APPENDIX 1

2009 PACIFIC SARDINE STOCK ASSESSMENT UPDATE, 2008 SCIENTIFIC AND STATISTICAL COMMITTEE STATEMENT AND SUBCOMMITTEE REPORT, AND CPS MANAGEMENT TEAM AND ADVISORY SUBPANEL REPORTS

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ASSESSMENT OF THE PACIFIC SARDINE RESOURCE IN 2008 FOR U.S. MANAGEMENT IN 2009

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TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

ABC	allowable biological catch (equivalent to HG in the CPS-FMP)
ADMB	automatic differentiation model builder (programming language)
ASAP	age structured assessment program
B	stock biomass (ages 1+), used for management
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	Centro Interdisciplinario de Ciencias Marinas
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, as defined in the CPS-FMP (equivalent to ABC)
INP-CRIP	Instituto Nacional de la Pesca – Centro Regional de Invest. 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
ODFW	Oregon Department of Fish and Wildlife
PFMC	Pacific Fishery Management Council
R	recruits (age-0, abundance)
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
WDFW	Washington Department of Fish and Wildlife

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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 September 2007, 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. At that time, the STAR Panel endorsed use of the 'SS2' model for conducting the annual assessment (STAR 2007). The PFMC adopted use of these methods and results for management during 2008 (Hill et al. 2007a).

This assessment follows data and modeling methods described in Hill et al. (2007a). Two model scenarios are presented. In the first case ('update' model), we incorporate new fishery and survey data collected in 2007 and 2008, appending all existing time series in the model. In the second case ('projection' model), we follow the SSC CPS Subcommittee recommendation (see Agenda Item G.2.c, SSC CPS Subcommittee Report) and project the 2007 model forward by adding only updated landings. The present draft will be reviewed by the full SSC and PFMC during meetings held in November, 2008 (San Diego, CA).

EXECUTIVE SUMMARY

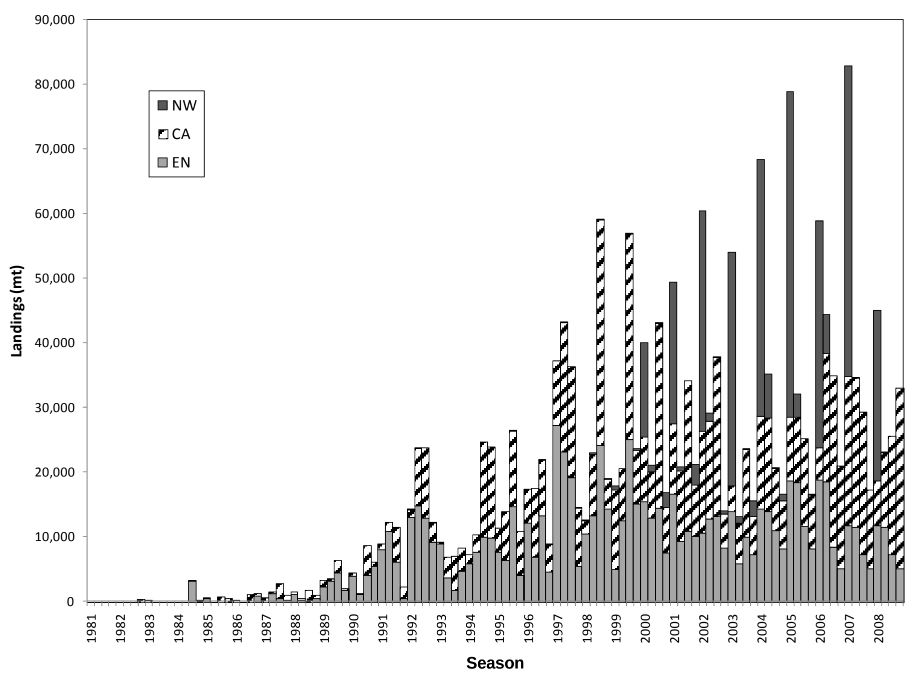
Stock

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 separating 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 to mid-2008.

Model Season	Ensenada (mt)	California (mt)	Pacific Northwest (mt)	Total (mt)
1998	62,333	51,005	563	113,901
1999	57,743	60,361	1,155	119,258
2000	50,457	52,916	17,923	121,295
2001	46,948	52,981	25,683	125,612
2002	44,938	60,714	36,123	141,775
2003	37,040	29,650	39,861	106,551
2004	47,379	45,858	47,747	140,985
2005	56,798	41,849	54,254	152,901
2006	50,762	67,389	41,221	159,372
2007	35,654	80,380	48,237	164,271



Data and assessment

This assessment, conducted using the ‘Stock Synthesis 2’ model (version 2.00i), uses fishery and survey data collected from mid-1981 to mid-2008. Fishery data include catch and biological samples for the fisheries off Ensenada, California, and the Pacific Northwest (1981-2008). Two indices of relative abundance are included: Daily Egg Production Method and Total Egg Production estimates of spawning stock biomass (1985-2008) based on annual surveys conducted off California. The model was constructed using an annual time step (‘Season’), based on the July-June biological year, with four quarters per season (Jul-Sep, Oct-Nov, Dec-Mar, and Apr-Jun).

Unresolved problems and major uncertainties

The present assessment revealed considerable model sensitivity to one new quarter of composition data from the Pacific Northwest fishery in 2007. The new data caused a shift in selectivity resulting in a significant downward scaling of recruitment and biomass estimates. The shift was driven by the 2003 cohort which has comprised a large portion of the NW catch for several years. In an earlier draft presented at the assessment update review (Oct 7, 2008), the STAT proposed a model in which the effective sample size (ESS) for the NW-07 data was down-weighted to the next largest ESS in for this fishery and time period. The STAT's treatment of the NW-07 ESS deviated from the TOR for assessment updates, so the SSC's CPS Subcommittee rejected this approach. Moreover, since results from the strict 'update' model were inconsistent with results from the final 2007 model, the SSC's CPS Subcommittee recommended rejecting the update and instead basing 2009 management on a 'projection' model in which the final 2007 model is updated with 2007-08 landings only (Agenda Item G.2.c, SSC CPS Subcommittee Report). Since the STAT, CPSMT, and SSC CPS Subcommittee are not in full agreement as to which model the 2009 management season should be based on, results from both the 'update' and 'projection' models are presented in this report.

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 (in particular, southern California's Fall fishery) used in the assessment include fish from the southern subpopulation, which presumably has different life history parameters (e.g. growth, maturity, and natural mortality rates). Moreover, timely access to recent Mexican catches (monthly resolution) and biological data remains an ongoing concern. The assessment does not include biological data for Ensenada after 2002.

Stock biomass

Stock biomass, used for management purposes, is defined as the sum of the biomass for sardine aged 1 and older. Stock biomass increased rapidly through the 1980s and 1990s, peaking in 2000 at 1.002 million mt in the update model, or 1.706 million mt in the projection model. Stock biomass has subsequently trended downward to the present (July 1, 2008) level of 662,886 mt in the update model, and 586,369 mt in the projection model.

	Stock Biomass (mt)	
Season	Update	Projection
1998	589,564	999,175
1999	887,809	1,490,210
2000	1,002,330	1,706,520
2001	878,841	1,542,430
2002	785,200	1,391,310
2003	610,683	1,132,110
2004	730,489	1,204,150
2005	847,585	1,211,420
2006	949,717	1,093,800
2007	867,100	832,546
2008	662,886	586,369

Recruitment

Recruitment was modeled using the Ricker stock-recruitment relationship. The estimate of steepness was high for both the update (h=2.708) and projection models (h=2.593). Virgin recruitment (R_0) was estimated at 3.41 billion age-0 fish for the update model and 4.99 billion for the projection model. Recruitment increased rapidly through the mid-1990s, peaking in 1998 at 16.4 billion fish in the update model and 24.5 billion fish in the projection model. Recruitments have been relatively low since the late 1990s, with the exception of the 2003 year class, which was the second largest in the series.

