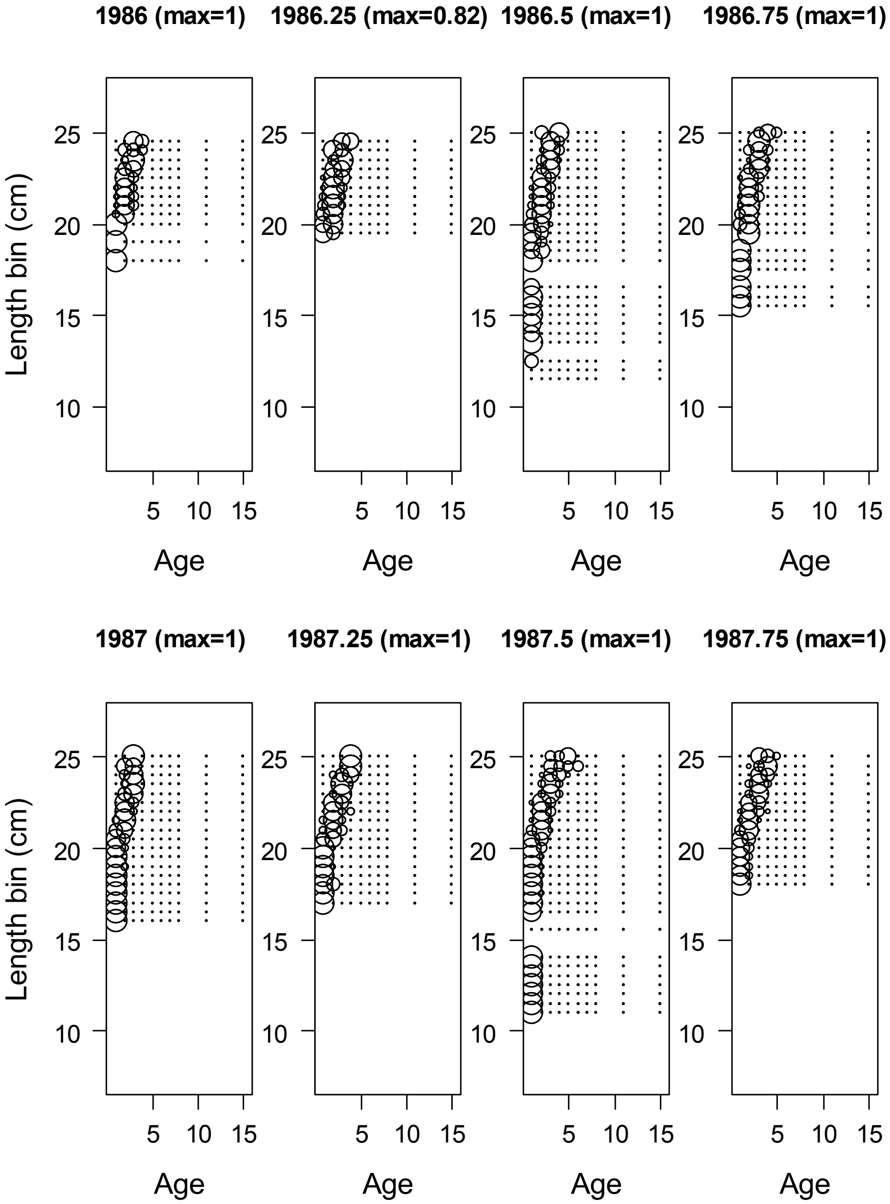

1986 (max=1)
1986.25 (max=0.82)
1986.5 (max=1)
1986.75 (max=1)
1987 (max=1)
1987.25 (max=1)
1987.5 (max=1)
1987.75 (max=1)

Figure12 cont. Conditional age-at-length data for the California fishery.

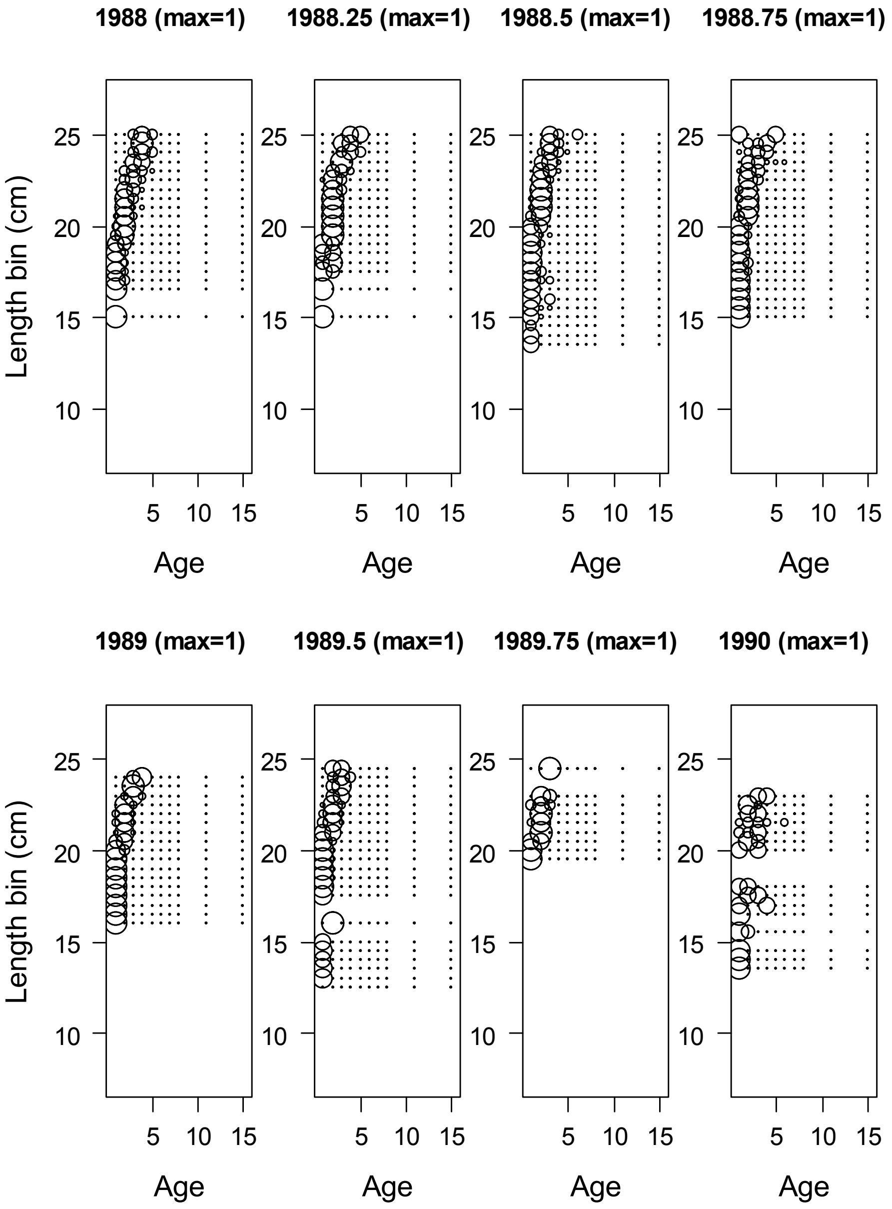


Figure 12 cont. Conditional age-at-length data for the California fishery.

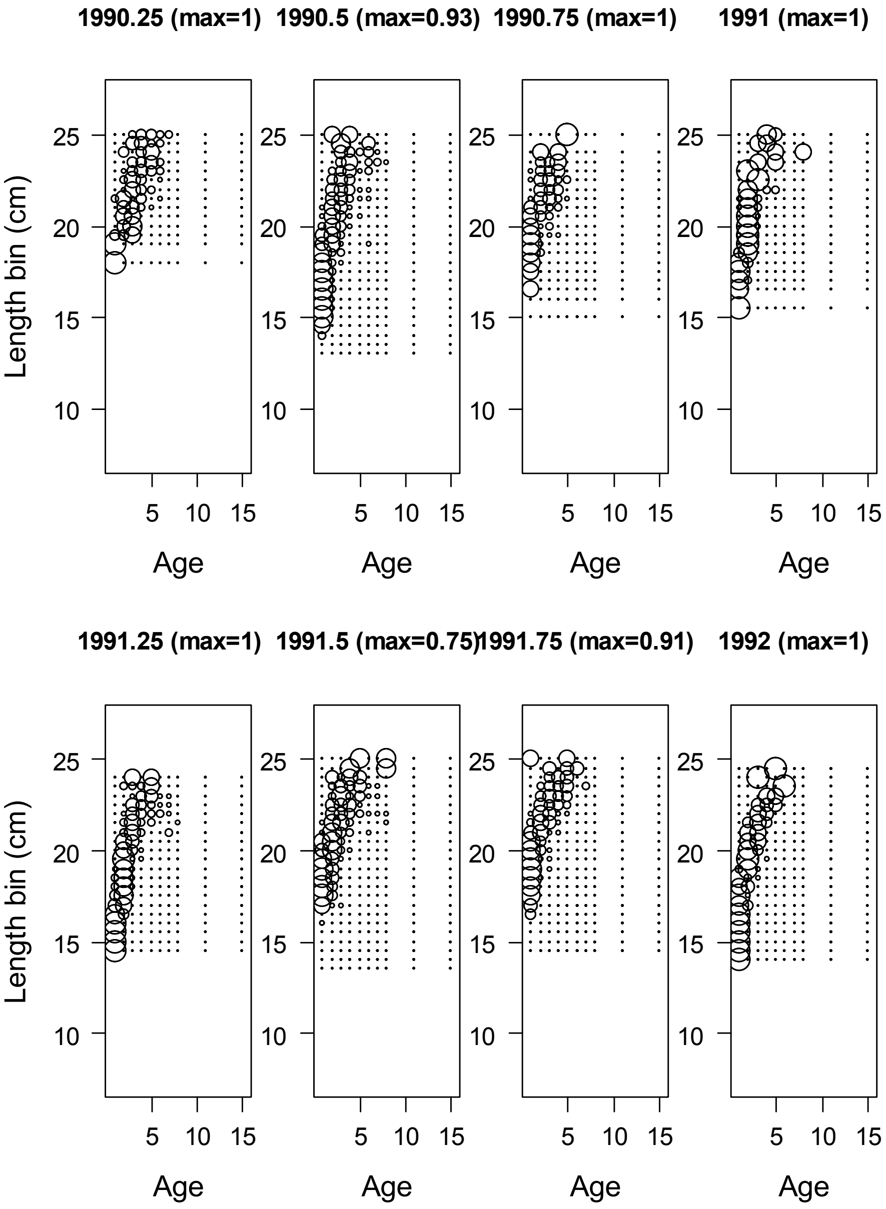


Figure 12 cont. Conditional age-at-length data for the California fishery.

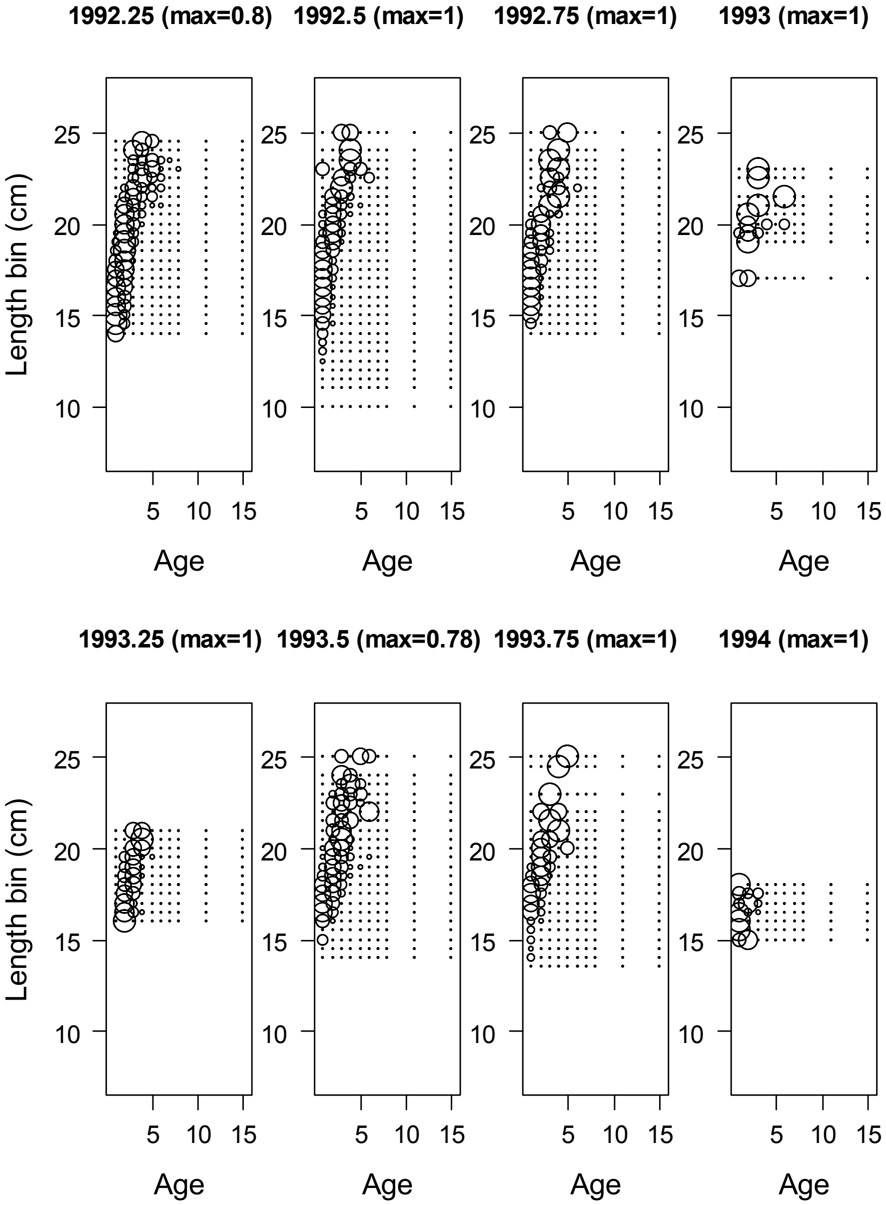


Figure 12 cont. Conditional age-at-length data for the California fishery.

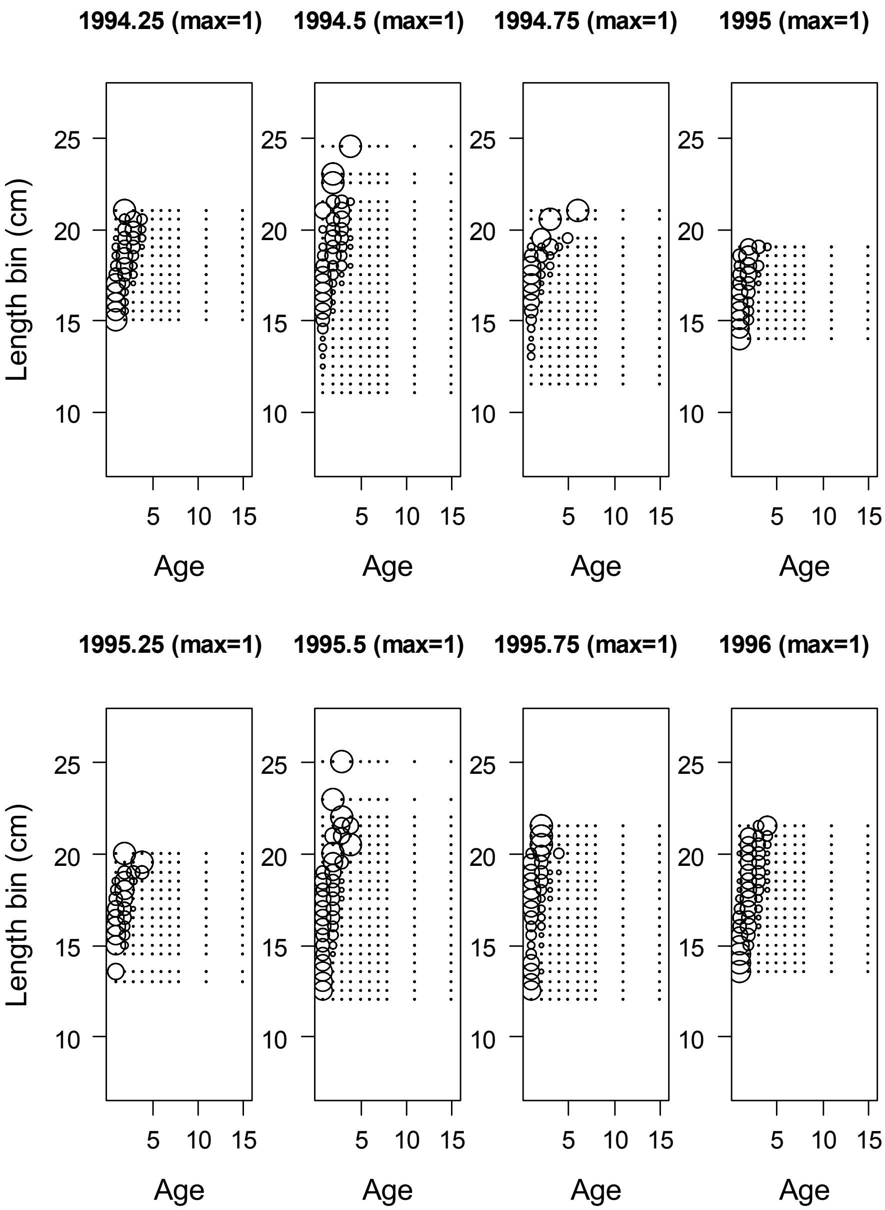


Figure 12 cont. Conditional age-at-length data for the California fishery.

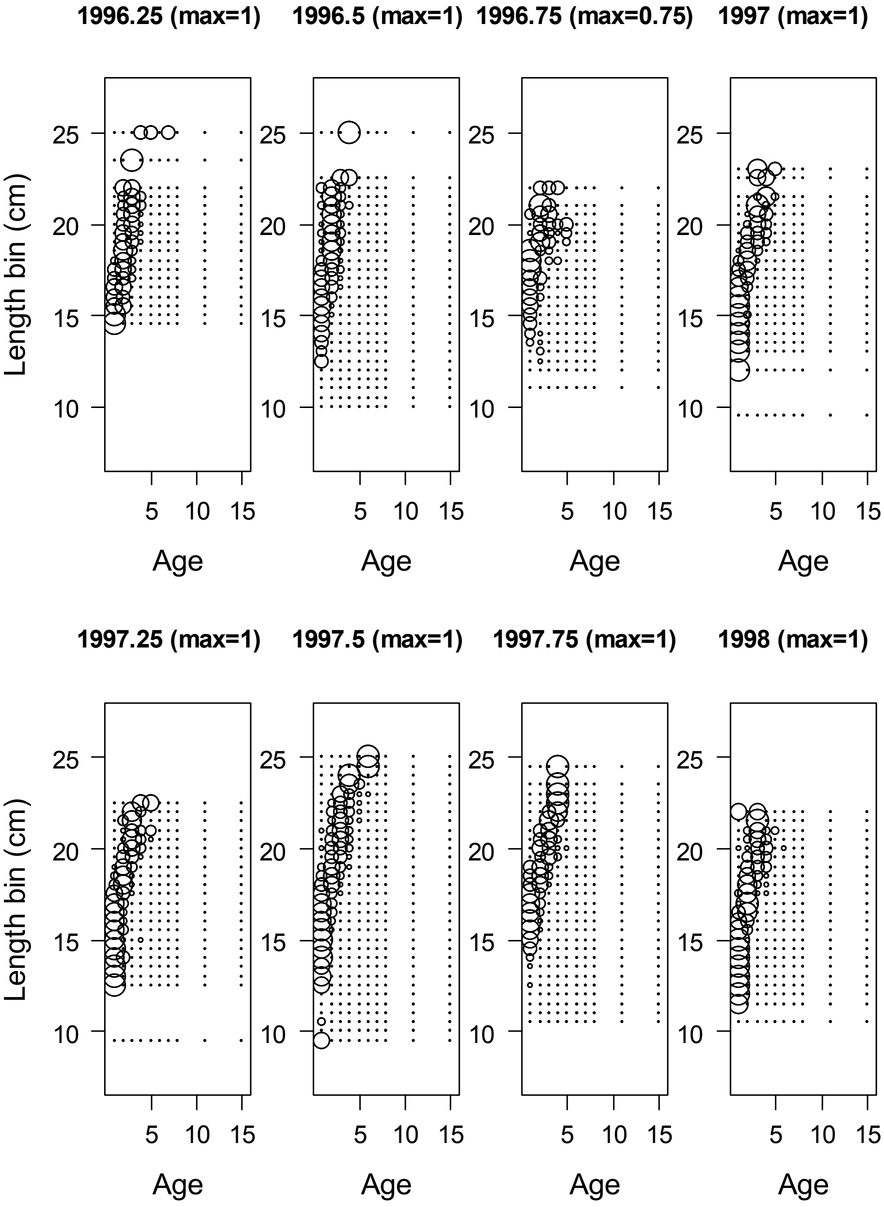


Figure 12 cont. Conditional age-at-length data for the California fishery.

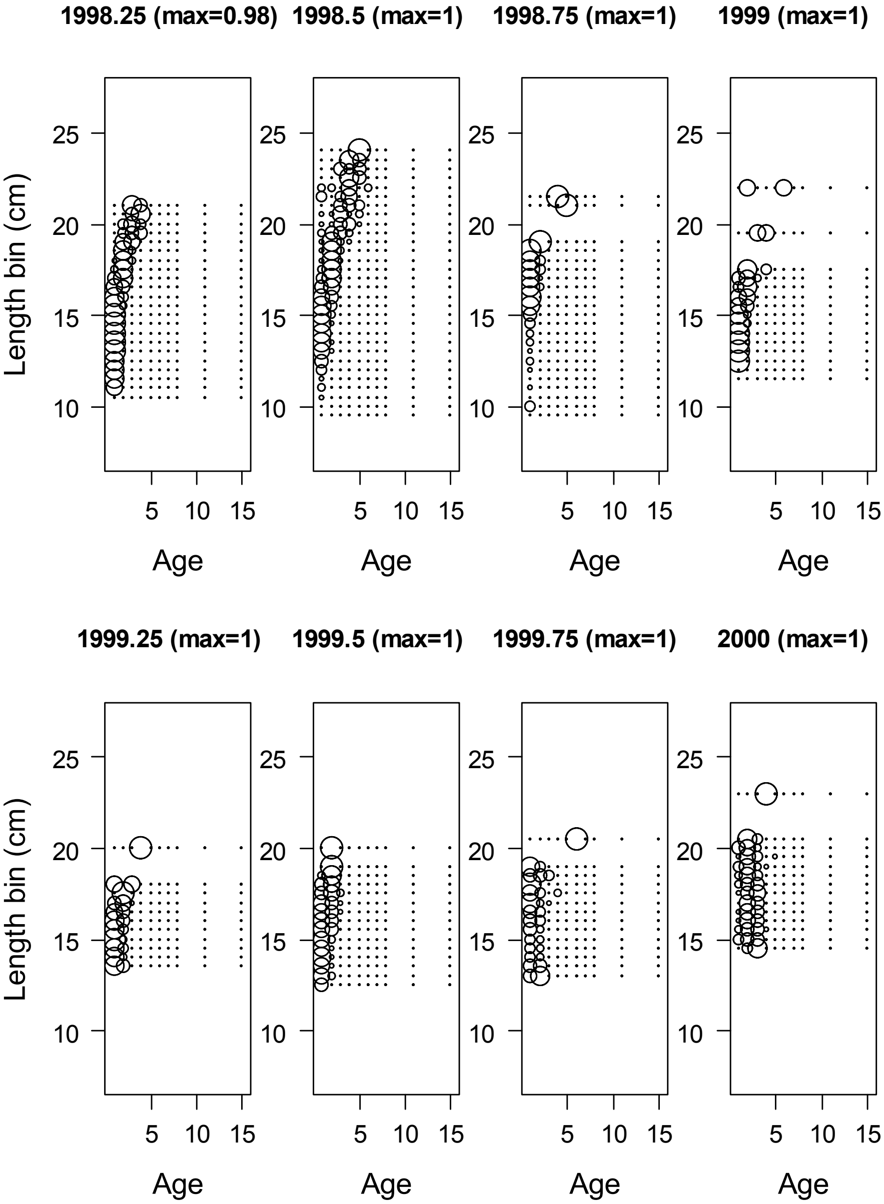


Figure 12 cont. Conditional age-at-length data for the California fishery.

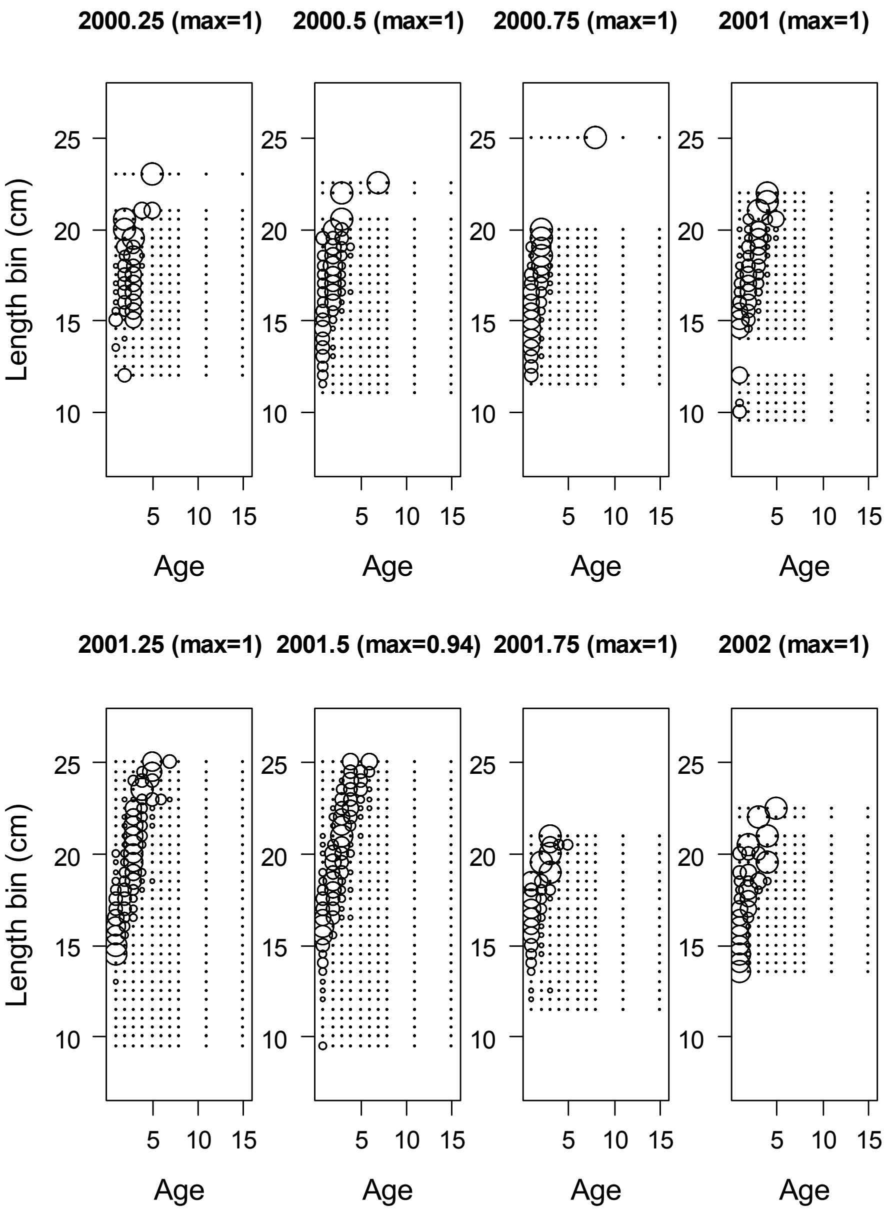
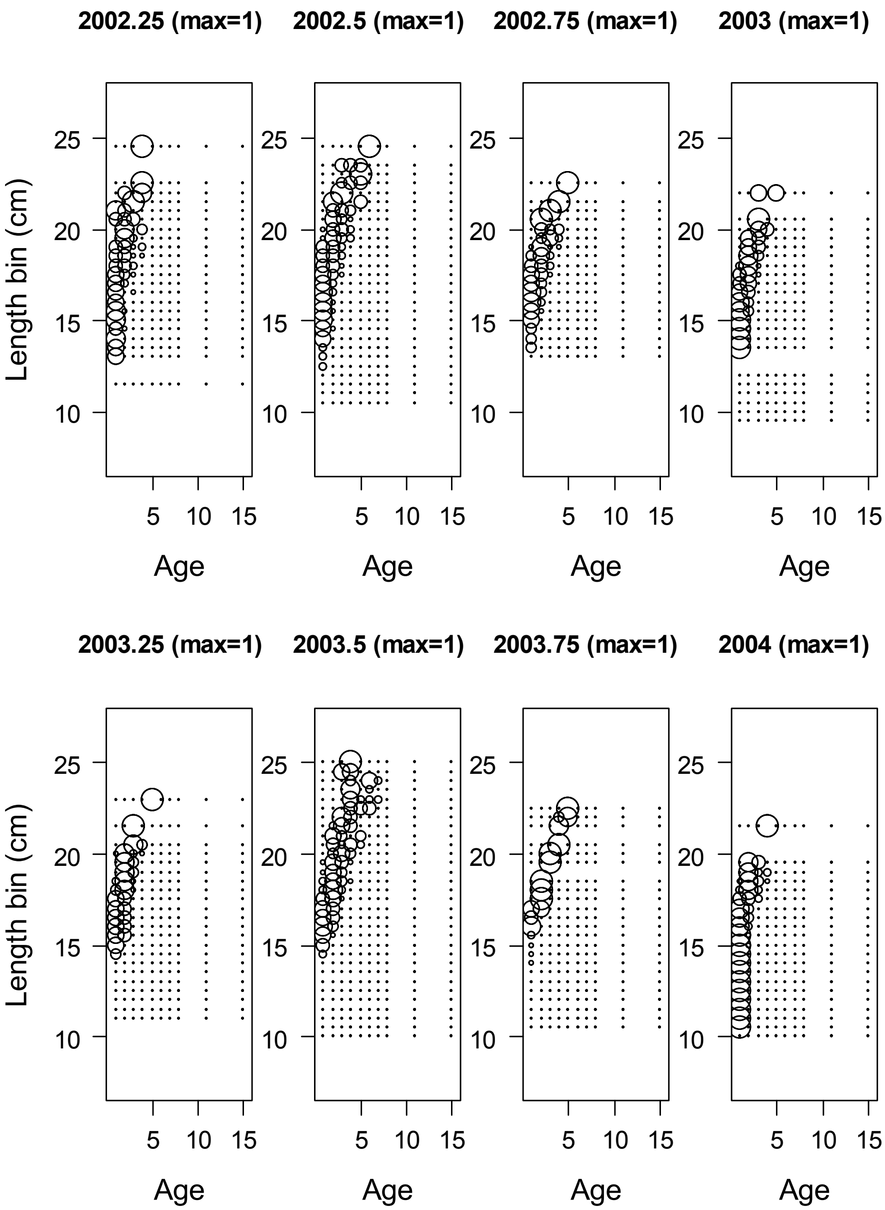


Figure 12 cont. Conditional age-at-length data for the California fishery.



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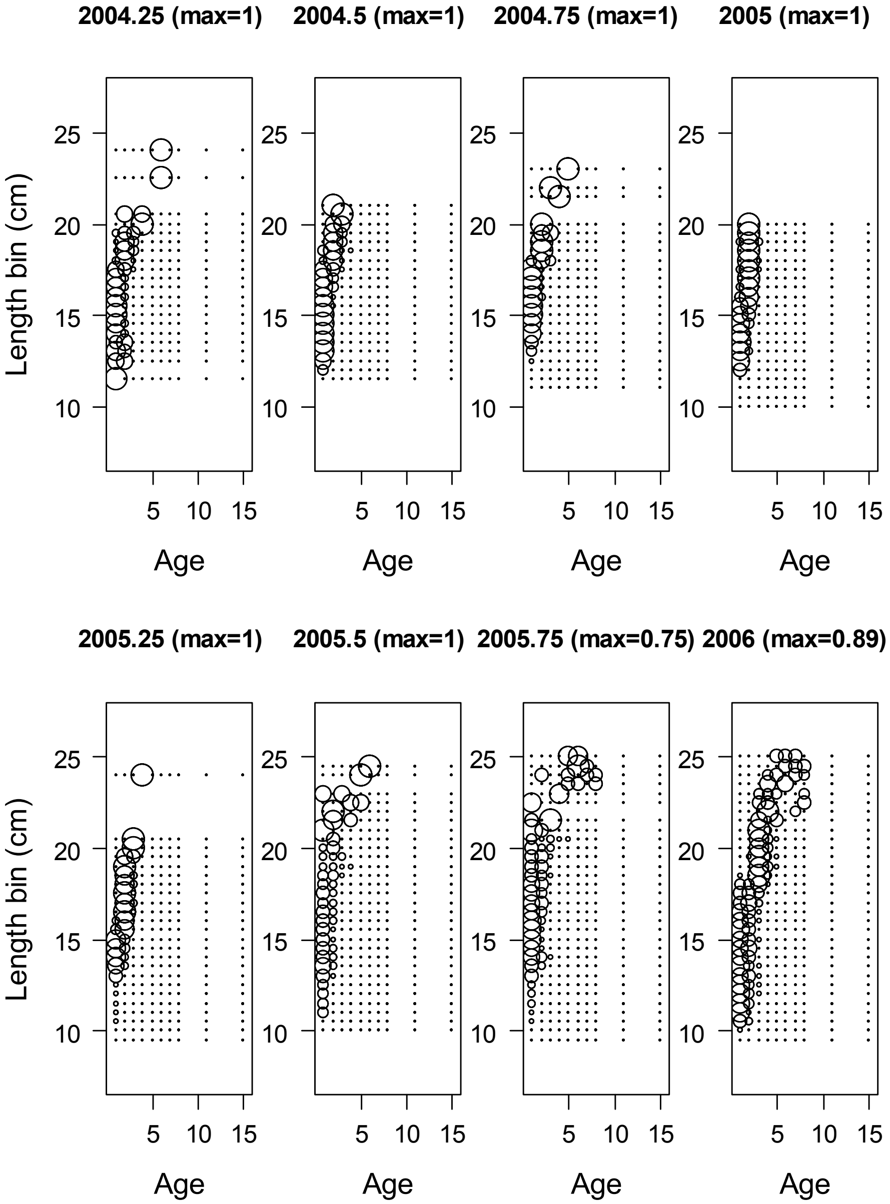
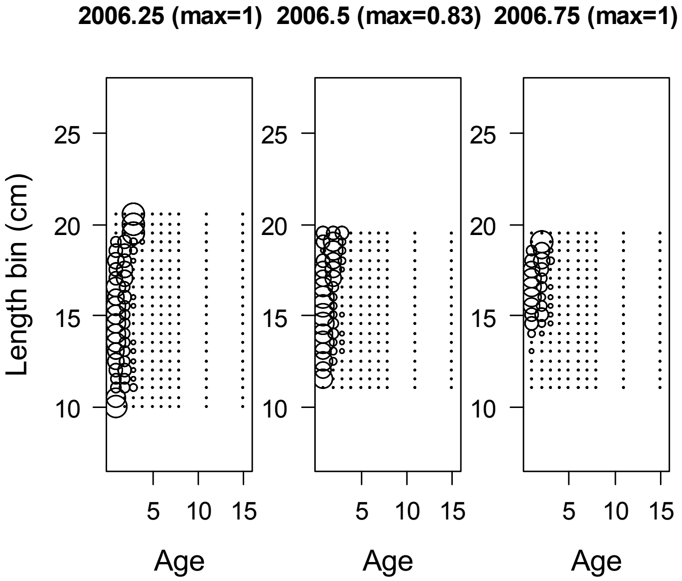


Figure 12 cont. Conditional age-at-length data for the California fishery.



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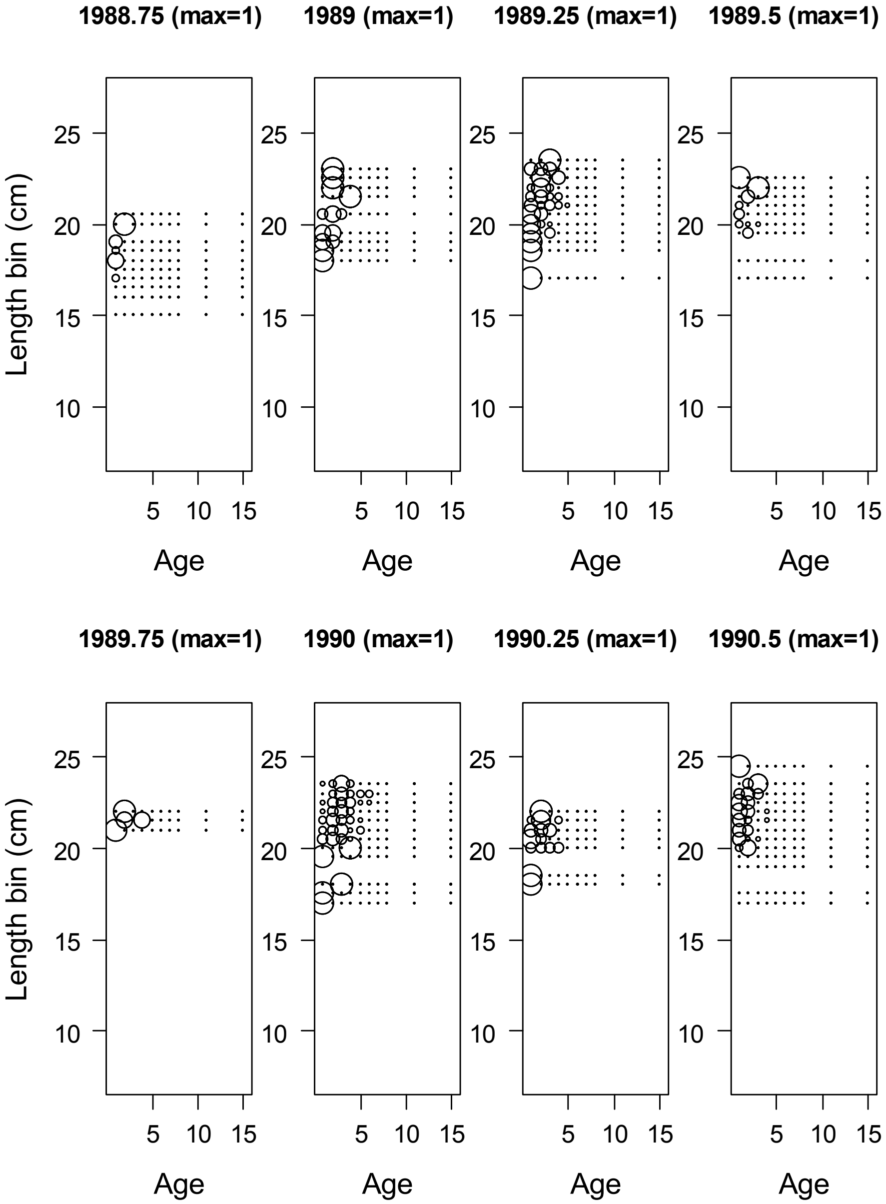

Figure 13. Conditional age-at-length data for the Ensenada fishery.

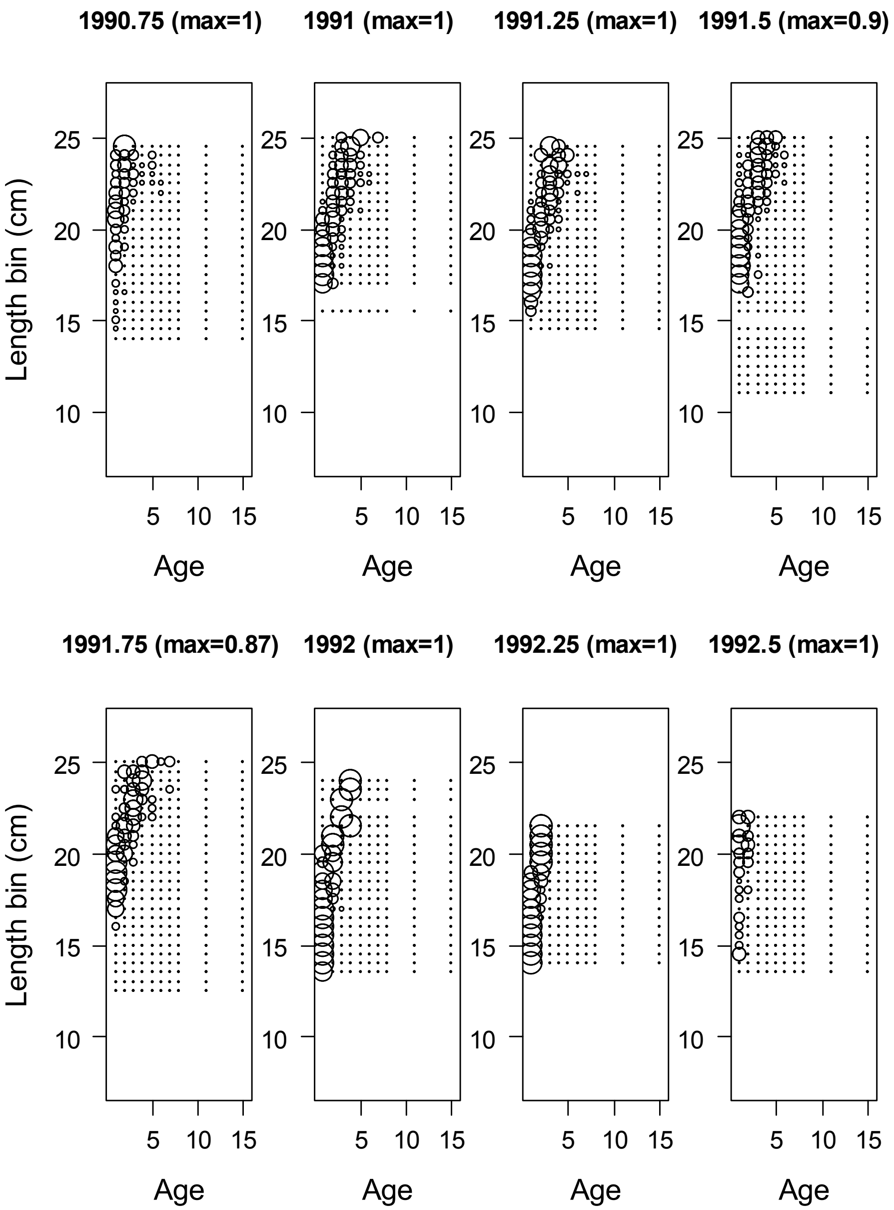

Figure 13 cont. Conditional age-at-length data for the Ensenada fishery.

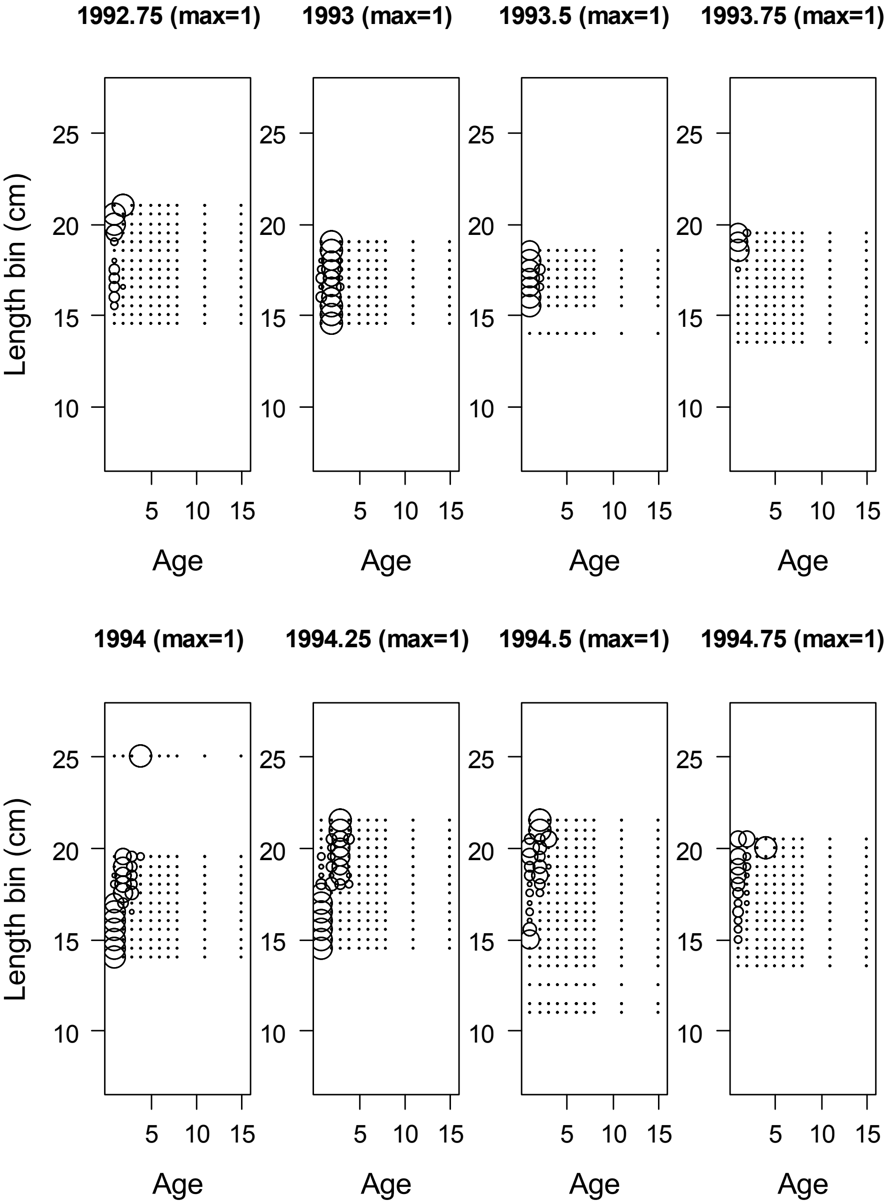

Figure 13 cont. Conditional age-at-length data for the Ensenada fishery.