	Recruits (age-0, billions)	
Season	Update	Projection
1998	16.351	24.501
1999	3.649	5.185
2000	1.903	2.594
2001	7.086	9.638
2002	1.076	1.547
2003	14.063	16.372
2004	7.158	5.126
2005	9.820	5.231
2006	2.299	1.009
2007	2.603	3.658
2008	2.101	6.244

Exploitation status

Exploitation rate for the U.S. and coast-wide sardine fisheries is defined as calendar year catch/total mid-year biomass (ages 0+). Total exploitation rate was relatively high during the early recovery period (mid-1980s), but declined and stabilized as the stock underwent the most rapid recovery phase. Exploitation rate differs for the update and projection models, but the exploitation rate since 1990 has been relatively low under either scenario. For the update model, U.S. exploitation has averaged 7.9% since 1990 and 11.4% since 2003; coast-wide exploitation has been 15.8% since 1990 and 16% since 2003. Based on the projection model, U.S. exploitation has averaged 5.8% since 1990, with an average of 10.1% since 2003; coast-wide exploitation was 10.9% since 1990 and 12.6% since 2003. Coast-wide exploitation has gradually increased until 2007, at just over 19% for both models.

	EXPLOITATION RATE			
	Update Model		Projection Model	
Season	U.S.	Total	U.S.	Total
1998	4.9%	10.7%	3.0%	6.5%
1999	6.1%	12.4%	3.7%	7.5%
2000	6.6%	13.3%	3.9%	7.9%
2001	7.7%	12.5%	4.5%	7.3%
2002	12.1%	18.1%	6.8%	10.2%
2003	8.5%	13.6%	5.1%	8.1%
2004	11.1%	16.9%	7.2%	11.0%
2005	9.0%	15.0%	7.0%	11.6%
2006	9.2%	15.2%	8.2%	13.5%
2007	15.0%	19.1%	15.3%	19.5%
2008	12.5%	---	12.7%	---

Management performance

Based on results from the update model, the harvest guideline for the U.S. fishery in calendar year 2009 would be 66,932 mt. Using the projection model, the harvest guideline for the U.S. fishery would be 56,946 mt. The HG (=ABC) is based on the control rule defined in the CPS-FMP:

$$HG_{2009} = (BIOMASS_{2008} - CUTOFF) \bullet FRACTION \bullet DISTRIBUTION;$$

where HG_{2009} is the total USA (California, Oregon, and Washington) harvest guideline in 2009, $BIOMASS_{2008}$ is the estimated July 1, 2008 stock biomass (ages 1+) from the assessment (update model = 662,886 mt; projection model = 586,369 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 average portion of $BIOMASS_{2008}$ 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_{2008}) SST estimate of 17.83 °C, the F_{msy} exploitation fraction should remain at 15%.

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	99,578
2002	118,442	96,876	136,140	141,369
2003	110,908	69,917	127,480	101,411
2004	122,747	92,723	141,089	141,388
2005	136,179	90,016	156,528	149,939

2006	118,937	91,039	136,709	149,667
2007	152,564	135,946	175,361	173,120
2008	89,093	86,608	102,406	---

Research and data needs

High priority research and data needs for Pacific sardine include:

1) gaining better information about Pacific sardine status through coast-wide surveys that include ichthyoplankton, hydroacoustic, and trawl sampling;
2) examining potential use of hydroacoustic data from the Pacific whiting survey in developing a new time series of sardine relative abundance in the region from Monterey to Canada;
3) refine methodology for re-weighting fishery composition data and determining input effective sample sizes in SS2;
4) standardizing fishery-dependent data collection among agencies, and improving exchange of raw data or monthly summaries for stock assessments;
5) obtaining more fishery-dependent and fishery-independent data from northern Baja California, México;
6) further refinement of ageing methods and improved ageing error estimates through a workshop of all production readers from the respective agencies;
7) 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;
8) 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). An 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 adult spawning stocks may move north and south in synchrony 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 in length, 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^{o}C to 15^{o}C and larvae are most abundant at 13^{o}C to 16^{o}C. Temperature requirements are apparently flexible, however, because eggs are most common at 22^{o}C to 25^{o} C in the Gulf of California and at 17^{o}C to 21^{o}C off Central and Southern Baja (Lluch-Belda et al. 1991).

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

Sardine are oviparous, multiple-batch spawners with annual fecundity that is indeterminate and 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 planktivorous omnivores and 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 less likely 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 for 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 2009' section**)**. A thorough description of PFMC management actions for sardine, including harvest guidelines, may be found in the most recent CPS SAFE document (PFMC 2008). 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

<u>Stock Structure</u>

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, maturation, and natural mortality would also be taken into account.

<u>Weight-at-length</u>

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 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 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 and applied 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 Model Results section).

Maturity

Maturity-at-length was estimated using sardine collected 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, and where:

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

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 all previous sardine 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 2007 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.

Landings

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. For the final time step (2008-09), landings were based on actual data for Qtr-1, and previous year landings for Qtr-2 to Qtr-4.

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 years 2005 to 2007 were taken from proceedings of the annual small pelagic workshops sponsored by INP, CICESE, and CICIMAR. Annual aggregate catches for these years were apportioned to month using monthly catches data from 2004 and 2005. Projected landings for 2008-09 were based on the 2007-08 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 (Jake Schweigert, pers. comm.).

The SS2 model includes commercial sardine landings in California, northern Baja California and the Pacific Northwest from 1981-82 through 2008-09. 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.

Length-composition data for the California fishery were 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 (STAR 2007). A summary of the sample sizes by season, quarter, and fishery is provided in Table 3. Length-compositions by fishery are displayed in Figures 6-11.

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.

Implied age-compositions were compiled based on the cross-product of observed length-frequencies and corresponding conditional age-at-length information (STAR 2007). 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 fishery-independent series were used in the previous assessment (Hill et al. 2007a), and both were based on an annual egg production survey that ranges from San Diego to San Francisco in April. The daily egg production method (DEPM) index of SSB (Index 1) is used when adult daily-specific fecundity data are available. The total egg production (TEP) index of SSB (Index 2) is used when survey-specific fecundity data are not available. Both time series are treated as indices of relative abundance.

Daily Egg Production Method (DEPM)

Daily egg production method (DEPM) spawning biomass estimates were available for calendar years 1986-1988 and 1994-2008 (Tables 6 and 7, 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 a,b). The latest DEPM estimate, based on eggs and adults collected from the standard survey area during March 24 to May 1, 2008, was 116,778 mt (CV=0.43) (Tables 5-7, Figures 21 and 22). Notably, the April 2008 DEPM estimate is the lowest estimate since the April 1994 survey. In SS2, the DEPM index was taken to represent sardine SSB (length selectivity option '30') in April (Qtr-4) of each season. The 2008 DEPM estimate was not included in the projection-based model.

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 collected during the egg production surveys (specifically, the 1995, 1996, 1998-2001, and 2003 survey years; see Lo et al. 2007b). 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 violated the assumption of independent observations among years and was discontinued for purposes of population modeling (Hill et al. 2007a). Beginning in 2007, 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 7 and displayed in Figure 21. Like DEPM, TEP was taken to represent sardine SSB, but the model is able estimate separate catchability coefficients (Q) for the two observation types.

Survey Issues Addressed During the 2007 STAR

The 2007 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 (STAR 2007, 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, 2007a,b), 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 'coast-wide' survey). The April 2004 survey map indicates small areas of low egg densities off Baja California relative to the standard area (Figure 23). 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 24; Lo et al. 2007a). Finally, examination of a map from the April 2008 coast-wide survey (Seattle to San Diego) reveals minimal presence of sardine north of San Francisco - one adult sardine and one egg were collected west of Pt. Arena, CA (Figure 25).

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 forward) 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 using 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). In 2007, a STAR Panel reviewed and endorsed an assessment using the model 'Stock Synthesis 2' (SS2, Methot 2005, 2007), and these results were adopted for management in 2008 (Hill et al. 2007a,b). The following assessment update is based on the methods of Hill et al. 2007a,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. These sub-models are fully integrated and the SS2 model uses forward-algorithms, which begin estimation prior or in the first year of available data and continues forward up to the last year of data (Methot 2005).

Assessment Program with Last Revision Date

SS2 Version 2.00i, compiled 7 August 2007, was used in this assessment update. This is the same version used in the 2007 assessment (Hill et al. 2007a,b). 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 28a and 28b). 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 (Hill et al. 2007a). 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 ascending width) to force a simple-logistic shape during the first period (Figures 26 and 27). This resulted in better fits to the size-composition and survey 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 2007 STAR Panel review, examination of Pearson residuals for fits to the NW fishery length- and age-compositions revealed marked patterns after 2003. A NW industry member present noted that the NW fishery had 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, breaking between the 2003 and 2004 seasons (STAR 2007, 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 starting in 1975, 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 off the central and southern California coast during April. In our SS2 model, 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).

Model runs based on the Ricker relationship were ultimately more stable and improved the trend in recruitment deviations (Hill et al. 2007a). 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.

For the update model, recruitment deviations were estimated 1975 through 2007. The projection model estimated recruitment deviations through 2006, per Hill et al. (2007a,b).

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 update and projection models are provided in Table 8. The models had the following specifications:

1. Year (= "Season") based on a July 1 birth date;
2. Four quarters per "season" (Jul-Sep, Oct-Nov, Dec-Mar, Apr-Jun);
3. Use of length-frequency and conditional age-at-length data for Ensenada, California and the Pacific Northwest fisheries;
4. M = 0.4yr^{-1}; Growth is estimated (time-invariant);
5. Length-based selectivity with time-blocking:
    a. Ensenada: 1981-91, 1992-98, and 1999-2008 (double normal function, fixed to simple logistic shape in first period);
    b. California: 1981-91, 1992-98, and 1999-2008 (double normal function, fixed to simple logistic shape in first period);
    c. Pacific Northwest: 1981-2003, and 2004-2008 (simple logistic function, both periods);

6. Ricker stock-recruitment relationship; σ_R = 0.765; Steepness estimated;
7. Initial recruitment (R_1) estimated; recruitment residuals estimated from 1975 to 2007 (update model), or 1975 to 2006 (projection model).

Uncertainty, Sensitivity, and Unresolved Problems

A broad suite of sensitivity analyses for the base model was performed during the 2007 STAR. Analyses included sensitivity to the indices, ageing error assumptions, exclusion of early catch data from Ensenada, and stock-recruitment assumptions. Likelihood profiles for natural mortality and steepness were also conducted. In addition, prospective and retrospective analyses were performed to examine the effect of the starting and ending year on derived values. All results from the above are described in Hill et al. (2007a,b) and STAR 2007. As there was no structural change to the updated assessment model, these analyses will not be repeated here. Instead, the discussion of model sensitivity will focus on the effect the addition of one year of new data has had on the scaling of recruitment and total population estimates.

Sensitivity to 2007-08 data

Initial model runs for the strict update case revealed a marked downward scaling of population estimates compared to the final model from 2007. Subsequently, we ran a series of seven models that incrementally introduced each new data source from the 2007-08 season: landings only; landings and CA length comps; landings and NW length comps; landings and all length comps; landings and all length and age comps; all new data minus the NW-07 compositions, and all new data. Likelihood components and some derived quantities of interest are shown in Table 9. The most striking result from this analysis is the effect that one quarter (Qtr-1, 2007) of new NW length composition data had on scaling of recruitment and biomass estimates throughout the model (Table 9).

The new NW-07 composition was quite consistent in pattern to the previous few years of samples from this fishery (Figures 10 and 11), but had a large input effective sample size (ESS=89.24) relative to those earlier samples (Table 3). The result of this new observation was a 1-cm increase in selectivity inflection for this fishery and time block (Figure 28c), attributable to a strong cohort effect driven by the 2003 year class. This also resulted in a minor rightward shift in selectivity for other fisheries and time blocks (Figures 28a-c), but these shifts translated to a downward scaling of recruitment estimates throughout the model.

This degree of sensitivity to one quarter of fishery composition data is an undesirable property. Model fit to the composition data is relatively poor, and the effective N estimated by the model is considerably lower than the input value. The STAT initially proposed to balance the influence of the NW-07 sample by lowering the ESS to the next highest level for this time block and fishery (i.e., replacing the nominal ESS of 89.24 with 55.56, the ESS of Qtr-1, 2004). The STAT considered this a reasonable short-term compromise to a problem that could only be addressed properly under a more extended review process, where alternative data weighting scenarios could be thoroughly explored. The STAT's treatment of the NW-07 ESS deviated from the TOR for assessment updates, so the SSC's CPS Subcommittee rejected this approach at the review held October 7, 2008. Moreover, since results from the strict 'update' model were inconsistent with results from the final 2007 model, the SSC's CPS Subcommittee recommended rejecting the 'update' model and instead basing 2009 management on a 'projection' model in which the final 2007 model is appended with 2007-08 landings only (Table 9, model 'PS08_a').

Since the STAT, CPSMT, and SSC CPS Subcommittee were not in full agreement as to which model the 2009 management season should be based on, results from both the 'update' and 'projection' models are presented below. Likelihood components and derived quantities of interest for the update and projection models are presented in Tables 9 and 10. Selectivity estimates from the two models are presented in Figure 28. Recruitment and biomass time series for the two models are displayed in Figures 59 and 61.

Reasons for the scaling difference between the two models are not entirely clear, but likely related to the relative emphasis (ESS) of the composition data among seasons within the NW 2004-08 time block. The NW composition was dominated by the 2003 year class throughout most of this time block, however, ESS prior to 2007 was relatively low (Table 3) so the model fits to prior observations of that year class were previously de-emphasized. The 2003 year class was the second strongest in the modeled time series, so changes to emphasis in data including this year class can affect selectivity estimates, change S-R steepness (Table 9), and rescale recruitments. The STAT experimented with the final 2007 model by gradually increasing ESS for the 2005 and 2006 compositions, and a similar downscaling occurred (results not presented in this document). The perception of the 2007 'baseline' would have likely been different had the NW composition been reweighted and ESS rescaled appropriately last year. This will be an important area of investigation prior to the next sardine STAR.

Model Results

Growth

The growth parameters (size at age 0.5, size at age 15, von Bertalanffy growth rate '*K*', and the CVs for size at minimum and maximum ages) were estimated within the model. Sardine were estimated to grow to 9.8 cm SL by age 0.5 and 23.9 cm SL by age 15 (Table 8). Growth rate (*K*) for the update model was estimated to be 0.548 yr^{-1}, lower than the projection model estimate (0.572 yr^{-1}). Estimated growth is displayed in Figure 29 and growth parameters are shown in Table 8.

Indices of abundance

Fits to the DEPM and TEP series are displayed in Figures 30-33. Input CVs for each index were iteratively adjusted to match the model estimates of variance. Catchability coefficient (*Q*) for the DEPM series was estimated to be 0.649 for the update model and 0.471 for the projection model. The TEP series was best fit with Q=0.779 (update) or Q=0.437 (projection).

Selectivity estimates

Length selectivity patterns estimated (projection model) for each fishery are displayed in Figure 26. For comparative purposes, the selectivity patterns by time block are displayed in Figure 27. 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 blocks, displayed a pronounced shift toward smaller fish after 2003 (Figure 28c), although this trend reversed by 1-cm with the addition of NW-07 data. Model fits to length frequencies are shown in Figures 34-36, and Pearson residuals to the fits are shown in Figures 37-39. Model fits to implied age-compositions are shown in Figures 40-42, and Pearson residuals to the fits are shown in Figures 43-45. Observed and effective sample sizes for the length frequency data are displayed in Figures 46-48. Observed and effective sample sizes for conditional age-at-length compositions are displayed in Figures 49-51.

Harvest and exploitation rates

Estimated harvest rates (catch per selected biomass) by fishery are displayed in Figure 52. A relatively high harvest rate of 87-89% 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 (time block 1) was shifted slightly lower to avoid any harvest rate penalty and to match observed and expected catch for that quarter.

Exploitation rates (calendar year catch/total mid-year biomass, ages 0+) for the U.S. and coast-wide sardine fisheries are displayed in Figure 53 and as a table in the Executive Summary. Total exploitation rate was relatively high during the early recovery period (mid-1980s), but declined and stabilized as the stock underwent the most rapid recovery phase. Exploitation rate differs for the update and projection models, but the exploitation rate since 1990 has been relatively low under either scenario. For the update model, U.S. exploitation has averaged 7.9% since 1990 and 11.4% since 2003; coast-wide exploitation has been 15.8% since 1990 and 16% since 2003. Based on the projection model, U.S. exploitation has averaged 5.8% since 1990, with an average of 10.1% since 2003; coast-wide exploitation was 10.9% since 1990 and 12.6% since 2003. Coast-wide exploitation has gradually increased until 2007, at just over 19% for both models.