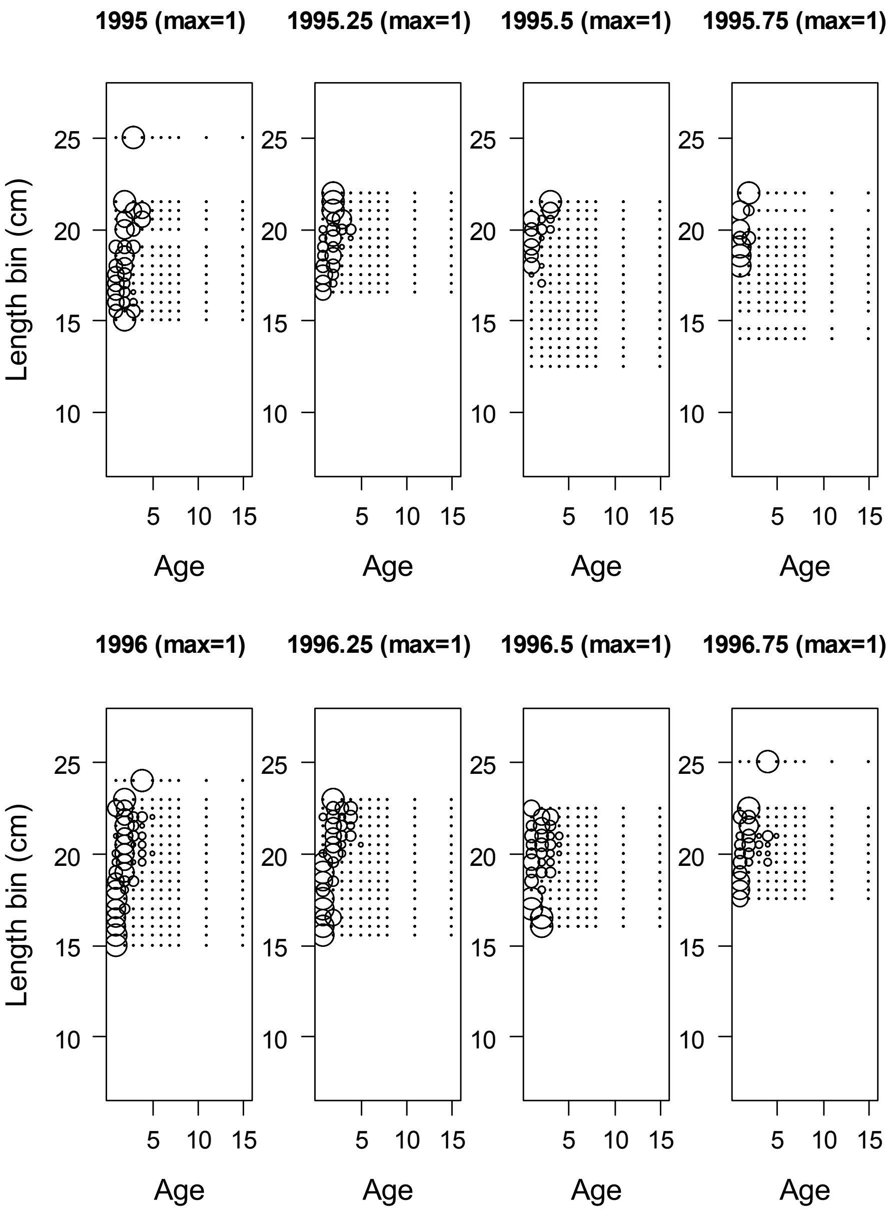

Figure13 cont. Conditional age-at-length data for the Ensenada fishery.

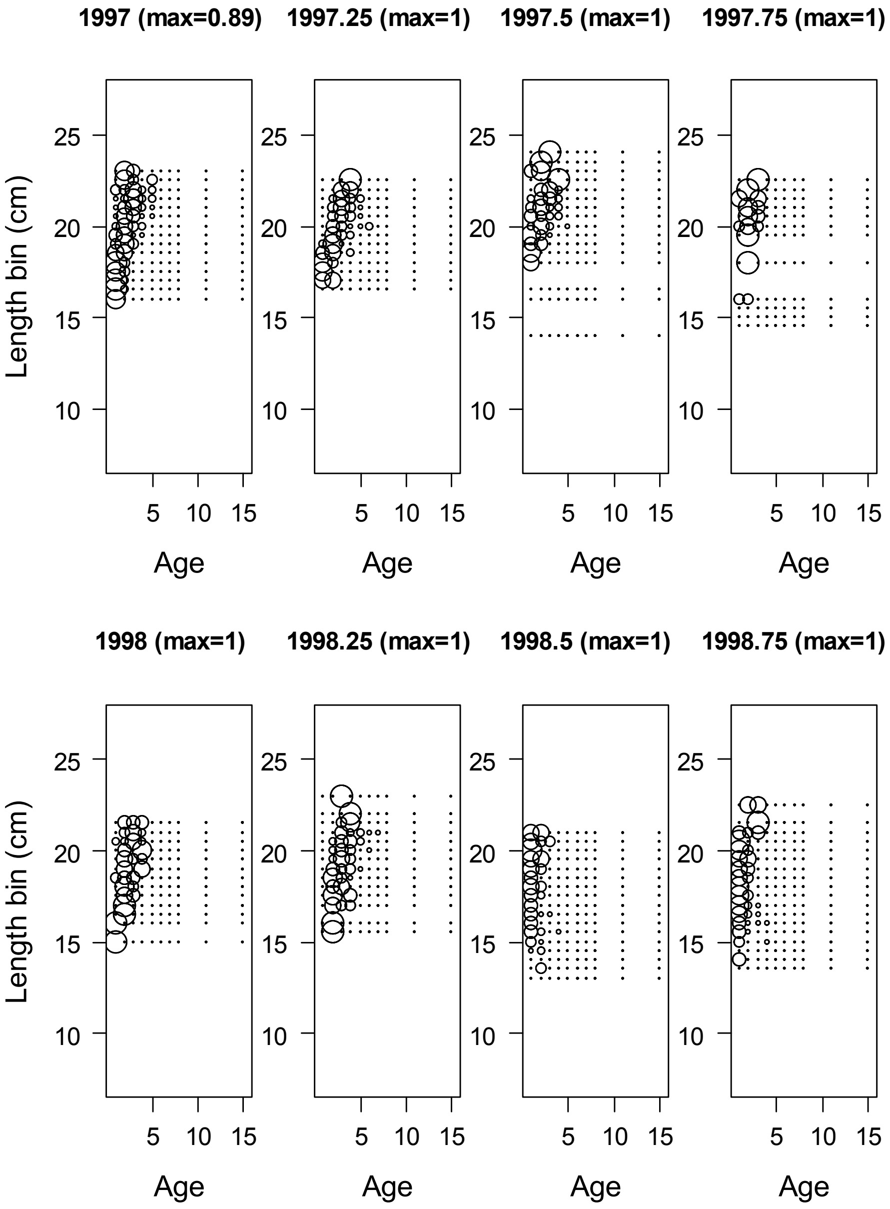

Figure 13 cont. Conditional age-at-length data for the Ensenada fishery.

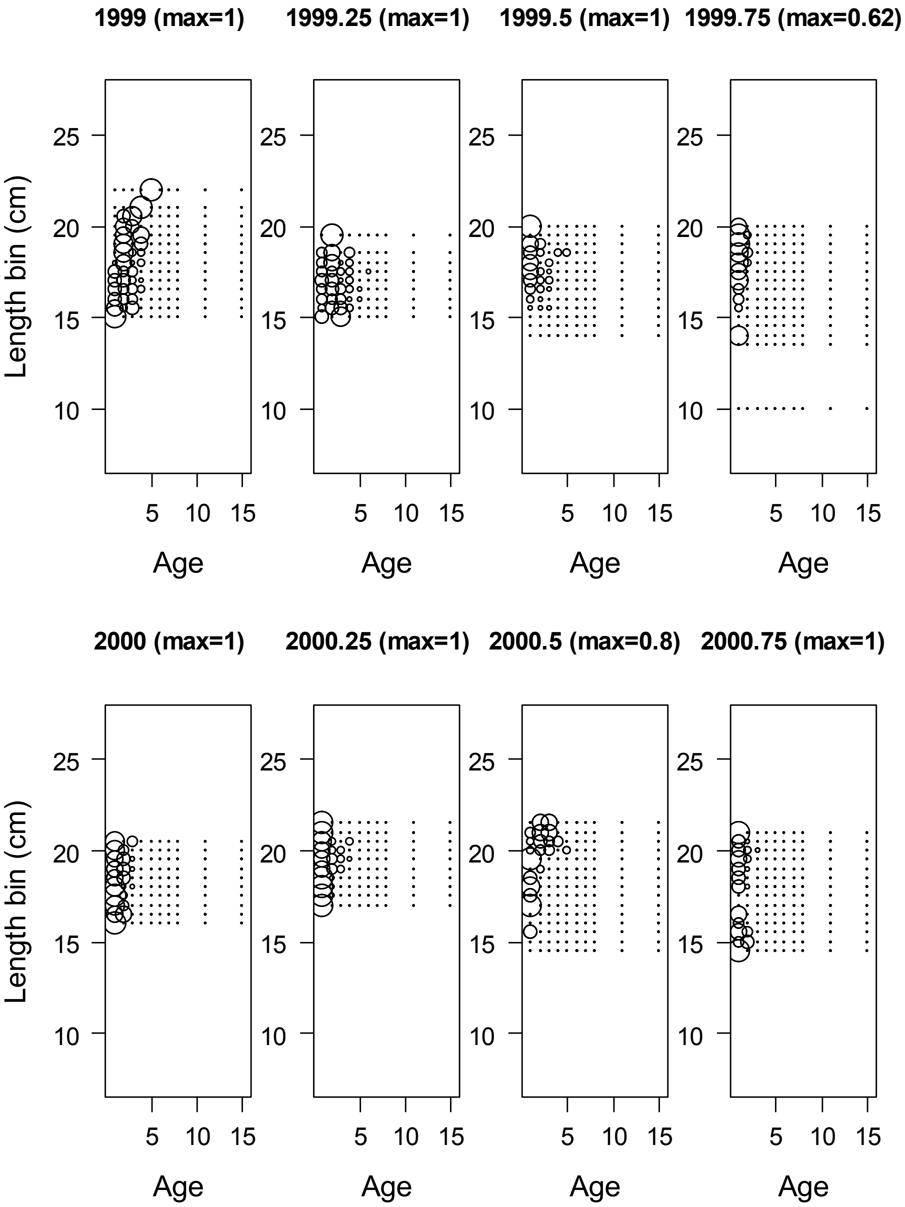

Figure 13 cont. Conditional age-at-length data for the Ensenada fishery.

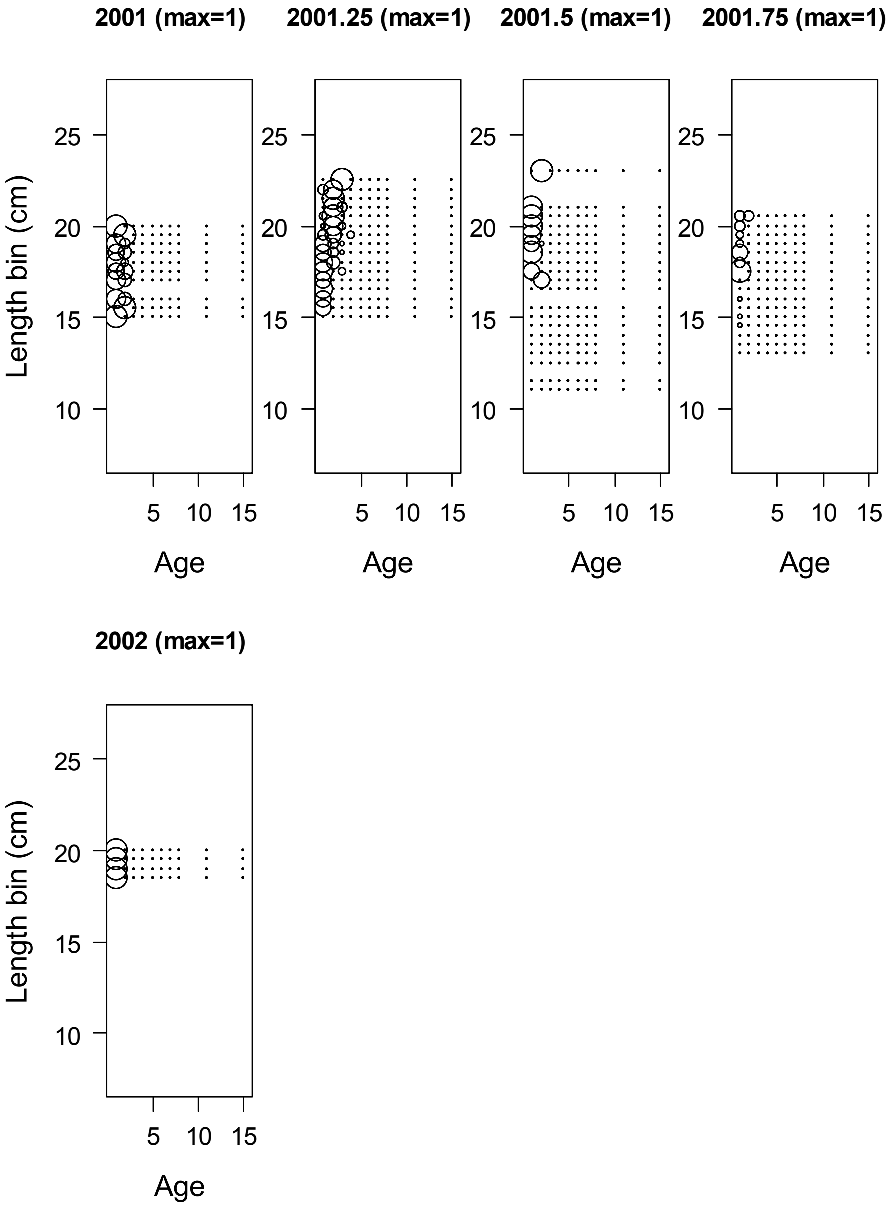

Figure13 cont. Conditional age-at-length data for the Ensenada fishery.

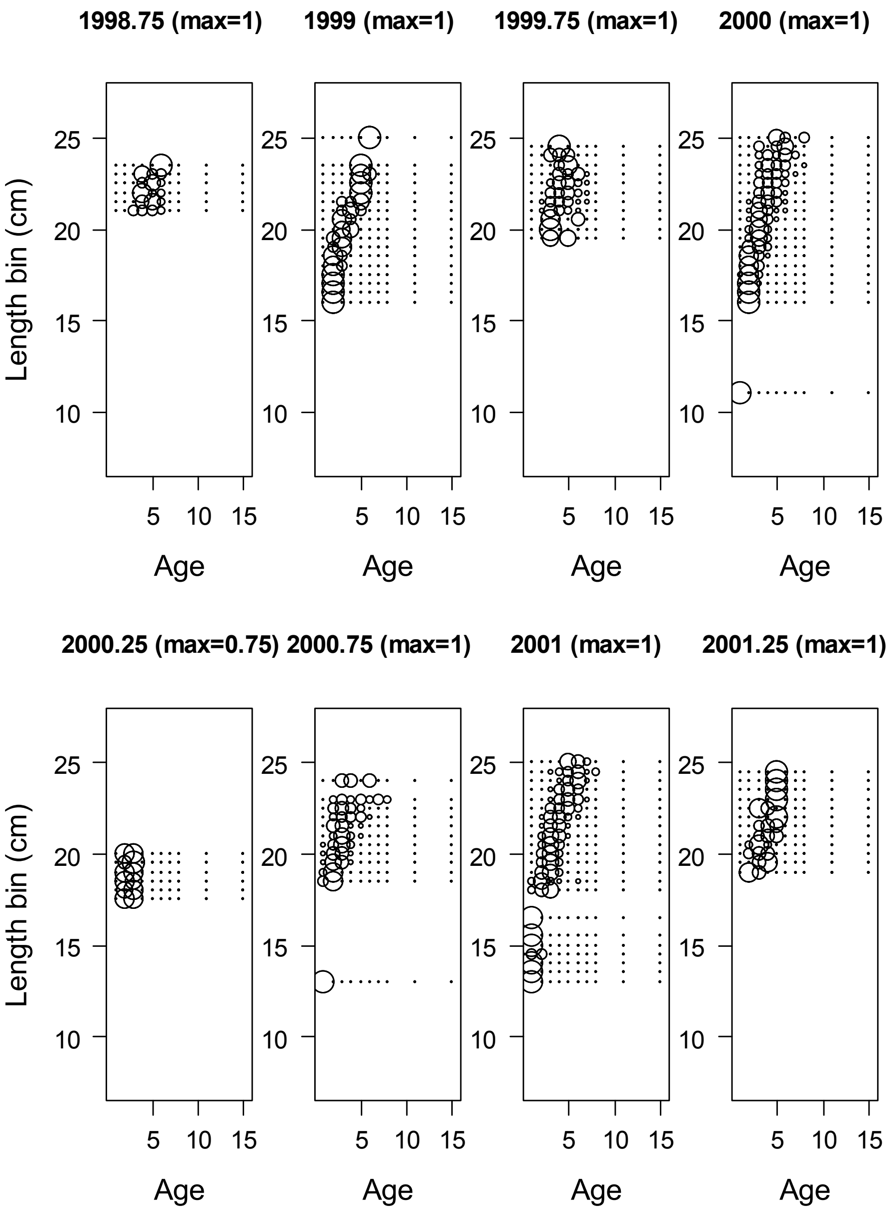

Figure 14. Conditional age-at-length data for the Pacific Northwest fishery.

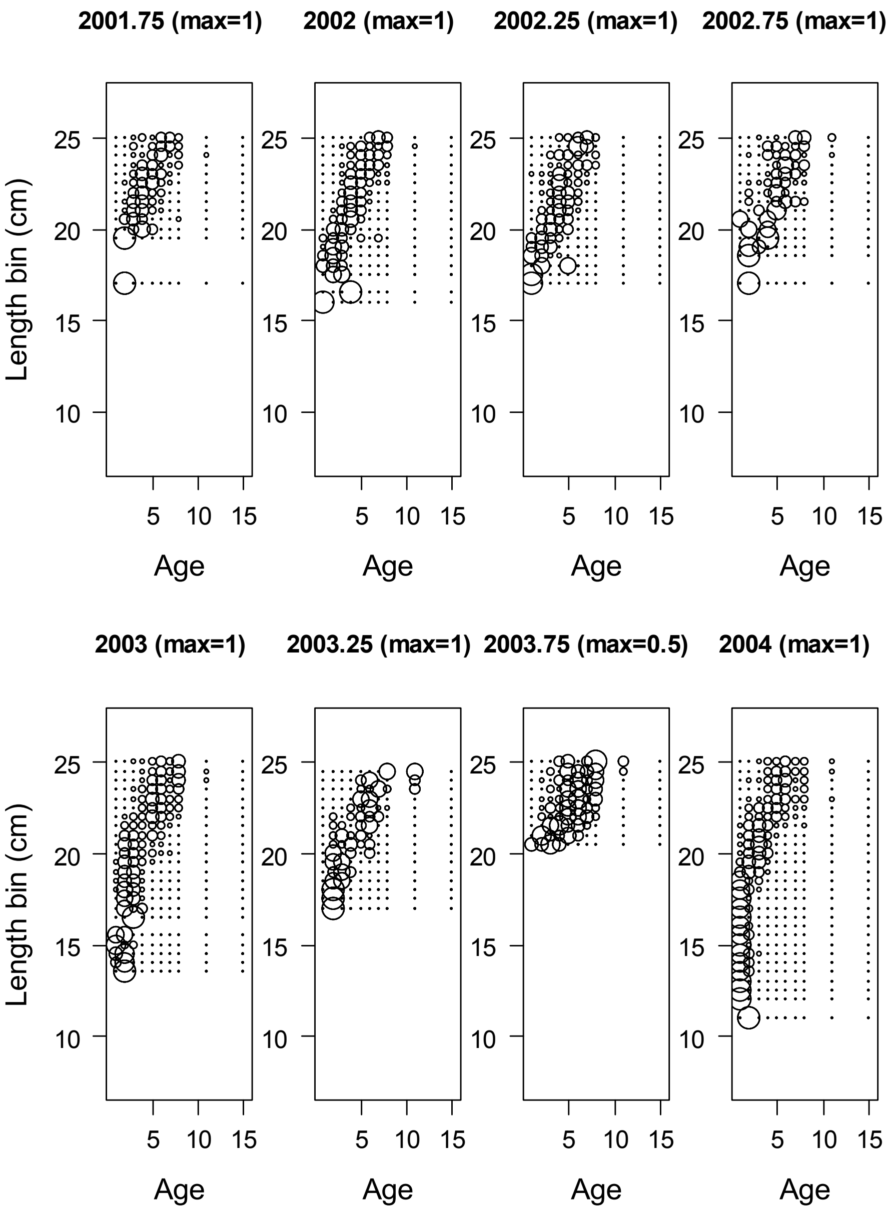

Figure 14 cont. Conditional age-at-length data for the Pacific Northwest fishery.

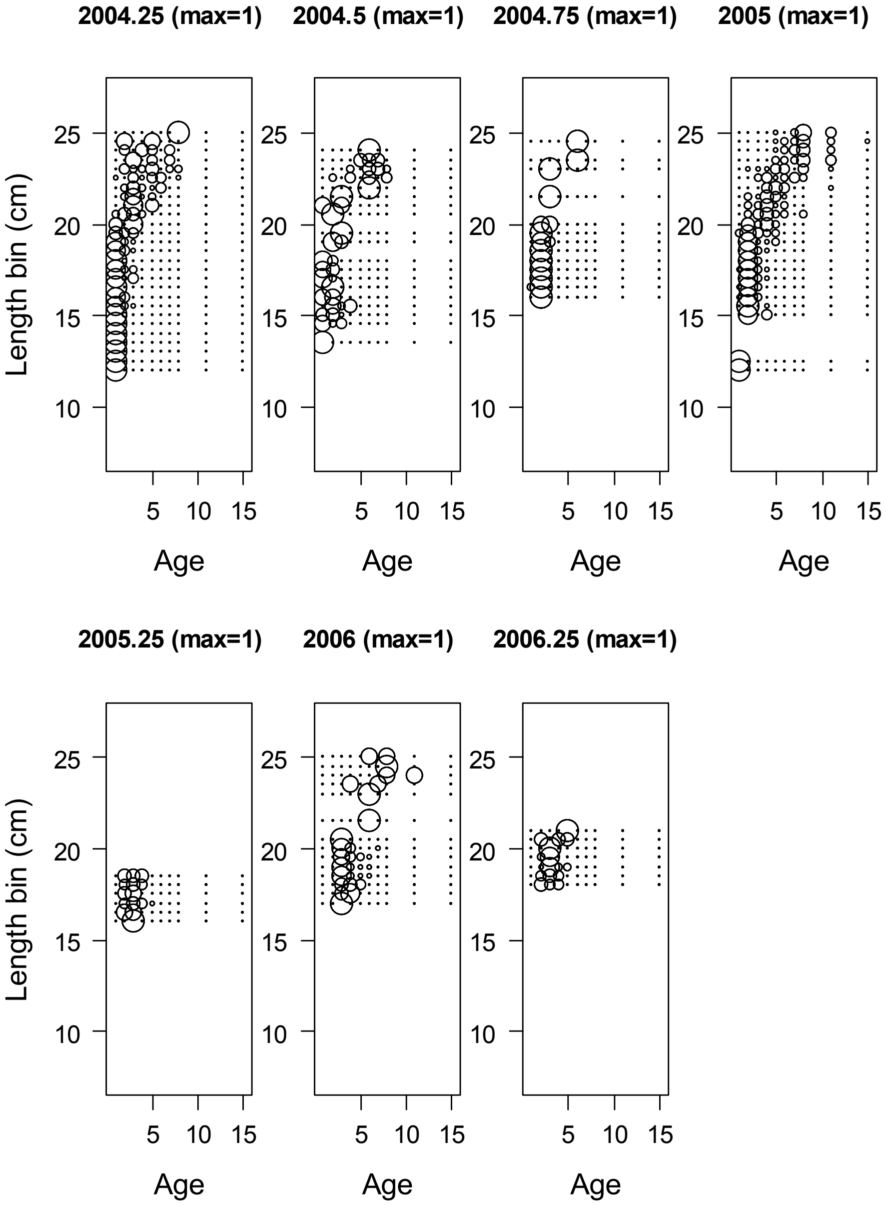

Figure 14 cont. Conditional age-at-length data for the Pacific Northwest fishery.

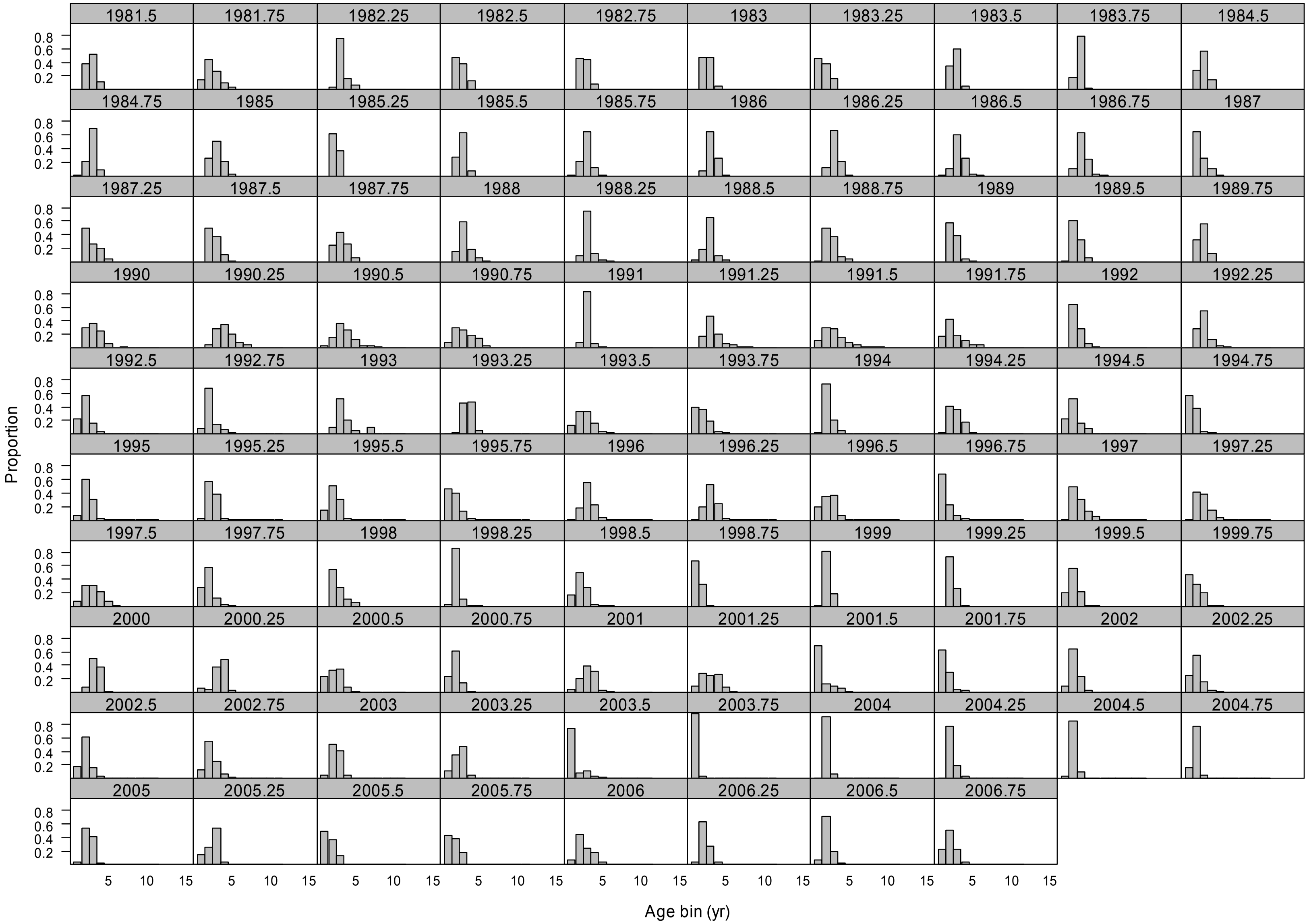

Figure 15. Implied age-composition data for the California fishery, 1981-2006.

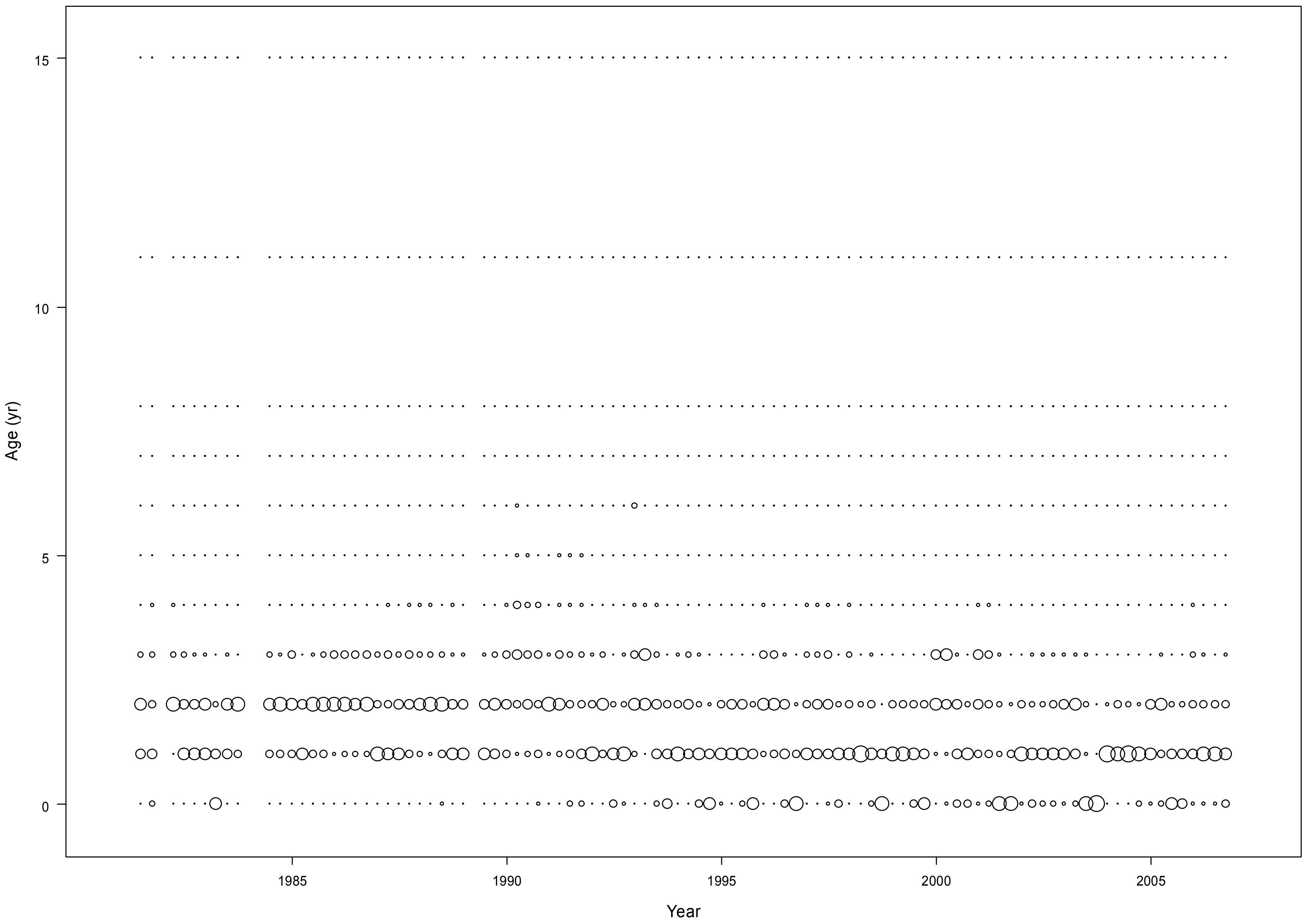

Figure 16. Implied age-composition data for the California fishery, 1981-2006.

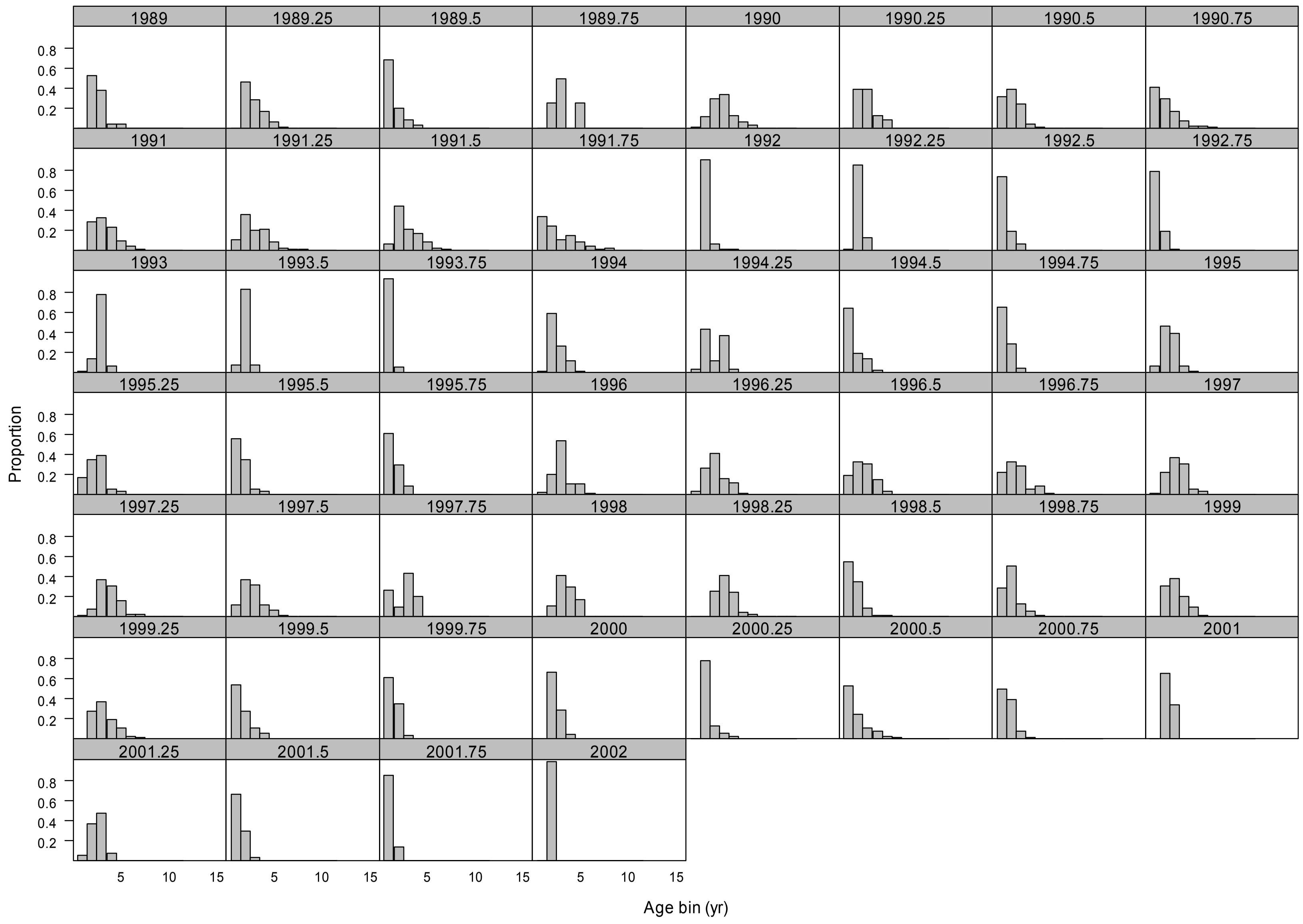

Figure 17. Implied age-composition data for the Ensenada fishery, 1989-2002.

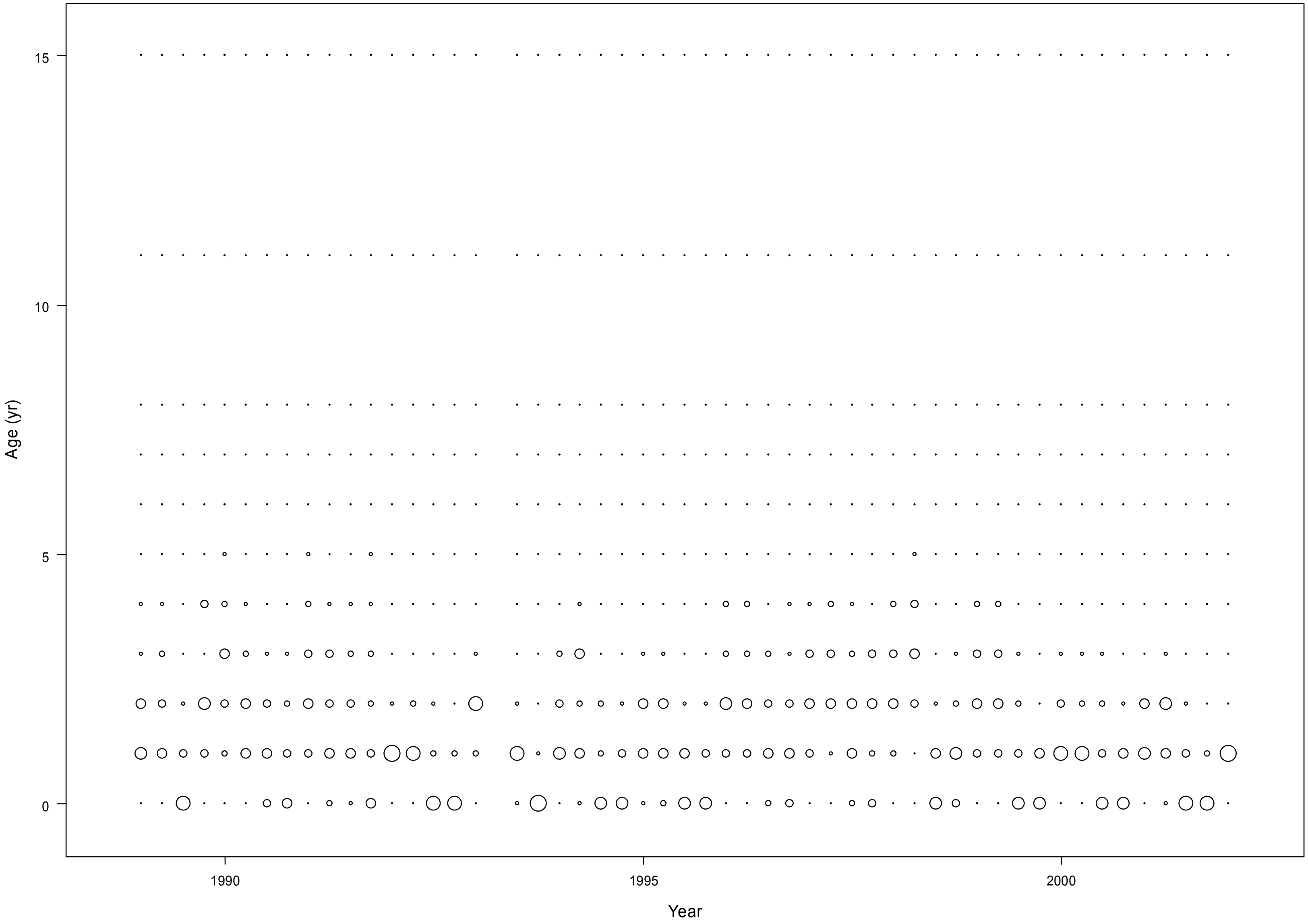

Figure 18. Implied age-composition data for the Ensenada fishery, 1989-2002.

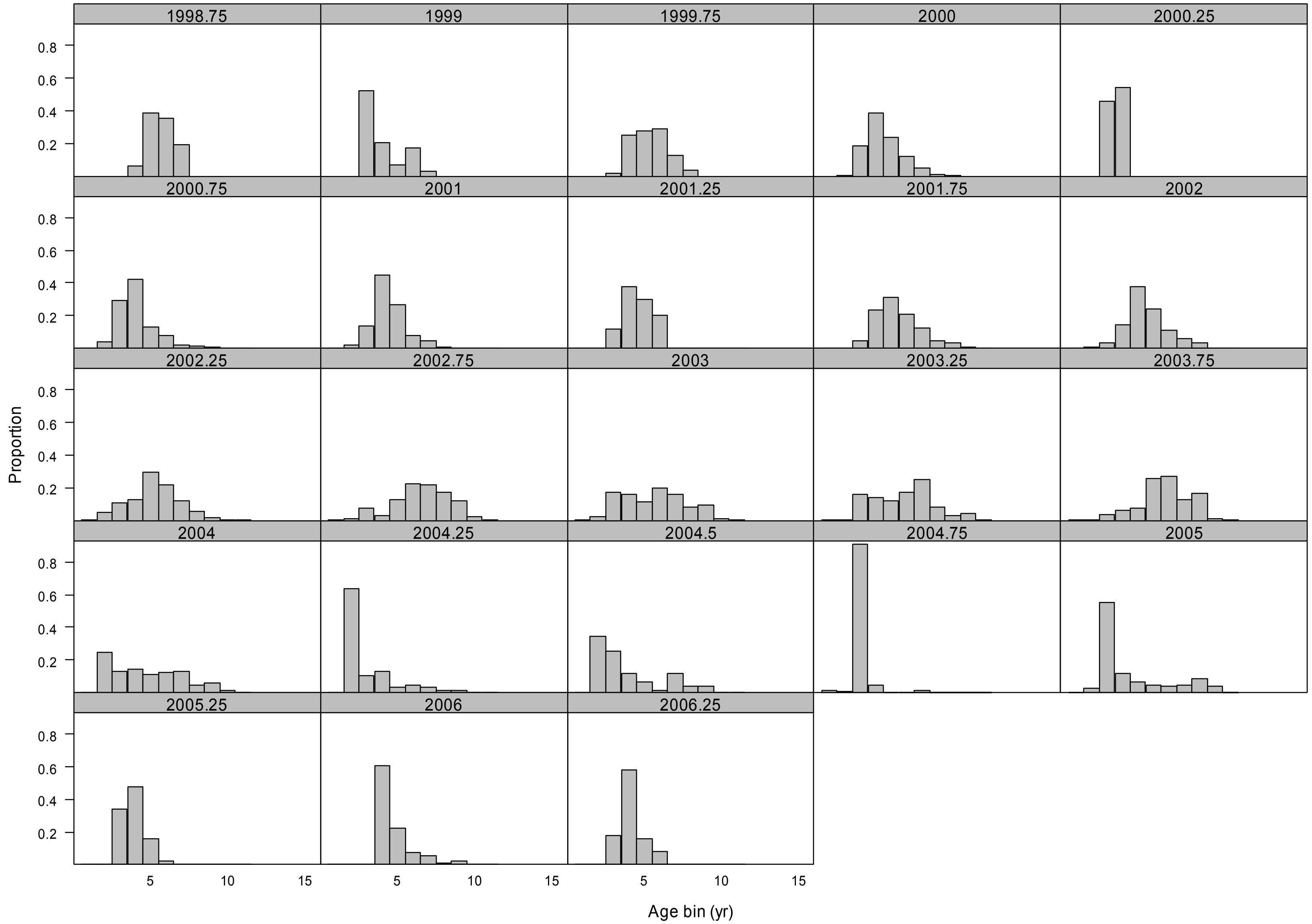

Figure 19. Implied age-composition data for the Pacific Northwest fishery, 1998-2006.

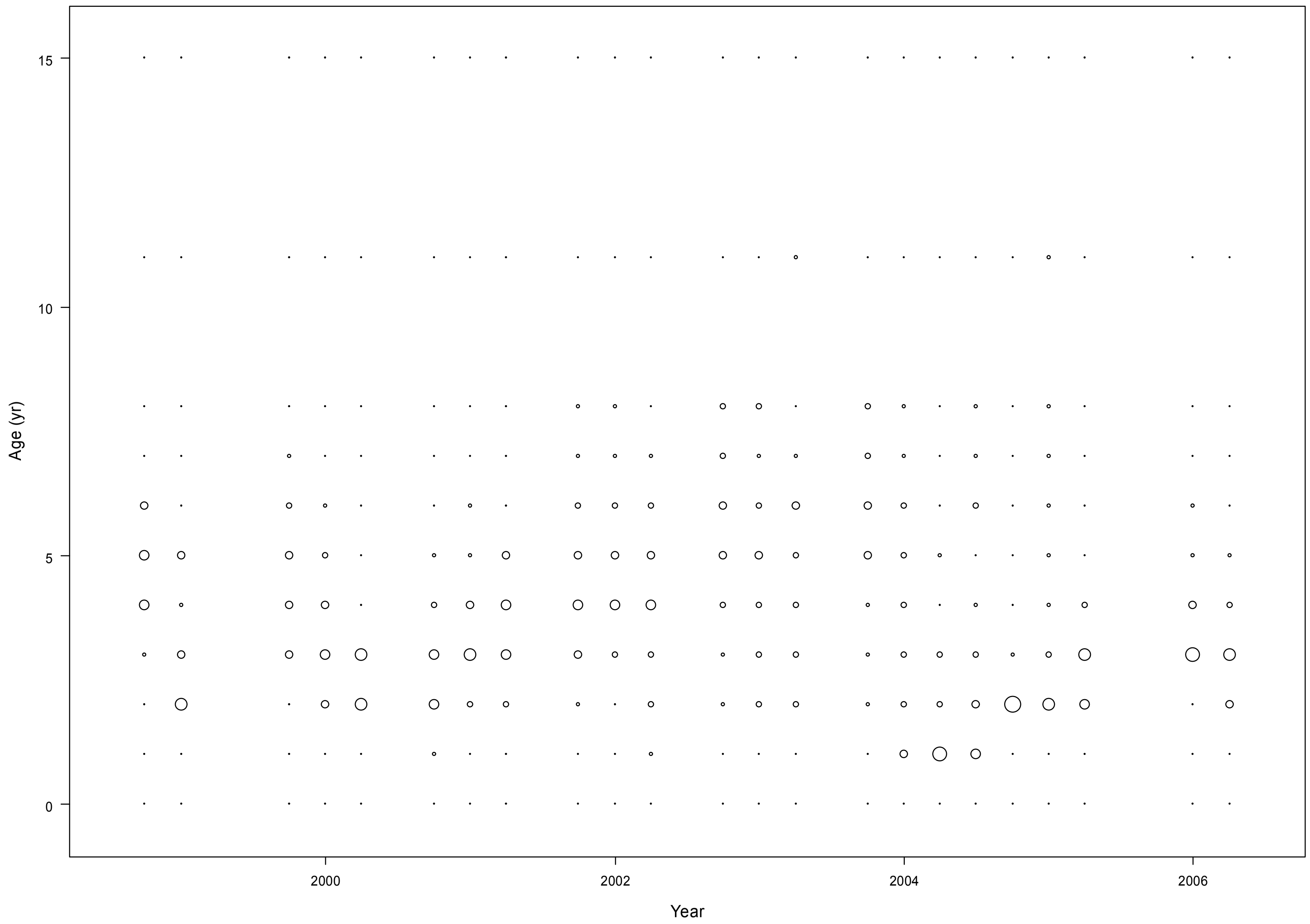

Figure 20. Implied age-composition data for the Pacific Northwest fishery, 1998-2006.