Spawning stock biomass

Update and projection model estimates of SSB since 1981 are presented in Table 10 and Figure 54. Unexploited SSB (S_0) from the update model was estimated to be 615,573 mt (Table 9), 33% lower than the S_0 estimate from the projection model (924,167 mt; Table 9). Peak SSB (July 2000) from the update model was 44% lower than the projection model (Table 9). While there is a notable divergence in scale of SSB between the two models, the time series do converge to similar levels from 2006 onward (Figure 54).

Recruitment

Time series of recruitment estimates are provided in Table 10 and Figures 55 and 61. Virgin recruitment (R_0) was estimated at 3.41 billion age-0 fish for the update model and 4.99 billion for the projection model (Table 9). Recruitment increased rapidly through the mid-1990s, peaking in 1998 at 16.4 billion fish in the update model, and 24.5 billion fish in the projection model. Recruitments have been relatively low since the late 1990s, with the exception of the 2003 year class, which was the second largest in the series. Recruitment series for the update and projection models are compared in Figure 61.

Stock-recruitment

Ricker stock-recruitment relationships for the update and projection models are displayed in Figure 56. The estimate of steepness was high for both the update (h=2.708) and projection models (h=2.593)(Table 9). Fits of the Ricker model to the recruitment time series are shown in Figure 57. Recruitment deviations and their asymptotic standard errors are shown in Figure 58.

Stock biomass (ages 1+) for PFMC management

Stock biomass, used for management purposes, is defined as the sum of the biomass for sardine aged 1 and older. Update and projection model estimates of stock biomass are shown in Figure 59 and Table 10. Stock biomass increased rapidly through the 1980s and 1990s, peaking in 2000 at 1.002 million mt in the update model and 1.706 million mt in the projection model. Stock biomass has subsequently trended downward to the present (July 1, 2008) level of 662,886 mt in the update model, and 586,369 mt in the projection model.

Comparison to previous assessments

Stock biomass (age 1+) and recruitment estimates from the update and projection models were compared to final values from all previous assessments used for PFMC management. Results are displayed in Figures 60 and 62. Stock biomass and recruitment estimates for update and projection models are within the same general range as previous assessments, but displayed different trends with respect to peaks and end points. Recruitments from the SS2 models 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 62). 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 62). 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 60). Comparisons of the update and projection models to the final 2007 model are also shown in Figures 59 and 61.

HARVEST GUIDELINE FOR 2009

Based on results from the update model, the harvest guideline for the U.S. fishery in calendar year 2009 would be 66,932 mt. Using the projection model for management, the harvest guideline for the U.S. fishery in calendar year 2009 would be 56,946 mt. Parameters used to determine this harvest guideline are discussed below and presented in Table 11. To calculate the proposed harvest guideline for 2009, 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:

$$HG_{2009} = (BIOMASS_{2008} - CUTOFF) \bullet FRACTION \bullet DISTRIBUTION;$$

where HG_{2009} is the total USA (California, Oregon, and Washington) harvest guideline in 2009, $BIOMASS_{2008}$ is the estimated July 1, 2008 stock biomass (ages 1+) from the current assessment (update model = 662,886 mt; projection model = 586,369 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 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 (1981-2008; Table 7, Figure 63), the appropriate F_{msy} exploitation fraction has consistently been 15%; and this remains the case under current conditions (T_{2008} = 17.83 °C).

RESEARCH AND DATA NEEDS

High priority research and data needs for Pacific sardine include:

1) gaining better information about Pacific sardine status through coast-wide surveys that include ichthyoplankton, hydroacoustic, and trawl sampling;
2) examining potential use of hydroacoustic data from the Pacific whiting survey in developing a new time series of sardine relative abundance in the region from Monterey to Canada;
3) refine methodology for re-weighting fishery composition data and determining input effective sample sizes in SS2;
4) standardizing fishery-dependent data collection among agencies, and improving exchange of raw data or monthly summaries for stock assessments;
5) obtaining more fishery-dependent and fishery-independent data from northern Baja California, México;
6) further refinement of ageing methods and improved ageing error estimates through a workshop of all production readers from the respective agencies;
7) 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;
8) 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 (STAR 2007), the 2008 CPS-SAFE document (PFMC 2008), and in the PFMC's Research and Data Needs document for 2006-2008 (PFMC 2006).

LITERATURE CITED

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Emmett, R. L., R. D. Brodeur, T. W. Miller, S. S. Pool, G. K. Krutzikowsky, P. J. Bentley, J. McCrae. 2005. Pacific sardine (*Sardinops sagax*) abundance, distribution, and ecological relationships in the Pacific Northwest. CalCOFI Rep. 46: 122-143.

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

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

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

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

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

463.

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

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

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

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

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

Hill, K. T., N. C. H. Lo, B. J. Macewicz, and R. Felix-Uraga. 2006b. Assessment of the Pacific sardine (*Sardinops sagax caerulea*) population for U.S. management in 2007. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-396. 99 p.

Hill, K. T., E. Dorval, N. C. H. Lo, B. J. Macewicz, C. Show, and R. Felix-Uraga. 2007a. Assessment of the Pacific sardine resource in 2007 for U.S. management in 2008. Pacific Fishery Management Council, November 2007 Briefing Book, Agenda Item G.1.b. 250 p

Hill, K. T., E. Dorval, N. C. H. Lo, B. J. Macewicz, C. Show, and R. Felix-Uraga. 2007b. Assessment of the Pacific sardine resource in 2007 for U.S. management in 2008. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-413. 178 p.

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

Janssen, J. F. 1938. Second report of sardine tagging in California. Calif. Fish Game 24(4): 376-389.

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

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

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

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

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

Lo, N. C. H., A. C. Allen, and S. Z. Herzka. 2006. Minutes of the 2005 Trinational Sardine Forum. Southwest Fisheries Science Center, National Marine Fisheries Service, Admin. Rep. LJ-06-05. 118 p.

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

Lo, N. C. H., B. J. Macewicz, D. A. Griffith, and R. L. Charter. 2007a. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2006. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-401. 32 p.

Lo, N. C. H., B. J. Macewicz, and R. L. Charter. 2007b. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2007. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-411. 31 p.

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

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

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

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

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

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

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

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

McFarlane, G. A., J. Schweigert, L., MacDougall, and C. Hrabok. 2005. Distribution and biology of Pacific sardine (*Sardinops sagax*) off British Columbia, Canada. CalCOFI Rep. 46: 144-160.

Methot, R. 2005. Technical description of the stock synthesis II assessment program. Version 1.17-March 2005.

Methot, R. 2007. User manual for the Integrated analysis program stock synthesis 2 (SS2). Model version 2.00c. March 2007.

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

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

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

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

PFMC. 2006. Research and Data Needs: 2006-2008. Pacific Fishery Management Council, Portland, OR. http://www.pcouncil.org/research/resdocs/Res_Data_Needs_0608_final_DEC06.pdf

PFMC. 2008. Status of the Pacific Coast Coastal Pelagic Species Fishery and Recommended Acceptable Biological Catches. Stock Assessment and Fishery Evaluation – 2008. Pacific Fishery Management Council, Portland, OR. http://www.pcouncil.org/cps/cpssafe/0608safe.html

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

Radovich, J. 1982. The collapse of the California sardine fishery: what have we learned?

CalCOFI Rep. 23: 56-78.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Table 1. Fishery performance since onset of federal management in 2000 (ABC=HG).

Year	U.S. ABC	U.S. Landings	Total ABC	Total Landings
2000	186,791	67,985	214,702	120,876
2001	134,737	75,732	154,870	99,578
2002	118,442	96,876	136,140	141,369
2003	110,908	69,917	127,480	101,411
2004	122,747	92,723	141,089	141,388
2005	136,179	90,016	156,528	149,939
2006	118,937	91,039	136,709	149,667
2007	152,564	135,946	175,361	173,120
2008	89,093	86,608	102,406	---

Table 2. Pacific sardine landings for major fishing regions off the West Coast of North America, calendar years 1981-2007. The stock assessment only includes catches from Ensenada, México to British Columbia, Canada. \1

	MÉXICO					UNITED STATES					CANADA	
Calendar Year	Gulf of California\2	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	25	286,403
1996	200,870	25,795	0	39,065	265,730	25,171	8,885	0	0	34,056	88	299,874
1997	203,529	14,656	0	68,439	286,624	32,837	13,361	0	0	46,198	34	332,856
1998	59,400	2,493	0	47,812	109,705	31,975	9,081	1	0	41,056	745	151,506
1999	51,266	11,795	0	58,569	121,630	42,863	13,884	776	1	57,523	1,250	180,404
2000	65,593	42,276	0	67,845	175,715	42,248	11,368	9,528	4,842	67,985	1,718	245,418
2001	190,862	40,572	0	46,071	277,505	44,722	7,104	12,780	11,127	75,733	1,600	354,838
2002	220,360	50,969	0	46,845	318,174	44,464	13,881	22,711	15,820	96,876	1,044	416,094
2003	198,757	53,862	0	41,342	293,961	24,832	7,922	25,258	11,920	69,931	954	364,846
2004	102,034	47,173	0	44,382	193,589	32,393	15,308	36,111	8,911	92,723	4,259	290,571
2005	94,341	40,000	0	56,715	191,056	30,253	7,940	45,110	6,714	90,016	3,200	284,272
2006	133,650	52,429	0	57,070	243,149	33,286	17,743	35,648	4,362	91,039	1,558	335,746
2007	178,205	55,084	0	35,654	268,943	54,714	34,517	42,052	4,663	135,946	1,520	406,409

\1 Landings are based on statistics provided in most recent CPS SAFE document, which was fully updated in 2008. Some values differ from Hill et al. (2007a,b).

\2 Gulf of California catch statistics are compiled by an Oct-Sep fishing season, e.g. the 2007 value represents landings made between Oct. 2006 and Sep. 2007.

Table 3. Number of samples for size and age composition by model season, quarter, and fishery (25 fish per sample). The following were used as input effective sample sizes (ESS) in SS2.

Season	Quarter	CA	EN	NW
1981	1	0.00	0.00	0.00
	2	0.00	0.00	0.00
	3	3.16	0.00	0.00
	4	5.00	0.00	0.00
1982	1	8.84	0.00	0.00
	2	4.00	0.00	0.00
	3	17.64	0.00	0.00
	4	7.16	0.00	0.00
1983	1	5.32	0.00	0.00
	2	9.76	0.00	0.00
	3	5.20	0.00	0.00
	4	3.68	0.00	0.00
1984	1	0.00	0.00	0.00
	2	0.00	0.00	0.00
	3	2.76	0.00	0.00
	4	5.80	0.00	0.00
1985	1	5.68	0.00	0.00
	2	1.56	0.00	0.00
	3	24.28	0.00	0.00
	4	14.48	0.00	0.00
1986	1	7.12	0.00	0.00
	2	9.04	0.00	0.00
	3	38.64	0.00	0.00
	4	5.88	0.00	0.00
1987	1	12.96	0.00	0.00
	2	8.88	0.00	0.00
	3	62.20	0.00	0.00
	4	30.12	0.00	0.00
1988	1	13.52	0.00	0.00
	2	8.96	0.00	0.00
	3	30.56	0.00	0.00
	4	12.20	1.36	0.00
1989	1	15.88	0.84	0.00
	2	0.00	3.04	0.00
	3	42.36	2.76	0.00
	4	1.00	0.16	0.00
1990	1	1.88	8.52	0.00
	2	4.92	0.92	0.00
	3	78.24	4.84	0.00
	4	8.84	21.76	0.00
1991	1	20.44	21.32	0.00
	2	15.92	16.72	0.00
	3	29.96	40.48	0.00
	4	15.40	8.64	0.00
1992	1	7.88	13.04	0.00
	2	72.84	5.84	0.00
	3	51.24	5.28	0.00
	4	15.36	4.60	0.00
1993	1	0.76	4.96	0.00
	2	11.04	0.00	0.00
	3	20.88	1.48	0.00
	4	13.24	7.40	0.00
1994	1	2.56	5.04	0.00
	2	19.48	4.56	0.00
	3	71.80	4.44	0.00
	4	52.88	5.72	0.00
1995	1	12.48	7.24	0.00
	2	17.28	4.80	0.00
	3	42.04	6.08	0.00
	4	33.24	1.88	0.00
1996	1	72.00	7.68	0.00
	2	47.76	3.72	0.00
	3	34.40	4.68	0.00
	4	26.20	3.04	0.00
1997	1	51.56	8.40	0.00
	2	40.44	5.36	0.00
	3	54.52	4.44	0.00
	4	25.68	1.20	0.00
1998	1	29.76	2.12	0.00
	2	49.52	5.44	0.00
	3	73.44	8.20	0.00
	4	25.80	5.72	1.24
1999	1	27.76	3.60	2.96
	2	13.88	5.12	0.00
	3	43.32	8.52	0.00
	4	21.68	4.88	4.16
2000	1	26.64	6.60	67.44
	2	18.84	3.92	0.96
	3	47.88	3.60	0.00
	4	34.48	6.36	10.56
2001	1	34.48	1.28	83.32
	2	44.28	4.52	2.00
	3	62.28	3.12	0.00
	4	30.28	5.56	17.92
2002	1	19.68	0.44	95.56
	2	19.60	0.00	10.88
	3	53.60	0.00	0.00
	4	35.76	0.00	4.96
2003	1	34.60	0.00	84.64
	2	22.68	0.00	3.96
	3	49.52	0.00	0.00
	4	36.08	0.00	10.92
2004	1	46.20	0.00	55.56
	2	33.92	0.00	10.92
	3	45.52	0.00	3.00
	4	36.64	0.00	5.00
2005	1	46.48	0.00	38.80
	2	36.64	0.00	2.00
	3	54.40	0.00	0.00
	4	55.40	0.00	0.00
2006	1	64.72	0.00	9.96
	2	45.88	0.00	2.00
	3	83.20	0.00	0.00
	4	56.88	0.00	0.00
2007	1	77.56	0.00	89.40
	2	47.56	0.00	0.00
	3	54.12	0.00	0.00
	4	28.40	0.00	0.00

Table 4. Pacific sardine landings (mt) by model season, quarter, and fishery for the base model.