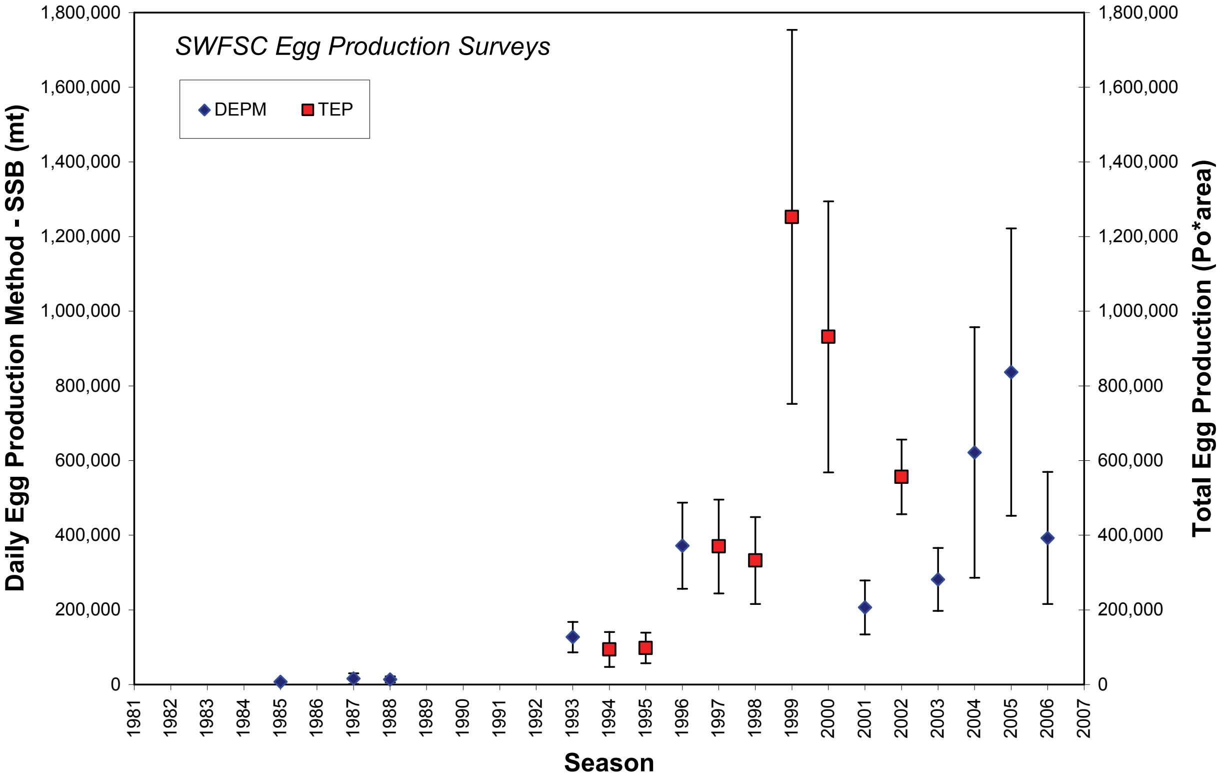

Figure 21. Estimates of Pacific sardine egg production from SWFSC surveys.

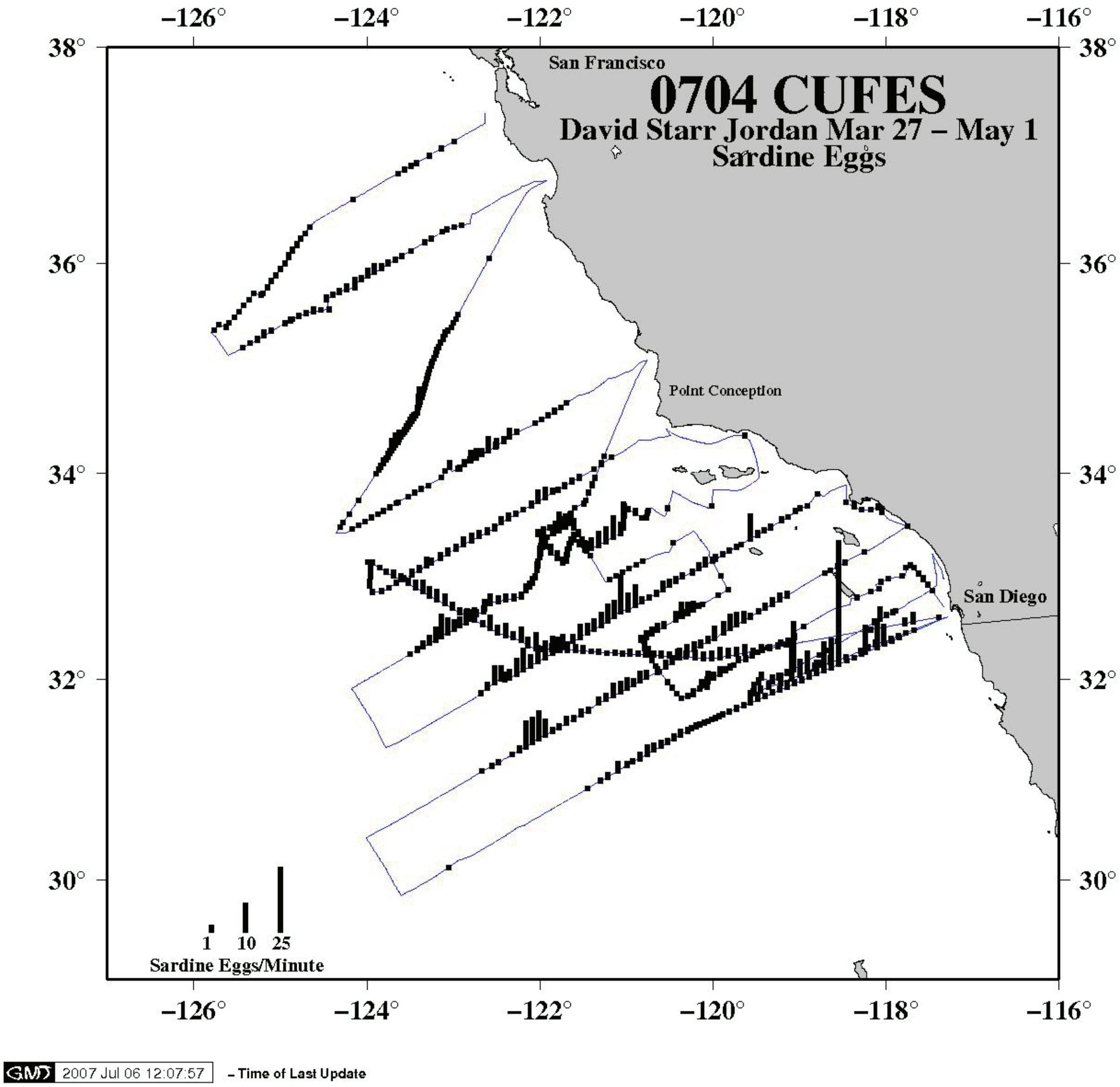

Figure 22. Sardine egg distribution from the SWFSC annual survey, March 27 to May 1, 2007.

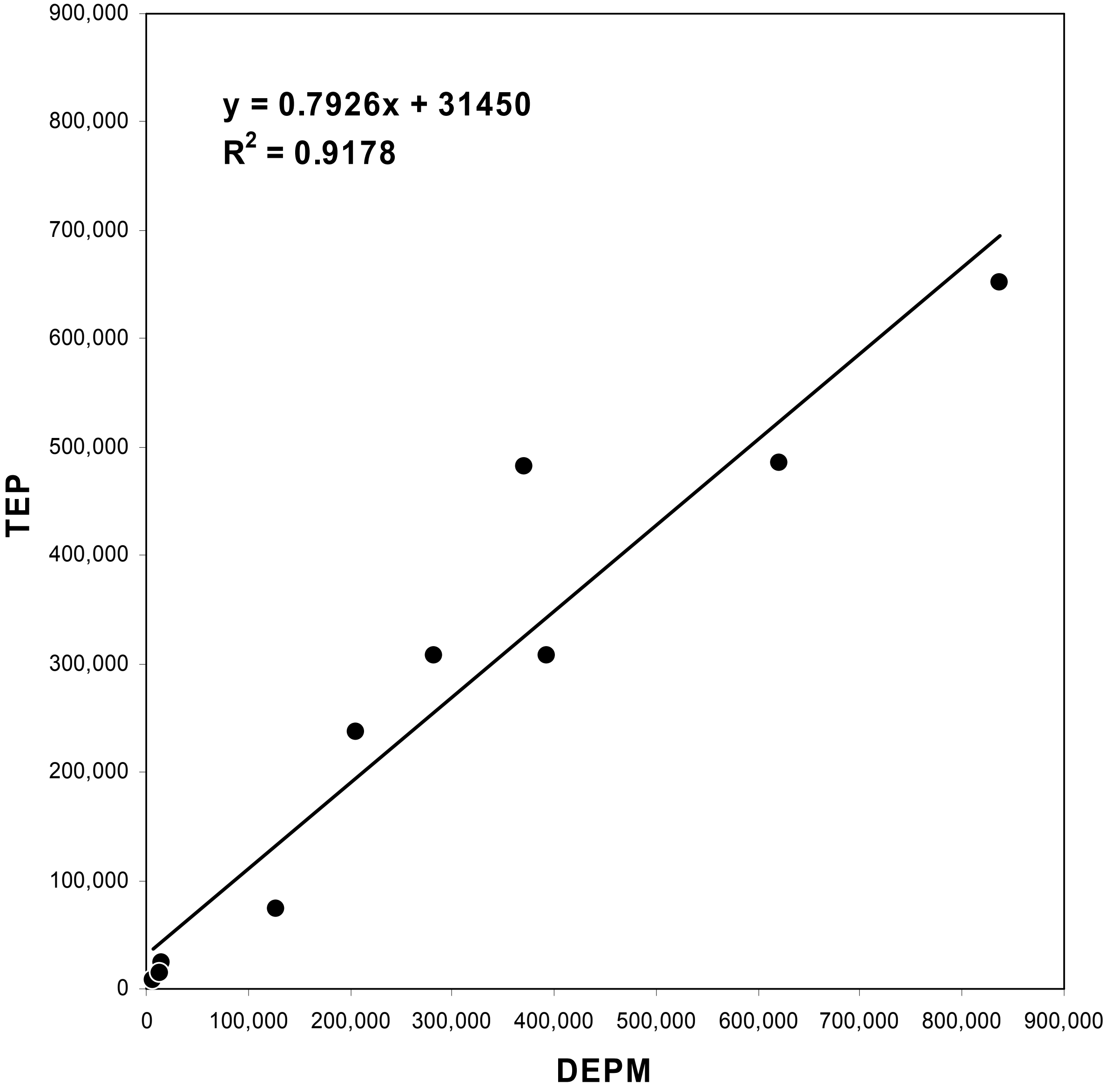

Figure 23. Comparison of paired observations from the DEPM and TEP surveys (corresponding years).

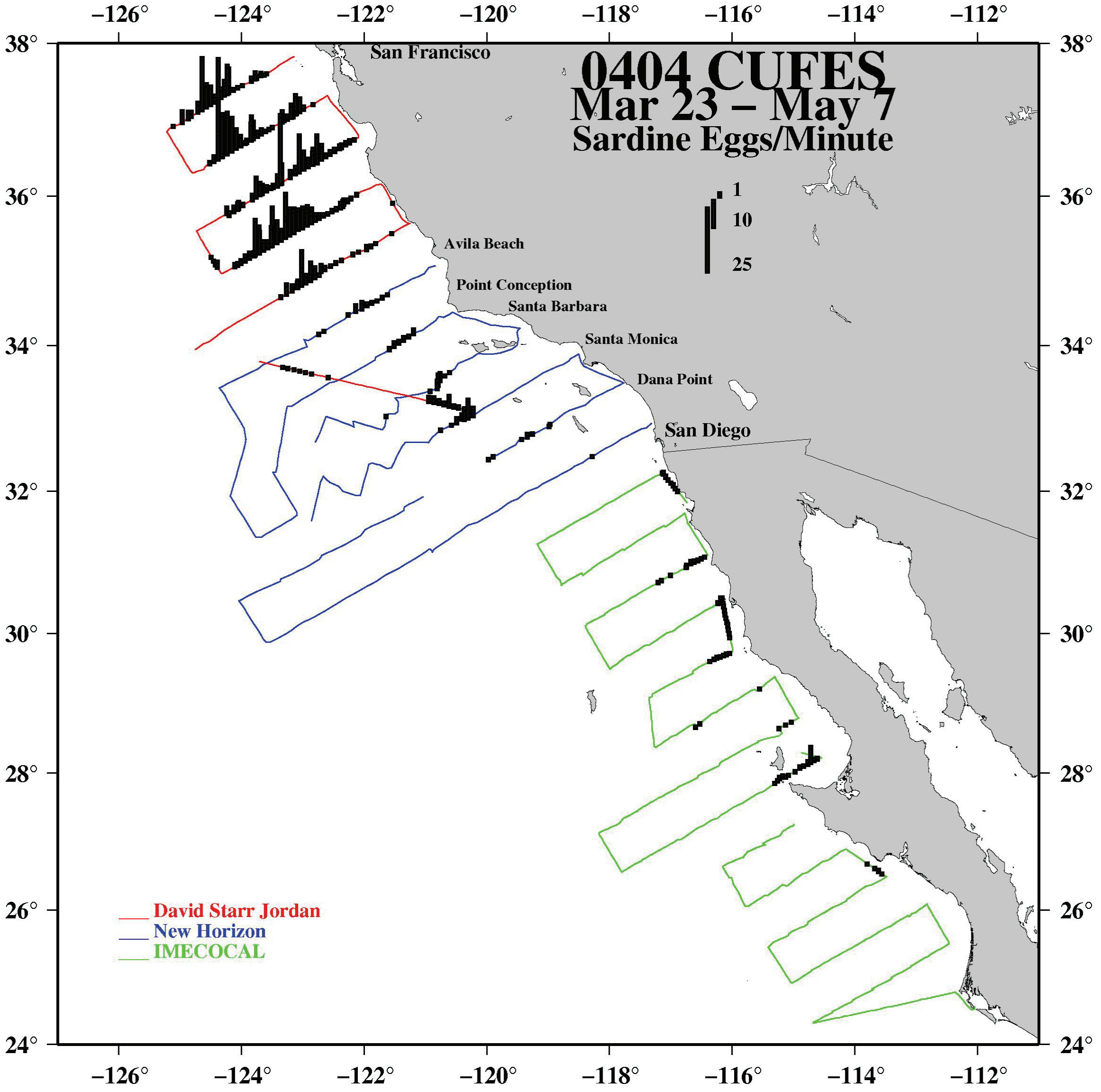

Figure 24. Distribution of Pacific sardine eggs collected by CUFES, between San Francisco and northern Baja California, from March to May, 2004. Northern Baja California egg data, collected during an IMECOCAL cruise, were provided courtesy Dr. Timothy Baumgartner (CICESE Ensenada).

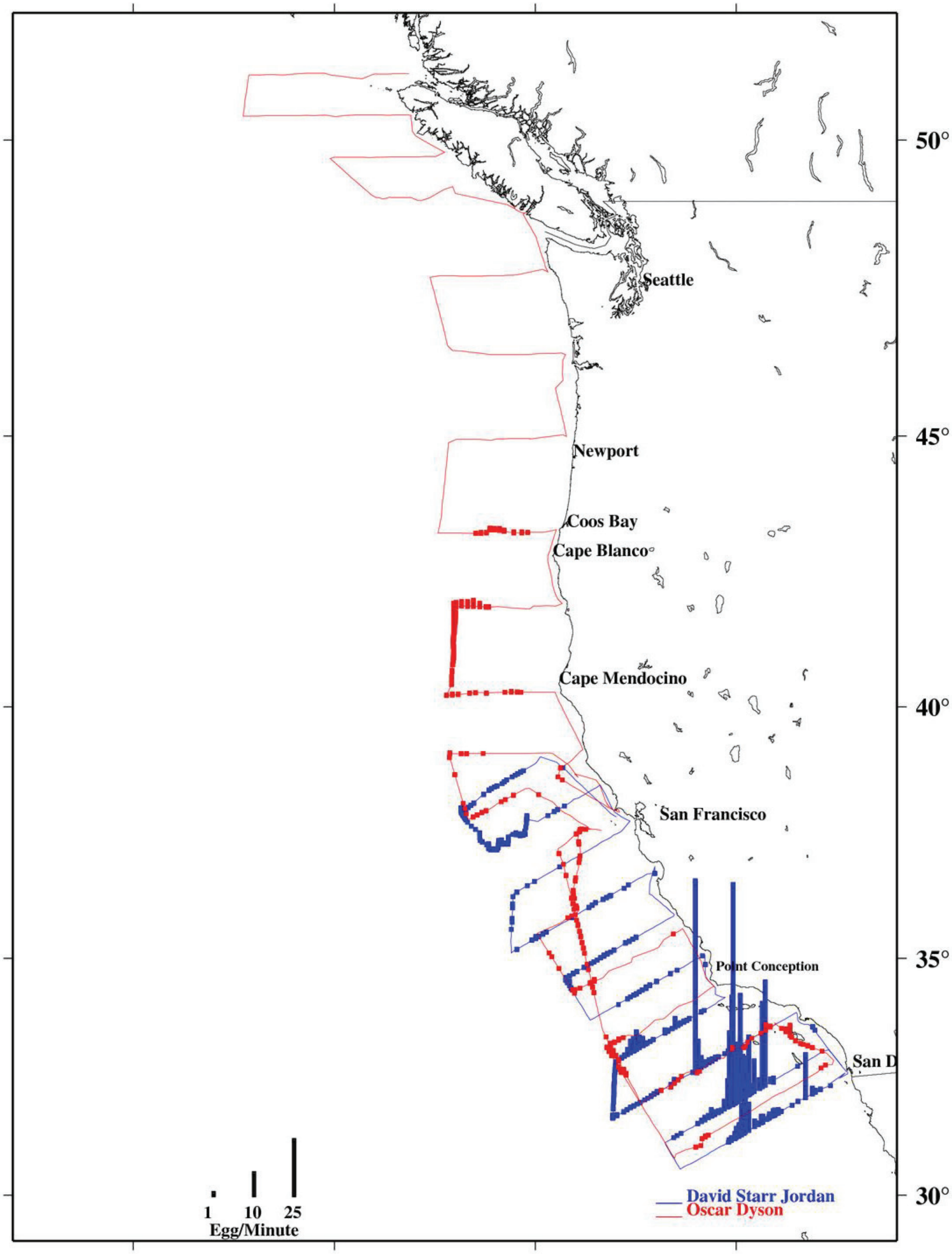

Figure 25. Distribution of Pacific sardine eggs collected by CUFES, between British Columbia and San Diego during April-May, 2006.

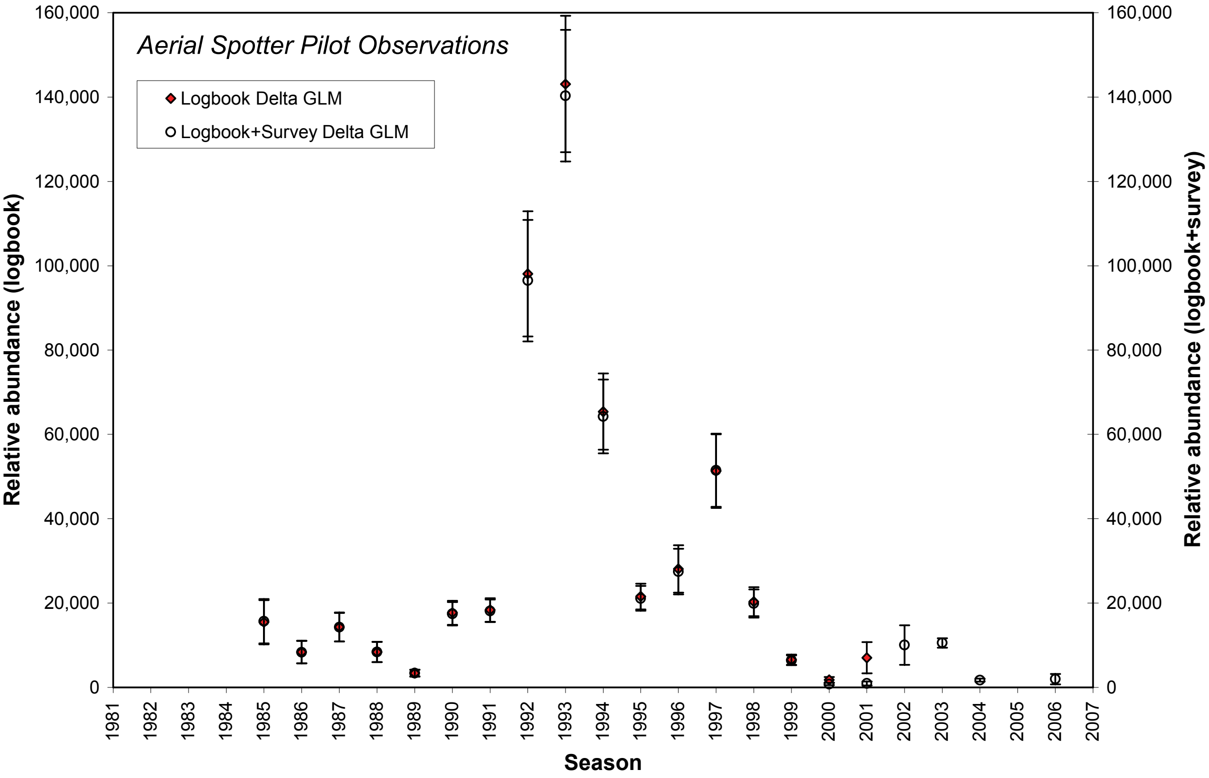

Figure 26. Time series of relative abundance from the SWFSC aerial spotter logbook and survey programs.

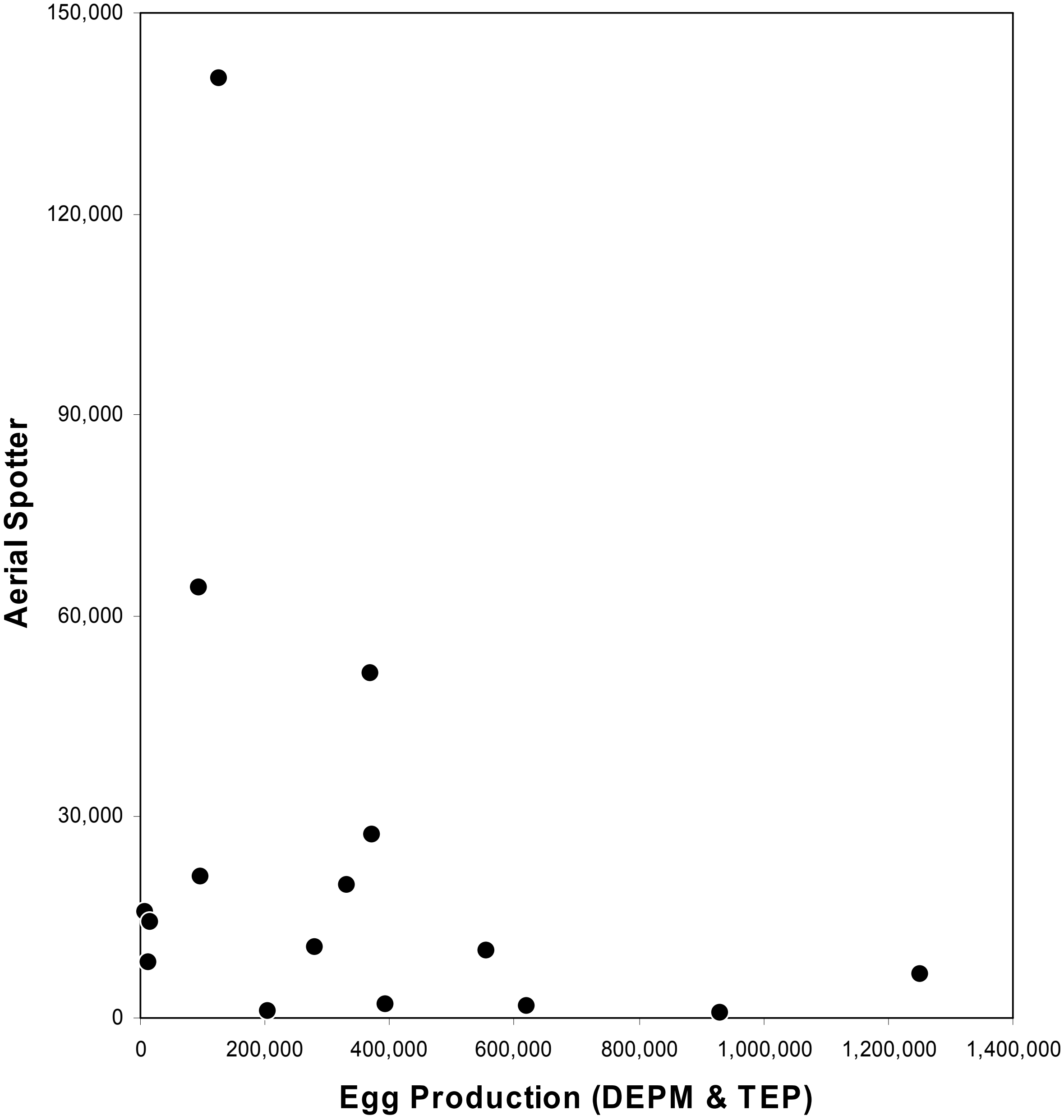

Figure 27. Comparison of paired observations for egg production and aerial spotter surveys.

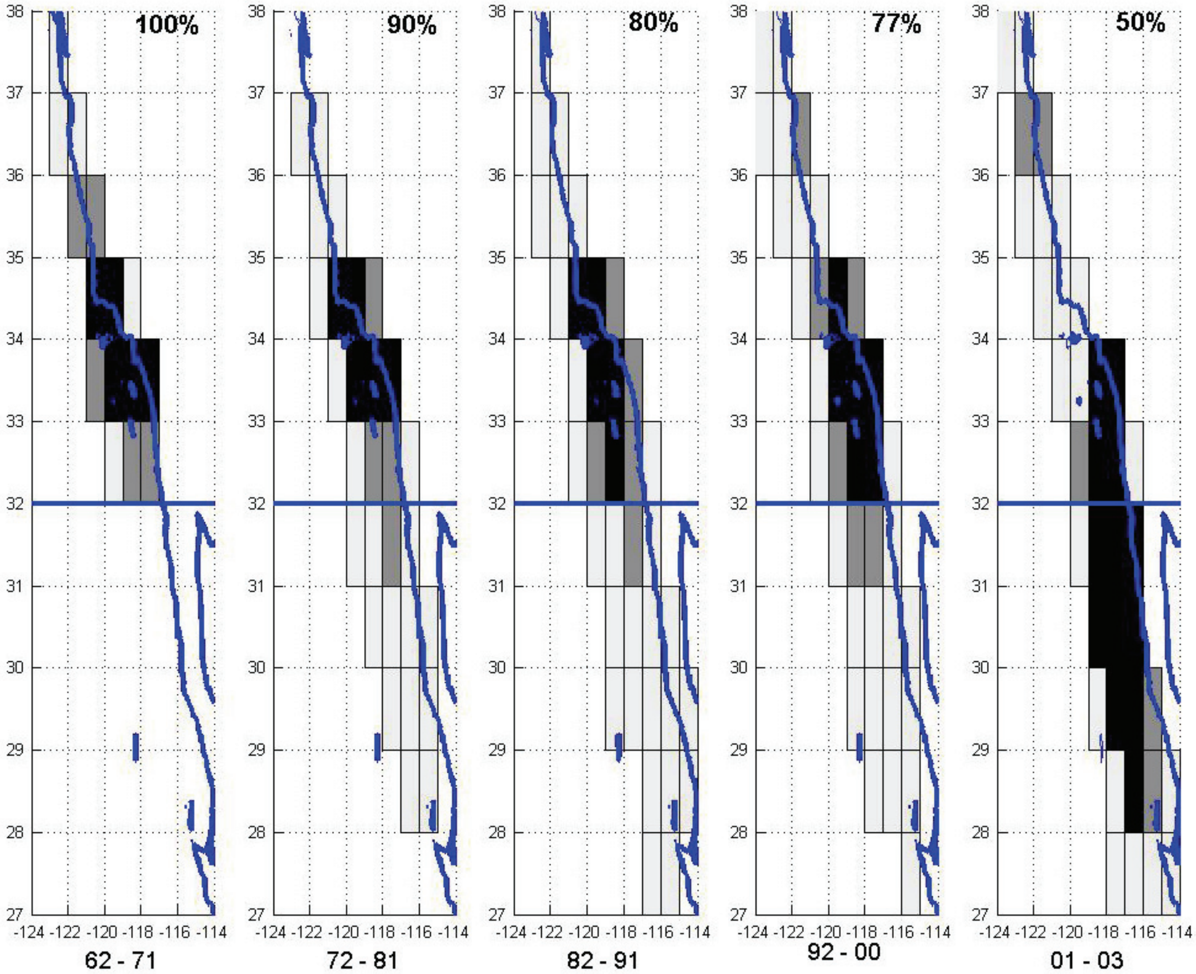

Figure 28. Distribution and southward shift of aerial spotter effort, Monterey Bay (California) to Cedros Island (Baja California), 1962 to 2003.

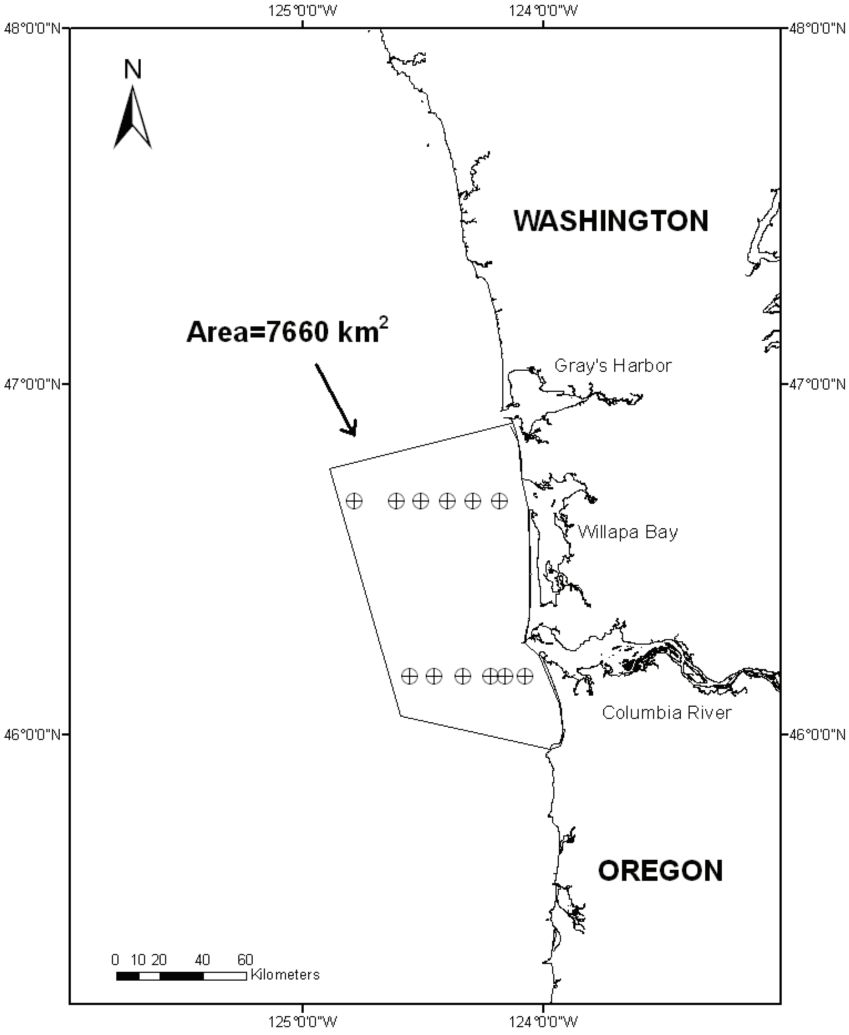

Figure 29. Location of the 12 surface trawl locations sampled at night approximately every 10 days near the Columbia River from late April through early August. Estimated representative survey area – 7,660 km^2 (From above Grays Harbor to Cape Falcon – and out ~35 nm).
Total volume (4 x 10^{11} m^3) within the survey area was calculated using 20 m (depth the net fished) x the survey area.

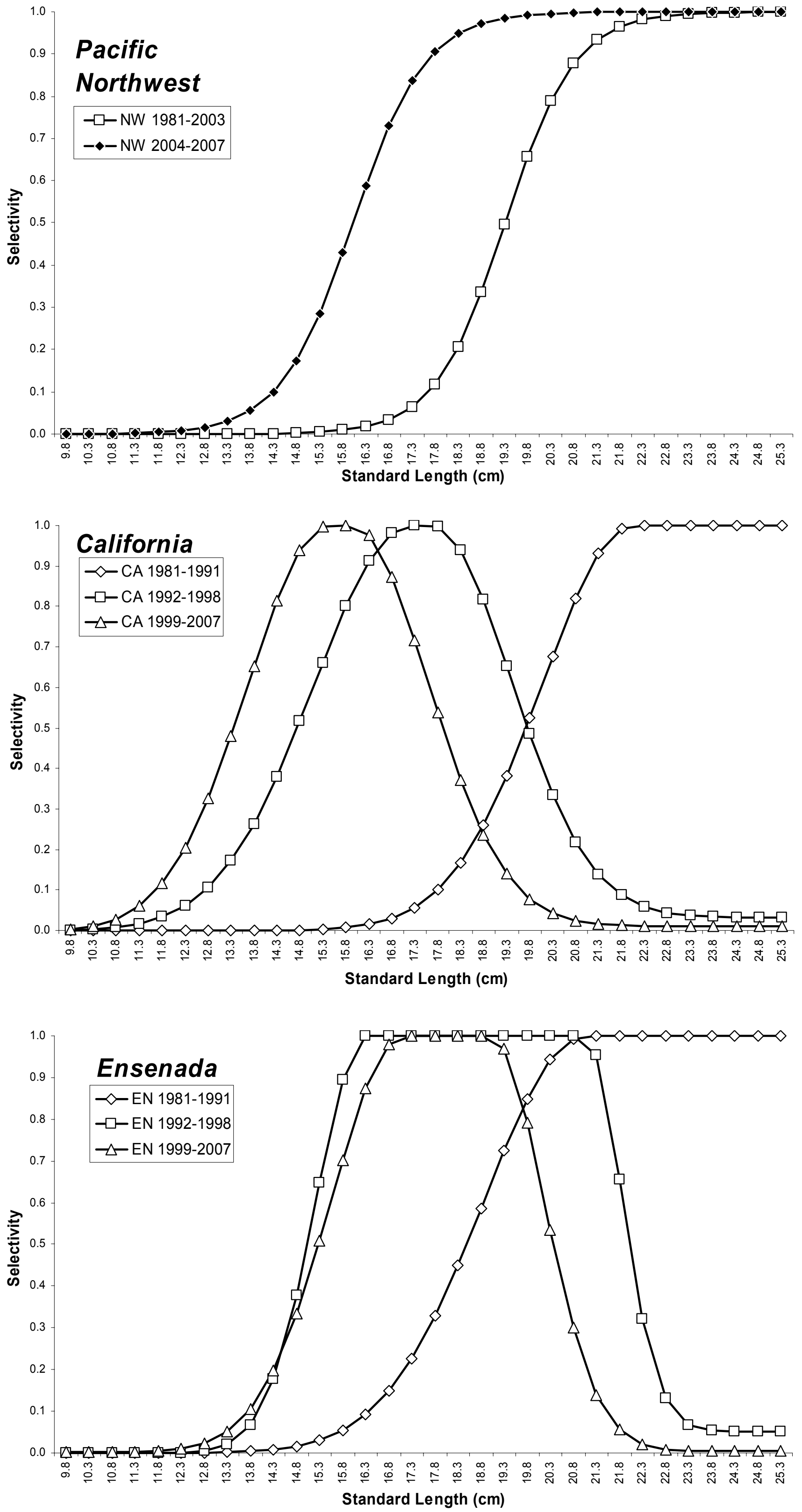

Figure 30. Length-based selectivity estimated for each fleet.

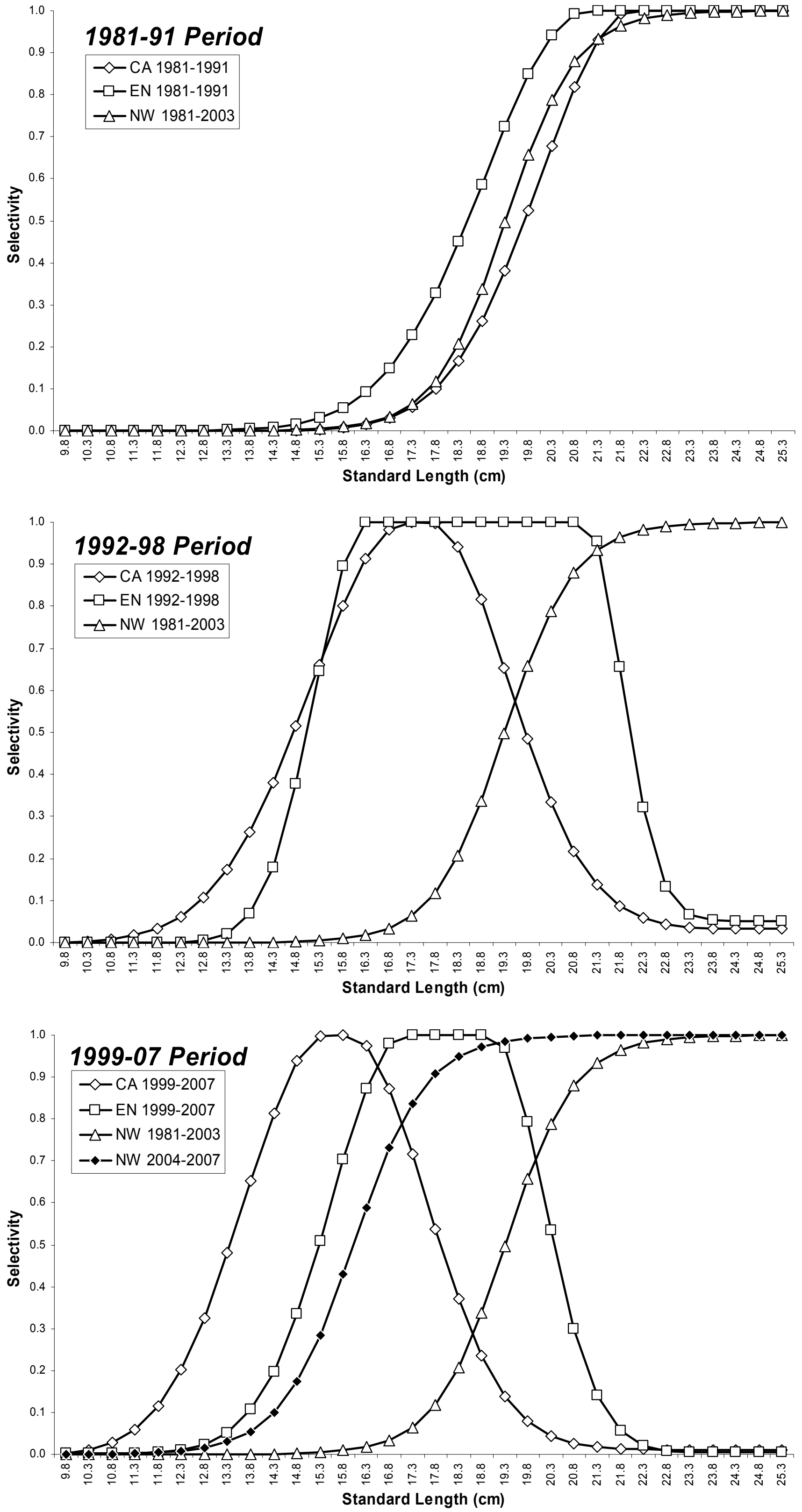

Figure 31. Length-based selectivity estimated for each time period.

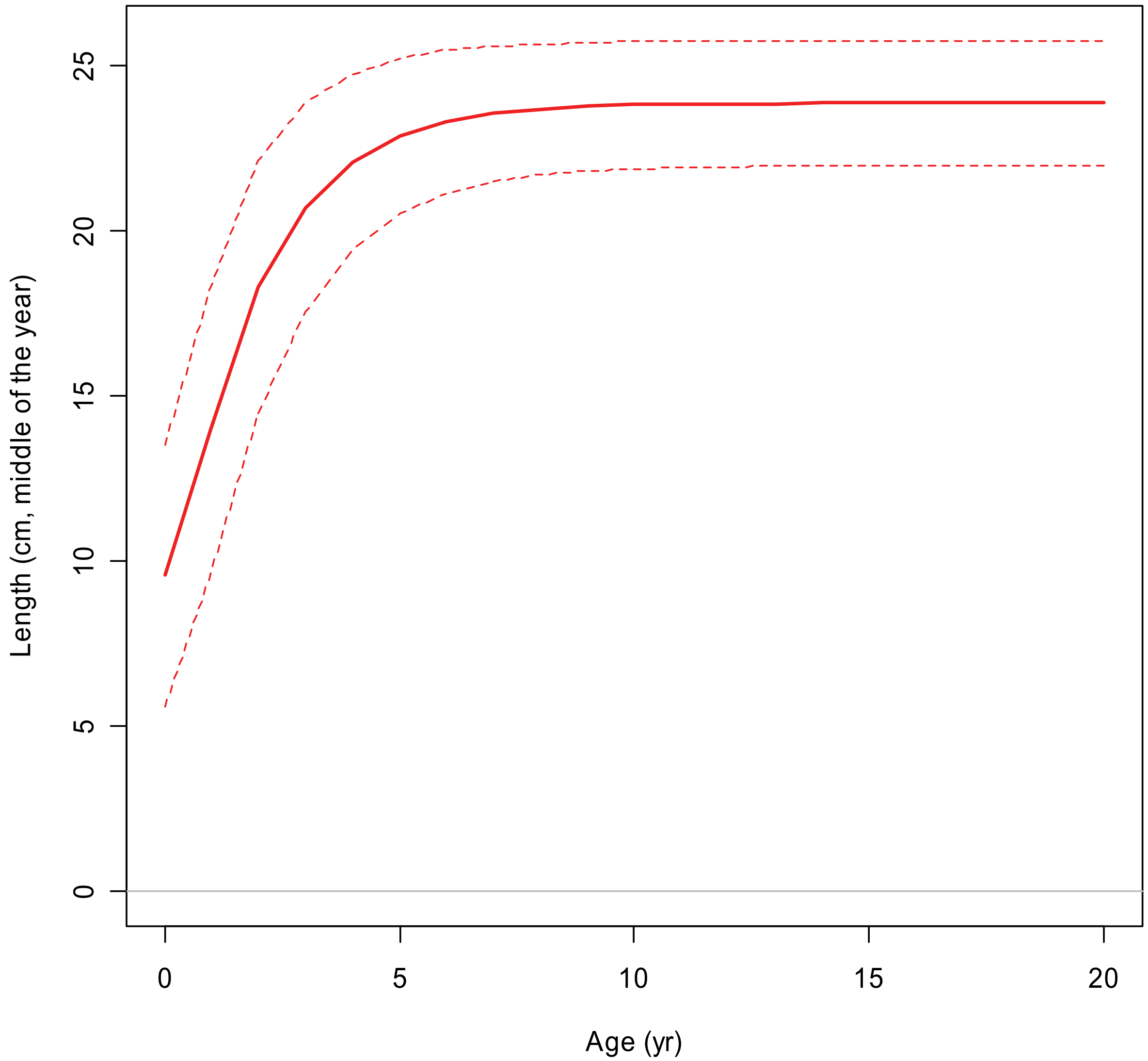

Figure 32. Growth curve for Pacific sardine estimated in base model J14.

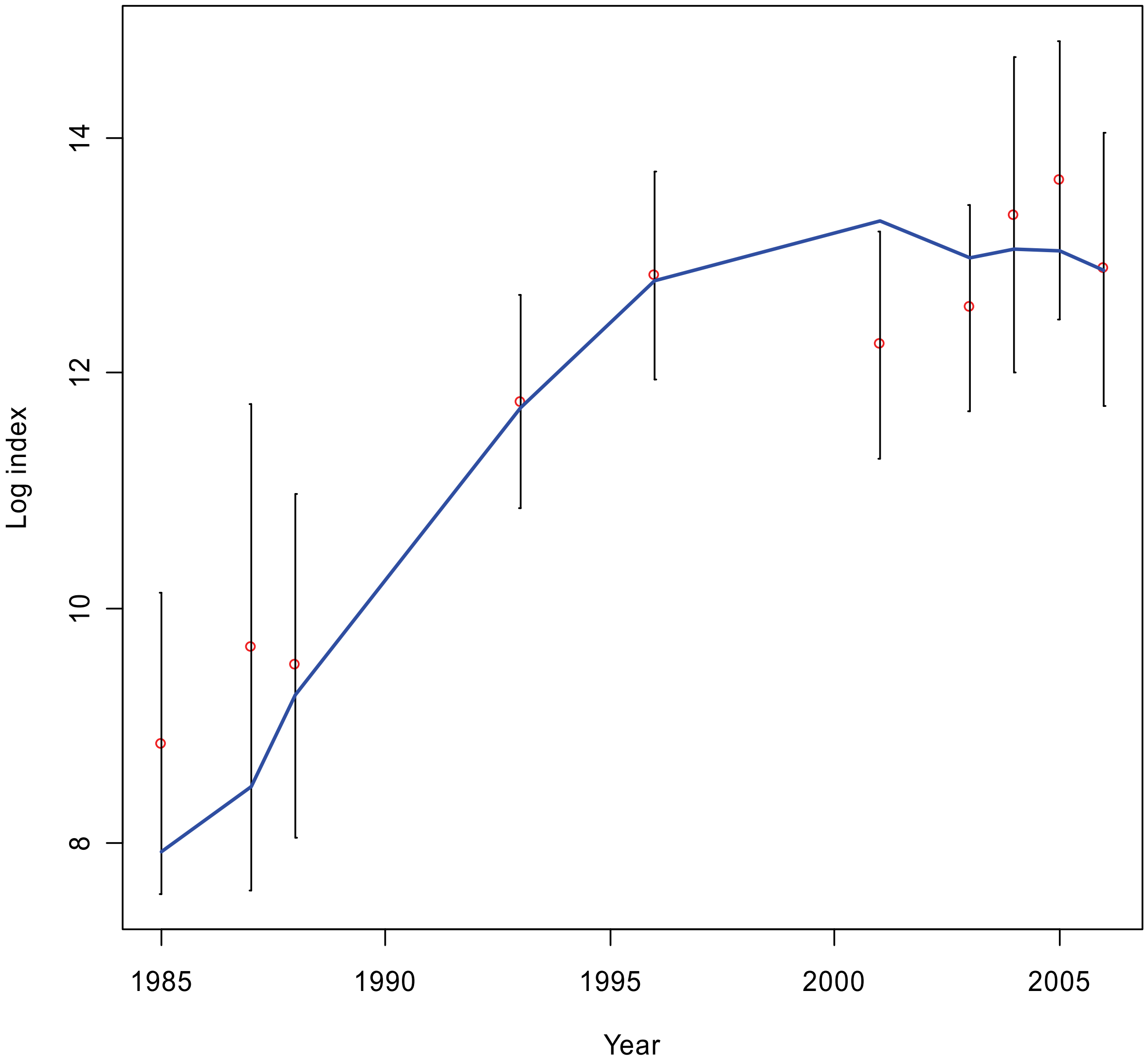

Figure 33. Base model fit to the Daily Egg Production Method series (log scale).

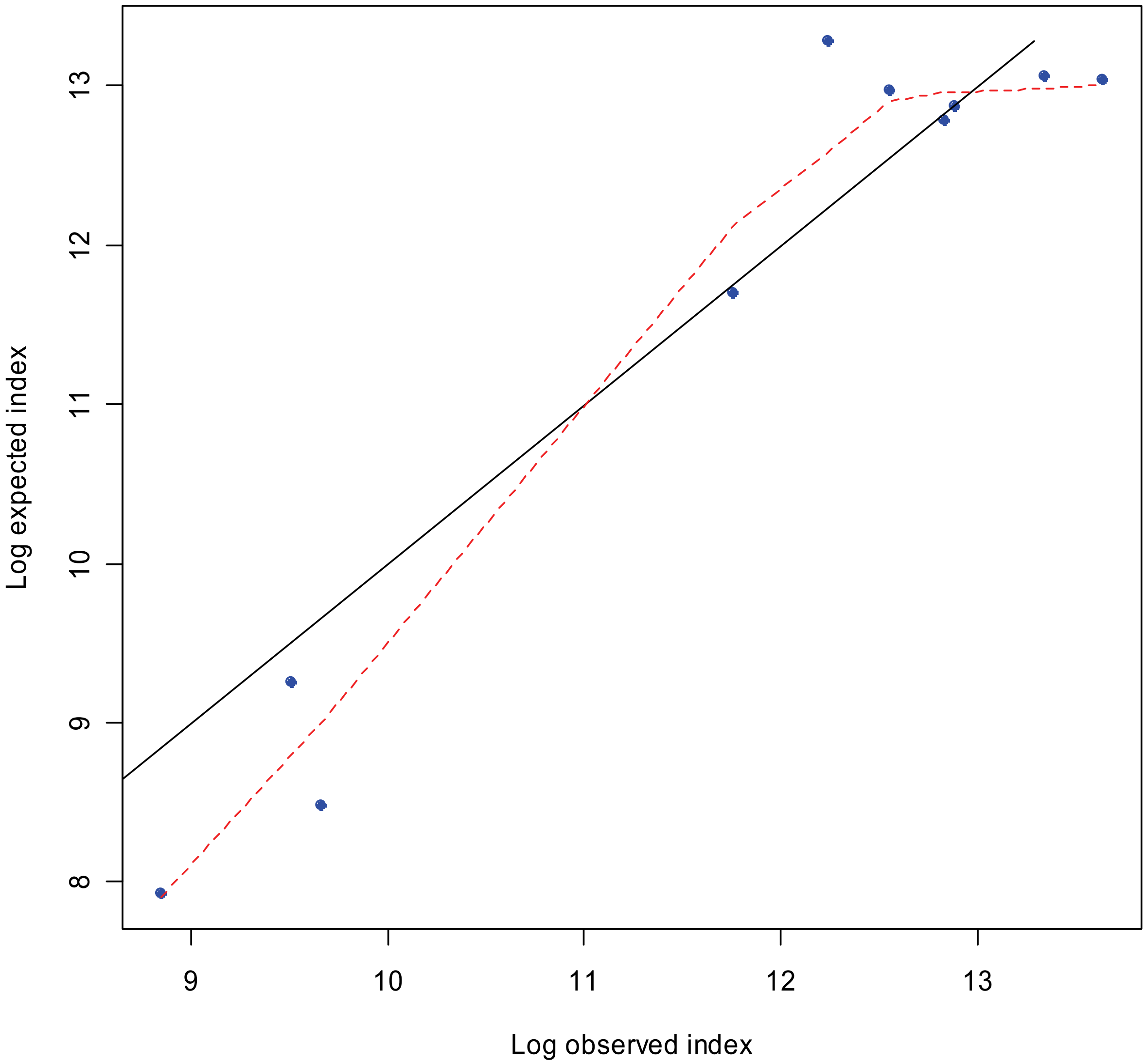

Figure 34. Relationship between observed and expected values (log scale) for the Daily Egg Production survey (base model). Straight line indicates a 1 to 1 relationship, and dashed line is the LOESS fit.

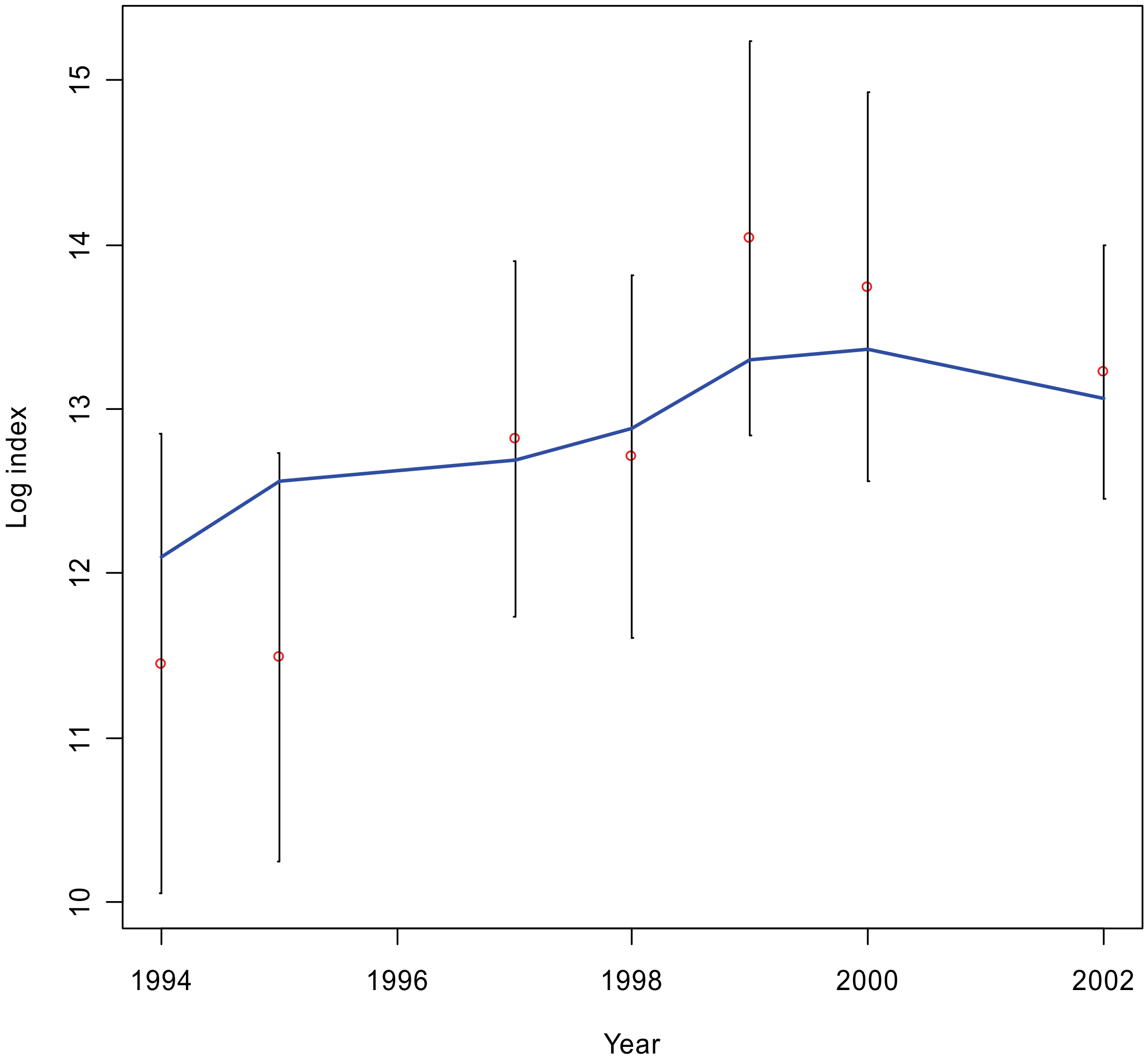

Figure 35. Base model fit to the Total Egg Production series.

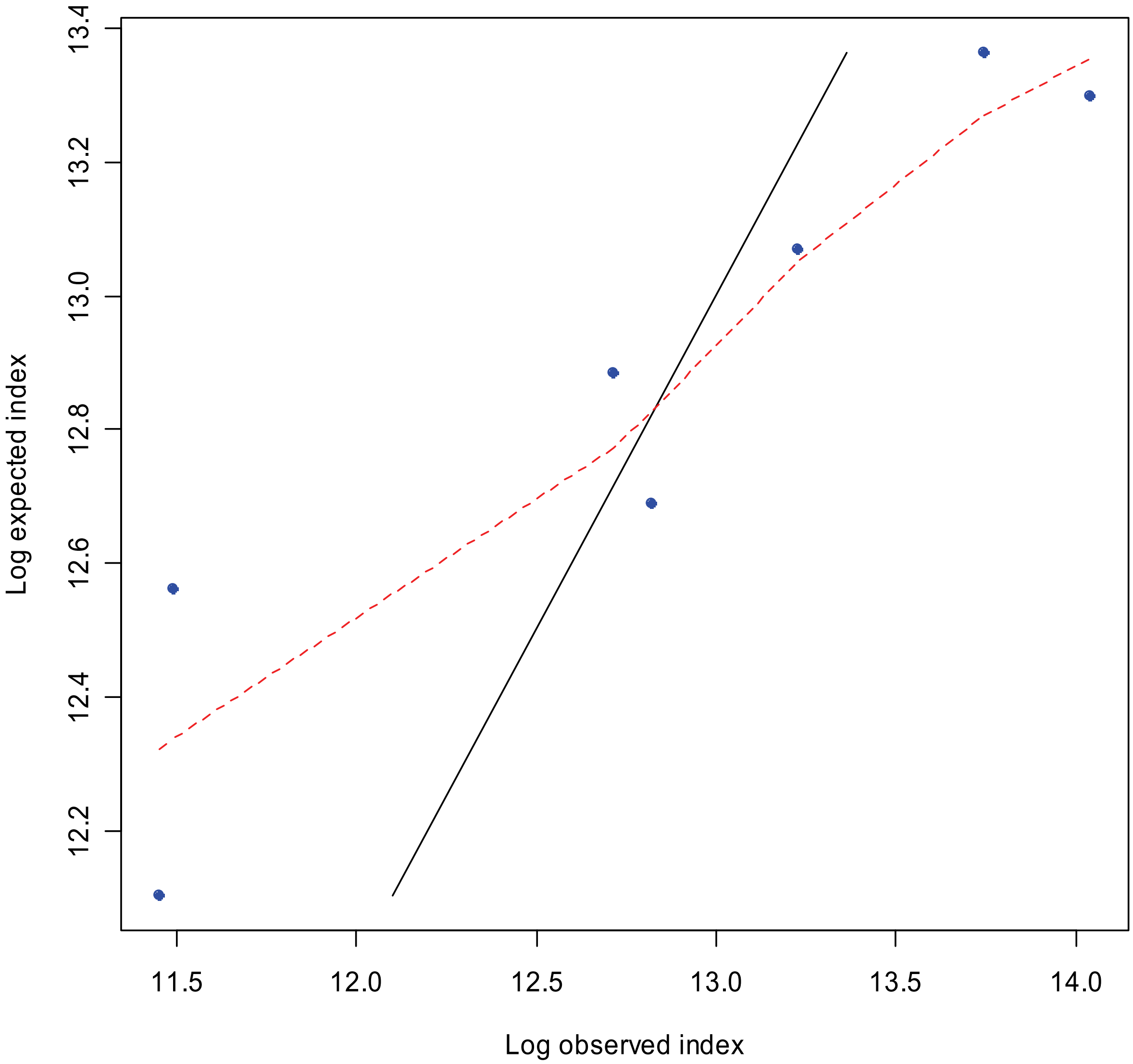

Figure 36. Relationship between observed and expected values (log scale) for the Total Egg Production survey (base model). Straight line indicates a 1 to 1 relationship, and dashed line is the LOESS fit.

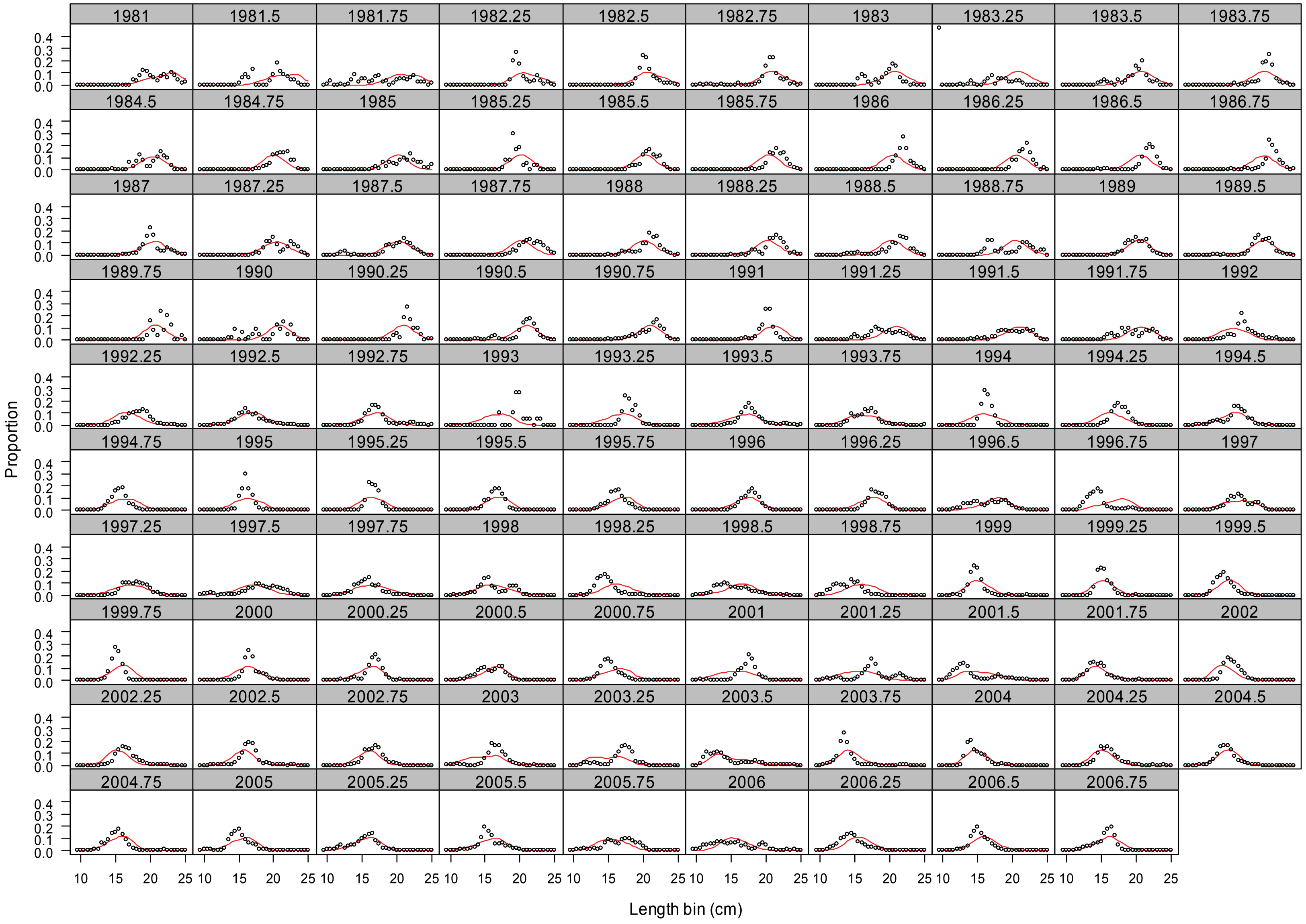

Figure 37. Fits to the length-frequency data for the California fishery.

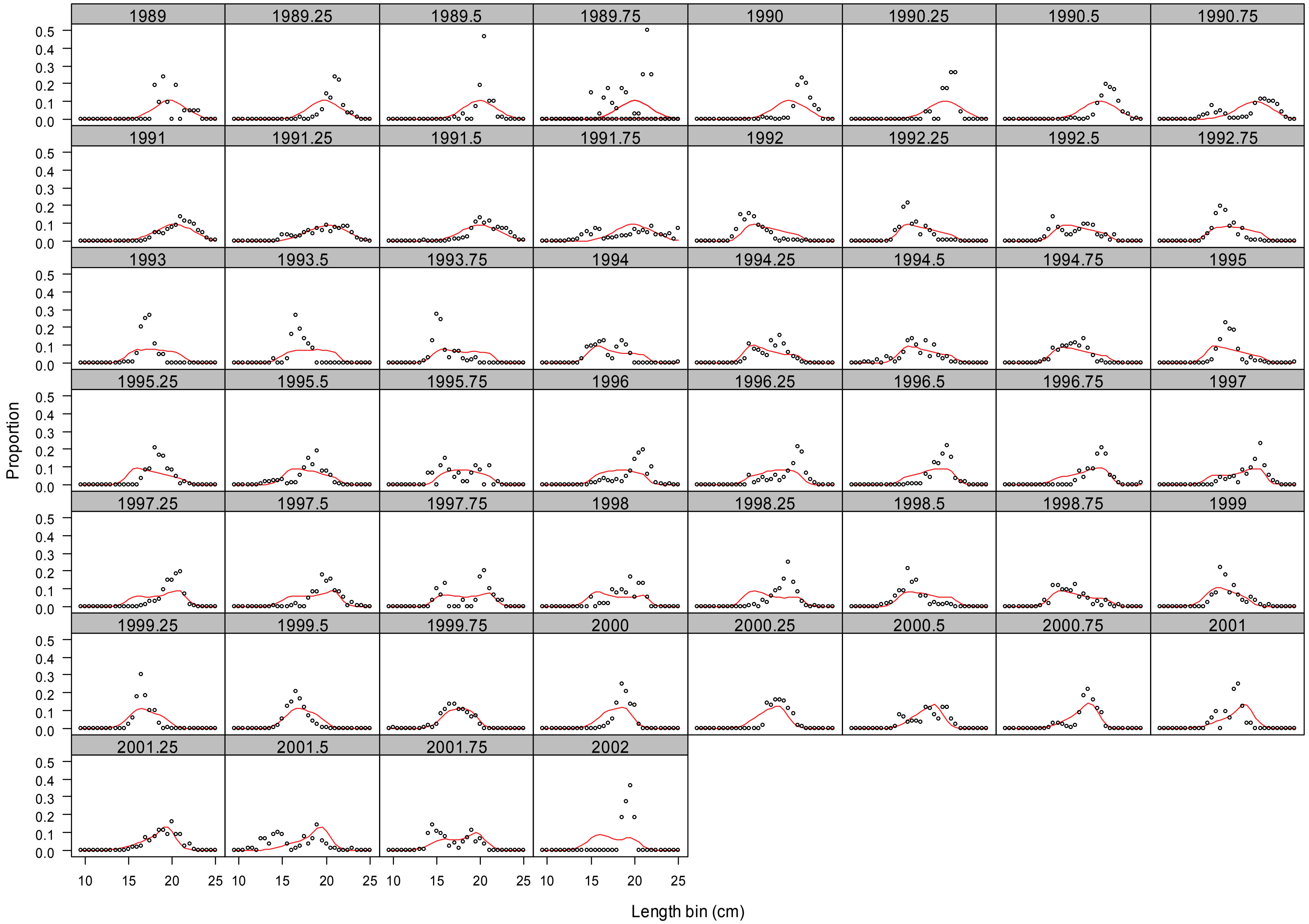

Figure 38. Fits to the length-frequency data for the Ensenada fishery.

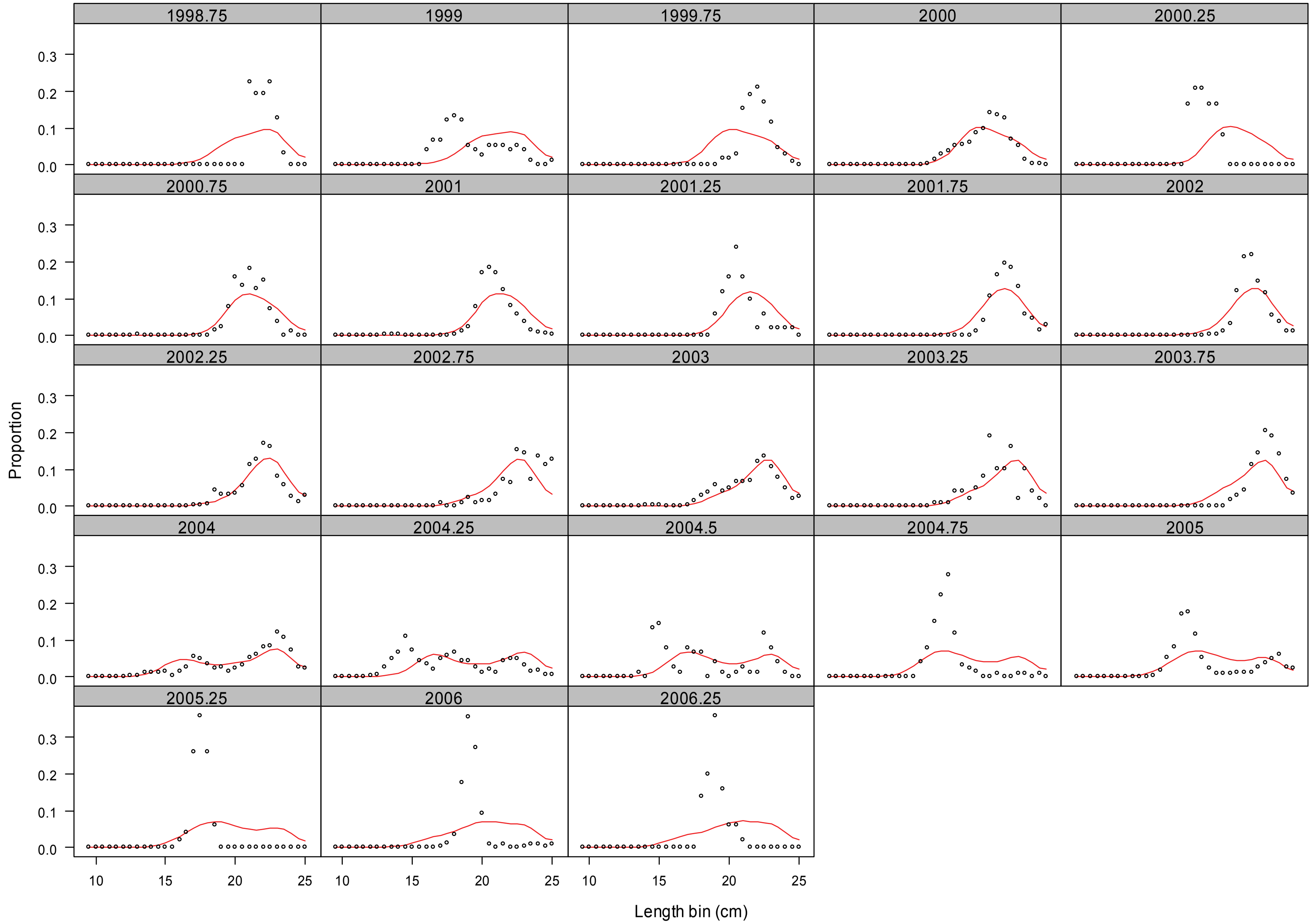

Figure 39. Fits to the length-frequency data for the Pacific Northwest fishery.

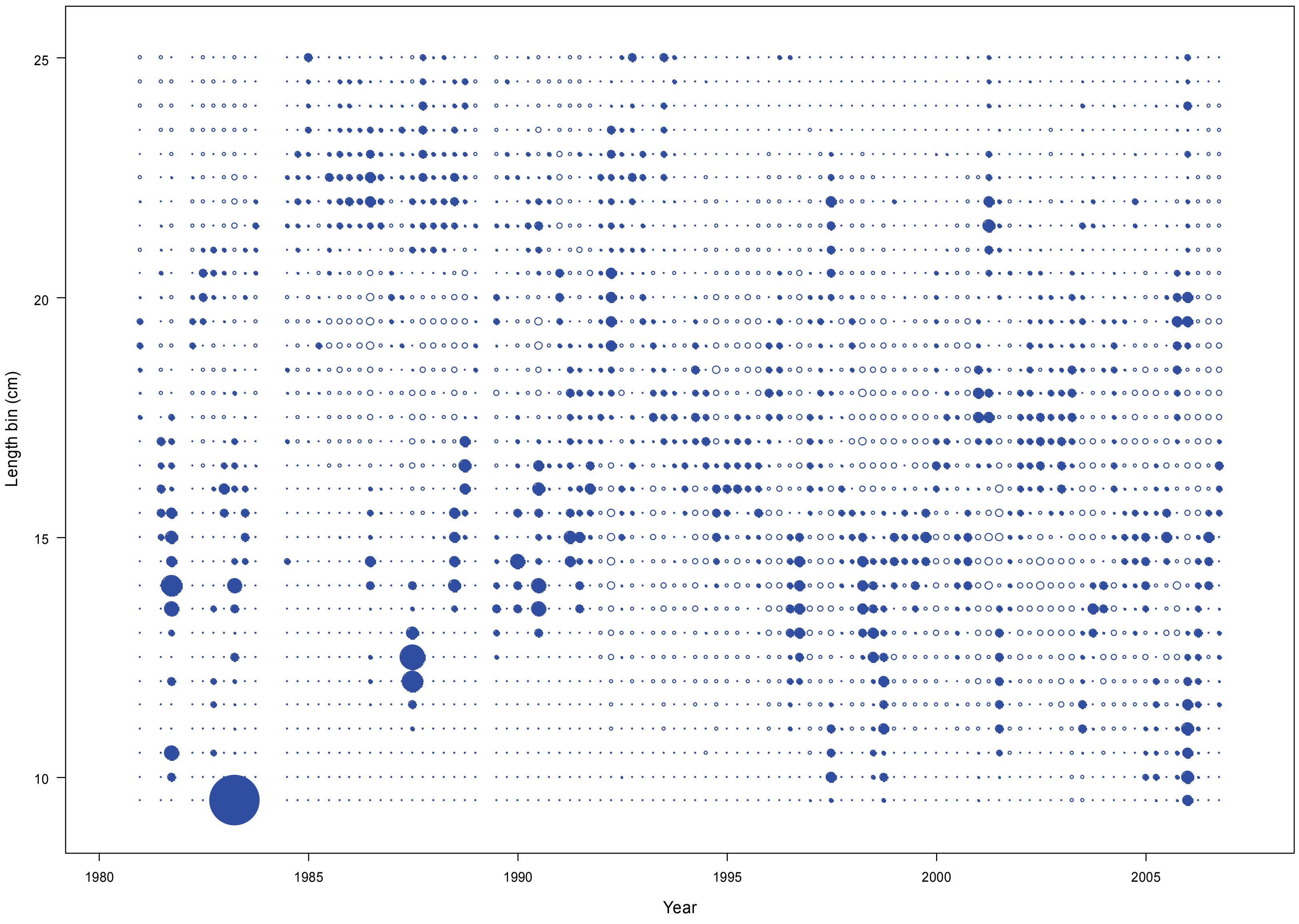

Figure 40. Pearson residuals for the fit to length-frequency data for the California fishery.

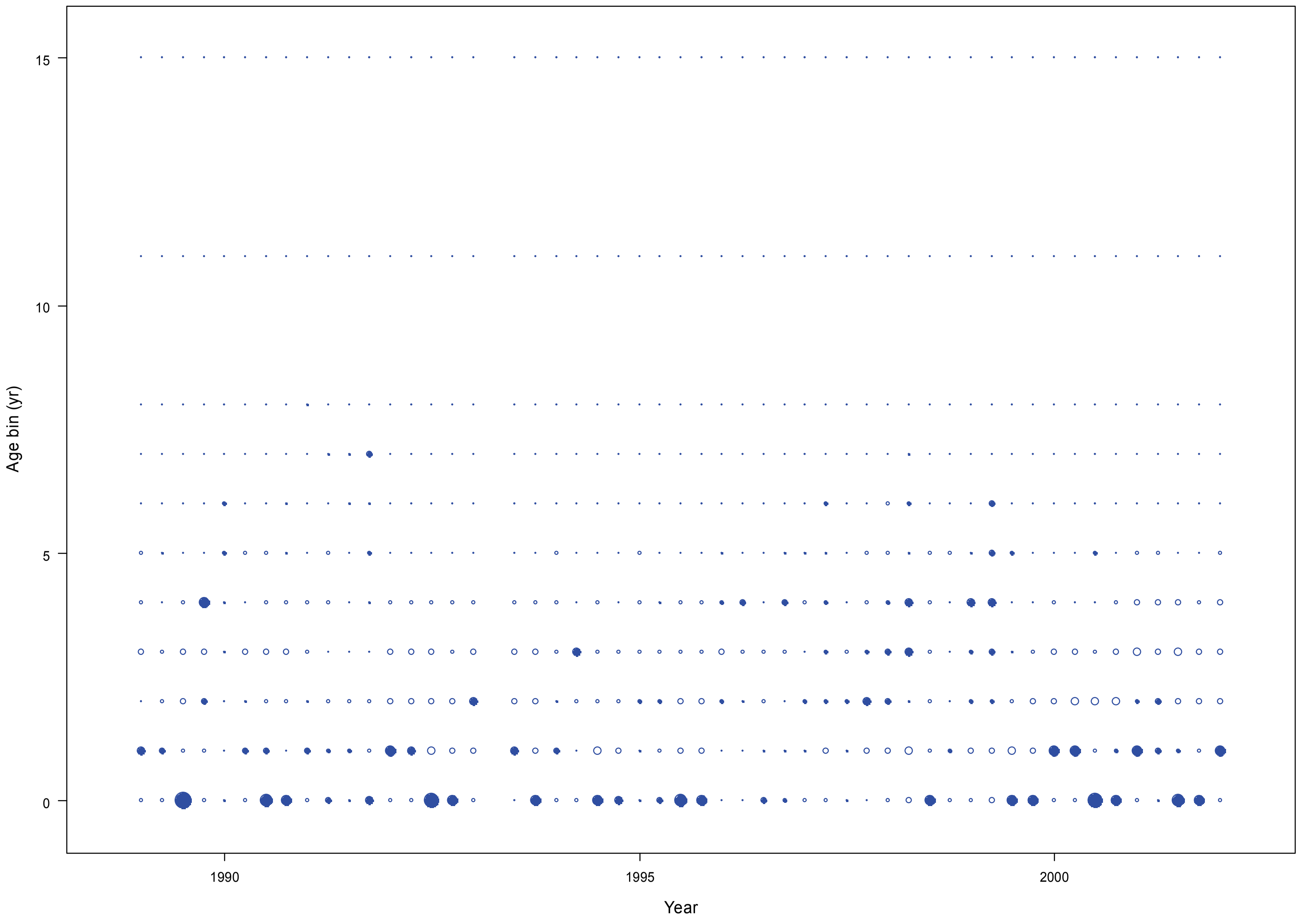

Figure 41. Pearson residuals for the fit to length-frequency observations for the Ensenada fleet.

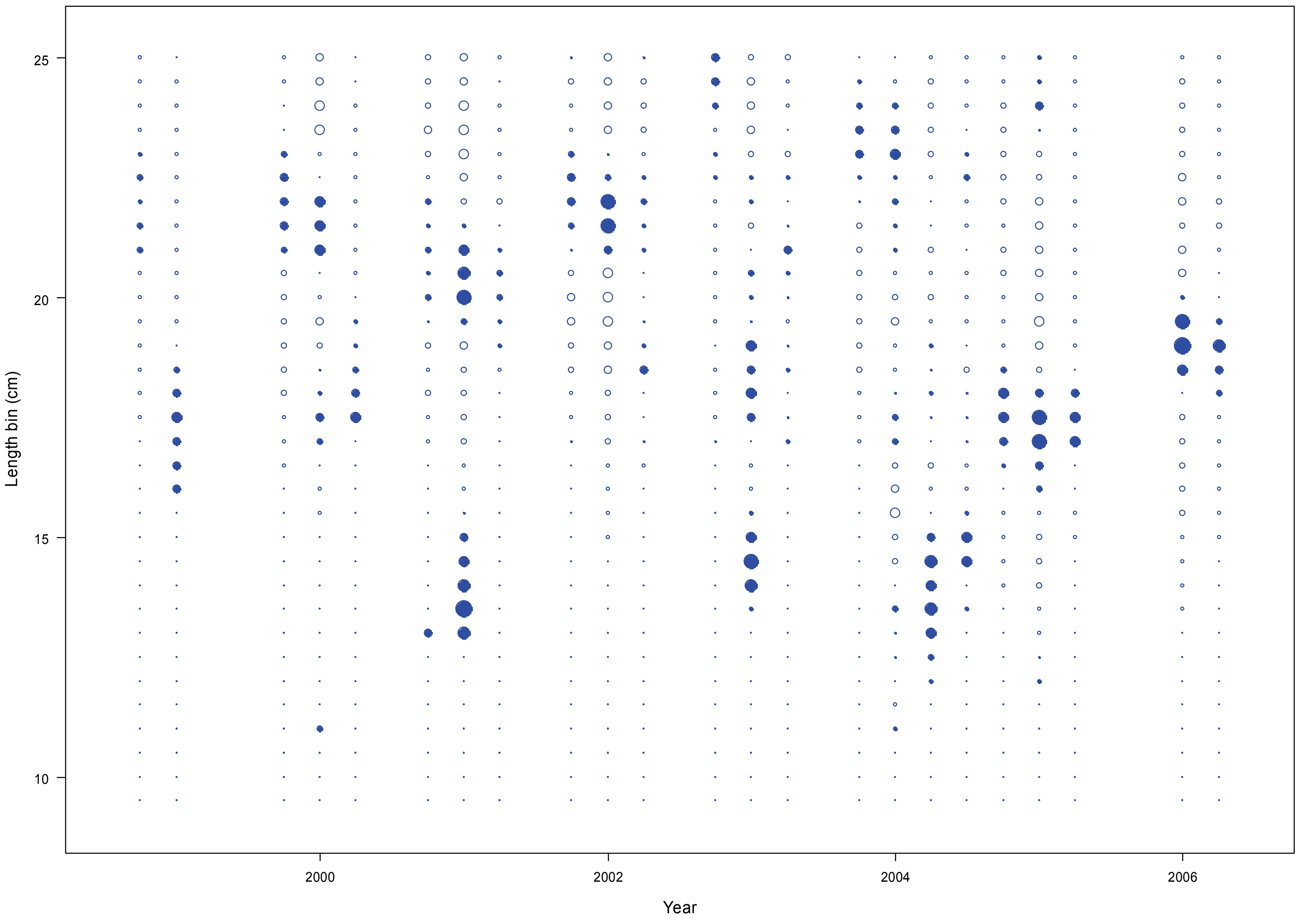

Figure 42. Pearson residuals for the fit to length-frequency data for the Pacific Northwest fishery.

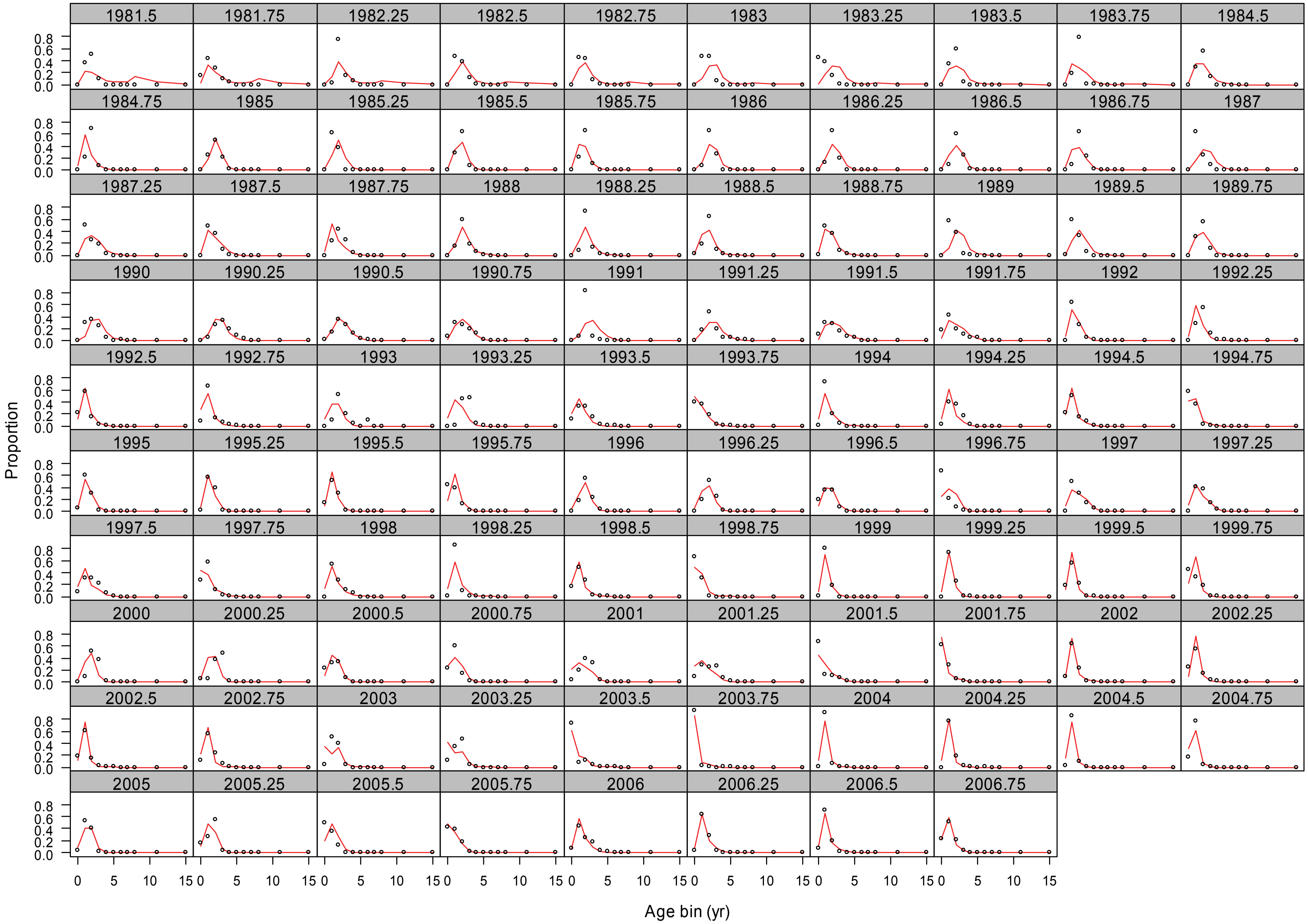

Figure 43. Fit to the (implied) age-frequency data for the California fishery.

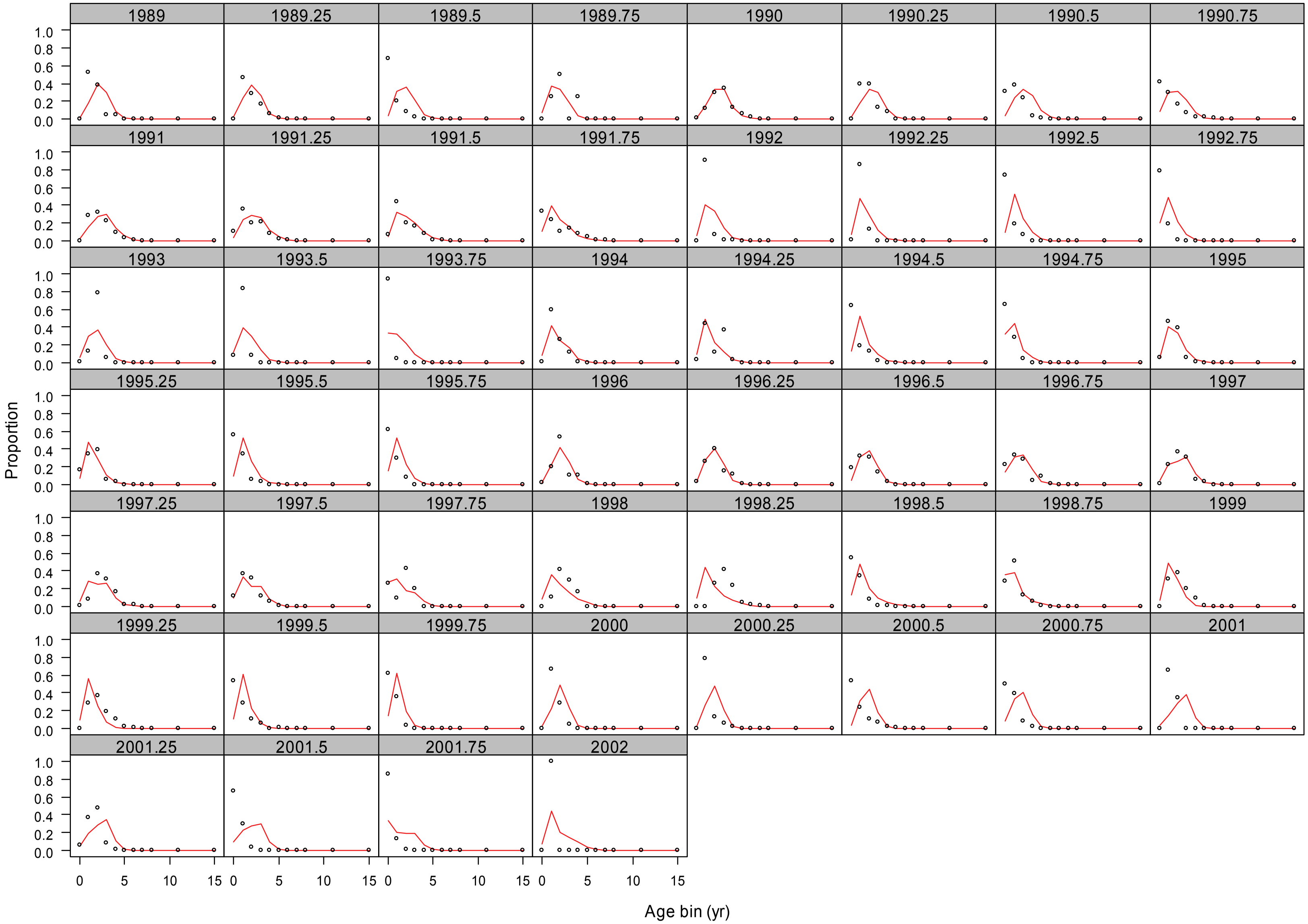

Figure 44. Fit to the (implied) age-frequency data for the Ensenada fishery.