Model Season	Quarter	CA	EN	NW	Total
1981	1	4	0	0	4
	2	2	0	0	2
	3	14	0	0	14
	4	43	0	0	43
1982	1	42	0	0	42
	2	31	0	0	31
	3	40	0	0	40
	4	224	150	0	373
1983	1	48	124	0	172
	2	37	0	0	37
	3	89	0	0	89
	4	74	0	0	74
1984	1	22	0	0	22
	2	51	0	0	51
	3	138	3,174	0	3,312
	4	186	0	0	186
1985	1	112	475	0	587
	2	43	73	0	117
	3	614	86	0	700
	4	422	13	0	435
1986	1	121	116	0	237
	2	83	28	0	111
	3	1,032	75	0	1,107
	4	311	900	0	1,212
1987	1	489	149	0	638
	2	245	1,206	0	1,451
	3	2,281	458	0	2,739
	4	795	264	0	1,059
1988	1	388	1,139	0	1,527
	2	312	180	0	491
	3	1,640	96	0	1,736
	4	580	461	0	1,041
1989	1	1,076	2,250	0	3,326
	2	355	3,163	0	3,518
	3	1,992	4,423	0	6,415
	4	236	1,828	0	2,064
1990	1	489	3,972	0	4,461
	2	131	1,187	0	1,318
	3	4,656	4,067	0	8,723
	4	580	5,521	0	6,100
1991	1	926	8,069	0	8,996
	2	1,419	10,814	0	12,233
	3	5,319	6,132	0	11,451
	4	1,909	432	0	2,342
1992	1	1,290	13,057	4	14,350
	2	8,968	14,781	0	23,749
	3	10,908	12,874	0	23,781
	4	3,155	9,179	0	12,334
1993	1	372	8,882	0	9,254
	2	3,199	3,742	0	6,941
	3	5,258	1,766	0	7,025
	4	3,602	4,718	0	8,320
1994	1	1,443	5,881	0	7,324
	2	2,672	7,655	0	10,327
	3	14,698	9,985	0	24,683
	4	14,089	9,872	0	23,961
1995	1	3,642	7,711	0	11,353
	2	7,604	6,371	0	13,975
	3	11,757	14,730	23	26,510
	4	6,818	4,022	0	10,840
1996	1	5,313	12,104	0	17,416
	2	10,680	6,901	0	17,581
	3	8,643	13,305	41	21,989
	4	4,391	4,587	3	8,981
1997	1	9,956	27,281	0	37,238
	2	20,021	23,184	27	43,232
	3	17,185	19,200	0	36,385
	4	9,010	5,514	1	14,525
1998	1	2,069	10,512	23	12,603
	2	9,463	13,270	337	23,069
	3	34,840	24,207	153	59,200
	4	4,634	14,345	50	19,029
1999	1	12,218	5,024	725	17,967
	2	7,966	12,582	0	20,548
	3	31,852	25,036	162	57,051
	4	8,324	15,101	267	23,692
2000	1	10,036	15,442	14,576	40,054
	2	7,200	12,943	1,009	21,152
	3	28,683	14,487	2	43,172
	4	6,997	7,584	2,337	16,917
2001	1	10,910	16,644	21,888	49,442
	2	10,904	9,273	658	20,835
	3	23,275	10,872	0	34,147
	4	7,892	10,159	3,136	21,187
2002	1	15,811	10,612	34,099	60,521
	2	15,041	12,842	1,326	29,209
	3	24,631	13,209	101	37,942
	4	5,231	8,275	597	14,103
2003	1	3,995	13,926	36,116	54,037
	2	6,268	5,819	1,127	13,214
	3	13,505	10,005	180	23,689
	4	5,882	7,290	2,439	15,611
2004	1	14,291	14,351	39,799	68,441
	2	14,521	13,959	6,719	35,199
	3	9,606	10,950	213	20,769
	4	7,441	8,119	1,016	16,576
2005	1	9,840	18,653	50,477	78,970
	2	10,124	18,378	3,676	32,178
	3	13,568	11,592	0	25,160
	4	8,317	8,174	102	16,593
2006	1	5,040	18,780	35,164	58,985
	2	19,879	18,503	6,057	44,439
	3	26,527	8,372	0	34,899
	4	15,943	5,107	0	21,050
2007	1	23,111	11,733	48,075	82,919
	2	22,980	11,560	163	34,702
	3	22,106	7,255	0	29,361
	4	12,183	5,107	0	17,290
2008	1	6,970	11,733	26,426	45,129
	2	11,506	11,560	81	23,147
	3	18,317	7,255	0	25,572
	4	27,904	5,107	0	33,011

Table 5. Pacific sardine female adult parameters for surveys conducted in the standard daily egg production method (DEPM) sampling area off California (1994 includes females from off Mexico).

		1994	1997	2001	2002	2004	2005	2006	2007	2008
Midpoint date of trawl survey		22-Apr	25-Mar	1-May	21-Apr	25-Apr	13-Apr	2-May	24-Apr	16-Apr
Beginning and ending dates of positive collections		04/15-05/07	03/12-04/06	05/01-05/02	04/18-04/23	04/22-04/27	03/31-04/24	05/01-05/07	04/19-04/30	04/13-04/27
N collections with mature females		37	4	2	6	16	14	7	14	12
N collection within Region 1		11	4	2	6	16	6	2	8	4
Average surface temperature (°C) at collection locations		14.36	14.28	12.95	12.75	13.59	14.18	14.43	13.6	12.4
Female fraction by weight	***R***	0.538	0.592	0.677	0.385	0.618	0.469	0.451	0.515	0.631
Average mature female weight (grams):										
with ovary	W_f	82.53	127.76	79.08	159.25	166.99	65.34	67.41	81.62	102.21
without ovary	W_{of}	79.33	119.64	75.17	147.86	156.29	63.11	64.32	77.93	97.67
Average batch fecundity[a] (mature females, oocytes estimated)	***F***	24283	42002	22456	54403	55711	17662	18474	21760	29802
Relative batch fecundity (oocytes/g)		294	329	284	342	334	270	274	267	292
N mature females analyzed		583	77	9	23	290	175	86	203	187
N active mature females		327	77	9	23	290	148	72	187	177
Spawning fraction of mature females[b]	***S***	0.074	0.133	0.111	0.174	0.131	0.124	0.0698	0.114	0.1186
Spawning fraction of active females[c]	S_a	0.131	0.133	0.111	0.174	0.131	0.155	0.083	0.134	0.1186
Daily specific fecundity	$\frac{RSF}{W}$	11.7	25.94	21.3	22.91	27.04	15.67	8.62	15.68	21.82

[a] 1994-2001 estimates were calculated using F_b = -10858 + 439.53 W_{of} (Macewicz et al. 1996), 2004 used F_b = 356.46W_{of}. (Lo and Macewicz 2004), 2005 used F_b = -6085 + 376.28 W_{of} (Lo and Macewicz 2006), 2006 used F_b = -396 + 293.39 W_{of} (Lo et al. 2007); and 2007 used F_b = 279.23W_{of}. (Lo et al. 2007).

[b] Mature females include females that are active and those that are postbreeding (incapable of further spawning this season).

[c] Active mature females are capable of spawning and have ovaries containing oocytes with yolk or postovulatory follicles less than 60 hours old.

Table 6. Estimates of daily egg production (P_0)[a] for the survey area, daily instantaneous mortality rates (Z) from high density area (Region 1), daily specific fecundity (RSF/W), spawning biomass of Pacific sardine and average sea surface temperature for the years 1994 to 2008.

Year	P_0 (CV)	Z (CV)	Area (km^2) (Region 1)	RSF/W	Spawning biomass (mt) (CV)[b]	Mean Temp. for positive egg or yolk-sac samples	Mean temperature all CalVETs
1994	0.193 (0.210)	0.120 (0.91)	380,175 (174,880)	11.38	127,102 (0.32)	14.3	14.7
1995	0.830 (05)	0.400 (0.4)	113,188.9 (113188.9)	23.55[c]	79,997 (0.6)	15.5	14.7
1996	0.415 (0.42)	0.105 (4.15)	235,960 (112,322)	23.55	83,176 (0.48)	14.5	15.0
1997	2.770 (0.21)	0.350 (0.14)	174,096 (66,841)	23.55[d]	409,579 (0.31)	13.7	13.9
1998	2.279 (0.34)	0.255 (0.37)	162,253 (162,253)	23.55	313,986 (0.41)	14.38	14.6
1999	1.092 (0.35)	0.100 (0.6)	304,191 (130,890)	23.55	282,248 (0.42)	12.5	12.6
2000	4.235 (0.4)	0.420 (0.73)	295,759 (57,525)	23.55	1,063,837 (0.67)	14.1	14.4
2001	2.898 (0.39)	0.370 (0.21)	321,386 (70,148)	23.55	790,925 (0.45)	13.3	13.2
2002	0.728 (0.17)	0.400 (0.15)	325,082 (88,403)	22.94	206,333 (0.35)	13.6	13.6
2003	1.520 (0.18)	0.480 (0.08)	365,906 (82,578)	22.94	485,121 (0.36)	13.7	13.8
2004	0.960 (0.24)	0.250 (0.04)	320,620 (68,234)	21.86[e]	281,639 (0.3)	13.4	13.7
2005	1.916 (0.417)	0.579 (0.20)	253,620 (46,203)	15.67	621,657 (0.54)	14.21	14.1
2006	1.936 (0.256)	0.31 (0.25)	336,774 (98,034)	15.57[f]	837,501[f] (0.46)	14.95	14.5
2007	0.864 (0.256)	0.133(0.36)	356,159 (142,403)	15.68	392,492 (0.45)	13.7	13.6
2008	0.430 (0.20)	0.13 (0.28)	296,306 (53,514)	21.82	116,778 (0.43)	13.3	13.1