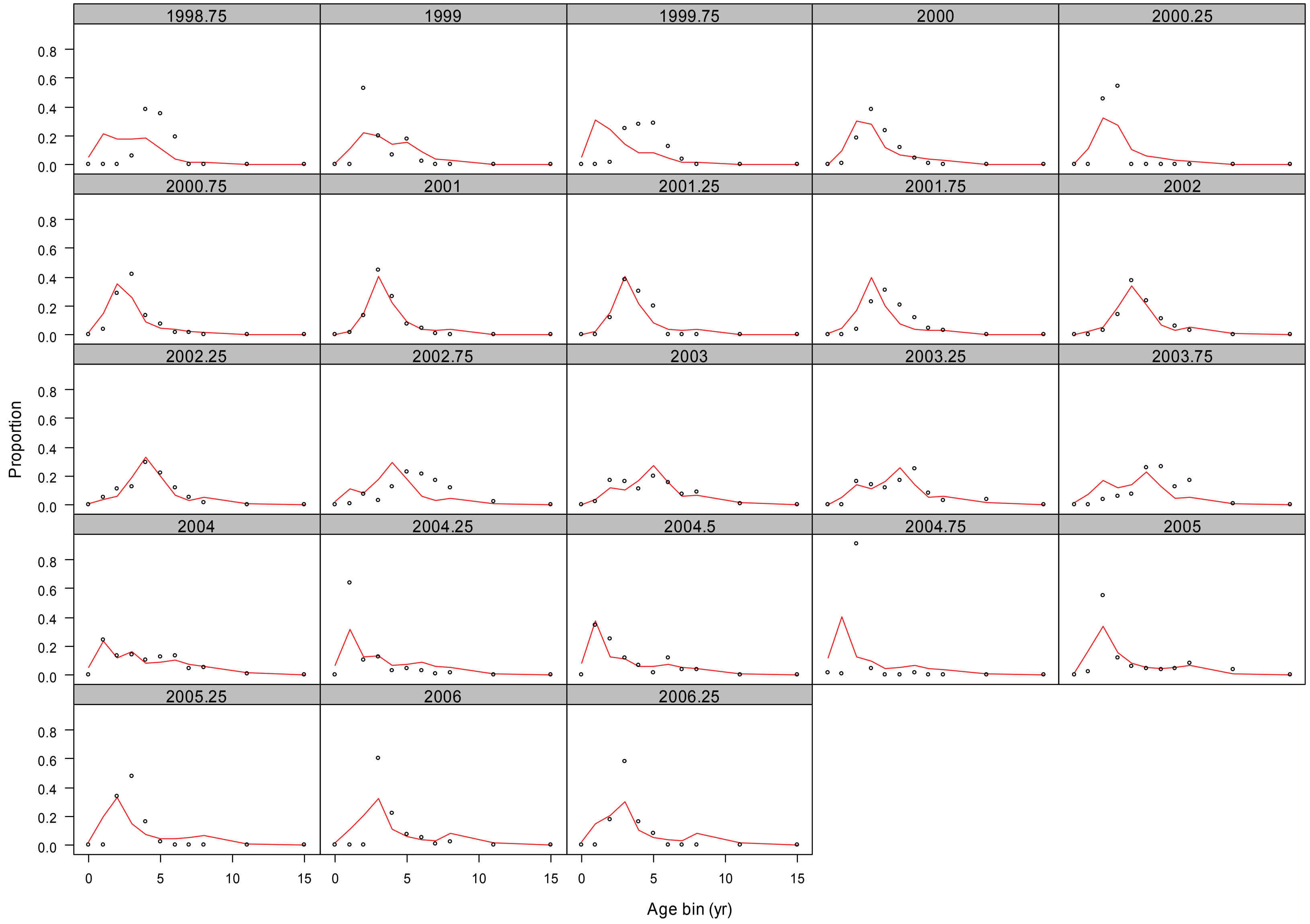

Figure 45. Fit to the (implied) age-frequency data for the Pacific Northwest fishery.

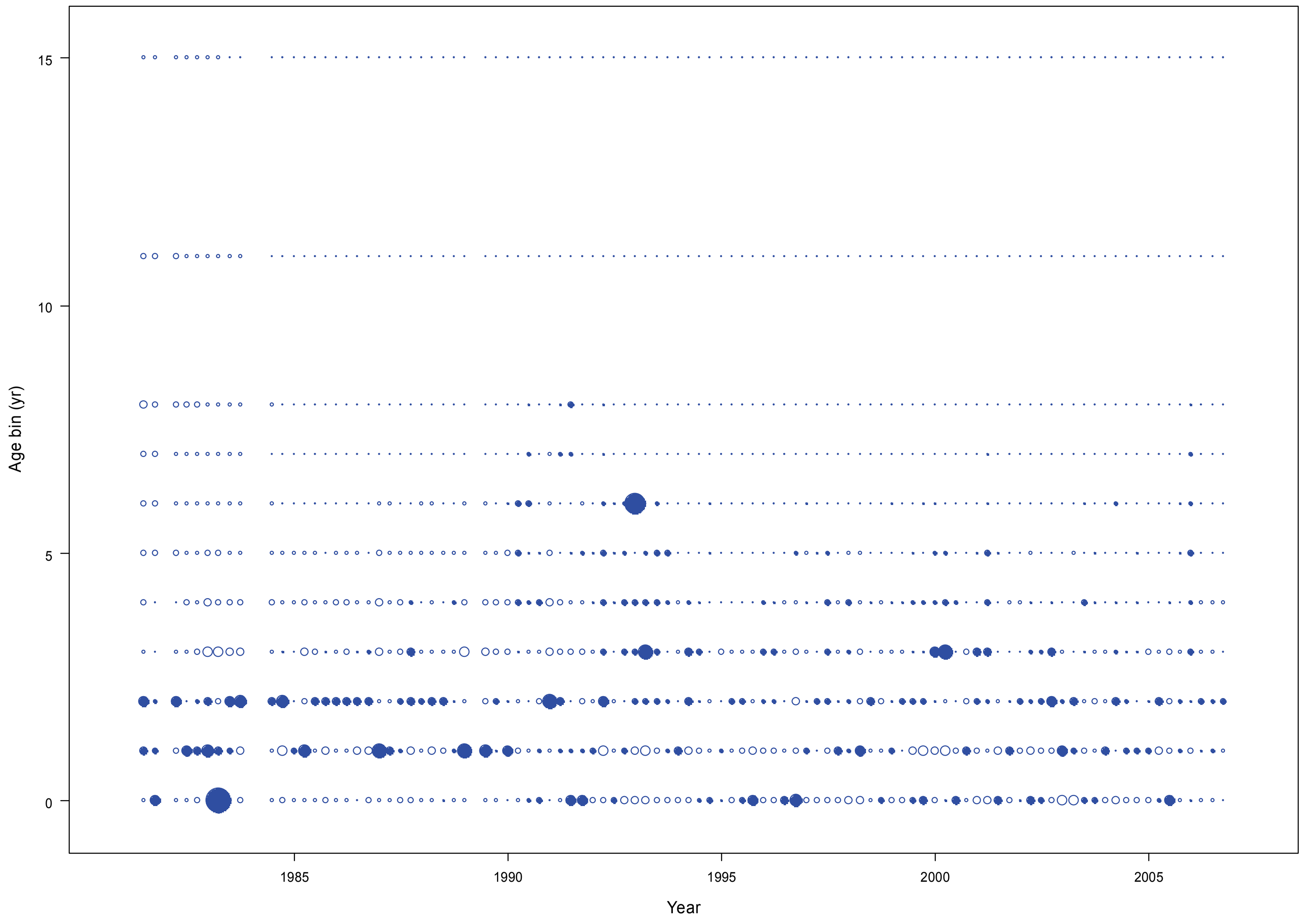

Figure 46. Pearson residuals for the fit to the (implied) age-frequency data for the California fishery.

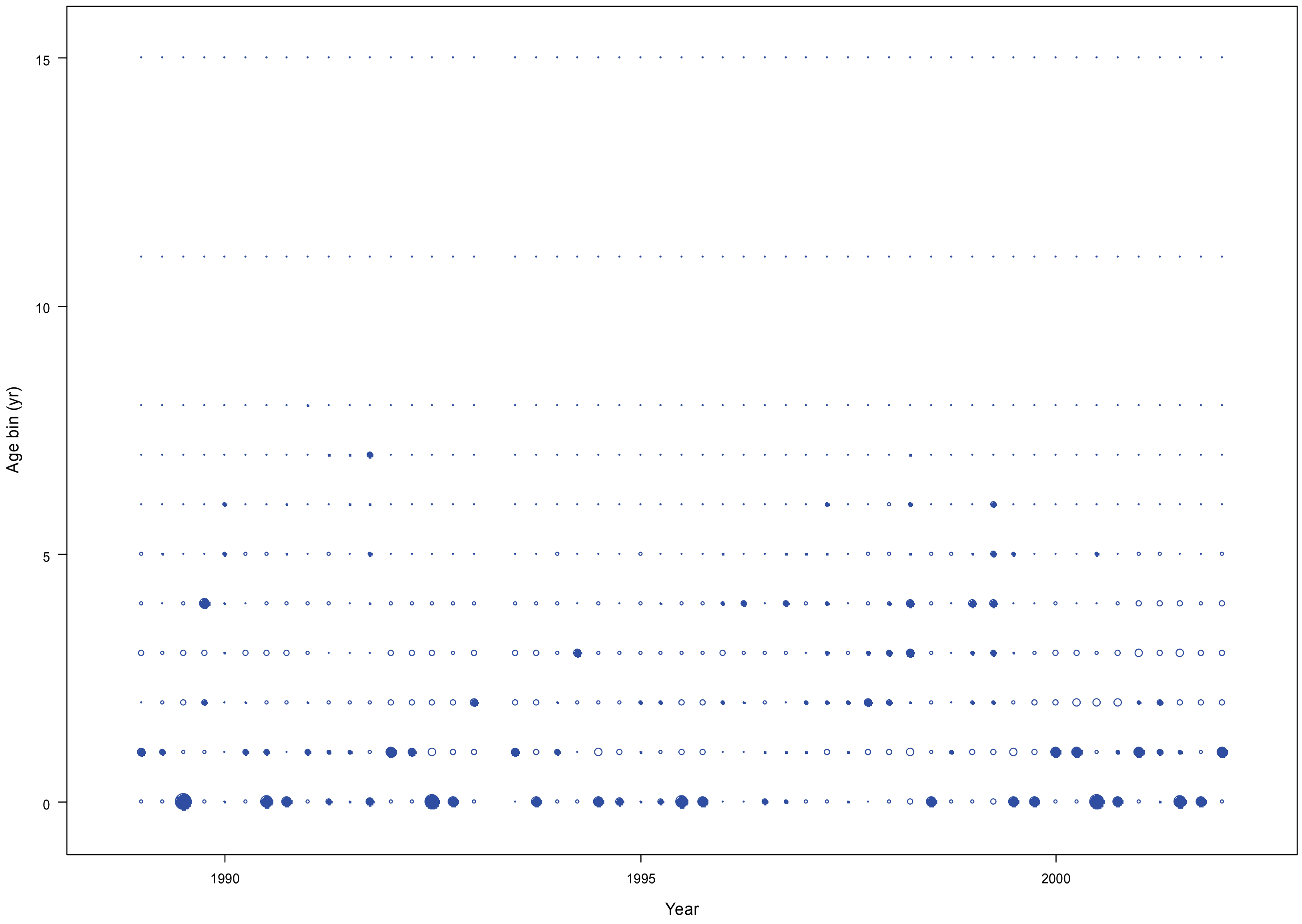

Figure 47. Pearson residuals for the fit to the (implied) age-frequency data for the Ensenada fishery.

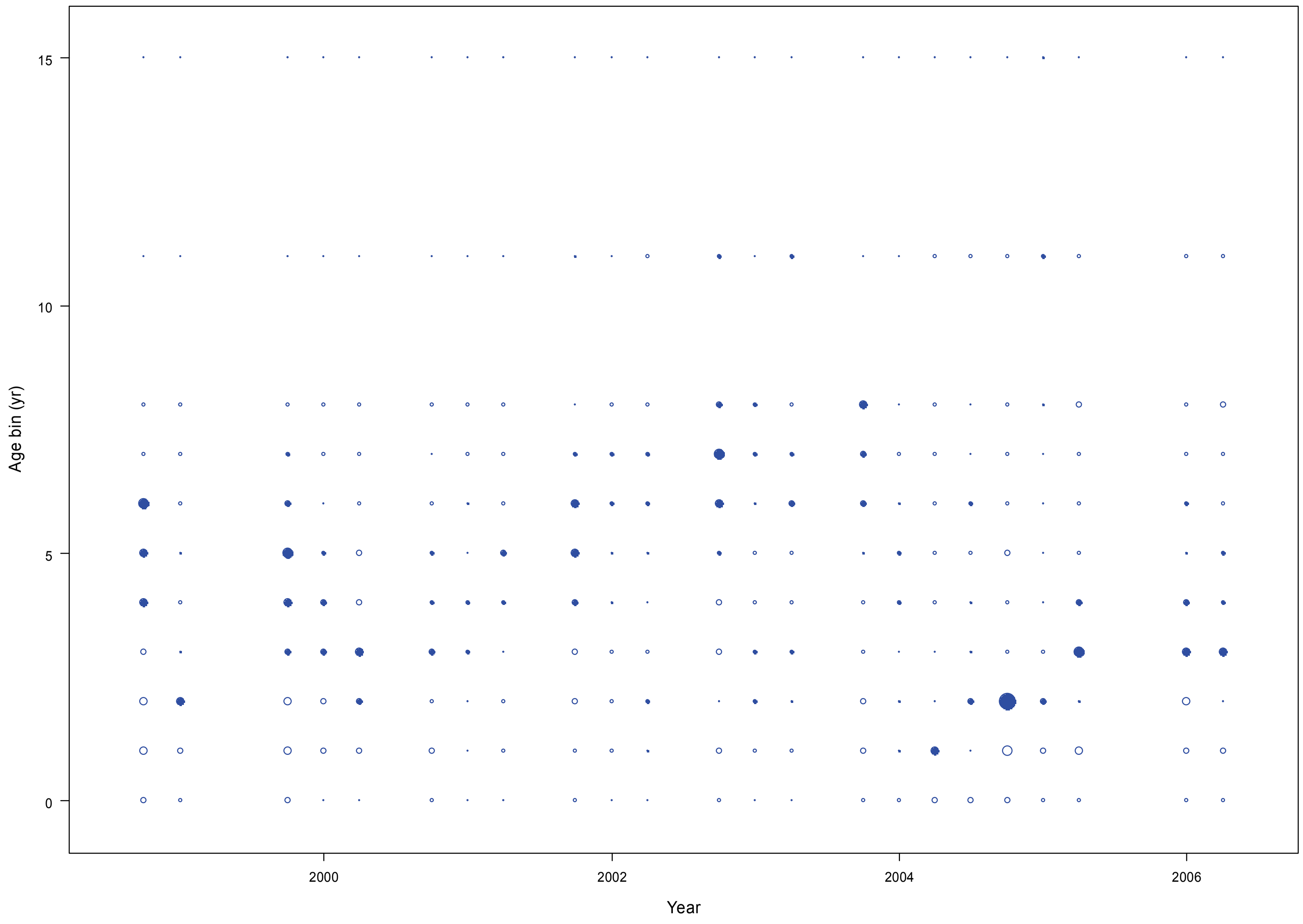

Figure 48. Pearson residuals for the fit to the (implied) age-frequency data for the Pacific northwest fishery..

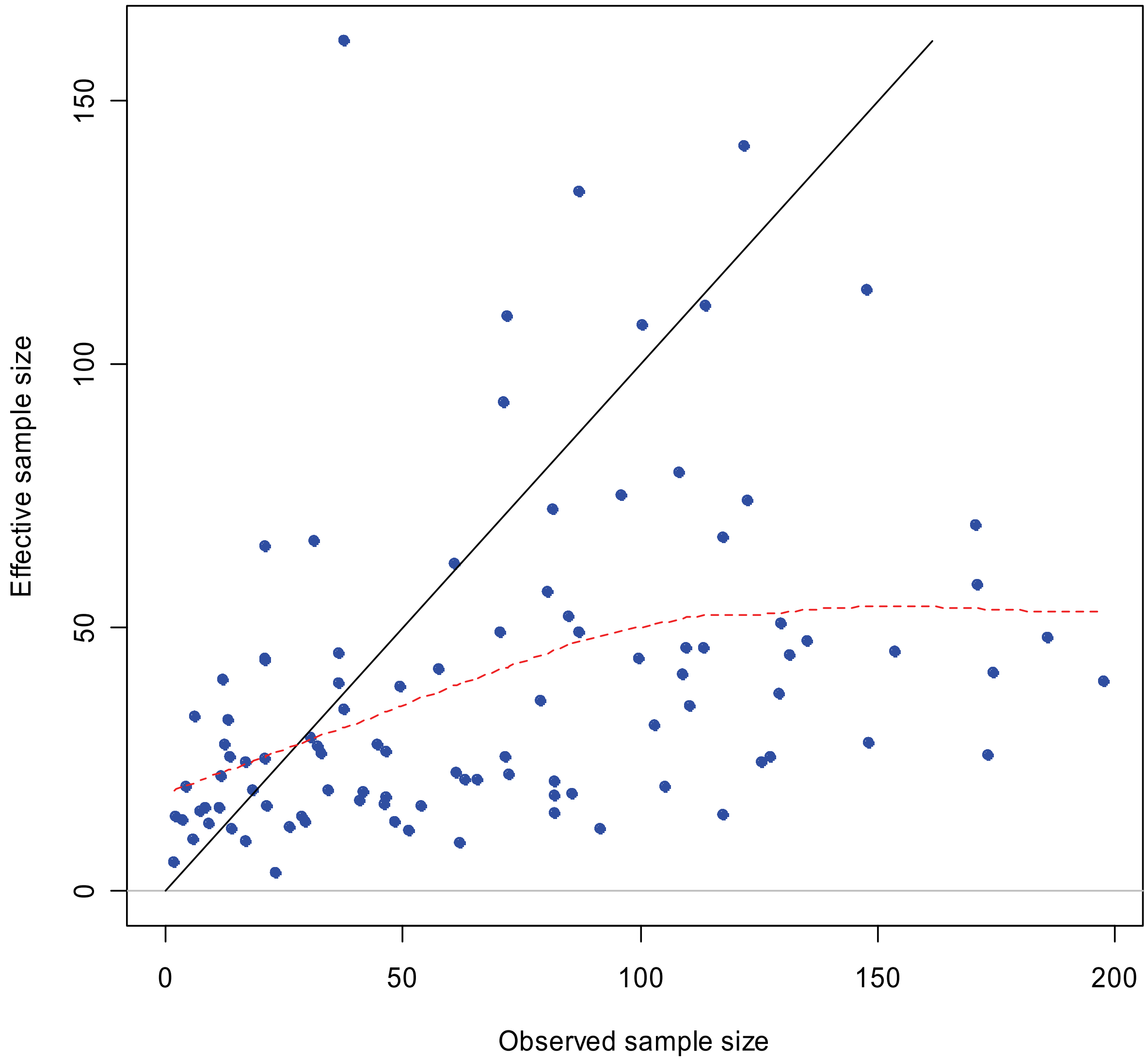

Figure 49. Observed and effective samples sizes for the California fishery length-frequency data.

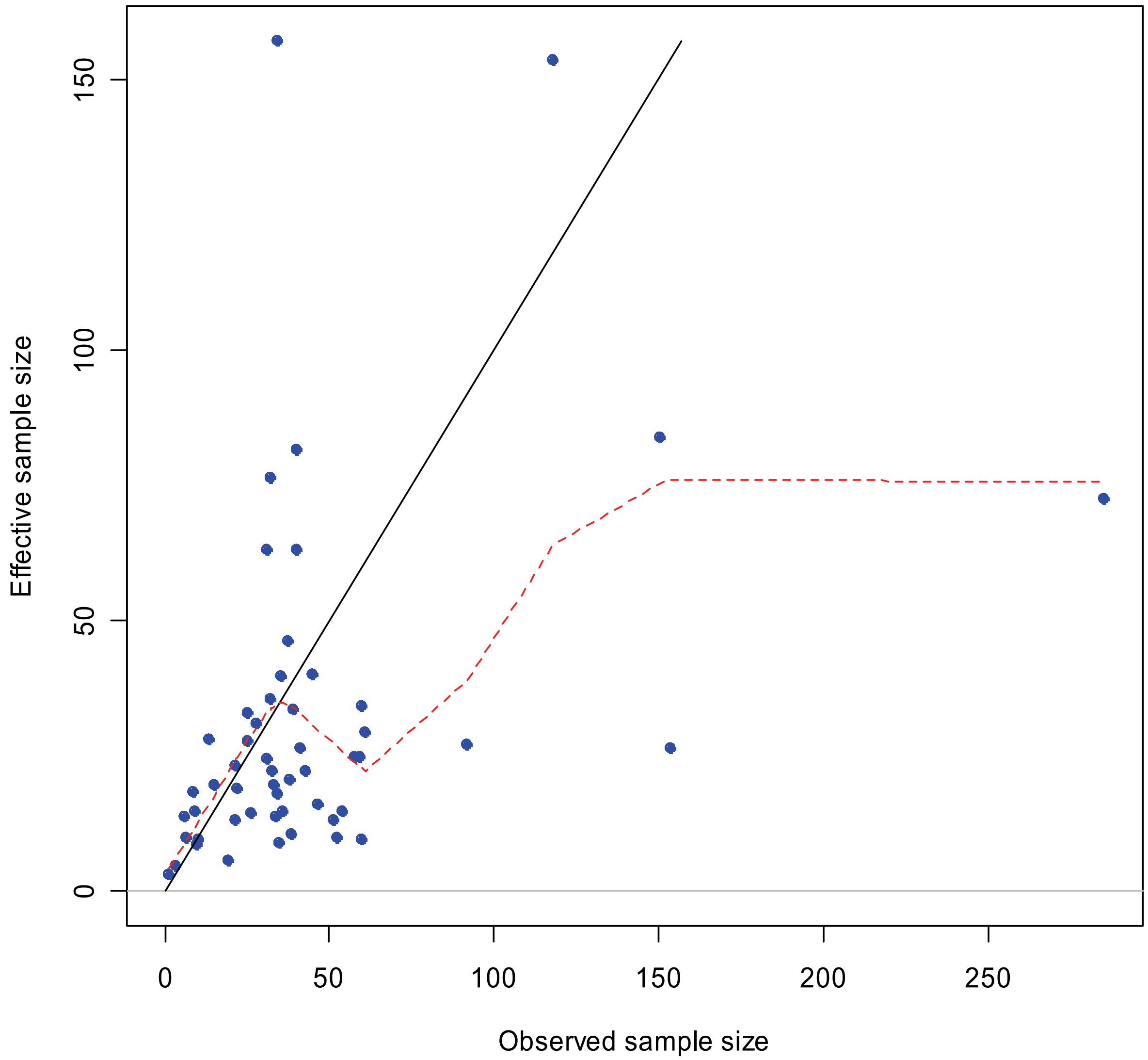

Figure 50. Observed and effective samples sizes for the Ensenada fishery length-frequency data.

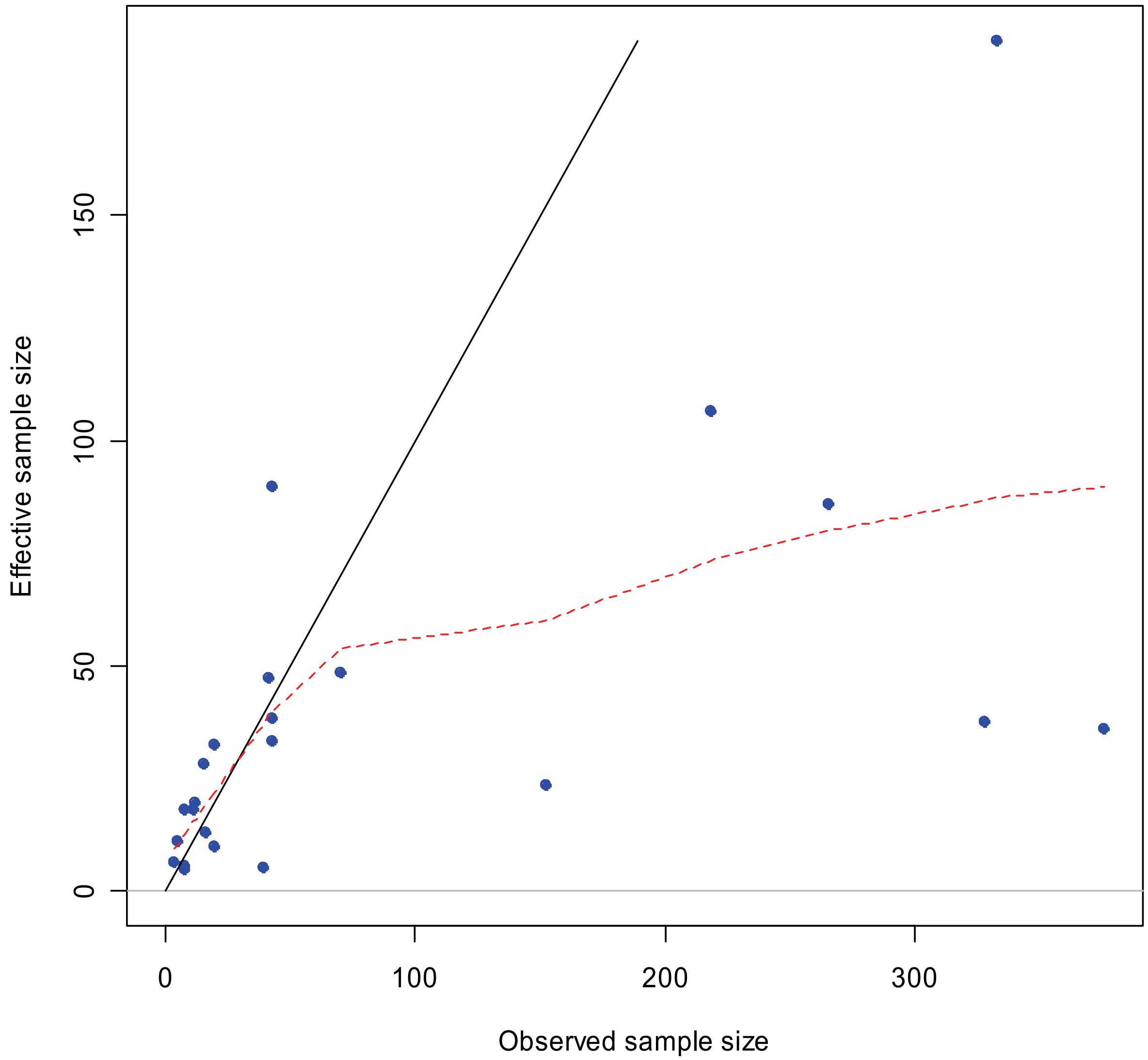

Figure 51. Observed and effective samples sizes for the Pacific Northwest fishery length-frequency data.

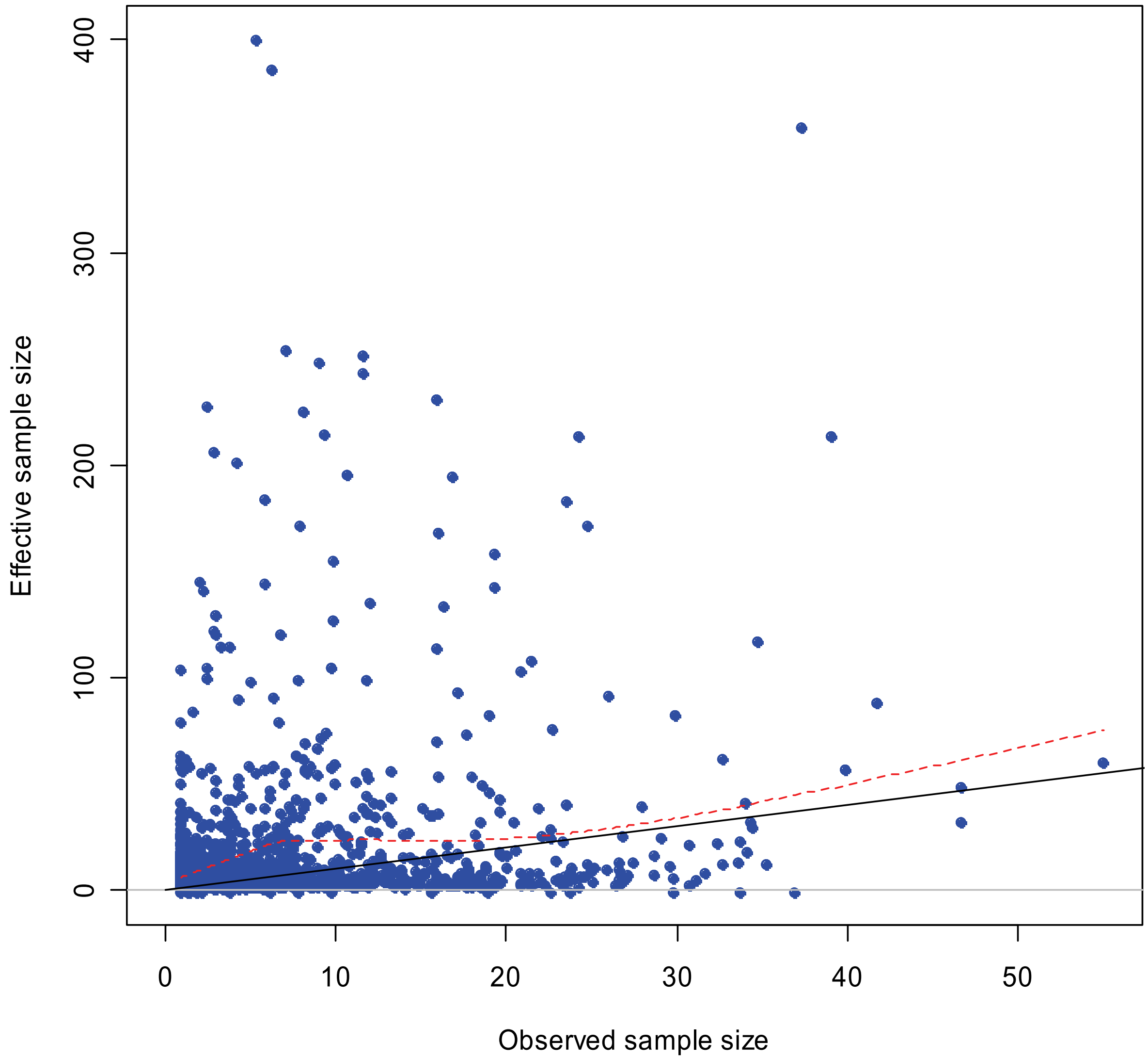

Figure 52. Observed and effective sample sizes for the California fishery conditional age-at-length frequency data.

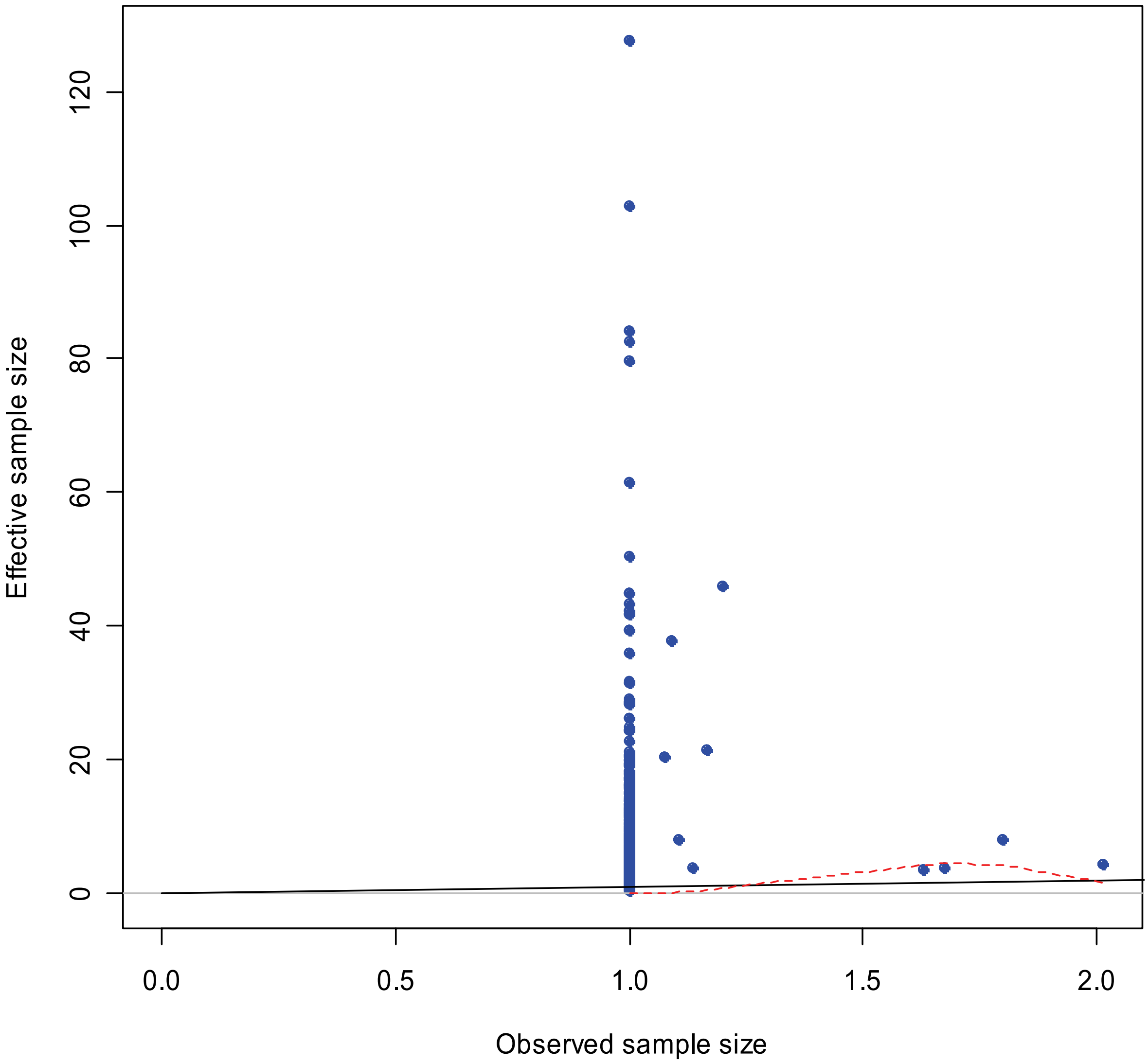

Figure 53. Observed and effective sample sizes for the Ensenada fishery conditional age-at-length frequency data.

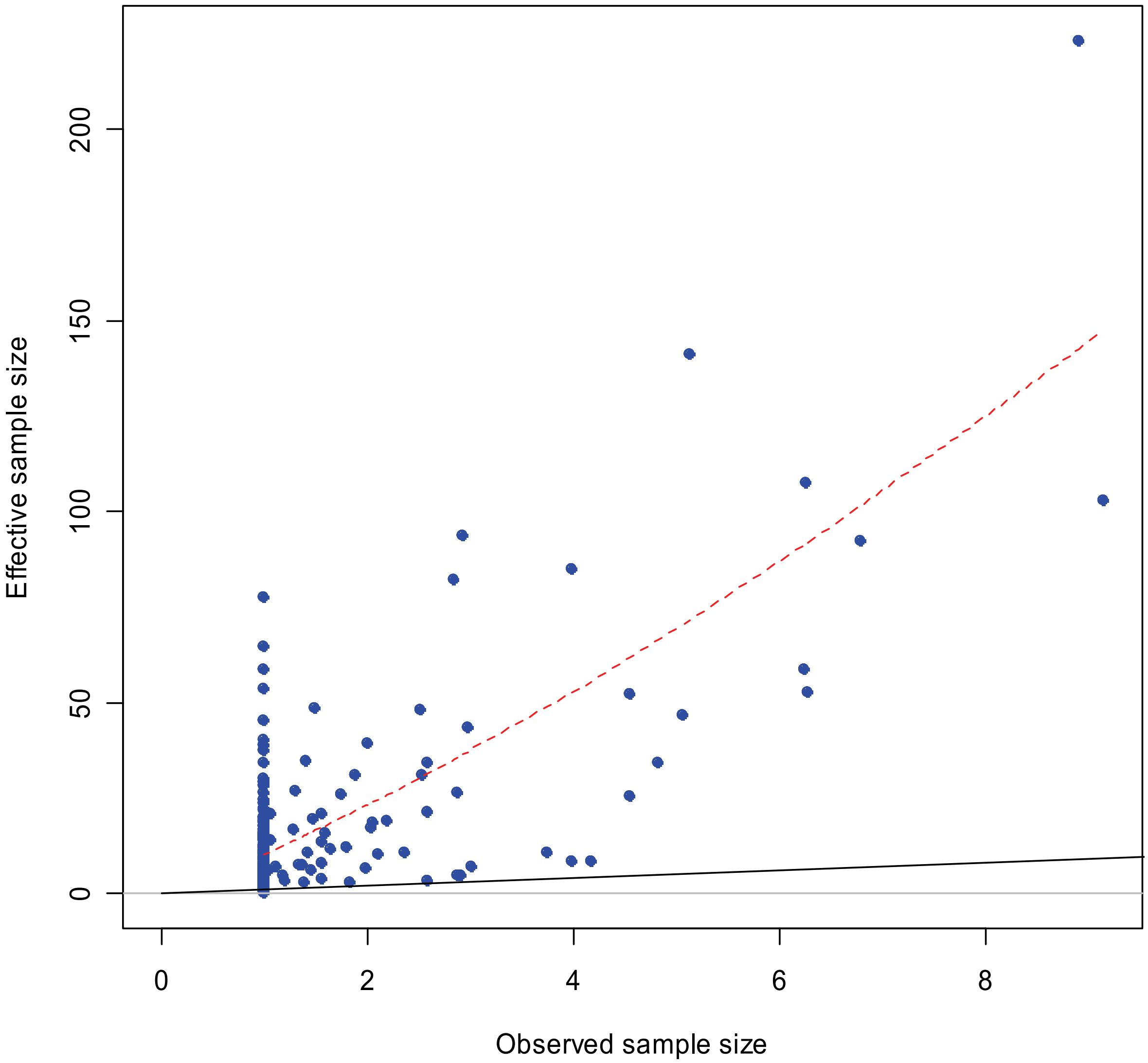

Figure 54. Observed and effective sample sizes for the Pacific Northwest fishery conditional age-at-length frequency data.

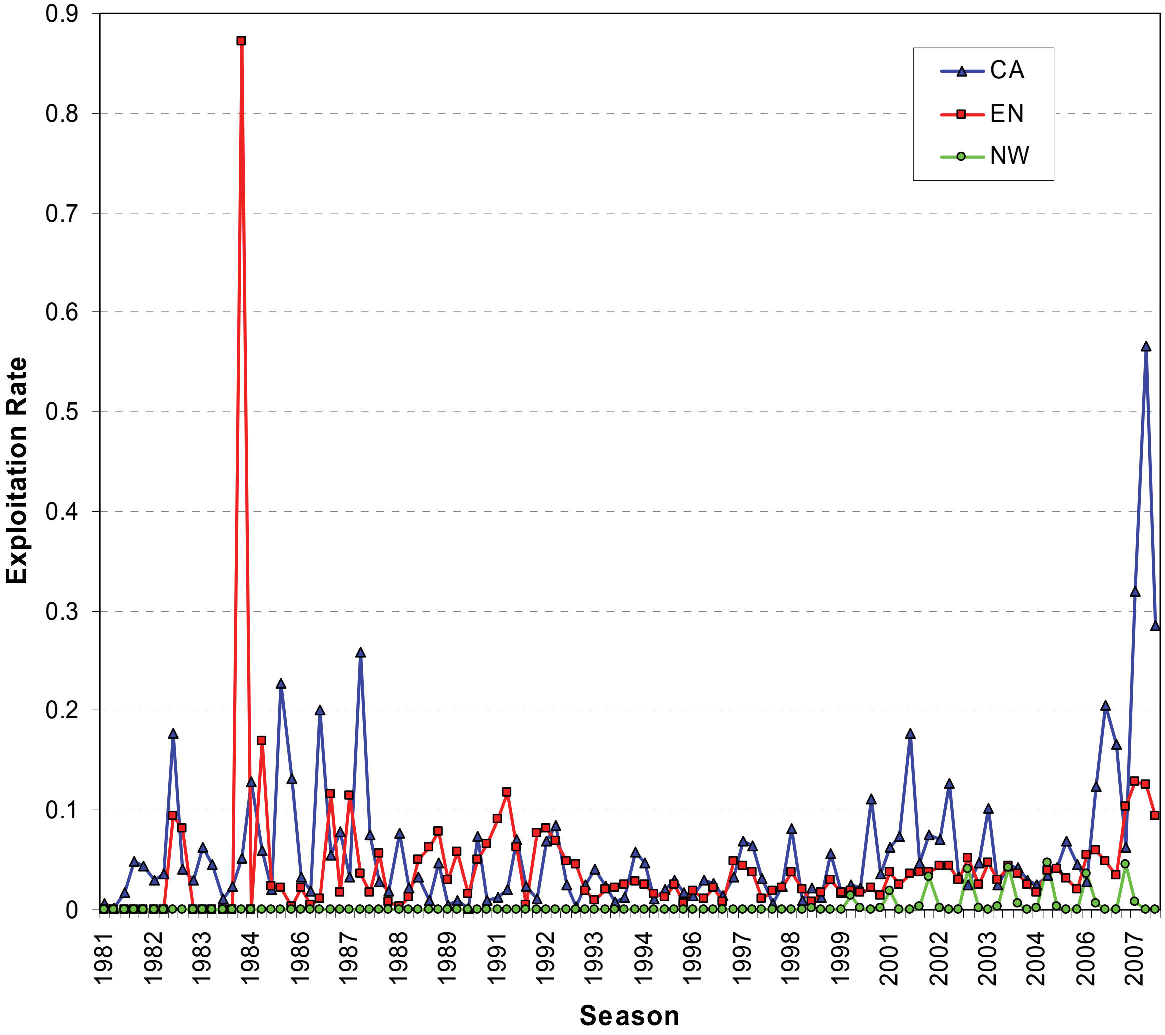

Figure 55. Estimated harvest rates for the three fisheries from the base model J14.

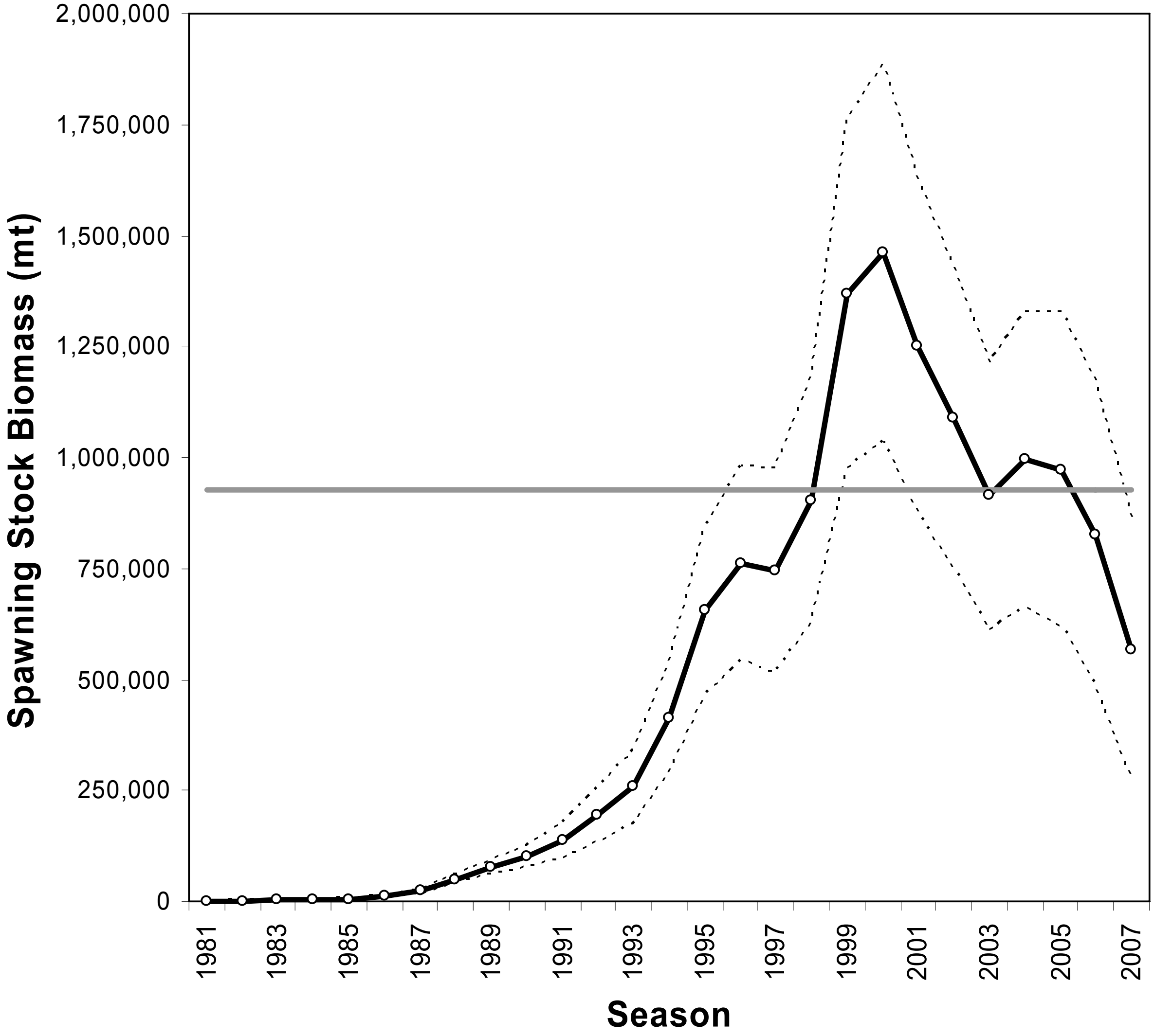

Figure 56. Total spawning stock biomass from the base model J14. B_0 is indicated by grey line.

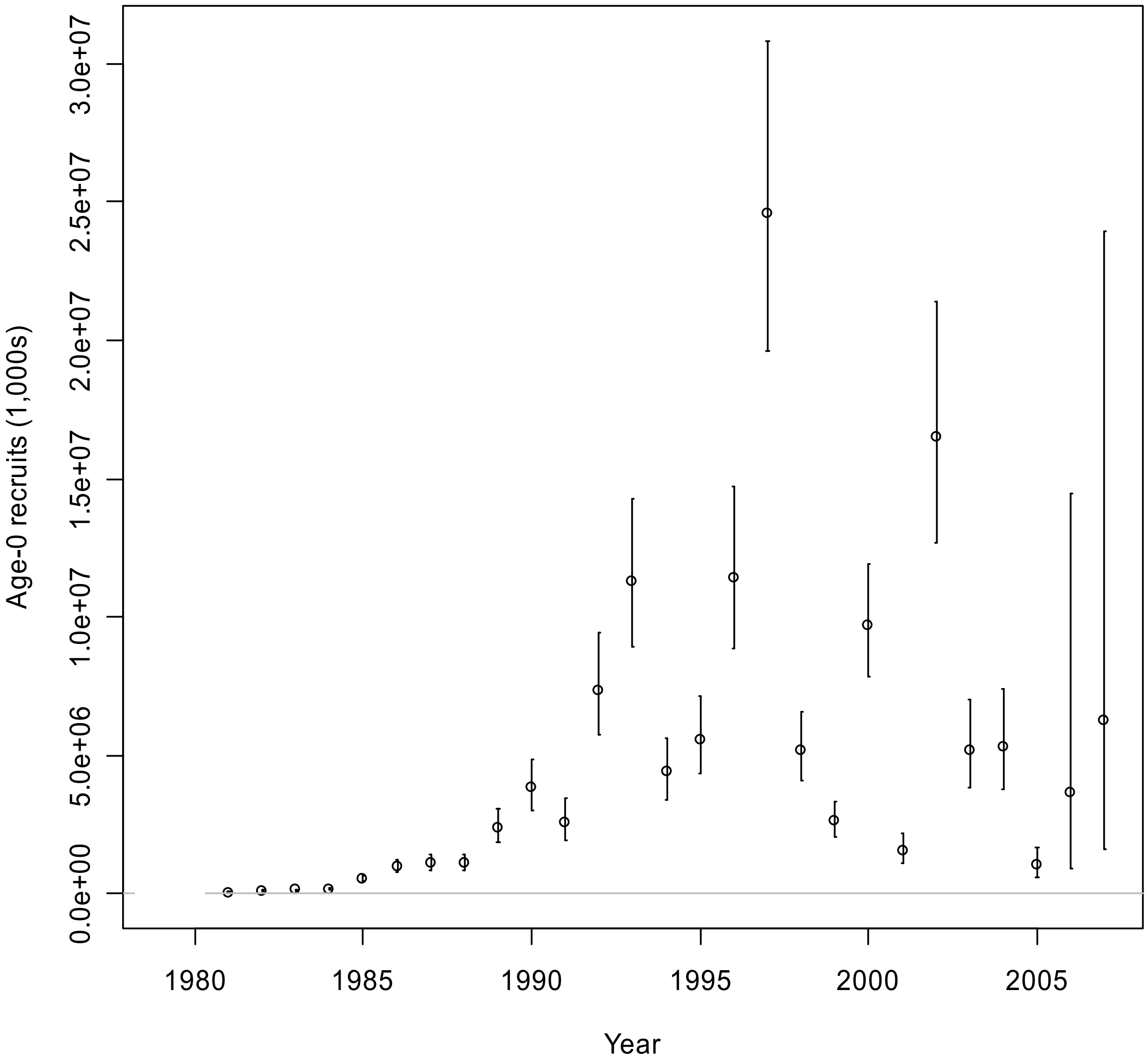

Figure 57. Recruitments and ~95% asymptotic confidence intervals from the base model J14.

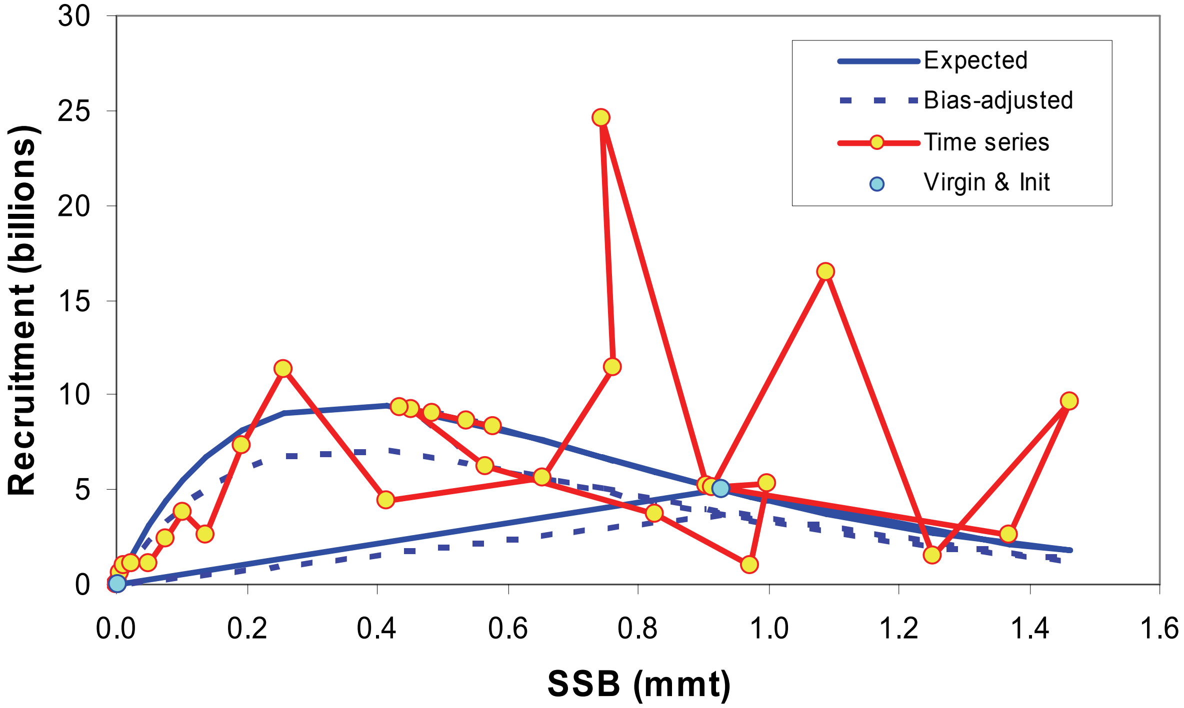

Figure 58. Spawner-recruitment relationship for the base model J14, showing the Ricker function fit.

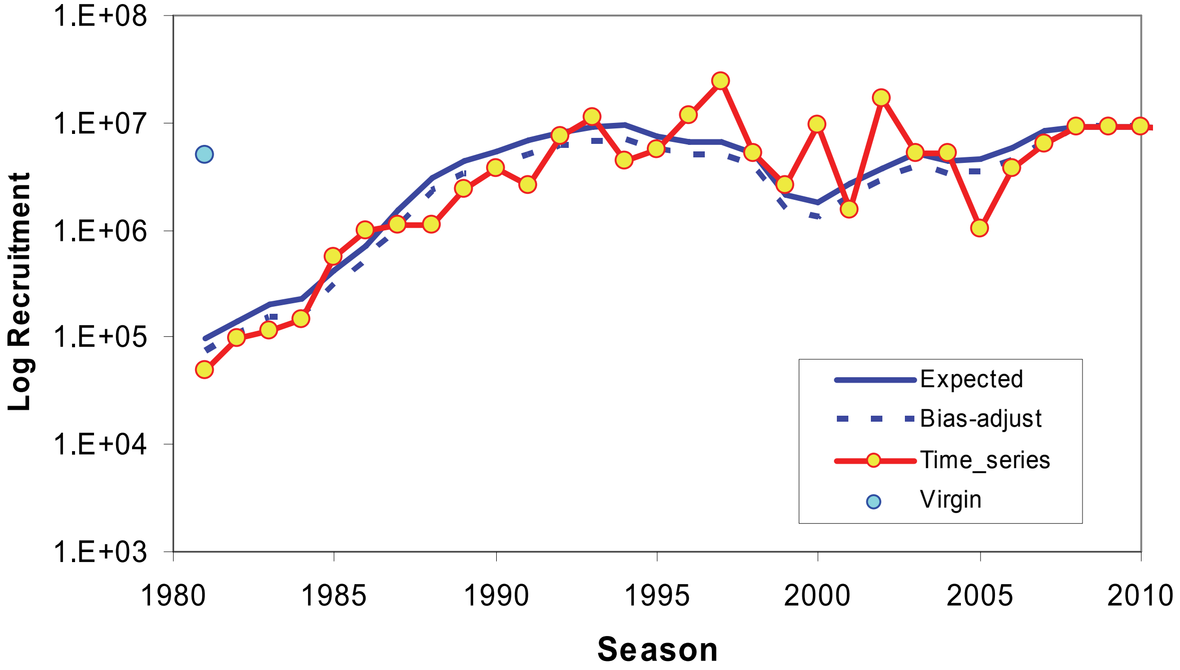

Figure 59. Ricker model fit to the recruitment time series.

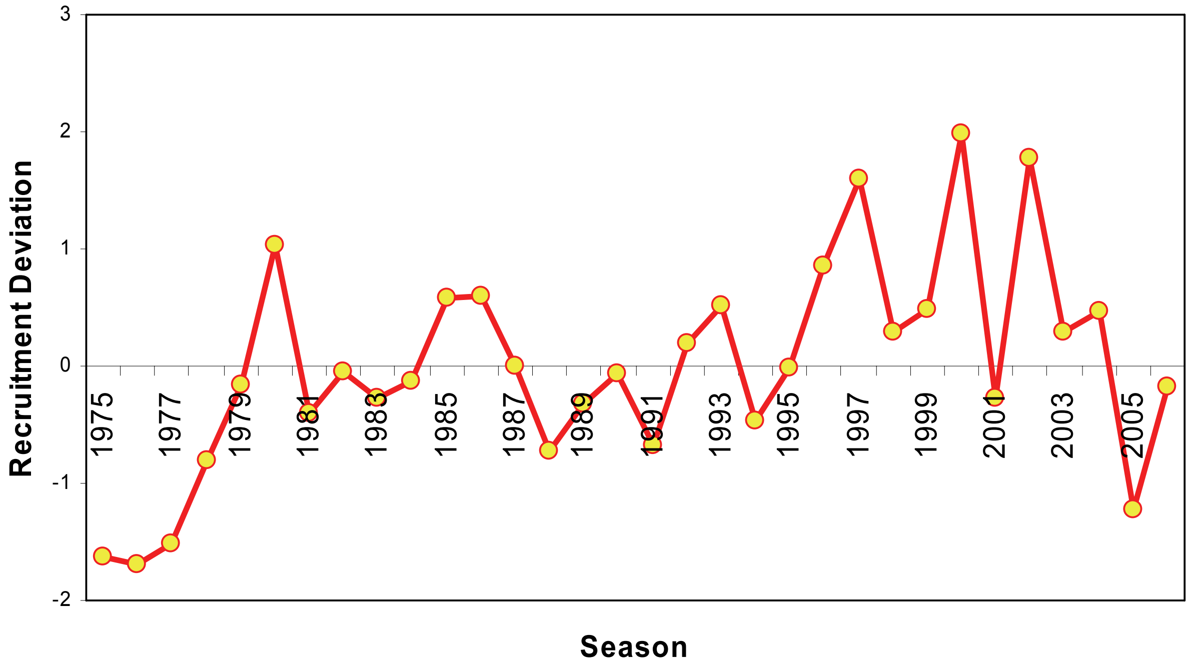

Figure 60. Recruitment deviations for the base model J14.

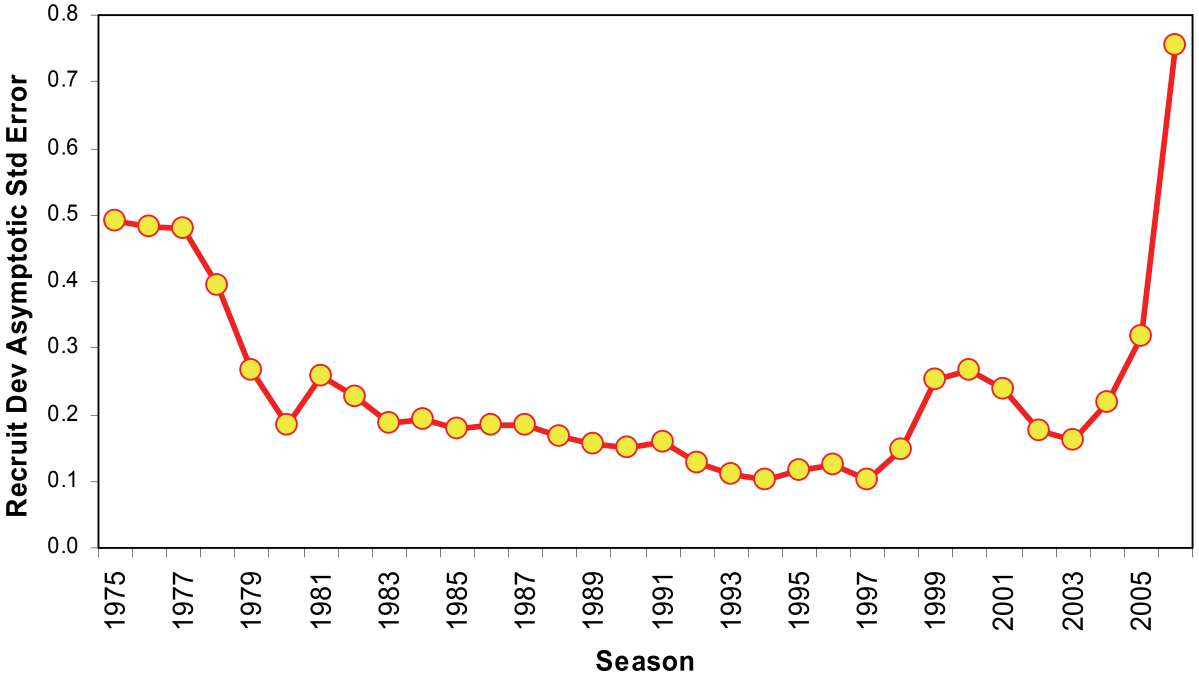

Figure 61. Asymptotic standard errors for estimated recruitment deviations in the base model J14.

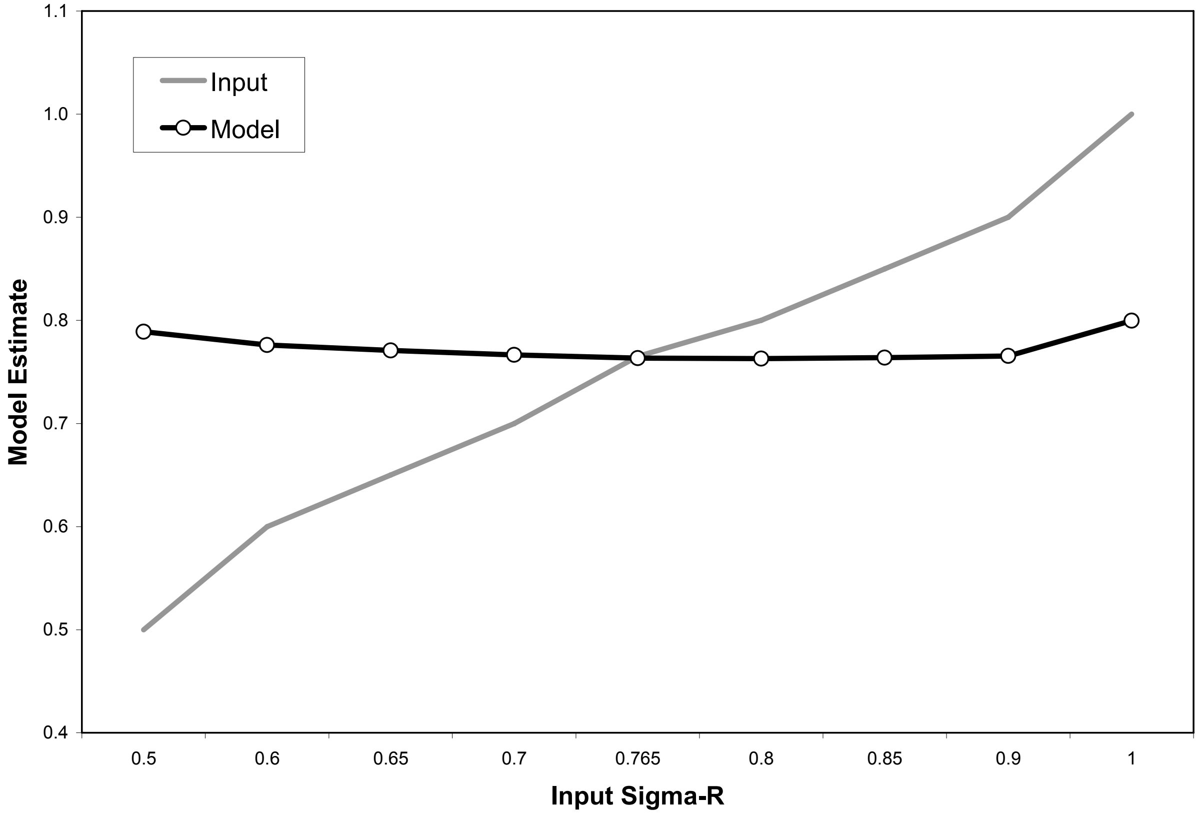

Figure 62. Root mean square error estimates for the recruitment deviations for a range of σ_R inputs in base model J14.

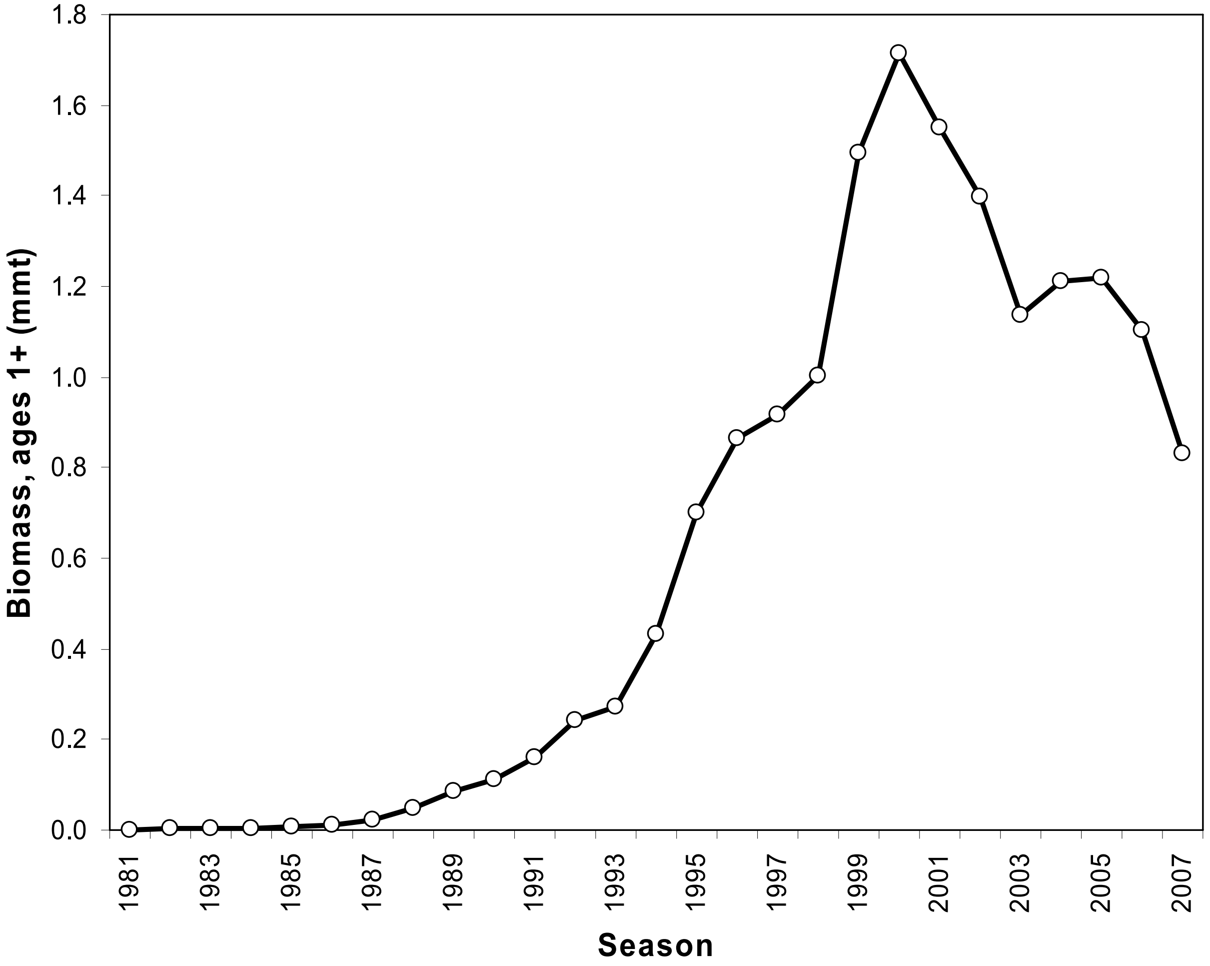

Figure 63. Pacific sardine stock biomass (ages 1+) estimates from base model J14.

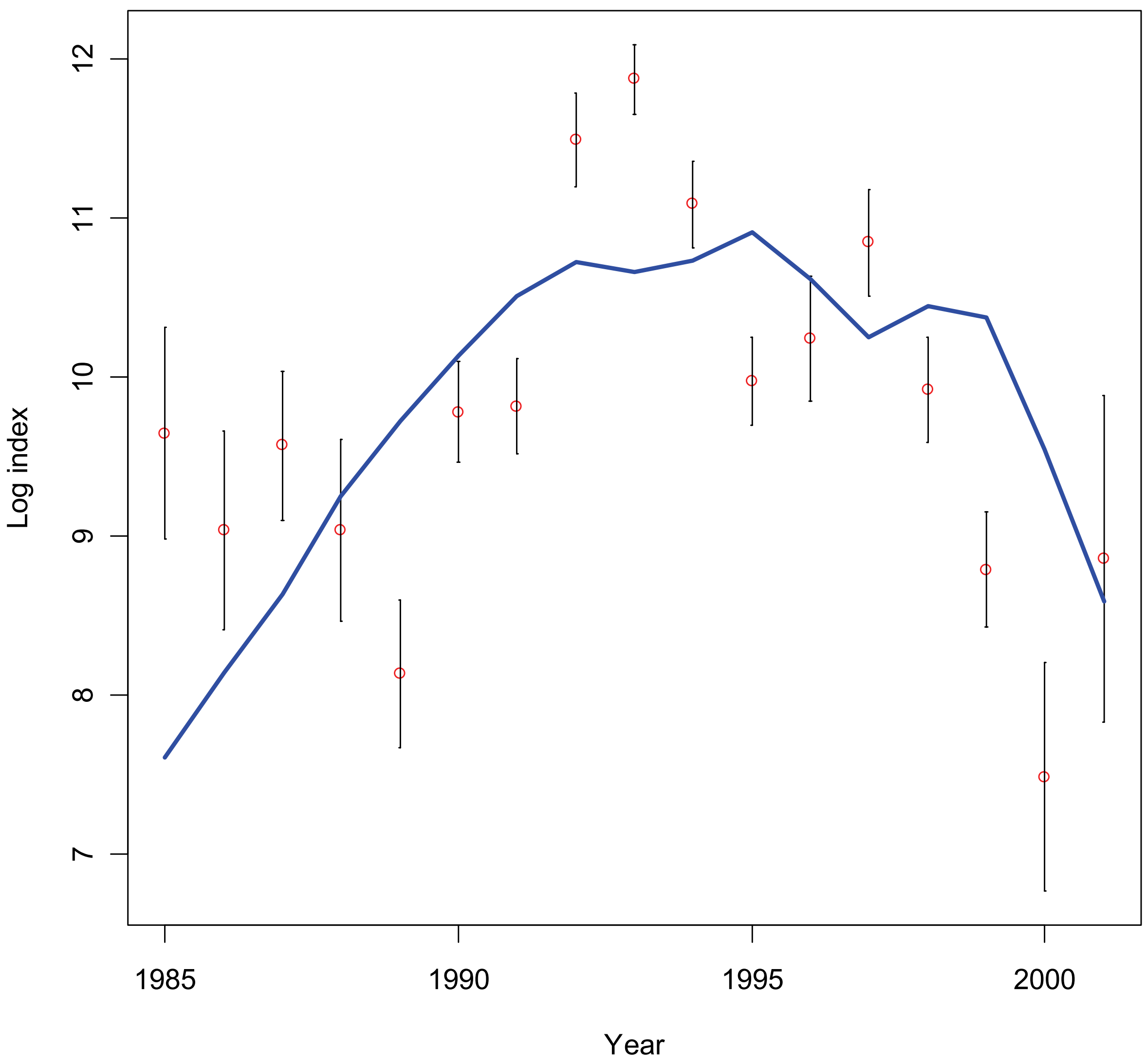

Figure 64. Model fit to Aerial Spotter logbook series when included in the likelihood for the base model.

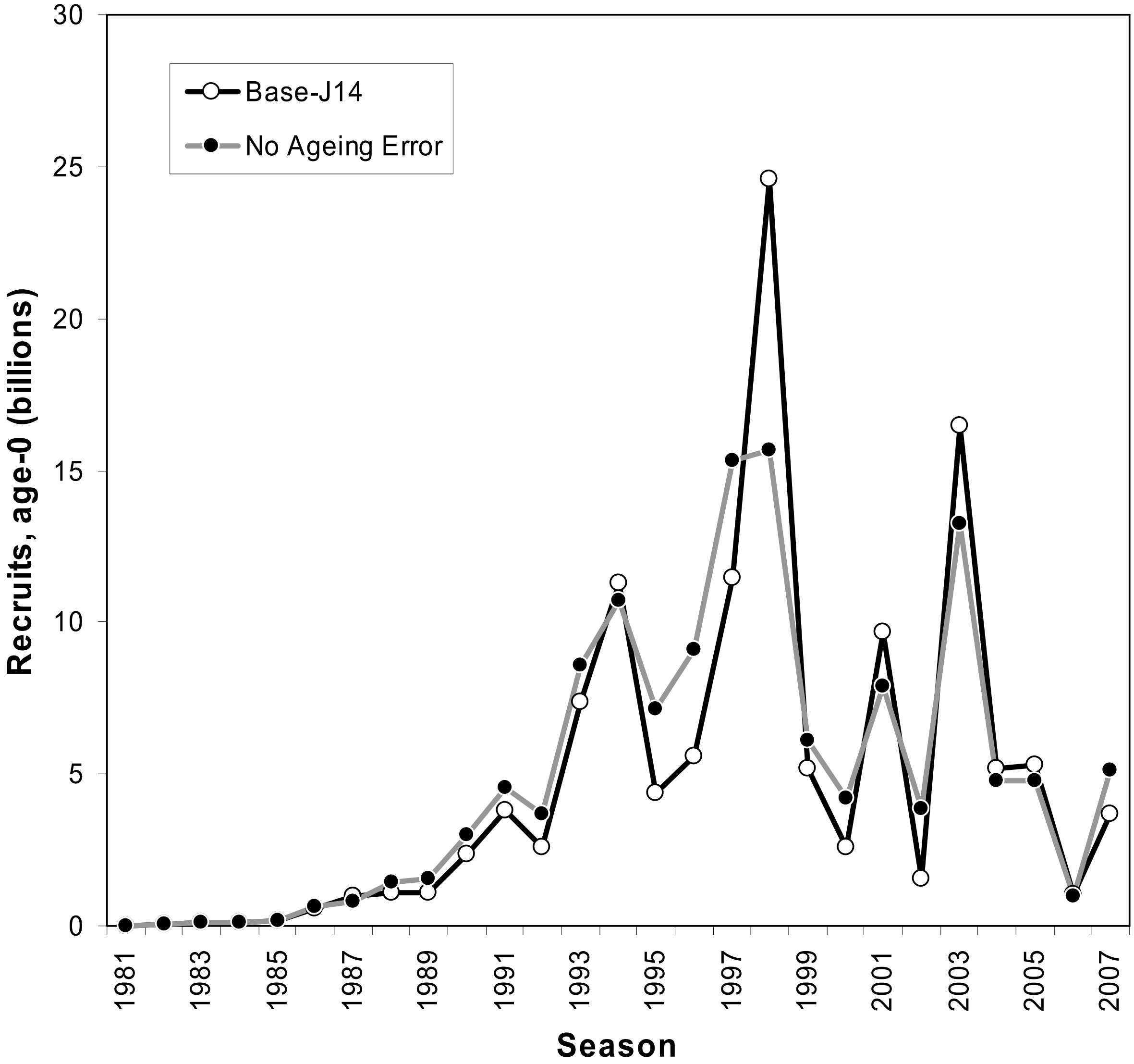

Figure 65. Sensitivity of year class estimates to ageing error assumptions.

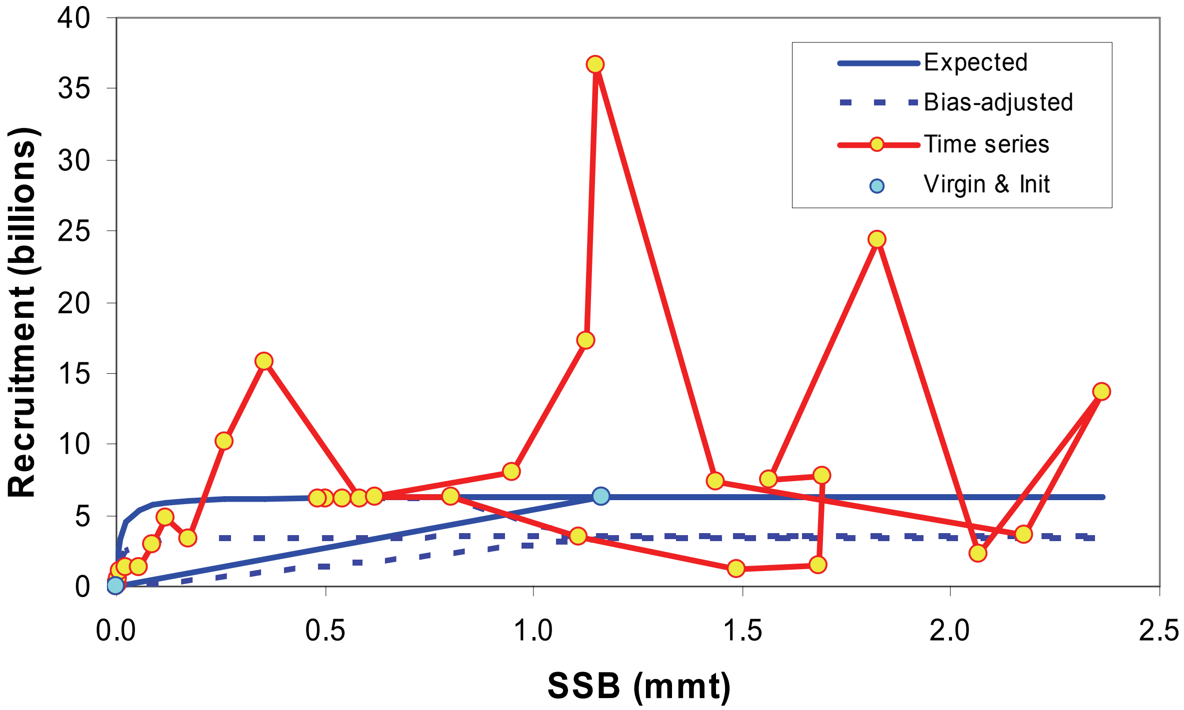

Figure 66. Spawner-recruitment relationship for the Beverton-Holt model.

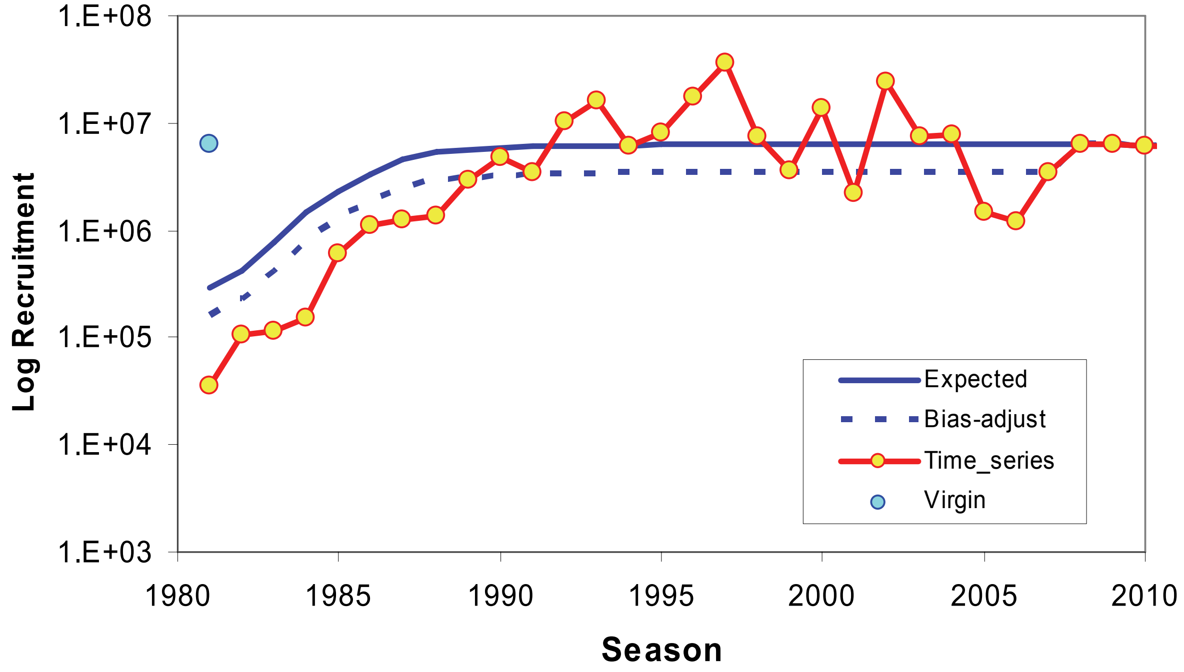

Figure 67. Recruitment series and the fit of the Beverton-Holt model.

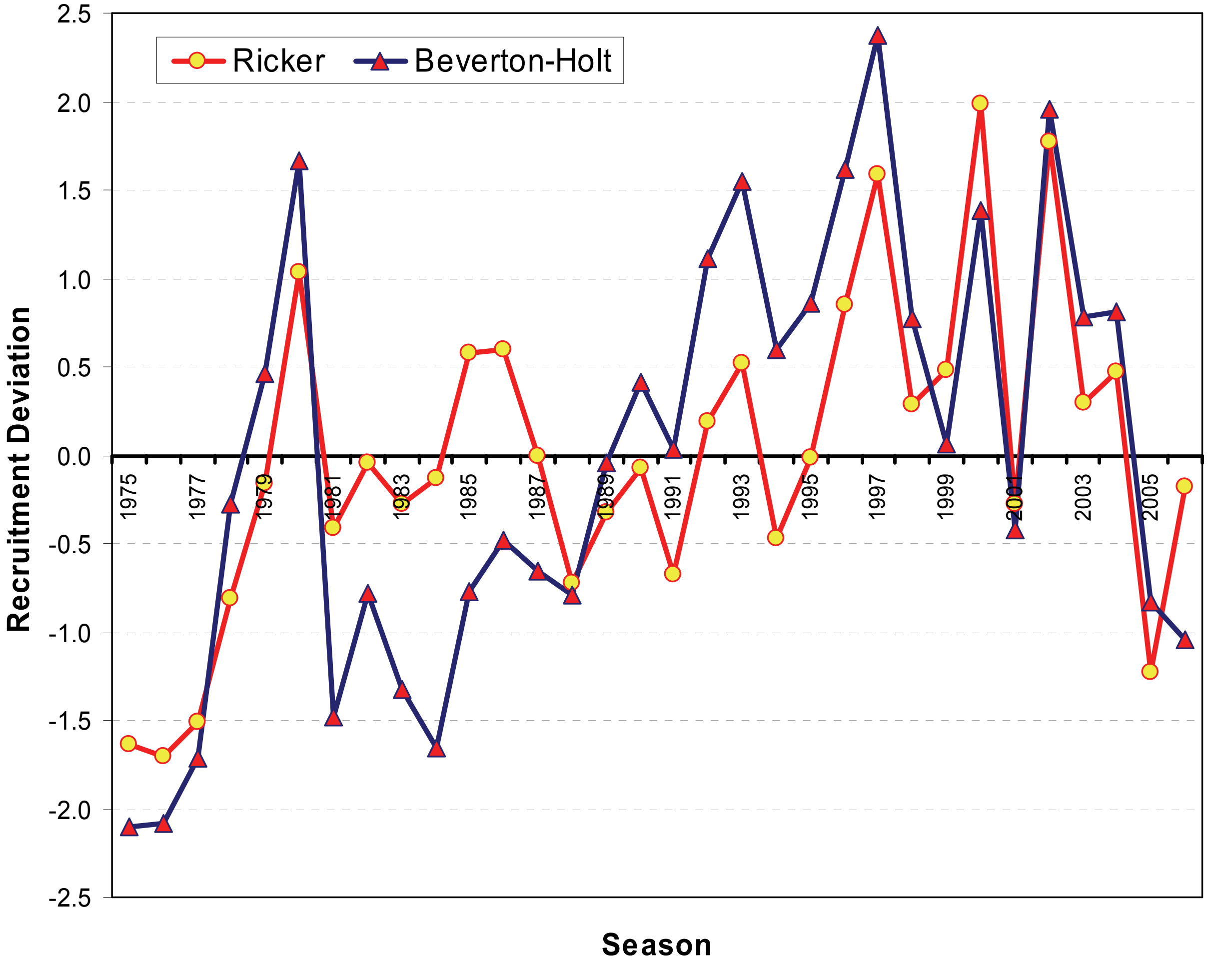

Figure 68. Recruitment deviations for the Ricker (base) and Beverton-Holt models.

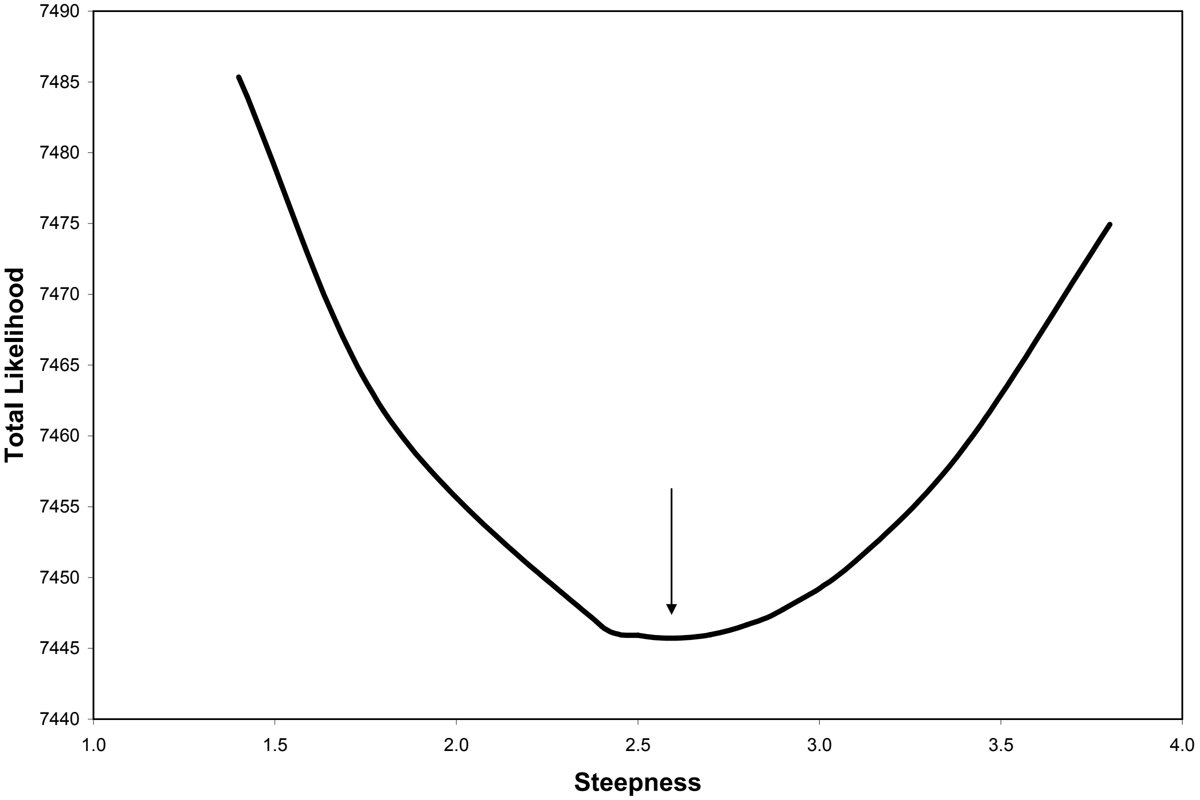

Figure 69. Likelihood profile over a range of steepness values fixed in the base model. Arrow indicates base model value.

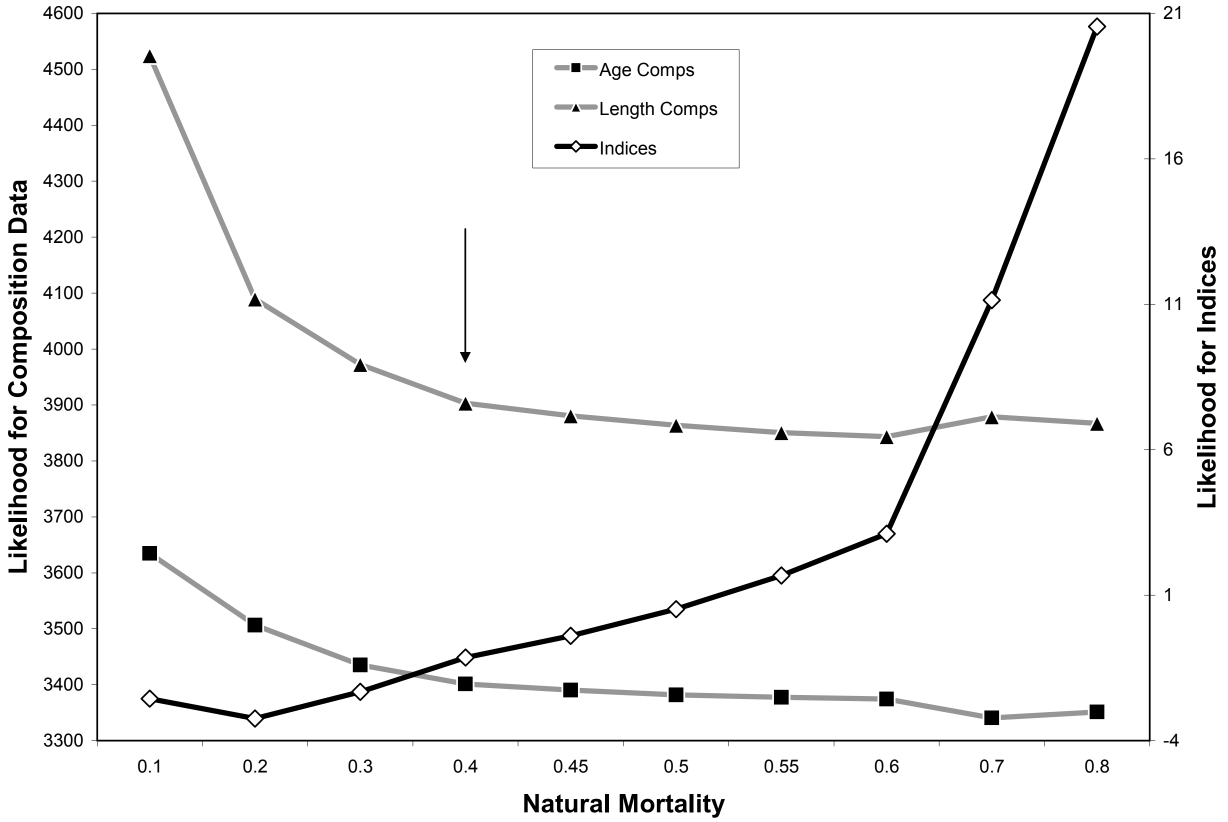

Figure 70. Likelihood profile over a range of natural mortality rates fixed in the base model. Natural mortality is fixed at $M = 0.4$ yr^{-1} in the base model (arrow).

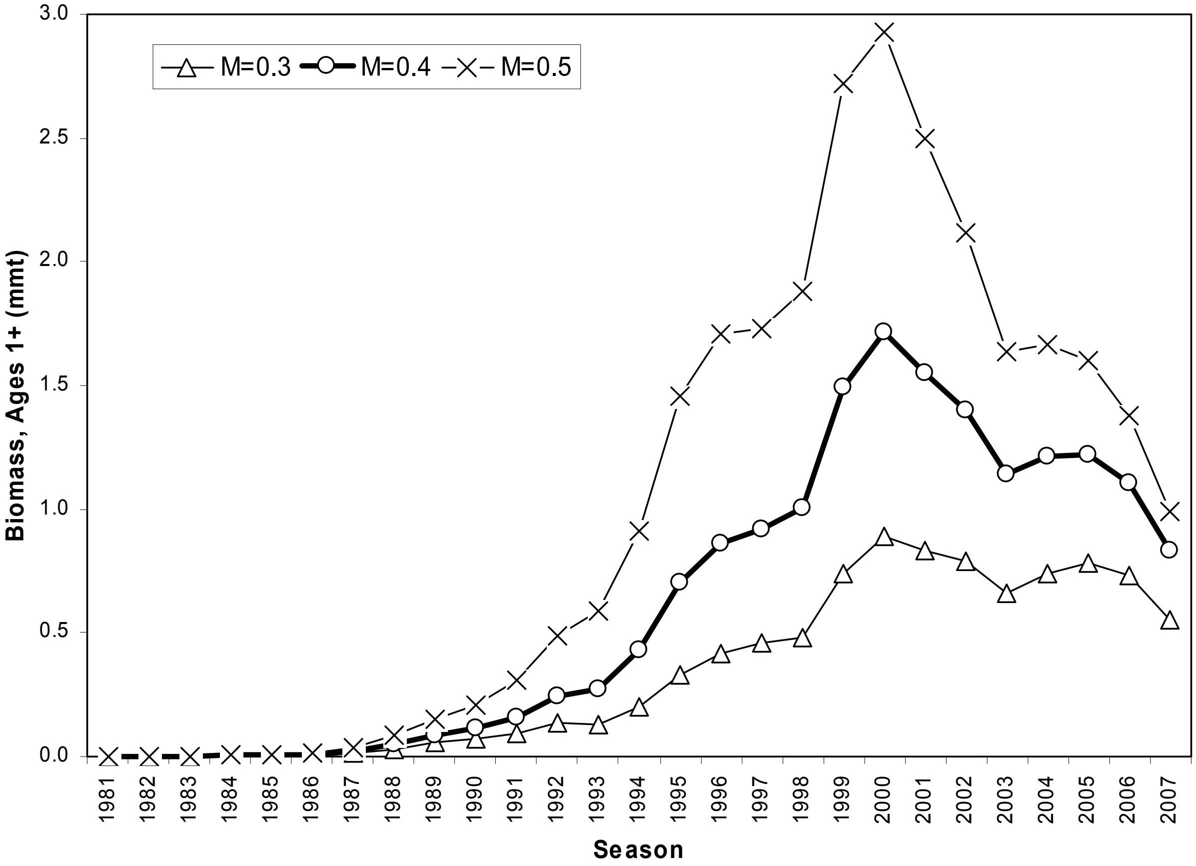

Figure 71. Uncertainty around stock biomass (age 1+) estimates based on a range of natural mortality.