[a] weighted non-linear regression on original data and bias correction of 1.04, except in 1994 and 1997 when grouped data and a correction factor of 1.14 was used (appendix Lo 2001).
[b] $CV(B_s) = (CV^2(P_0) + \text{allotherCOV}^2)^{1/2} = (CV^2(P_0)+0.054)^{1/2}$. For years 1995-2001 allotherCOV^2 was from 1994 data (Lo et al. 1996). For year 2003, allotherCOV was from 2002 data (Lo and Macewicz 2002)
[c] 23.55 was from computation for 1994 based on S = 0.149 (the average spawning fraction (day 0 + day 1) of active females from 1986-1994; Macewicz et al. 1996).
[d] is 25.94 when calculated from parameters in table 6 and estimated spawning biomass is 371,725 mt with CV = 0.36.
[c] uses R = 0.5 (Lo and Macewicz 2004); if use survey R = 0.618, then value is 27.0 and biomass is estimated at 227,746 mt
[f] value for standard DEPM sampling area off California when calculated using S = 0.126, the average of females spawning the night before capture ("day 1") from 1997, 2004, 2005, and 2007. When survey S of 0.0698 was previously used (Lo et al. 2007), the 2006 DEPM spawning biomass was estimated as 1,512,882 mt (CV 0.46) and the 2006 coast-wide spawning biomass was estimated as 1,682,260 mt.

Table 7. Fishery-independent indices of Pacific sardine abundance and the SST at Scripps Pier (three-year running average). The 2007 DEPM estimate (based on the April 2008 survey) was not included in the projection model.

Season	DEPM	CV	TEP	CV	SST at SIO Pier °C
1981	---	---	---	---	16.98
1982	---	---	---	---	17.05
1983	---	---	---	---	17.25
1984	---	---	---	---	17.58
1985	6,948	0.51	---	---	17.80
1986	---	---	---	---	17.87
1987	15,685	0.91	---	---	17.71
1988	13,514	0.60	---	---	17.55
1989	---	---	---	---	17.24
1990	---	---	---	---	17.19
1991	---	---	---	---	17.35
1992	---	---	---	---	17.61
1993	127,102	0.32	---	---	17.84
1994	---	---	93,947	0.50	17.97
1995	---	---	97,923	0.42	18.04
1996	371,725	0.31	---	---	18.07
1997	---	---	369,775	0.34	18.08
1998	---	---	332,177	0.35	18.47
1999	---	---	1,252,539	0.40	18.08
2000	---	---	931,377	0.39	17.75
2001	206,333	0.35	---	---	17.24
2002	---	---	556,177	0.18	17.31
2003	281,639	0.30	---	---	17.46
2004	621,657	0.54	---	---	17.60
2005	836,960	0.46	---	---	18.03
2006	392,492	0.45	---	---	18.11
2007	116,778	0.43	---	---	18.12
2008	---	---	---	---	17.83

Table 8. Parameter estimates and standard deviations for the update and projection models.

		UPDATE MODEL		PROJECTION MODEL	
Parameter	Estimated / Fixed / Derived	Value	Std_Dev	Value	Std_Dev
NatMort_young	Fixed	4.000E-01	---	4.000E-01	---
NatMort_old	Fixed	4.000E-01	---	4.000E-01	---
Length_Amin	Estimated	9.78E+00	9.95E-02	9.75E+00	1.00E-01
Length_Amax	Estimated	2.39E+01	9.63E-02	2.38E+01	7.87E-02
VonBert_K	Estimated	5.48E-01	1.37E-02	5.72E-01	1.11E-02
CV_young	Estimated	1.94E-01	4.55E-03	2.00E-01	4.35E-03
CV_old	Estimated	3.87E-02	1.72E-03	3.64E-02	1.57E-03
Log_R0	Estimated	1.50E+01	1.84E-01	1.54E+01	1.41E-01
R1_(R0 offset)	Estimated	-5.94E+00	4.01E-01	-6.19E+00	2.27E-01
Steepness	Estimated	2.71E+00	1.99E-01	2.59E+00	1.50E-01
Sigma-R	Fixed	7.649E-01	---	7.649E-01	---
Rdev-1975	Estimated	-1.60E+00	4.93E-01	-1.63E+00	4.91E-01
Rdev-1976	Estimated	-1.66E+00	4.84E-01	-1.70E+00	4.81E-01
Rdev-1977	Estimated	-1.46E+00	4.85E-01	-1.51E+00	4.81E-01
Rdev-1978	Estimated	-7.35E-01	3.99E-01	-8.11E-01	3.95E-01
Rdev-1979	Estimated	-8.97E-02	2.78E-01	-1.64E-01	2.66E-01
Rdev-1980	Estimated	1.20E+00	2.03E-01	1.04E+00	1.83E-01
Rdev-1981	Estimated	-4.02E-01	3.33E-01	-4.10E-01	2.57E-01
Rdev-1982	Estimated	-2.15E-01	4.20E-01	-4.67E-02	2.27E-01
Rdev-1983	Estimated	-4.84E-01	3.21E-01	-2.74E-01	1.87E-01
Rdev-1984	Estimated	-2.60E-01	2.00E-01	-1.28E-01	1.92E-01
Rdev-1985	Estimated	4.45E-01	1.98E-01	5.75E-01	1.78E-01
Rdev-1986	Estimated	5.39E-01	1.96E-01	5.95E-01	1.84E-01
Rdev-1987	Estimated	-1.89E-01	2.13E-01	-5.99E-03	1.84E-01
Rdev-1988	Estimated	-8.94E-01	1.92E-01	-7.28E-01	1.66E-01
Rdev-1989	Estimated	-4.95E-01	1.81E-01	-3.24E-01	1.57E-01
Rdev-1990	Estimated	-1.59E-01	1.68E-01	-6.88E-02	1.50E-01
Rdev-1991	Estimated	-7.64E-01	1.77E-01	-6.73E-01	1.59E-01
Rdev-1992	Estimated	1.71E-01	1.41E-01	1.94E-01	1.27E-01
Rdev-1993	Estimated	4.78E-01	1.23E-01	5.16E-01	1.09E-01
Rdev-1994	Estimated	-5.22E-01	1.07E-01	-4.68E-01	1.02E-01
Rdev-1995	Estimated	-9.22E-02	1.22E-01	-1.15E-02	1.18E-01
Rdev-1996	Estimated	7.09E-01	1.31E-01	8.53E-01	1.26E-01
Rdev-1997	Estimated	1.37E+00	9.68E-02	1.59E+00	1.02E-01
Rdev-1998	Estimated	6.90E-02	1.46E-01	2.92E-01	1.47E-01
Rdev-1999	Estimated	1.90E-01	2.77E-01	4.83E-01	2.54E-01
Rdev-2000	Estimated	1.63E+00	2.73E-01	1.99E+00	2.67E-01
Rdev-2001	Estimated	-6.88E-01	2.16E-01	-2.74E-01	2.38E-01
Rdev-2002	Estimated	1.59E+00	1.34E-01	1.77E+00	1.77E-01
Rdev-2003	Estimated	6.67E-01	1.18E-01	2.93E-01	1.62E-01
Rdev-2004	Estimated	1.28E+00	1.66E-01	4.58E-01	2.18E-01
Rdev-2005	Estimated	1.09E-01	2.49E-01	-1.23E+00	3.18E-01
Rdev-2006	Estimated	4.29E-01	3.62E-01	-1.84E-01	7.53E-01
Rdev-2007	Estimated	-1.64E-01	7.53E-01	---	---
Q_DEPM (Ln scale)	Estimated	-4.32E-01	2.56E-01	-7.53E-01	2.24E-01
Q_TEP (Ln scale)	Estimated	-2.50E-01	2.86E-01	-8.27E-01	2.55E-01

Table 8 cont. Parameter estimates and standard deviations for the update and projection models.