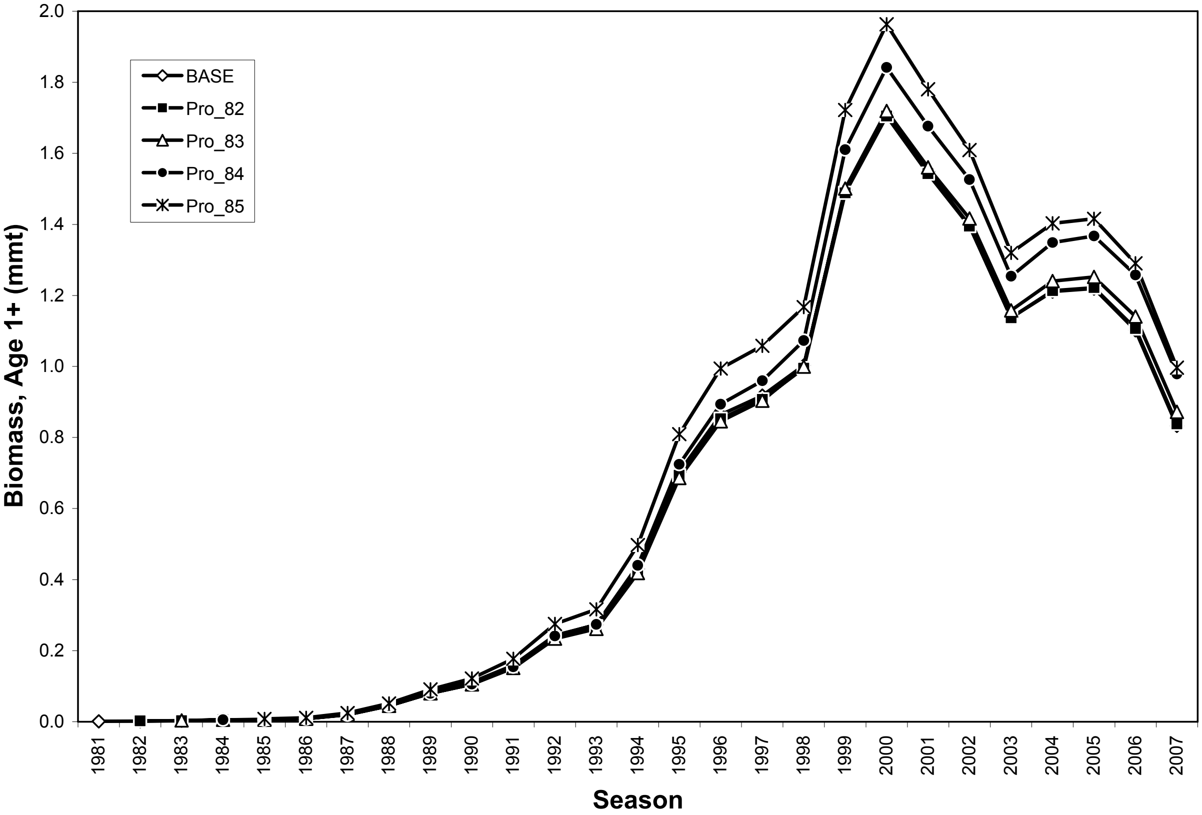

Figure 72. Prospective analysis of biomass from base model J14.

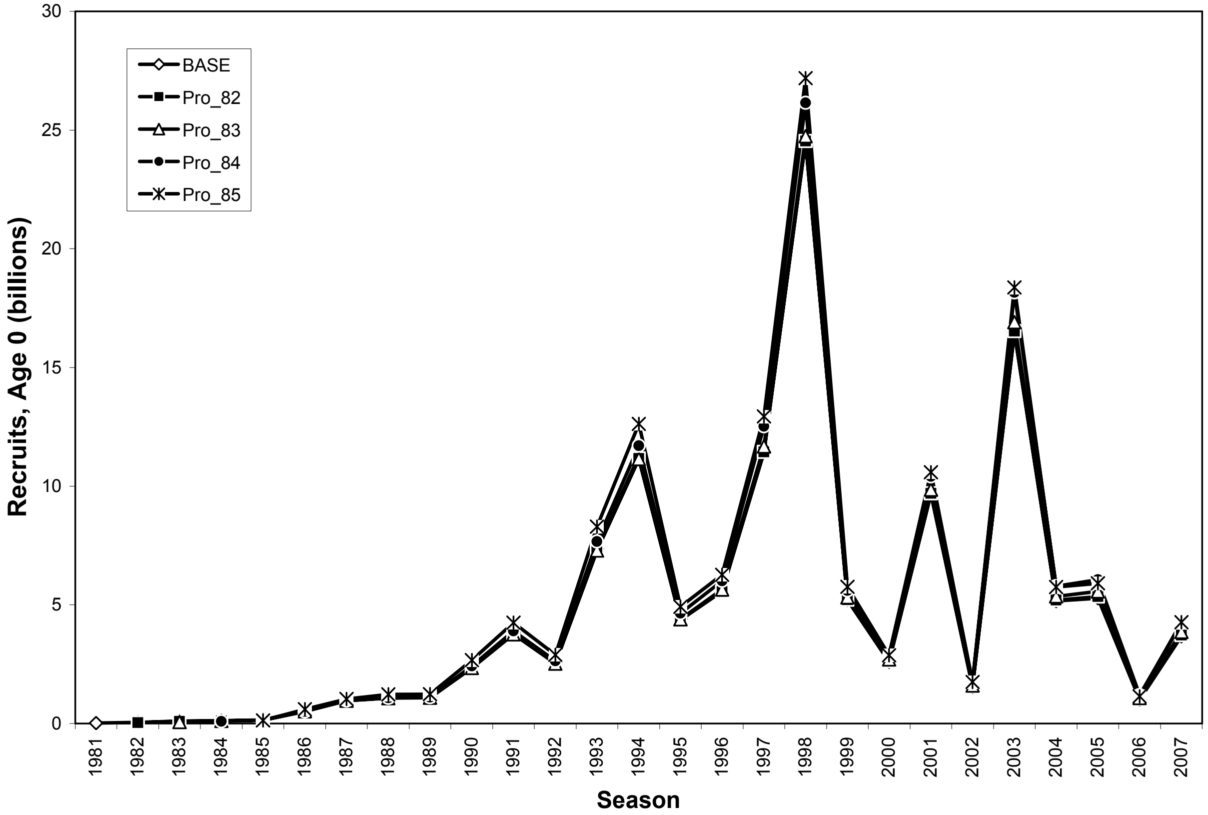

Figure 73. Prospective analysis of recruits from base model J14.

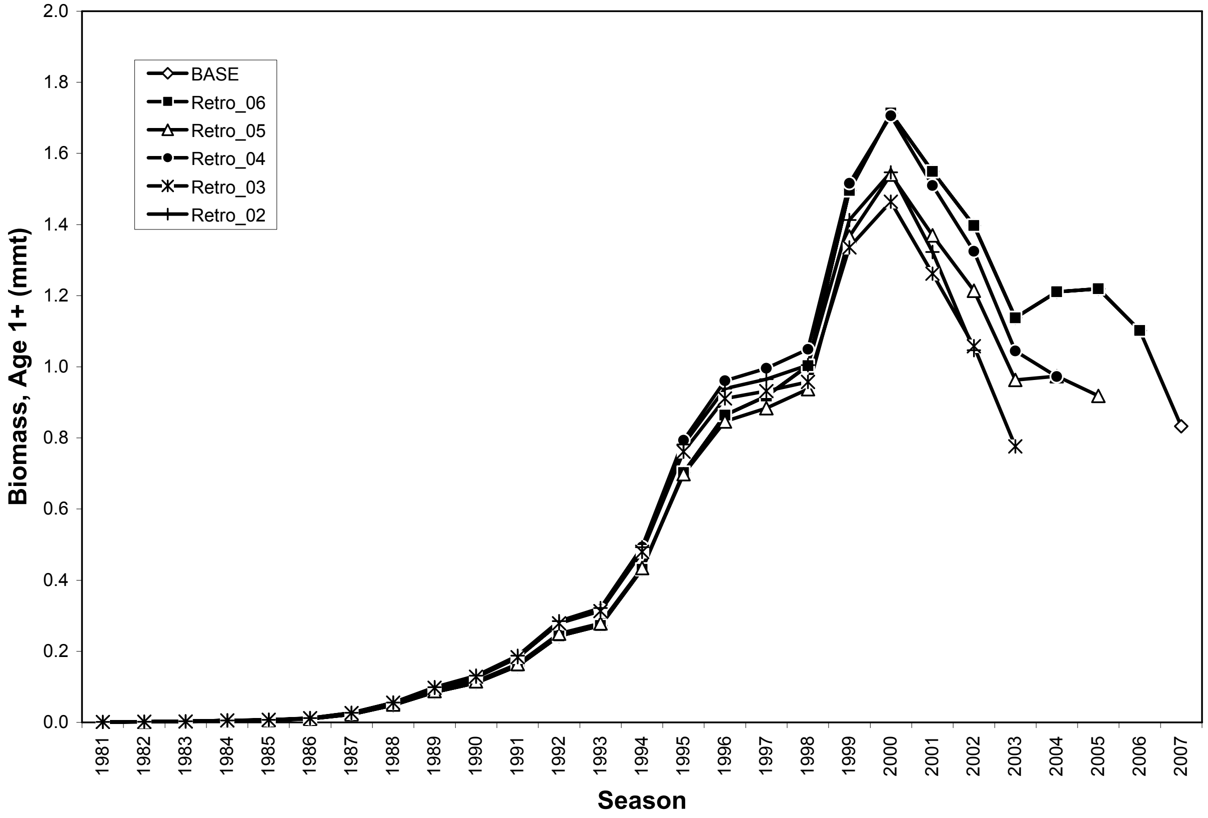

Figure 74. Retrospective analysis of biomass from base model J14.

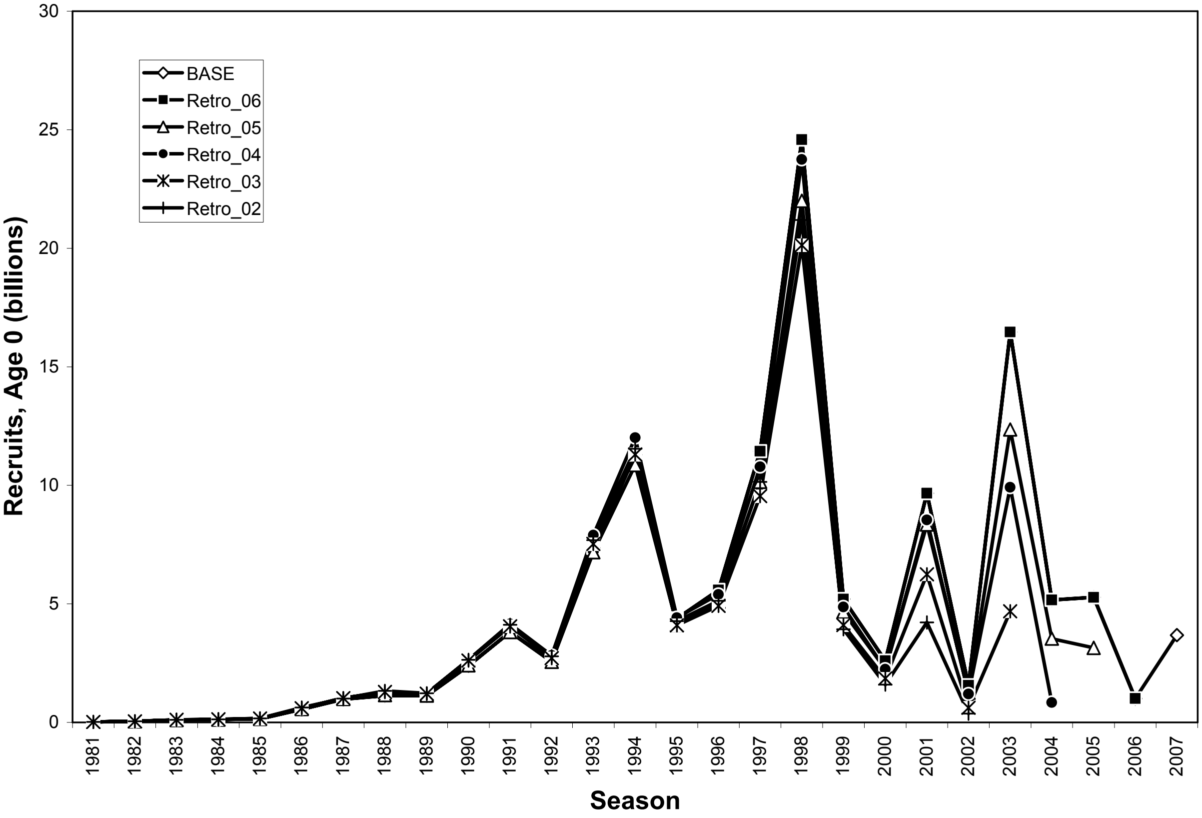

Figure 75. Retrospective analysis of recruits (age-0) from base model J14.

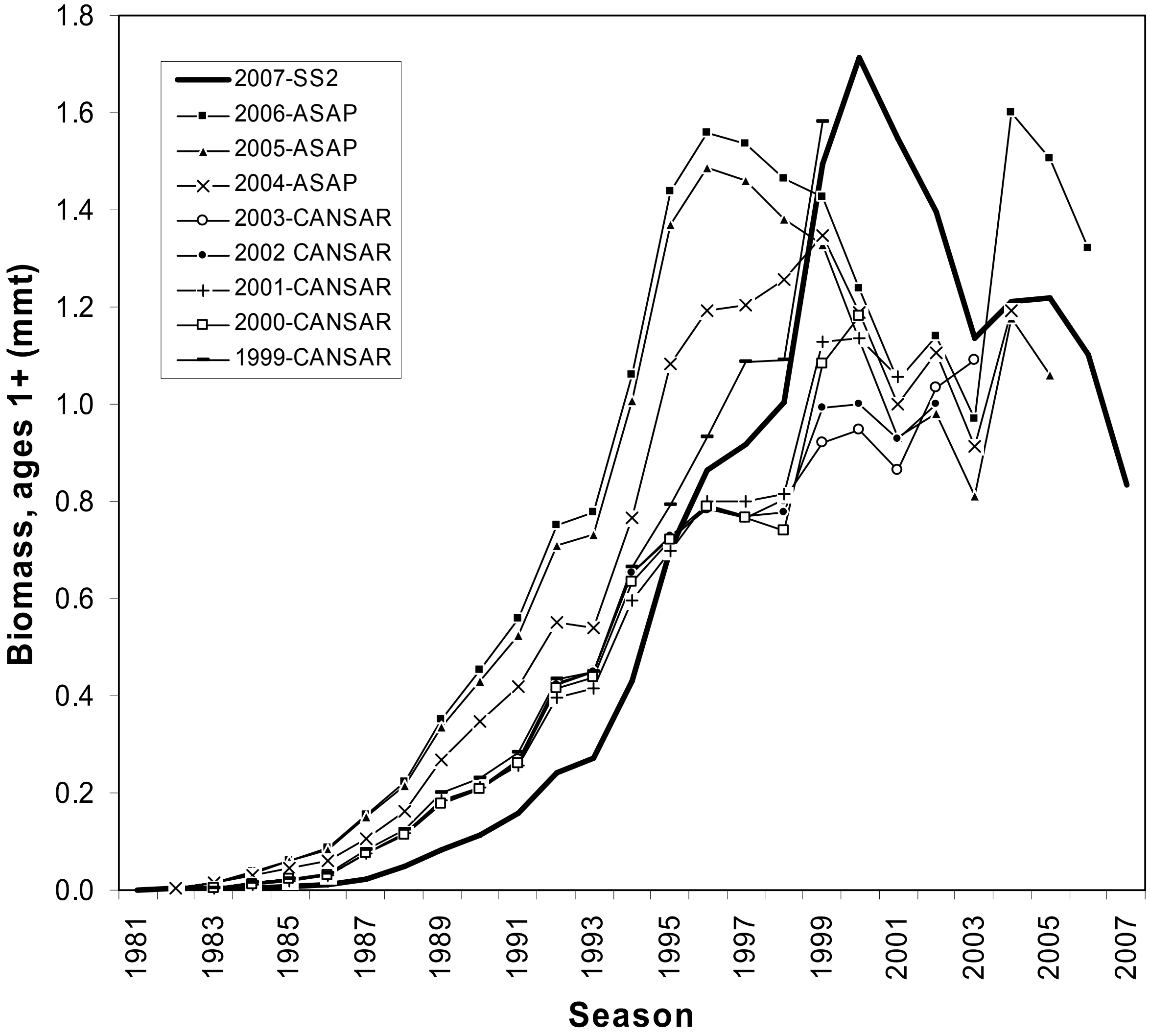

Figure 76. Pacific sardine stock biomass (ages 1+) from base model J14 compared to previous assessments used for PFMC management.

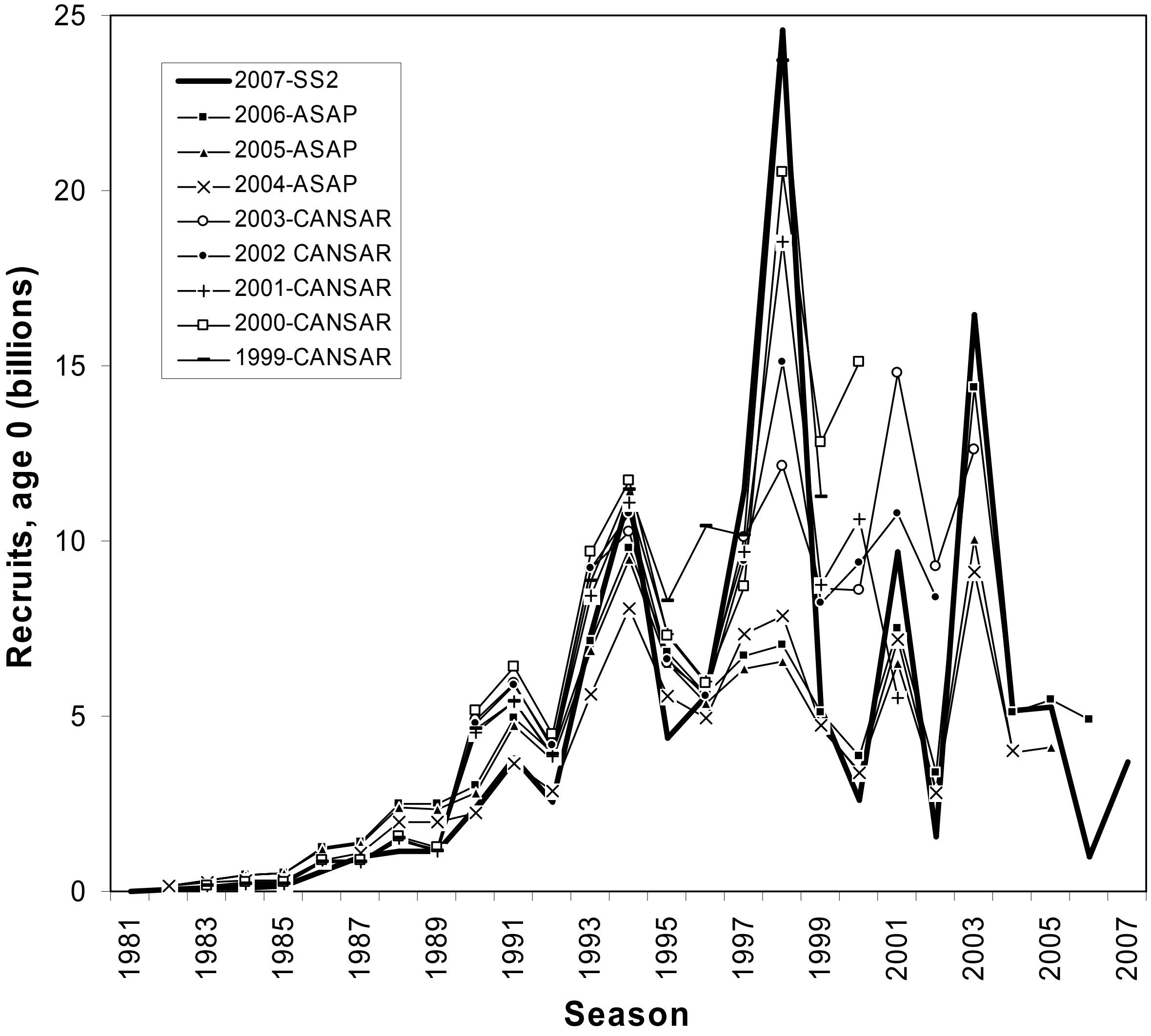

Figure 77. Pacific sardine recruit (age-0) abundance from base model J14 compared to previous assessments used for PFMC management.

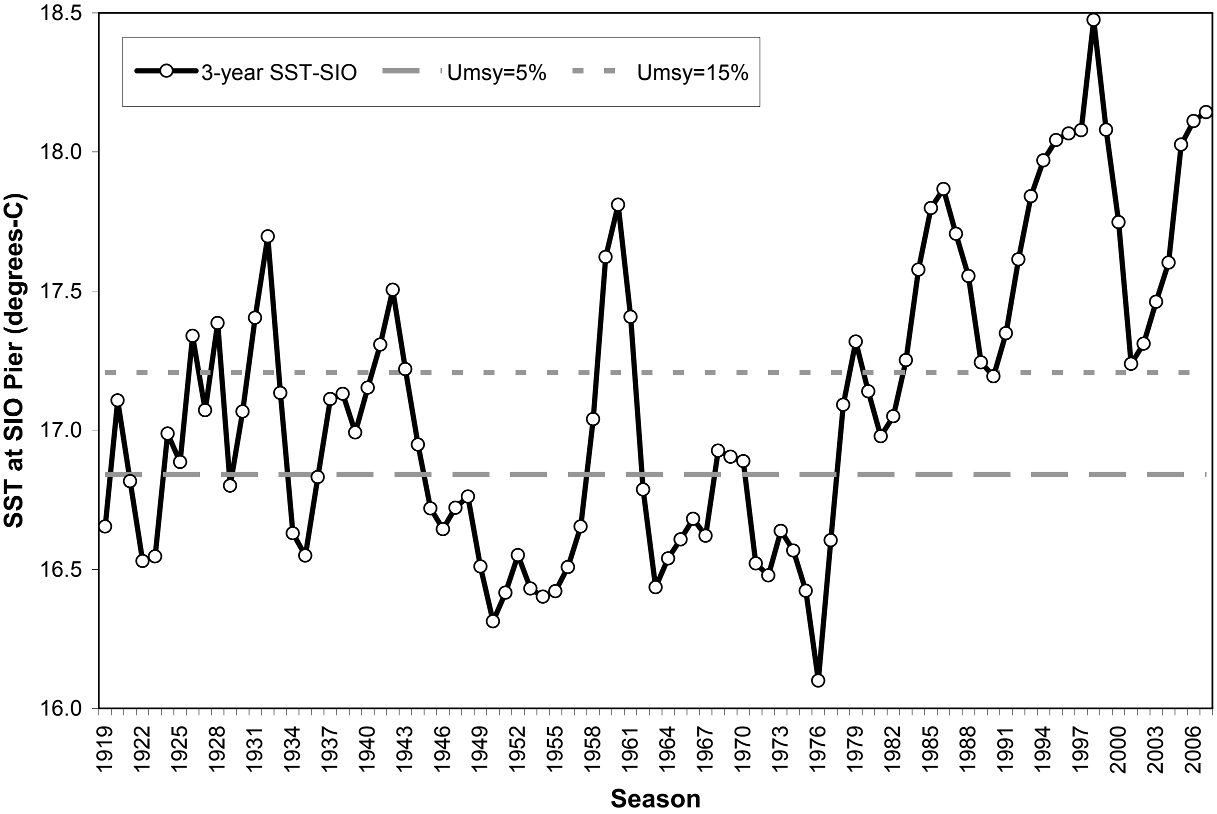

Figure 78. Three-season running average of sea surface temperature (SST) data collected daily at Scripps Institution of Oceanography pier since 1916. For any given season, SST is the running average temperature during the preceding three seasons (July-June), e.g. the 2007 estimate is the average from July 1, 2004 through June 30, 2007. The 2007 value used for management in 2008 was calculated to be 18.14 °C, so a 15% exploitation fraction (F_{msy}) should be applied in the harvest control rule.

APPENDICES

APPENDIX I

Spotter data analysis for sardine in 1985-2007 using Delta-GLM model

Nancy Lo
NOAA-fisheries
Southwest Fisheries Science Center

Introduction

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 to NOAA Fisheries for a fee per flying hour (\$1-\$5). Spotter indices for young sardine were calculated as year effects estimated using delta log-normal linear models (LLM; Lo et al. 1992). The spotter index covers the period 1985 through 2001 . 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 started to contract professional spotter pilots to survey the Southern California Bight region beginning in 2004. Newly available data from this enhanced survey were incorporated into the index, and a single time series was calculated using a delta Generalized Linear Model (GLM) so as to obtain the time series for 1985-2007. To include data from the historical surveys and the new surveys, a categorical independent variable: survey type was included in the model to account for possible effect due to the two survey types.

The old time series had an informal design. Pilots flew the year around at night and in the day, and in areas and seasons frequented by the fishery (Figure 1). The pilots searching behavior, like most fishermen, might be characterized as adaptive, that is, searches for target species may be concentrated in areas where schools were previously sighted. No doubt exists that a formal fishery independent survey design, would be more precise and less biased than the present indices. However, by altering the design one loses the old aerial surveys most valuable property, i.e., a time series that could be extended back to 1961. Regardless of its merit, a new index will have little value in stock assessment until it extends over at least 5-10 years. Clearly, the time series that ended in 2000 needs to be extended, but it would also be valuable to develop a new, more precise index with less potential bias.

The data collected starting in 2004 were based on a line transect design with regular occupation of fixed grid lines spaced at regular intervals with random starting points for each survey and one survey includes transect lines to cover the whole area. To mimic the old survey, having found one school, the fishermen is allowed to search the vicinity to find other fish schools. After searching the pilot will return to the transect line and continue along the line. In this way we can gather information to some extend similar to the old survey. In the data base, the extra searching was assigned a code different from those of regular lines to facilitate comparison of sightings between these two types of lines. The month, and area covered by the new surveys are close to those standardized conditions used in the spotter index model developed by Lo et al (1992). For the new surveys, experienced pilots under contracts were instructed to fly along the predetermined track lines in March and April from San Diego to San Francisco, at a maximum of 100 nm offshore(Figure 2). However, in reality, pilots were unable to accomplish all assigned surveys in March and April due to weather conditions and their flying commitments to fishermen. Because their flights are not associated with fishing vessels, they are willing to fly only in the day time and not in the night alone (Table 1). A total of 39 flights were conducted in 2004 throughout the entire year with based on 9 surveys with predetermined transect lines, some of which were conducted by only one pilot: a total of 5 surveys by month (3,4,5,7, and 9) were accomplished from March-November, including two single-pilot surveys in September and November. This restriction was relaxed to the first half of the year in the following years. In 2005,twenty flights were conducted based on two 3-pilot complete surveys, and four 2-pilot surveys survey during March and April. In 2007, again 20 flights were conducted from a total of 9 surveys: three 1-pilot surveys, and 6 two-pilot surveys during March-May (figure 2). No surveys were conducted in 2006.

Two analyses were planned for the new surveys. One is based on Delta GLM, a change from the delta log-linear model used prior to 2004. For this time series, new datasets were used together with the historical aerial survey data and the other one estimator produces a stand alone estimate based on the strip transect method for each year. A set of these two estimates for 5-10 years datasets can be used to calibrate these two estimates and to link the data from the past to the future. The goal of contracted pilots is for the future to use the strip transect method on data collect from the predetermine track lines, area and time of the year.

In the following sections, we will describe delta linear model in general and delta GLM.

Statistical methods

Delta Linear models

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

$$\text{Φιγυρε 8.}\ I = DA$$

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

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

$$(2)\ D = dP$$

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

Delta GLM model

To continue including spotter pilot data for the stock assessment, we decided to switch from Delta lognormal linear model to a more flexible model, like GLM using S+ (Lo et al. 1992; Hill et al. 2006b). This allows us to incorporate other possible distribution of tonnages/block (y) of sardine sighted by the pilots for the positive flights and the proportion of positive flights (p) with appropriate link functions for the expected values (d and P) respectively. As stated in Lo et al. (1992),' …Although we used lognormal linear models for components of the delta distribution, other linear or nonlinear models based on other statistical distributions could be used instead.

For the delta GLM, we chose family of Poisson and used log as the link function for the tons/block of positive flights (d), e.g. log (the expected tonnage/block) = x'B and family of Binomial and the link function of the logistic, for the proportion positive (P), e.g. log(P/(1-P)) = x'B. I included **survey type** as one of the independent variables (survey type=1 for the old survey and 2 for the new survey) to account for any variability possibly caused by the two types of surveys. The estimate of density of sardine is $\hat{D} = \hat{d}\hat{P}$ with variance:

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

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

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

Where A is total number of blocks within the tradition area covered by spotter pilots prior to 2004 and $\hat{I}$ is the relative abundance of young sardine standardized for night time flights in region 2, during January-March, pilot number 17 and survey type 1.

Results.

The entire time series from 1985-2006 fishing years using delta-GLM with approximate upper and lower 95% confidence limits was given (Figure 3 and Table 2).

The final GLM model for tons/blocks of the positive flights was
Y ~ factor(ND) + factor(season) + factor(region) + factor(season) * factor(region)
+ factor(region) * factor(ND) + factor(surveytype) + factor(pilot) + factor(year)

and for the proportion positive (ratio of the total blocks of positive flights to the total blocks) was

Y ~ factor(ND) + factor(season) + factor(region) + factor(pilot) + factor(year).

The survey type was significant for the tons/blocks for the positive flight but not for the latter, so were interaction terms.

Based on the delta-GLM model, for the positive flights, the tonnage/block of Pacific sardine of age 2 and younger peaked at the fishing year 1993 with minor peaks in 1997 and 2002 and declined since then (Figure 4, Table 2). The effect of survey type for the tons/block for the positive flights was significant so were many interaction terms. The proportion positive has been increasing since 1985, declined since 1993 till 2001 (Figure 5, Table 2). Flights from the new surveys had over 70% positive flights (Table 3). However, the effect of the survey type was not significant for the proportion positive. Regardless, the final results were adjusted to region 2, season 1, pilot number 17, night flight and survey 1. The relative abundance of Pacific sardine from the delta-GLM model indicated the sardine of 2 years and younger peaks at the early-1990s and has been declining since for the area occupied by the spotter pilots. The current level is similar to that in the late 1980s.

Discussion

The time series of the relative abundance of Pacific sardine from 1985-2006 was constructed using data from both of the original surveys and the new surveys initiated in 2004 (Figure 3 and Table 2). The survey type was included in the GLM to account for possible difference in these two designs. The effect of survey type was significant for the tons/block of positive flights but insignificant for the proportion positive. Regardless, the final estimates were standardized to the old surveys. I included two surveys in one analysis to increase the sample size and the power of the analysis, i.e. the degree of freedom of the residuals. In addition, such an analysis provided the estimates for years after 2004. Although all flights since 2004 are all daytime flights, the GLM based on the entire data set enables one to obtain estimates standardized to the night time flights. The estimates of tons/block for years from 1985-2001 fishing years were very similar with or without data from the new surveys (Figure 6).

The Delta distribution (Aitchison and Brown 1957; Pennington 1983) was used because of low proportion of positive flights in many years. As the current survey designs continue for long period of time, the Delta distribution may not be needed because of the high proportions of positive flights (Table 2 and 3).

The time series or relative abundance of sardine sighted by the spotter pilot may underestimate the recruits of the whole population since 1992- 1993 as the population increases and is expanded offshore in the mid-1990s(Lo et al. 1996). Based on limited trawl survey data, fish of age 0 (160mm) were observed in the non-port area (area away from ports and islands) and offshore area (Figure 7 and 8) based on 2005 daily egg production survey (Lo and Macewicz 2006). Therefore the decrease of the relative abundance since the mid-1990s was partially due to the expansion of the population. The fluctuation of the relative abundance coincided well with the changes of spatial distribution of sardine eggs from 1997-present (http://swfsc.noaa.gov/textblock.aspx?Division=FRD&id=1121). The availability of fish to the spotter pilot survey area needs to be considered in the future stock assessment.

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Table 1 Number of day and night flights for positive flights in 1985-2007 calendar year. A = Day Flights
B = Night Flights and C = Total Flights

Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	07
A	64	64	85	107	62	140	136	152	203	125	141	54	105	86	96	54	51	21	3	39	20	20
B	51	59	121	132	103	121	158	76	103	214	171	112	82	88	55	18	0	0	0	0	0	0
C	115	123	206	239	165	261	294	228	306	339	312	166	187	174	151	72	53	21	3	39	20	20

Table 2. Summary of tonnage/clock for positive flights (T/B+;d), proportion positive (%BLK;p), relative abundance(REA-ABN;I),their standard errors(SE), and coefficient of variation (CV) for 1985-2006 fishing year

YEAR	T/B+;d	SE_T/B+	%BLK;p	SE_%BLK	T/B;D	SE_T/B	TOT.BLKS ;A	REL_ABN;I	SE_RA	CV_RA
1985	171.2	2.12	0.24	0.08	40.96	13.79	383	15686.46	5281.43	0.34
1986	93.39	1.31	0.25	0.08	23.3	7.39	358	8342.01	2644.56	0.32
1987	84.37	1.25	0.42	0.1	35.83	8.5	398	14258.72	3383.86	0.24
1988	54.98	0.6	0.4	0.11	21.92	6.27	383	8395.43	2402.81	0.29
1989	25.59	0.32	0.37	0.09	9.45	2.23	356	3365.32	794.32	0.24
1990	81.72	0.64	0.55	0.09	44.61	7.08	391	17442.71	2769.66	0.16
1991	85.62	0.68	0.57	0.09	49.2	7.31	369	18155.65	2697.69	0.15
1992	404.59	2.49	0.6	0.09	241.77	36.11	399	96464.29	14408.84	0.15
1993	455.27	2.82	0.7	0.08	320.38	35.63	438	140327.11	15604.52	0.11
1994	246.49	1.75	0.66	0.09	163.05	22.2	394	64240.46	8748.16	0.14
1995	89.1	0.69	0.67	0.09	59.97	8.35	352	21110.72	2938.17	0.14
1996	126.25	1.18	0.58	0.11	72.99	14.44	376	27443.22	5428.95	0.2
1997	170.91	1.42	0.59	0.1	100	16.82	515	51497.6	8662.17	0.17
1998	76.15	0.73	0.58	0.1	43.94	7.36	453	19904.31	3332.94	0.17
1999	26.5	0.33	0.54	0.1	14.31	2.62	449	6425.31	1176.54	0.18
2000	4.74	0.22	0.41	0.15	1.92	0.7	410	788.63	288.72	0.37
2001	6.13	0.44	0.35	0.18	2.17	1.13	434	940.39	492.06	0.52
2002	72.45	8.63	0.61	0.28	44.52	20.71	226	10061.44	4679.84	0.47
2003	33.86	2.05	0.92	0.08	31.06	3.26	340	10560.06	1109.14	0.11
2004	7.33	0.51	0.8	0.16	5.84	1.22	297	1735.51	361.9	0.21
2006	11.9	0.88	0.64	0.39	7.64	4.72	258	1972.27	1217.68	0.62

Table 3 Total number of flights by year (A), flights with sightings (B) and proportion of positive flights (C) for calendar years from 1985-2007

Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	07
A	783	692	591	595	599	849	541	432	586	609	692	513	553	514	429	340	270	107	13	44	22	23
B	115	123	206	239	165	261	294	228	306	339	312	166	187	174	151	72	53	21	3	39	20	20
C	0.15	0.18	0.35	0.4	0.28	0.31	0.54	0.53	0.5	0.56	0.45	0.32	0.34	0.34	0.35	0.3	0.196	0.196	0.23	0.886	0.91	0.869

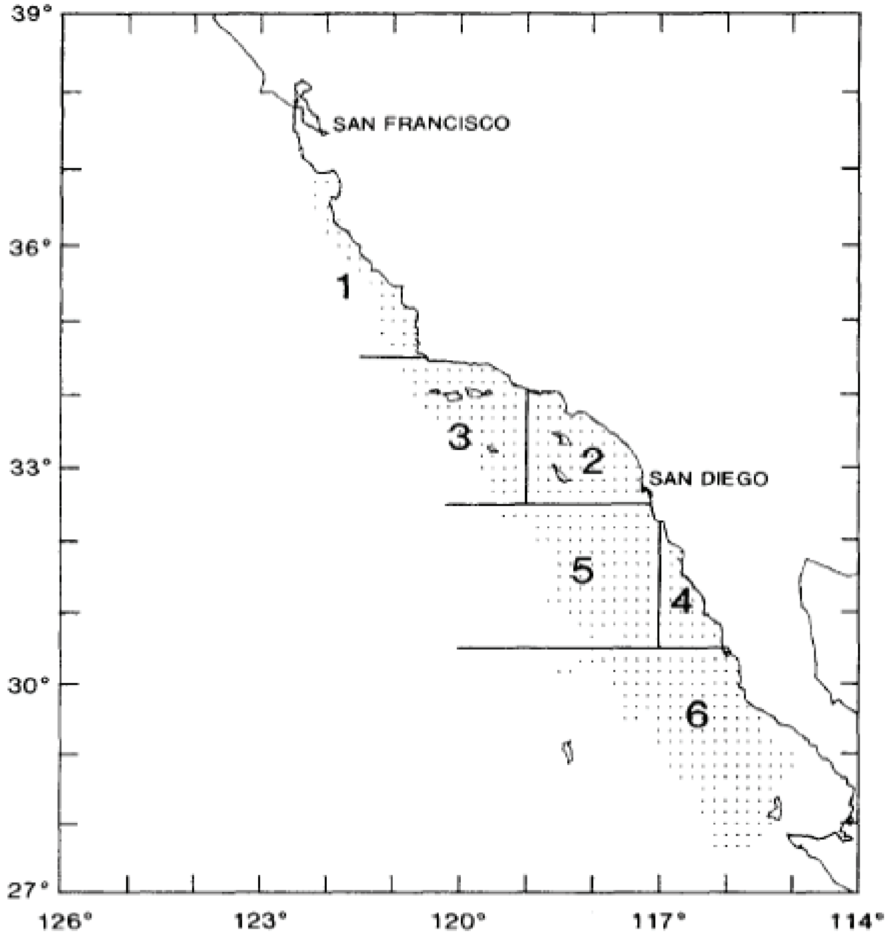

Figure 1 Study area, regions, and blocks covered by fish spotter in 1989. Regions are outlined and denoted by numbers. Blocks are denoted by dots (reproduced from Lo et al. 1992).

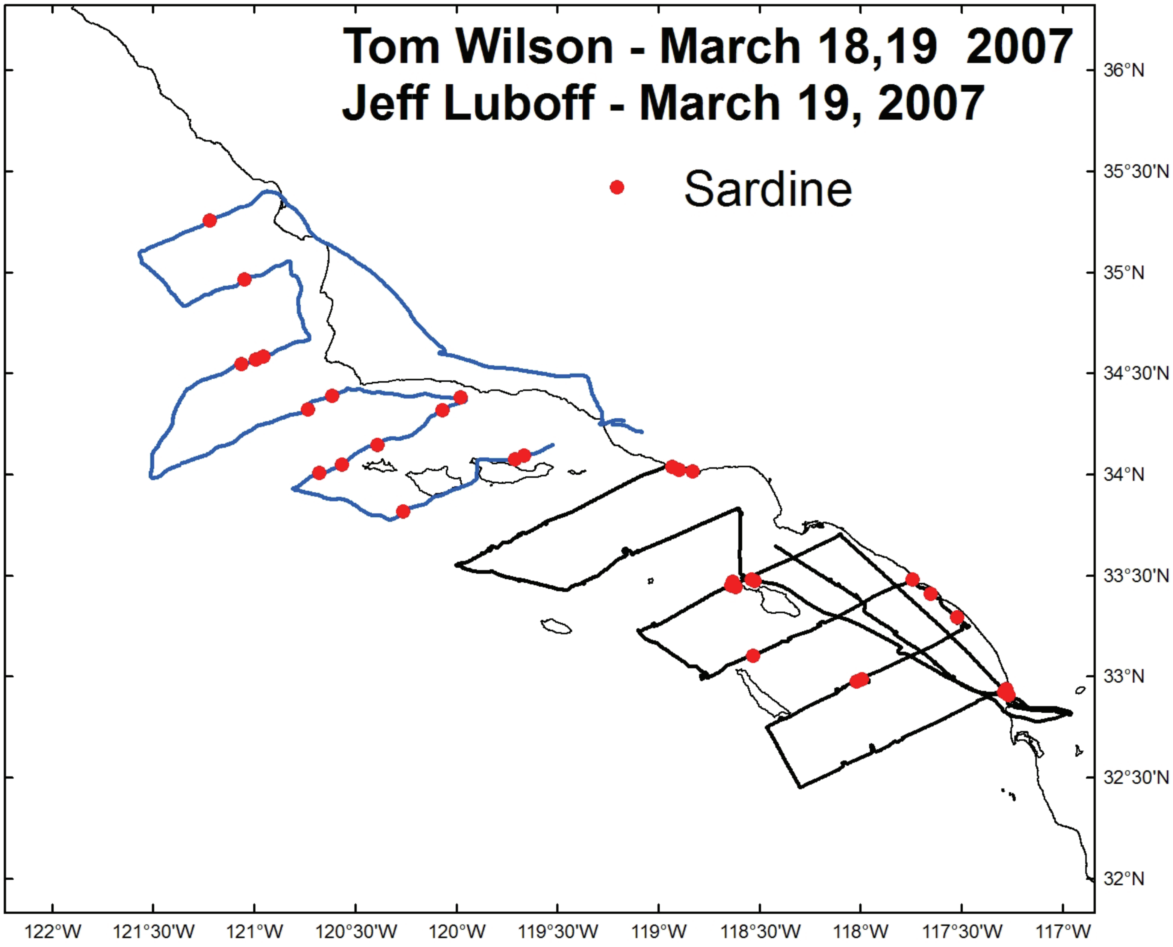

Figure 2: One survey conducted in March,2007 by two pilots (indicated by shade of lines) with sightings of sardine (dots).

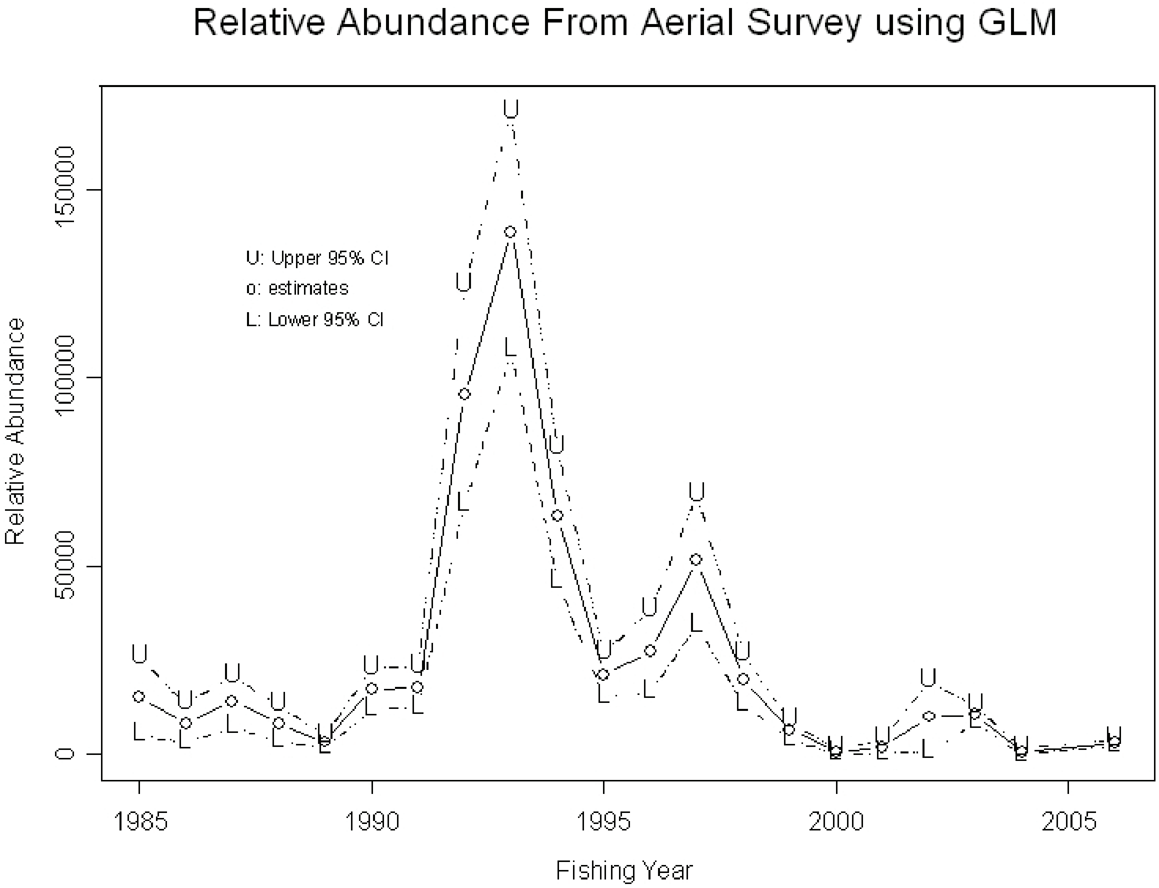

Figure 3: Time series of relative abundance of young sardine from 1985-2006 (Fishing year) with upper and lower 95% confidence intervals. (c:\data\sardin\aerial\2007\timeseriesRA.jpg)

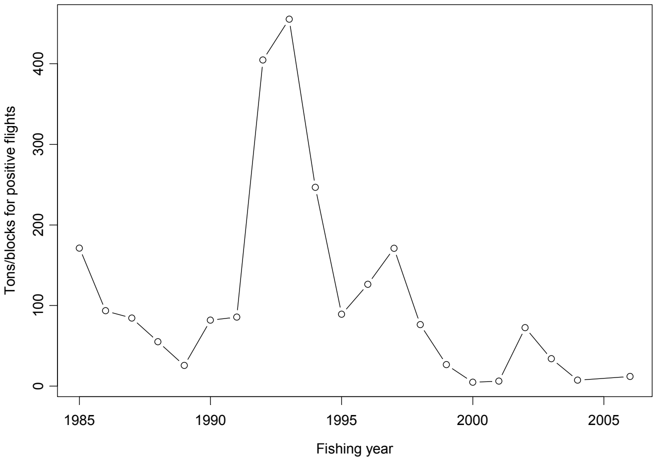

Figure 4 Standardized tons/blocks for the positive flights in fishing years 1985-2006 (Table 3).

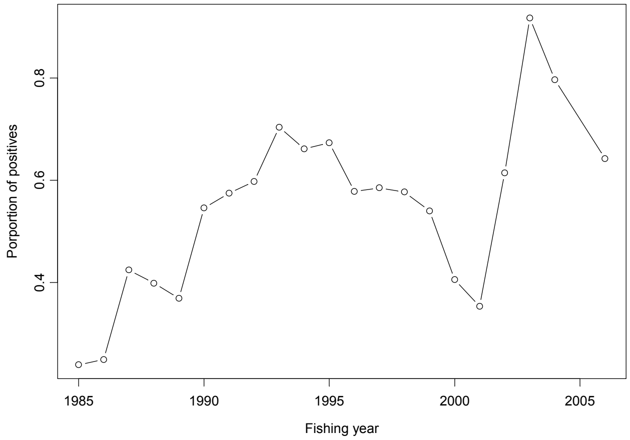

Figure 5. Standardized proportion positive from fishing year 1985-2006 (Table 3)

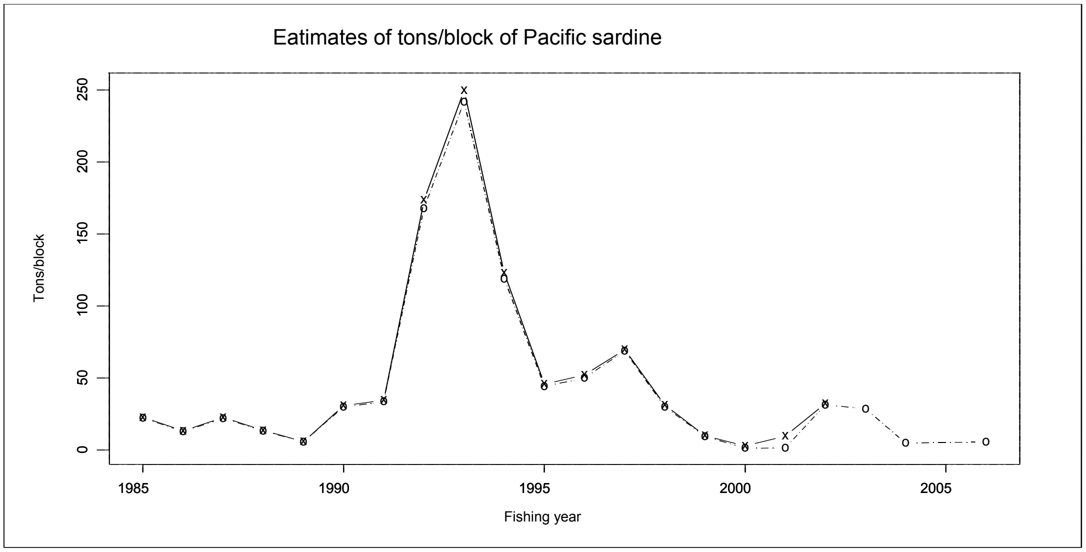

Figure 6. Standardized Tons/blocks of Pacific sardine based on data collected in fishing years 1985-2006(o) and based on data collected in fishing years 1985-2001 (x).

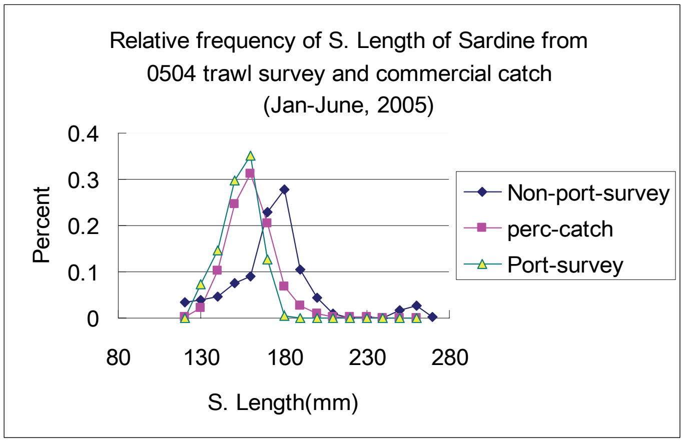

Figure 7. Relative frequency of standard length of Pacific sardine form 2005 DEPM trawl survey and samples from commercial catches.

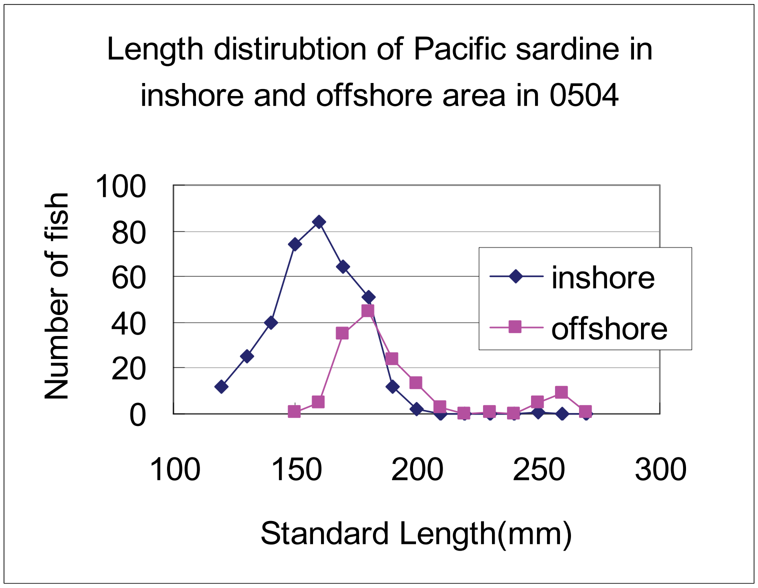

Figure 8.Standar length distribution of Pacific sardine in the inshore and offshore area from 2005 DEPM trawl survey.

APPENDIX II

PFMC scientific peer reviews and advisory body reports of this stock assessment:

A) Report of the STAR Panel held September 18-21, 2007, in La Jolla, CA

B) Report of the Scientific and Statistical Committee meeting held November 6, 2007, in San Diego, CA.

C) Reports of the Coastal Pelagic Species Management Team and Advisory Subpanel meetings held November 7-8, 2007, in San Diego, CA.

Agenda Item G.1.b
Attachment 2
November 2007

Pacific Sardine

STAR Panel Meeting Report

NOAA / Southwest Fisheries Science Center
La Jolla, California
September 18-21, 2007

STAR Panel
André Punt, University of Washington (Chair)
Tom Barnes, CDF&G (SSC representative)
John Casey, Cefas (CIE)

PFMC
Diane Pleschner-Steele (CPSAS)
Brian Culver (CPSMT)

STAT
Kevin Hill, NOAA / SWFSC
Emmanis Dorval, NOAA / SWFSC
Nancy Lo, NOAA / SWFSC
Bev Macewicz, NOAA, SWFSC
Christina Show, NOAA / SWFSC

1) Overview

The Pacific Sardine STAR Panel (Panel) met at the Southwest Fisheries Science Center, La Jolla, CA Laboratory from September 18-21, 2007 to review a draft assessment by the Stock Assessment Team (STAT) for Pacific Sardine. Introductions were made (see list of attendees, Appendix 1), and the Panel chair (André Punt) reviewed the Terms of Reference for CPS assessments with respect to how the STAR Panel would be conducted. A draft assessment document and background material were provided to the Panel in advance of the meeting on an FTP site. The Panel received the draft assessment four days before the STAR Panel. Although the draft assessment was received later than the deadline of two weeks before the STAR Panel, and this added to difficulties preparing for the meeting, the Panel was nevertheless able to conduct a thorough review of the draft assessment following the Terms of Reference for CPS assessments.

Kevin Hill (SWFSC) presented the assessment methodology and the results from an initial base-model utilizing SS2. The previous sardine assessment, used for PFMC management decisions for the period July 1, 2005 to July 30, 2007, employed a forward projection age-structured assessment model (ASAP) to estimate the 1+ biomass of Pacific sardine. The ASAP model has several deficiencies which the SS2 model can, in principle, overcome: (a) some sardine spawn in their first year of life, (b) ASAP is unable to deal with the timing of the fisheries throughout the range of the species, (c) the initial conditions had to be pre-specified in ASAP (and the CANSAR model) - ASAP (and CANSAR) produced unrealistic results when the initial numbers-at-age were treated as estimable parameters, (d) weight-at-age varies among the fisheries and between the fisheries and population, but ASAP is unable to account for this, (e) ASAP does not include the log-normal bias correction factor for the stock-recruitment relationship, and (f) the parameterization of selectivity in ASAP leads to very high correlation among the parameters of the model in the starting year.

The Panel evaluated the draft base-model in terms of: (a) why there were differences from the ASAP base-model used for the 2006 assessment, in particular why the 1997 and 1998 year-classes were much stronger in the SS2 assessment than in the ASAP assessment (these year-classes are also strong in the catch-at-age data), and (b) whether it is possible to remove the patterns in the residuals about the fit to the length-frequency data. The STAT made use of the R code to display diagnostics for alternative model configurations developed by Dr Ian Stewart (NWFSC) and modified for seasonal SS2 models by Ms Christina Show (SWFSC). Having software to rapidly display alternative model runs made the task of the Panel considerably easier.

The Panel was able to identify a model configuration that performed adequately and recommends that this model configuration form the basis for the 2007 assessment and hence harvest guideline for 2008.

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

The stock assessment methodology for Pacific sardine has changed substantially in recent years. The Panel notes that, given this, as well as its recommendations for further model development, consideration should be given to holding the next STAR Panel for this species in 2009 rather than 2010 as envisaged in the Terms of Reference for CPS assessments.

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

Set #1

A. Identify the sampling units (strata) on which the catch-at-length data are based and determine whether it is necessary to weight the data for each stratum. If a weighting scheme is required, recalculate the length-compositions with a STAT-preferred stratum weighting and aggregate the resulting data by quarter, and then run the base model using new length-frequency data. Compute the length- and age-composition residuals and determine if the patterns in the residuals evident in the draft stock assessment remain.

   Reason: The draft assessment was based on raw (unweighted) length-frequency data, but the Panel was concerned that the catch length-frequency distributions may differ among months and ports.

   Response: Length composition data were re-calculated by the STAT for California by weighting the data for the northern and southern California ports by month, based on tons landed by port area. The model was re-run with the re-weighted length-composition data. The length-composition likelihood improved. However, the residuals about the fit to the data for Ensenada and the Pacific Northwest continued to exhibit trends. The Panel agreed that the re-weighted length-frequency data would form the basis for all further model runs.

B. Better explain why the additional surveys (Oregon, British Columbia, and Mexico) that are available were not used in the assessment.

   Reason: Several data sources in addition to DEPM and TEP were available for possible inclusion in the assessment.

   Response: The STAT provided the STAR with extracts from the report of the Sardine Trinational Forum. This information does not suggest that these other data sources should be included in the assessment at this time. Full details of these alternative series and why they cannot be included in the assessment need to be included in the assessment document.

C. Plot the DEPM estimates of spawning biomass against the TEP estimates for the years for which it is possible to estimate both DEPM and TEP estimates.

   Reason: TEP is assumed to be related linearly to spawning biomass and this analysis would help to evaluate the validity of the assumption.

Response: A comparison was provided. The slope was 0.79 and the intercept was near zero. R^2 was 0.9178. The Panel agreed that the assumption of linearity between DEPM and TEP is not violated to any substantial extent.

D. Compare the model-predictions of the catch age-compositions to the age-compositions implied by the length-frequencies and the conditional age-at-length information. To avoid the age-composition data informing the model the effective samples sizes for the "implied" age-compositions should be set very close to zero.

Reason: The Panel noted what appear to be cohort-related patterns in the residuals about the fits to the length-frequency data and wanted to confirm that these reflected cohorts.

Response: A run was made to allow this comparison. The fits to the age-composition data for California were quite good, and did not exhibit troublesome patterns. However, for the Ensenada fishery, the residuals about the catches of age-0 animals varied substantially among years. More importantly, the residuals for the 1998 and 2004 cohorts in the Pacific Northwest were systematic and suggested that the model was underestimating the sizes of these cohorts (see request #H) .

E. Provide egg density estimates for California and Mexico for April, and show available data (CUFES and historical CalCOFI) for north of San Francisco and offshore.

Reason: The DEPM estimates are based on the "standard" area, and are assumed to be proportional to total spawning biomass, but changes over time in stock abundance may have led to changes in the spatial distribution of spawners, potentially leading to changes in *q* for the DEPM estimates.

Response: Charts depicting this information were provided. Ten percent of the total spawning biomass was estimated to be north of the survey area in 2006. However, there does not appear to be a systematic bias, i.e. there is no evidence, for example, that the surveys consistently missed spawning to the north of the "standard" area. The extension of the egg and larval survey to the north of the "standard" area has proven very useful in terms of quantifying the overall distribution of spawning in April, and should be continued.

F. Provide information on the location of samples relative to catches.

Reason: There was a concern that the observer sampling for the Pacific Northwest might not be reflective of catches.

Response: Plots were provided that showed that the samples appeared to be representative of catch location, with one or two exceptions (the sampling missed fishery expansion to the north in 2006).

G. Examine whether data exist on slippage and discard.

Reason: The draft assessment ignored any discard mortality.

Response: Information from the 2000-4 WDFW observer program estimated that discard mortality in the Pacific Northwest ranged up to nearly 20%, but declined to just over 1% in the final year of the study. The 5-year average discard mortality was approximately 10% (see request #M).

Set #2

H. Explore a dome-shaped selectivity pattern for the Pacific Northwest fishery after 2003. If this run leads to a better residual pattern, it should become the base-model.

Reason: The Panel noted comment from the public that markets have been identified for smaller fish in the Pacific Northwest in recent years.

Response: Selectivities were changed to allow for dome-shaped selectivity, with two time blocks separated between 2003 and 2004. A logistic function was assumed for the years up to 2003, and a double normal thereafter. The estimated selectivity pattern for the post-2003 period had a lower length-at-50%-selection, and selectivity dropped off for older ages. Total likelihood improved by over 200 points, and there was a slight improvement for the indices of abundance. The Panel and STAT agreed that allowing for two selectivity blocks for the Pacific Northwest fishery was warranted.

I. Consider the implications of dome-shaped (double-normal) selectivity for the California and Ensenada fisheries before 1991. If this run leads to a better residual pattern, it should become the base-model.

Reason: There is a poor fit to the data for the earliest years of the assessment period – this might reflect the impact of the assumption of asymptotic selectivity during these years.

Response: While this run did improve the fit of the model, it resulted in an unreasonably low q for the DEPM indices (0.03). This model configuration was not pursued further.

J. Conduct a sensitivity test in which age-readings are assumed to be correct.

Reason: The Panel wished to assess the implications of allowing for ageing error in the current assessment when fitting to the conditional age-at-length data.

Response: Results from this sensitivity run conformed to expectations: ignoring ageing error weakened the large year classes, and strengthened the small ones. Current age 1+ biomass decreased to 814,000 mt. The base-model continued to include age-reading error.

K. Plot fecundity as a function of length for the 4th quarter and compare this relationship with weight as function of length. Run SS2 using fecundity based on this relationship.

Reason: The assumption that reproductive output is proportional to weight may over-estimate the reproductive value of small fish.

Response: This sensitivity run did not change the outcome of the assessment substantially. Age 1+ biomass remained about the same, while the absolute value of "spawning biomass" was reduced for the entire time series because of the change in unit. q for the TEP increased from roughly 0.4 in the base case to 1.2 in this run (although the model units were eggs rather than spawning biomass).

L. Run SS2 with the same survey weighting as used in the 2006 ASAP model and with lower weights on the length and conditional age-at-length data.

Reason: The SS2 assessment led to much higher estimates for the sizes of the 1997 and 1998 cohorts than ASAP, although the year-classes in the SS2 runs better match those evident in the catch-at-age matrix used in the ASAP runs.

Response: An initial version of this analysis involved changing the CVs for the indices to 0.3. The model results were not changed markedly. Request # O considers this issue further.

M. Conduct a sensitivity test in which catches are increased by 10%.

Reason: The observer data for the Pacific Northwest indicates that discard mortality averaged approximately 10% during a 5-year study. This sensitivity test reflects an extreme case, because all catches were inflated even though there is no suggestion of noteworthy amounts of discard in fisheries outside the fishery in the Pacific Northwest. In addition, discard mortality trended sharply downward during the final years of the study.

Response: As expected, biomass increased by 10%. The Panel was satisfied that there were no major management consequences of discard in the range observed in the Pacific Northwest, but noted that discard mortality warranted further consideration in future assessments. Continued monitoring to inform this consideration would be useful.

N. Conduct a sensitivity analysis leaving out the catch in 1st quarter of 1985 for the Ensenada fishery.

Reason: While this catch clearly occurred, the Panel was concerned that it reflected a possible influx of southern fish. The Panel was interested to assess whether this catch had any noticeable impact on management-related quantities.

Response: Dropping this catch had a major impact the estimate of current age 1+ biomass. The fit to the data was marginally better, but the estimate of current age 1+ biomass was reduced from 1,039,000 mt to 856,000 mt. This issue is examined further in request Q.

Set #3

O. Run SS2 with the same survey data and weightings as used in the 2006 ASAP model and with lower weights on the length and conditional age-at-length data.

Reason: The SS2 assessment led to much higher estimates for the sizes of the 1997 and 1998 cohorts than ASAP. Compared to ASAP, SS2 better identified the strong year-classes in the catch-at-age matrix.

Response: Irrespective of how the data were weighted, SS2 estimated stronger 1997 and 1998 cohorts. Moreover, the fits to the DEPM data were consistently better in SS2 than in ASAP.

P. Compare the empirical annual weights-at-age by fleet with the weights-at-age by fleet predicted by SS2.

Reason: Weight-at-age differs among fisheries, and the Panel wanted to assess whether differences in selectivity-at-length and the timing of the fisheries is adequate to account for these differences.

Response: Weight-at-age is year-specific for ASAP, while for SS2 weight-at-age differs among fisheries, quarters and selectivity blocks. The STAT compared empirical weight-at-age with the weights-at-age estimated by SS2 for the last selectivity block. For the Pacific Northwest and Ensenada, the SS2 weights-at-age are within the range of empirical weights-at-age (although the empirical weights-at-age for Ensenada are very variable among years). For California, the SS2 weights-at-age are somewhat higher than those used in ASAP for the ages that constitute the bulk of the catch. The Panel was satisfied that there were no major concerns with the use a single weight-at-age vector for each selectivity block and quarter.

Q. Re-run the assessment with a start date of July 1985.

Reason: Starting the assessment in July 1985 eliminates the catches prior to July 1985, including the potentially anomalous catch for the 1st quarter of 1985.

Response: This sensitivity run was based on an alternative approach to dealing with the issue associated with request “N”, above. As is the case for request “N”, the results from this run fit the index data better than for the base-case model. However, in this case the age 1+ biomass in the ending year was 1,469,000 mt, i.e. larger than the base-case value. In addition to excluding the potentially anomalous catch off Ensenada, this sensitivity test also excluded the composition data for July 1981-June 1985. However, there is no clear basis to select between removing the catch for the 1st quarter of 1985, starting the assessment in July 1985, and the base-model choice of including this datum. Moreover, although this catch may reflect fish from the southern subpopulation being off Ensenada, removing it would not address the issue whether similar events have occurred in other years. The Panel and STAT were reluctant to “cherry pick” and remove this one catch and agreed to retain this catch in the base-model. “Prospective analyses” are undertaken to illustrate the impact of changing the start year of the model (see request S), and this issue is further discussed under “Future Work” (see Section 7).

Following discussion of request #Q, the Panel and STAT agreed on a modification of the original base model in which selectivity for the Pacific Northwest fishery changed in 2004 and in which the re-weighted length-frequency data are used.

Set #4

R. Conduct the revised base-model, including tuning the effective sample sizes.

Reason: The Panel wanted to confirm that the final base-model did not exhibit any anomalous patterns that were not identified before.

Response: The residual patterns for the final base-model were similar to those for the original base-model.

Set #5

S. Construct likelihood profiles for M, steepness, and σ_R.

Reason: To further examine the properties of the base-model and provide a basis for suggesting a way to bracket uncertainty.

Response: The lowest value for the likelihood function occurred for values of M larger than base-model value (0.4yr^{-1}; which also formed the basis for the development of the control rule). However, there is a conflict between lower values for M (better fits to the index data) and higher values for M (better fits to the composition data). Increasing M leads to higher estimates of current 1+ biomass and *vice versa*. The fit of the model to the data (and the estimates of 1+ biomass) are relatively insensitive to value assumed for steepness. The base-model value of σ_R (0.765) was chosen so that the input value for σ_R matched the standard deviation of the recruitment deviations. Higher values for σ_R lead to higher estimates of current 1+ biomass.

T. Conduct a “retrospective” analysis by removing recent data from the assessment (show sensitivity to using the DEPM estimate for 2006 on which the 2006 assessment was based).

Reason: To further examine the properties of the base-model, to provide a basis for suggesting a way to bracket uncertainty, and to assess some of the reasons for the change in 1+ biomass in 2006 from 1,300,000 mt (ASAP) to 1,100,000 mt (SS2).

Response: The assessment exhibits a retrospective pattern in that as more data are included in the assessment, the estimates of 1+ biomass for the most recent years increase.

U. Conduct a “prospective” analysis to changing the start year of the assessment.

Reason: To further examine the properties of the base-model and provide a basis for suggesting a way to bracket uncertainty. Changing the start year was postulated to be particularly important in this case because the stock is estimated have increased from a low population level (rather being fished down from average unfished conditions).

Response: The estimates of current (1 July 2007) 1+ biomass are sensitive to the first year considered in the model. In particular, increasing the first year from 1984 to 1985 leads to a 12% increase in current 1+ biomass.

3) Technical Merits and/or Deficiencies of the Assessment

Conducting the assessment using SS2 addresses the concerns identified by previous STAR Panels with earlier assessments (CANSAR and ASAP). In particular, SS2 does allow: (a) some sardine to spawn in their first year of life, (b) for differences in the timing of the fisheries throughout the range of the species, (c) the initial conditions to be estimated, (d) weight-at-age to vary among the fisheries and between the fisheries and population, and (e) for the log-normal bias-correction factor for the stock-recruitment relationship. The Panel therefore agreed with the STAT that SS2 provides a better basis for future assessments of Pacific sardine.

The final base-model incorporates the following specifications:

1. Year ("season") based on a July 1 birth date (assessment years 1981-82 to 2006-07).
2. Four quarters per "season" (July-Sept, Oct-Nov, Dec-March, April-June).
3. Use of conditional age-at-length and length-frequency data for Mexico, California and the Pacific Northwest (re-weighted based on revised strata).
4. Time-invariant growth (estimated).
5. M = 0.4yr^{-1}; $\sigma_R = 0.765$.
6. Length-specific selectivity (California & Ensenada: double normal; Pacific Northwest: logistic) with time-blocking:
    a. Mexico: 1981-91, 1992-98, and 1999-present
    b. California: 1981-91, 1992-98, and 1999-present
    c. Pacific Northwest: 1981-2003, and 2004-present
7. Ricker stock-recruitment relationship
8. Initial recruitment estimated; recruitment residuals estimated for 1975-2006.
9. DEPM and TEP indices treated as relative indicesof spawning biomass.

The 2007 SS2 assessment is less optimistic about stock status than the 2006 ASAP assessment. Specifically, SS2 estimates that the 1997 and 1998 cohorts were stronger and the 2003 cohort was weaker than ASAP does. Recent cohorts also appear to be weak. The reasons for the differences between the 2007 SS2 and 2006 ASAP assessments are partially data-driven, but could not be fully determined as it is not possible to move from ASAP to SS2 by making incremental changes. However, they relate (to varying degrees) to: (a) different weightings, (b) different model structure, (c) revised index data, (d) a different way of entering the composition data, and (e) allowance for ageing error. The Panel supported SS2 as the preferred assessment platform for the 2007 assessment: a) because it allows for features identified as missing from ASAP at the May 2007 STAR

Panel, b) because it better captured the cohorts that were strong based on a visual examination of the data, and c) because it fitted the indices of relative abundance better.

The Panel recommends that uncertainty be bracketed by runs in which M=0.3yr^{-1} and 0.5yr^{-1}. The Panel and STAT could not assign probabilities to the base-model and the two bracketing runs.

4) Areas of Disagreement

There were no areas of disagreement between the STAT and Panel.

5) Unresolved Problems and Major Uncertainties

The stock assessment for Pacific sardine relies on indices based on egg and larval surveys conducted off southern and central California. The aerial spotter index used in previous assessments is not included in the assessment, owing to uncertainty about selectivity and anomalous assessment results when this data source is included in the assessment. The assessment includes northern California, the Pacific Northwest and Mexico as well as southern California. California (southern and central combined), the Pacific Northwest and Mexico are treated as separate "fleets". The assessment relies on the assumption that indices of spawning biomass for the "standard" survey area are linearly proportional to total spawning biomass. While there is no direct evidence for failure of this assumption (see request #E), there is indirect evidence that this assumption is violated to some extent (e.g. some spawning in the Pacific Northwest, cohorts recruiting in different proportions to different areas). The STAT attempted to address this issue by allowing selectivity to change over time, but this did not fully resolve the issue. This problem can (potentially) be overcome by moving to a spatial model, but SS2 does not have the capability at present to include both movement and local recruitment patterns.

Access to recent Mexican data remains a concern. The assessment reviewed by the Panel assumed that the 2006-07 catch for Mexico equalled that for 2005-06. Moreover, there are no composition data for the Mexican catches after 2002 and before 1989.

The concern expressed during the June 2004 STAR Panel that stock structure is uncertain continues to be a major issue. Although there are several hypotheses for stock structure of Pacific sardine, the working hypothesis is still that Pacific sardine off northern Mexico, southern California, northern California and the Pacific Northwest constitute a single biological stock with substantial mixing / migration. At present, the assessment is based on the assumption that all of the catches from Ensenada north are from the northern subpopulation. However, it is conceivable that temporal changes in the distribution of the southern and northern subpopulations mean that some of the catches used in the assessment may have been from the southern subpopulation. The impact of including catches and composition data from the southern subpopulation in the assessment has not been determined.

The results of the assessment are sensitive to the potentially anomalous catch in the first quarter of 1985 off Ensenada. The STAT and Panel suspect that this catch *may* reflect intrusion of fish from the southern subpopulation, but there are no data (e.g. CalCOFI data) for this quarter to support this hypothesis. The Panel support keeping this catch in the base-model, noting that its exclusion may be warranted once additional analyses (e.g. based on relationships between distribution and temperature) have been completed.

6) Concerns raised by the CPSMT and CPSAS representatives during the meeting

Data to inform the stock structure and relative spawning contributions of Pacific sardine by area are still incomplete. The CPSMT continues to recommend that coastwide synoptic surveys be conducted twice per year to help address these questions. The CPSMT notes that length and age samples from the fisheries off the Pacific Northwest have fallen off in recent years and recommends that sampling be increased to previous levels. The CPSMT also endorses an inter-agency ageing workshop to better define the ageing error incorporated into the current SS2 model.

The CPSAS representative emphasized the importance, when presentations are made to the public, of explaining what in the assessment has been changed and why the changes were made. In addition, she emphasized the need for such presentations to reflect the uncertainty associated with the assessment and its outcomes, and the need to include information for the Pacific Northwest in a more substantive way in the assessment. She concurs with the CPSMT regarding the need for the collection and incorporation of additional data, specifically synoptic cruises including the Pacific Northwest during the summer (e.g. a July CalCOFI survey) to capture the extension of the spawning biomass. She noted that the assessment is currently based on only one source of survey data, which pertains only to California.

The Panel and STAT endorsed these comments.

7) Research Recommendations

A. Much of the Panel's time was spent dealing with data-related issues (see Section 2, requests A, B, E, F, G, K, and L) and the Panel recommends that standard data processing procedures be developed for CPS species, similar to those developed for groundfish species.

B. A sensitivity run of SS2 assuming no ageing error resulted in compression of the range of spawning biomass and recruitment estimates compared to those estimated assuming ageing error (i.e. strong year-classes were estimated to be lower and weak year-classes were estimated to be larger when ageing error is ignored). This highlights the importance of the precision of the age data on model outputs. The Panel therefore recommends that ageing comparisons be continued to determine the most appropriate estimates of ageing precision.

C. The results of SS2 runs which treated the egg survey data either as an index of egg production or as an index of spawning biomass did not affect the outcome of the assessment, although estimates of survey q were, unexpectedly, markedly different. The Panel recommends that SS2 be adapted to enable indices of egg production and spawning biomass to be fitted simultaneously.

D. Noting that there is potential for sardine from different stock subcomponents to recruit to adjacent stock areas, it would be desirable to account for this in the assessment model. To do so requires development of a new assessment model or modification of an existing one, and hence the Panel recommends that, if feasible, SS2 be amended to include such an enhancement. Further, tagging experiments (or other means to facilitate the estimation of movement rates) should be considered.

E. The catch history for the Mexico and southern California fisheries should be examined to estimate the catch from the southern subpopulation. For example, use temperature and/or seasonality to separate catches by subpopulation. Based on the results of this analysis, determine the biological data (length- and conditional age-at-length) by subpopulation. The analysis of subpopulation structure should ideally be conducted in conjunction with a re-evaluation of the current harvest control rule.

F. The estimate of the catchability coefficient for the DEPM estimates was 0.4 (for the base model). This value seems low to the Panel. Analyses should be conducted, for example, based on prior distributions for the factors leading to differences between DEPM estimates and spawning biomass to assess the plausibility of values for DEPM-*q* of this magnitude.

G. Development of alternative (preferably coastwide) indices will enhance the ability to monitor changes in the abundance Pacific sardine. At present, the assessment relies on the indices of abundance from southern and central California, although these regions constitute the core of the distribution when the population is low, a substantial fraction of the catch is now taken from other areas.

H. Develop an index of juvenile abundance. The indices used in the assessment pertain only to spawning fish. An index of juvenile abundance will enhance the ability to identify strong and weak year-classes earlier than is the case at present.

Appendix 1

STAR Panel Members in Attendance
Dr. André Punt, (Chair), SSC - University of Washington
Mr Tom Barnes, SSC – CDF&G
Dr John Casey, CIE – CEFAS (UK)
Mr Brian Culver, CPSMT - WDFW
Ms. Diane Pleschner-Steele, CPSAS - California Wetfish Producers Association

STAT Members in Attendance
Dr Kevin Hill, NMFS, SWFSC
Dr. Emmanis Dorval, NMFS, SWFSC
Dr. Nancy Lo, NMFS, SWFSC
Ms Bev Macewicz, NMFS, SWFSC
Christina Show, NMFS / SWFSC

Others in Attendance
Mr. Dale Sweetnam, CDF&G
Mr Richard Carroll, Ocean Gold Seafoods
Mr Steve Joner, Makah Tribe
Dr. Ray Conser, NMFS, SWFSC
Dr. Paul Crone, NMFS, SWFSC
Ms. Jennifer McDaniel, NMFS, SWFSC
Dr. Sam Herrick, NMFS, SWFSC
Mr Kevin Piner, NMFS, SWFSC

Appendix 2

Additional Items for Inclusion in the Stock Assessment Document

The Panel identified the following items for inclusion in the stock assessment to be presented to the SSC at the November 2007 Council meeting:

1. Include catches of sardine for all subpopulations in the catch history table.
2. Add a table (or figure) that compares the annual total catch from the northern subpopulation with the annual stockwide HGs.
3. More detail is needed in the report to justify why the spotter index should not be used.
4. Include the fit of the logistic curve to the data on maturity-at-length.
5. Provide more detail on why the available additional surveys (OR, BC, and Mexico) were not used in the assessment.
6. Provide egg density estimates for California and Mexico for April, and show available data (CUFES and historical CalCOFI) data for north of San Francisco and offshore.
7. Include confidence intervals on the estimates of 1+ biomass.

Agenda Item G.1.d
Supplemental SSC Report
November 2007

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON PACIFIC SARDINE AND PACIFIC MACKEREL MANAGEMENT

Pacific Sardine

The Scientific and Statistical Committee (SSC) reviewed the Pacific sardine stock assessment and Stock Assessment Review (STAR) Panel report. An overview of the stock assessment was provided to the SSC by Dr. Kevin Hill. Recent assessments of sardine were based on the forward projection age-structured assessment model (ASAP) and the September 2007 STAR Panel review focused on new assessment results based on the Stock Synthesis 2 (SS2) model platform. The STAR Panel concluded that the ASAP model had a number of difficulties that SS2 was able to overcome, including: 1) allowance for some sardine to spawn at age-0, 2) differences in timing of the fisheries throughout the range, 3) estimation of initial conditions, 4) variability in weight-at-age among fisheries and between the fishery and population, and 5) log-normal bias correction for the stock-recruitment relationship. Residual patterns in the fit to the length frequency data were also removed using SS2 and model fits to the survey index data were improved. Based on these improvements in the sardine model, the SSC concurs with the STAR and Stock Assessment Team (STAT) that results from SS2 providing a better basis for modeling sardine population dynamics.

Conversion of the Pacific sardine assessment into the SS2 modeling framework produced assessment results that are less optimistic about current stock status than that based on the 2006 ASAP assessment. In particular, age 1+ Pacific sardine biomasses are at lower levels and have declined more precipitously in recent years. This trend in biomass is largely driven by SS2 estimates of recruitment which show strong 1997 and 1998 cohorts and a weaker 2003 cohort. Recent cohorts estimated by SS2 appear to be weaker compared to the ASAP model estimates. Differences in 2007 SS2 and 2006 ASAP assessment results were identified to be largely driven by new data (a sharp decline in the daily egg production method [DEPM] index of abundance from 2006 to 2007). Treatment of the data (quarterly partition of the length and conditional age compositions) in SS2 as well as other factors including model structure, weighting, and a revised survey index also contributed to differences from the last assessment.

Major uncertainties in the assessment were identified. The assessment assumes that indices of spawning biomass for the “standard” survey area are linearly proportional to total spawning biomass, which has yet to be verified. The assessment lacks fishery independent data from the Pacific Northwest. A routine, coastwide survey would greatly improve the assessment of the sardine population. Historic information on sardine is extensive and efforts should be directed at evaluating and, if deemed reliable, incorporating it into future assessments.

Lack of catch data from Mexico makes total removals for recent years uncertain. Stock structure for sardine continues to be a major source of uncertainty, and southern sub-population catches may have contributed to the unusually high 1985 catches. Finally, the value of natural mortality is uncertain. Uncertainty in the assessment was captured by a lower and upper value for natural mortality, M=0.3 and M=0.5.

The SSC acknowledges the improvement of the sardine assessment with the use of SS2 and commends the STAT on their work. The SSC endorses the sardine stock assessment as the best available science and its use for management. The STAR Panel recommended that consideration should be given to holding the next STAR Panel for sardine in 2009 rather than 2010. The SSC concurs with this.

Pacific Mackerel

The SSC reviewed the STAR Panel report for Pacific mackerel. The STAR Panel review held in September 2007 focused only on assessment methodology, specifically on whether future mackerel assessments should be conducted using the SS2 platform. The STAR Panel concluded that the use of SS2 would be preferred (in principle), but that model results produced unrealistically high exploitation rates. The SSC recommends that continued effort be directed at developing an acceptable SS2 model configuration. If sufficient progress is made, a new mackerel stock assessment could be scheduled for May 2009 to establish harvest guidelines for the 2009-2010 fishery season. The SSC agrees with the recommendations of the STAR Panel and notes that 2008 harvest guidelines have already been set by the Council based on the 2007 assessment conducted using ASAP.

PFMC
11/07/07

COASTAL PELAGIC SPECIES MANAGEMENT TEAM STATEMENT ON PACIFIC SARDINE AND PACIFIC MACKEREL MANAGEMENT

Pacific Sardine

The Coastal Pelagic Species Management Team (CPSMT), along with the Coastal Pelagic Species Advisory Subpanel, received an overview of the assessment for Pacific sardine from Dr. Kevin Hill. The CPSMT agrees that the base model forwarded by the Stock Assessment Review Panel and endorsed by the Scientific and Statistical Committee represents the best available science to inform management of the West Coast sardine fishery. Based upon the 832,706 mt age 1+ biomass from the assessment, the Council's harvest control rule produces an acceptable biological catch (ABC) for the 2008 fishery of 89,093 mt. This ABC is 42% less than the 2007 ABC/harvest guideline (HG) adopted by the Council.

The CPSMT recognizes that there are substantial differences in the presentation of uncertainty in the Coastal Pelagic Species (CPS) models as compared to groundfish decision tables the Council receives to select appropriate harvest values. Due to the dynamic annual fluctuations in CPS like sardines, forward projections to evaluate impacts of different catches are not practicable, so the CPSMT cannot characterize the biological risk associated with adopting harvest levels different than the base model. The CPSMT notes that the uncertainty associated with forward projections is precisely the reason sardine assessments are conducted annually.

The base model uses alternative values of natural mortality (M) as one axis to bracket the uncertainty around the point estimate of biomass. The CPSMT deliberated whether the range of biomass values resulting from the profile across different values of M represent alternate states of nature to be incorporated in the Council's selection of a sardine ABC, or rather a within-model evaluation of uncertainty. The CPSMT recognizes that, as with all models, other areas of uncertainty exist (e.g., stock structure, changes in geographic spawning area), but that such uncertainties are largely qualitative and difficult to quantify.

In view of the distinct possibility that each seasonal allocation of the annual HG could be reached prematurely, the CPSMT recommends that incidental catch set asides be established for each allocation period (as set forth in Table 1), and an incidental catch allowance be established for sardines caught in other fisheries once the seasonal allocation is reached. Without the incidental catch set aside, a greater potential exists for shutting down other fisheries that catch sardines incidentally. The CPSMT recommends an incidental catch structure based on a California Department of Fish and Game (CDFG) analysis of 2001-2006 incidental sardine catches off California (Agenda Item G.1.c, Supplemental CDFG Report) is presented in Table 1 for the 2008 HG of 89,093 mt. Incidental sardine catches from the Pacific Northwest (PNW) are minimal (< 5mt) and not included in Table 1. If the incidental set aside is not fully attained or is exceeded in a given allocation period, the CPSMT recommends that NMFS adjust the directed harvest allocation to account for the discrepancy in the following allocation period as an automatic action.

TABLE 1. Seasonal set asides based on a 10% annual incidental harvest of the Pacific sardine HG.

	Jan 1- June 30	July 1- Sept 14	Sept 15 – Dec 31	Total
Seasonal Allocation (mt)	31,183	35,637	22,273	89,093
Set Aside %	5.2%	1.2%	3.6%	10%
Set Aside (mt)	4,632	1,070	3,208	8,910
Adjusted Allocation (mt)	26,550	34,568	19,065	80,083

If the directed commercial sardine harvest is attained and other CPS fisheries achieve their incidental set aside, the CPSMT expectation is that retention of sardines would be prohibited. However, some level of incidental discard mortality would continue to occur. If the combined directed and incidental sardine HG is set at the ABC, this continuing discard mortality, as well as mortality occurring in the directed fisheries, would represent overfishing. This risk of overfishing could also be mitigated by setting an HG at some level below the ABC. The CPSMT also notes that sardine catches in the live bait fishery will be counted toward the ABC.

The CPSMT recommends additional research to fully evaluate stock structure, differential growth and migration rates of subpopulations, and the contribution of PNW sardine to the spawning biomass as a whole. The CPSMT recommends the Council encourage NMFS to continue to fund comprehensive coastwide annual CPS research, including the survey off the PNW, and encourage similar cooperative surveys in Canada and Mexico. The CPSMT also recommends that NMFS continues to fund the observer program. The CPSMT continues to believe strongly that coordinated international management of CPS fisheries is essential to avoid the potential for coastwide overfishing. Moreover, the CPSMT also agrees that inclusion of complete Mexican catch statistics is vital to the CPS assessment process. The CPSMT encourages the Council and NMFS and the State Department to continue working to achieve timely receipt of research data from Mexico.

<u>Pacific Mackerel</u>

On November 7, 2007 the Coastal CPSMT reviewed the Pacific Mackerel Stock Assessment Review (STAR) Panel Meeting Report (Agenda Item G.1.b, Attachment 3, November 2007), a summary by Tom Barnes, and the Scientific and Statistical Committee's (SSC) report on Pacific Mackerel Management (Agenda Item G.1, Situation Summary, November 2007). The CPSMT agrees with the recommendations of the STAR Panel and also notes that the 2008 HG has already been set by the Council for 2007/2008 management cycle using the Age Structured Assessment Program (ASAP) model. An assessment update using the ASAP model will be conducted in May 2008. The CPSMT concurs with the STAR Panel and the SSC that the use of the Stock Synthesis 2 (SS2) model would be preferred for the next new assessment set for May 2009 (establishing HGs for the 2009/2010 fishery season) but further refinement and review of the model is needed prior to its use.

PFMC
11/08/07

Agenda Item G.1.d
Supplemental CPSAS Report
November 2007

COASTAL PELAGIC SPECIES ADVISORY SUBPANEL REPORT ON PACIFIC SARDINE AND PACIFIC MACKEREL MANAGEMENT

The Coastal Pelagic Species Advisory Subpanel (CPSAS) heard a presentation by Dr. Kevin Hill regarding the 2007 Pacific sardine stock assessment and projected harvest guideline for the 2008 fishery. The CPSAS voices the strongest concern possible that the new Stock Synthesis 2 (SS2) model results grossly underestimated the volume of sardine observed in the water in 2007.

The CPSAS believes the model did not accurately predict the biomass observed in the field, based on reliable observations from fishermen and spotter pilots. The difference is in millions of tons. The CPSAS agrees unanimously that additional research and different research approach is essential to capture the full extent of the resource, particularly the volume of fish observed in the Pacific Northwest. Specifically, the CPSAS agrees a spotter pilot index of abundance is required for the 2008 assessment and should be continued into the future. A qualified spotter pilot survey can be easily started and maintained to provide reliable and cost effective results. It has been used in the past and is now available with new technology. This survey should be conducted in both the Pacific Northwest and California both to validate egg production, a highly variable index, and for use as a second independent index of stock abundance.

If the landings and market demand continue in 2008 as they progressed in 2007, all seasons will be prematurely closed. The harvest guideline resulting from the stock assessment approved by the Scientific and Statistical Committee (SSC) will cause extreme hardship to all coastal pelagic species (CPS) fishery sectors in 2008. This includes market squid as well as the other CPS. We estimate, for Pacific sardine alone, the economic impact will be a 5 to 6.5 million dollar loss in exvessel value and a 15.5 to 25 million dollar loss to the processing sector coastwide.

The CPSAS supports a joint Council/industry effort, including in-person meetings with national NOAA officials, to emphasize the need for substantial additional research funding for sardine in the fiscal year 2009 budget cycle.

The CPSAS voiced strong concern that the current process does not provide flexibility to test model results with observations in the field or other existing models including Age-structured Assessment Program (ASAP). To that end, the majority of the CPSAS recommends the Stock Assessment Team (STAT) run and review in parallel the ASAP and the SS2 models for possible discrepancies in outcomes for several years.

We recommend that the Council approve a data modeling workshop, including fishermen, spotter pilots, and other industry representatives be convened in conjunction with the next Stock Assessment Review (STAR) Panel, and that review be held as soon as possible, no later than 2009.

We recommend the STAT reevaluate the assumption that the fishery harvests a single stock. For example, test the possibility that the fishery harvests multiple stocks. We further recommend including a representative from the Pacific Northwest on the next STAT meeting.

In the event the Council adopts the harvest guideline recommendations of the SSC and the CPSMT, the CPSAS concurs with the CPSMT proposal that 10 percent of the harvest guideline for incidental take in fisheries other than Pacific sardine. This incidental harvest set aside will be allocated across the three allocation time blocks adopted under Amendment 11. Any unused incidental landing set aside from one allocation period shall be rolled into the directed harvest guideline of the next allocation period. In addition, the CPSAS recommends a maximum incidental landing allowance of 20 percent by weight.

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11/08/07

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