		UPDATE MODEL		PROJECTION MODEL	
Parameter	**Estimated / Fixed / Derived**	**Value**	**Std_Dev**	**Value**	**Std_Dev**
CA_selex_P1_Block1	Fixed	2.200E+01	---	2.200E+01	---
CA_selex_P1_Block2	Estimated	1.73E+01	1.42E-01	1.71E+01	1.29E-01
CA_selex_P1_Block3	Estimated	1.55E+01	9.41E-02	1.54E+01	9.08E-02
CA_selex_P2_Block1	Fixed	0.000E+00	---	0.000E+00	---
CA_selex_P2_Block2	Estimated	-2.06E+01	6.12E+03	-2.05E+01	5.80E+03
CA_selex_P2_Block3	Estimated	-2.43E+01	1.77E+04	-2.43E+01	1.54E+04
CA_selex_P3_Block1	Estimated	2.00E+00	6.31E-02	2.06E+00	4.99E-02
CA_selex_P3_Block2	Estimated	2.19E+00	7.35E-02	2.16E+00	7.23E-02
CA_selex_P3_Block3	Estimated	1.84E+00	6.64E-02	1.82E+00	7.17E-02
CA_selex_P4_Block1	Fixed	2.600E+00	---	2.600E+00	---
CA_selex_P4_Block2	Estimated	1.76E+00	1.42E-01	1.77E+00	1.26E-01
CA_selex_P4_Block3	Estimated	1.64E+00	7.79E-02	1.72E+00	7.18E-02
CA_selex_P5_Block1	Fixed	-1.000E+01	---	-1.000E+01	---
CA_selex_P5_Block2	Estimated	-7.52E+00	1.11E+00	-7.48E+00	1.11E+00
CA_selex_P5_Block3	Estimated	-6.84E+00	6.96E-01	-6.61E+00	7.40E-01
CA_selex_P6_Block1	Fixed	1.000E+01	---	1.000E+01	---
CA_selex_P6_Block2	Estimated	-3.10E+00	3.53E-01	-3.40E+00	3.45E-01
CA_selex_P6_Block3	Estimated	-4.03E+00	2.07E-01	-4.48E+00	2.00E-01
EN_selex_P1_Block1	Fixed	2.100E+01	---	2.100E+01	---
EN_selex_P1_Block2	Estimated	1.65E+01	2.47E-01	1.63E+01	2.20E-01
EN_selex_P1_Block3	Estimated	1.72E+01	4.37E-01	1.71E+01	4.18E-01
EN_selex_P2_Block1	Fixed	0.000E+00	---	0.000E+00	---
EN_selex_P2_Block2	Estimated	7.41E-02	1.14E-01	6.02E-02	1.23E-01
EN_selex_P2_Block3	Estimated	-1.41E+00	4.58E-01	-1.46E+00	4.65E-01
EN_selex_P3_Block1	Estimated	2.23E+00	6.01E-02	2.25E+00	5.75E-02
EN_selex_P3_Block2	Estimated	9.75E-01	2.20E-01	8.49E-01	2.19E-01
EN_selex_P3_Block3	Estimated	1.63E+00	3.15E-01	1.58E+00	3.20E-01
EN_selex_P4_Block1	Fixed	2.600E+00	---	2.600E+00	---
EN_selex_P4_Block2	Estimated	1.84E-01	4.38E-01	2.11E-01	4.51E-01
EN_selex_P4_Block3	Estimated	8.83E-01	3.85E-01	9.63E-01	3.54E-01
EN_selex_P5_Block1	Fixed	-1.000E+01	---	-1.000E+01	---
EN_selex_P5_Block2	Estimated	-8.98E+00	4.36E+00	-8.70E+00	3.77E+00
EN_selex_P5_Block3	Estimated	-6.66E+00	2.86E+00	-6.47E+00	2.74E+00
EN_selex_P6_Block1	Fixed	1.000E+01	---	1.000E+01	---
EN_selex_P6_Block2	Estimated	-2.67E+00	6.92E-01	-2.92E+00	6.78E-01
EN_selex_P6_Block3	Estimated	-5.06E+00	1.82E+00	-5.55E+00	2.04E+00
NW_selex_P1_Block1	Estimated	1.95E+01	1.44E-01	1.93E+01	1.32E-01
NW_selex_P1_Block2	Estimated	1.69E+01	1.65E-01	1.60E+01	1.97E-01
NW_selex_P2_Block1	Estimated	2.28E+00	1.61E-01	2.21E+00	1.72E-01
NW_selex_P2_Block2	Estimated	2.27E+00	1.56E-01	2.30E+00	2.27E-01

Table 8 cont. Parameter estimates and standard deviations for the update and projection models.

		UPDATE MODEL		PROJECTION MODEL	
Parameter	**Estimated / Fixed / Derived**	**Value**	**Std_Dev**	**Value**	**Std_Dev**
B0	Derived	6.16E+05	1.15E+05	9.24E+05	1.31E+05
Binit	Derived	1.62E+03	8.05E+02	1.89E+03	3.90E+02
SSB-1981	Derived	1.26E+03	6.75E+02	1.35E+03	2.19E+02
SSB-1982	Derived	1.87E+03	1.04E+03	1.95E+03	3.00E+02
SSB-1983	Derived	2.80E+03	1.27E+03	2.86E+03	2.60E+02
SSB-1984	Derived	2.90E+03	4.00E+02	3.14E+03	2.96E+02
SSB-1985	Derived	5.19E+03	6.28E+02	5.88E+03	5.62E+02
SSB-1986	Derived	8.89E+03	9.66E+02	1.03E+04	9.78E+02
SSB-1987	Derived	1.85E+04	2.09E+03	2.23E+04	2.38E+03
SSB-1988	Derived	4.18E+04	3.79E+03	4.96E+04	4.80E+03
SSB-1989	Derived	6.04E+04	5.78E+03	7.57E+04	7.98E+03
SSB-1990	Derived	7.56E+04	8.27E+03	1.01E+05	1.20E+04
SSB-1991	Derived	9.25E+04	1.31E+04	1.37E+05	1.96E+04
SSB-1992	Derived	1.19E+05	2.05E+04	1.93E+05	3.11E+04
SSB-1993	Derived	1.53E+05	2.75E+04	2.57E+05	4.14E+04
SSB-1994	Derived	2.47E+05	4.21E+04	4.12E+05	6.19E+04
SSB-1995	Derived	3.90E+05	6.51E+04	6.53E+05	9.41E+04
SSB-1996	Derived	4.50E+05	7.62E+04	7.59E+05	1.10E+05
SSB-1997	Derived	4.16E+05	7.98E+04	7.41E+05	1.15E+05
SSB-1998	Derived	5.04E+05	9.66E+04	9.01E+05	1.38E+05
SSB-1999	Derived	7.78E+05	1.37E+05	1.36E+06	1.95E+05
SSB-2000	Derived	8.17E+05	1.47E+05	1.46E+06	2.12E+05
SSB-2001	Derived	6.76E+05	1.31E+05	1.25E+06	1.89E+05
SSB-2002	Derived	5.73E+05	1.18E+05	1.08E+06	1.69E+05
SSB-2003	Derived	4.72E+05	1.07E+05	9.08E+05	1.50E+05
SSB-2004	Derived	5.92E+05	1.35E+05	9.91E+05	1.66E+05
SSB-2005	Derived	6.89E+05	1.65E+05	9.66E+05	1.77E+05
SSB-2006	Derived	7.54E+05	1.89E+05	8.24E+05	1.72E+05
SSB-2007	Derived	6.26E+05	1.83E+05	5.63E+05	1.48E+05
SSB-2008	Derived	4.80E+05	1.62E+05	4.26E+05	1.38E+05

Table 8 cont. Parameter estimates and standard deviations for the update and projection models.

		UPDATE MODEL		PROJECTION MODEL	
Parameter	**Estimated / Fixed / Derived**	**Value**	**Std_Dev**	**Value**	**Std_Dev**
R0	Derived	3.41E+06	6.27E+05	4.98E+06	7.01E+05
Rinit	Derived	8.97E+03	4.43E+03	1.02E+04	2.09E+03
R-1981	Derived	5.19E+04	1.15E+04	4.81E+04	6.11E+03
R-1982	Derived	9.28E+04	1.09E+04	9.94E+04	1.07E+04
R-1983	Derived	1.06E+05	1.19E+04	1.16E+05	1.26E+04
R-1984	Derived	1.37E+05	1.61E+04	1.47E+05	1.77E+04
R-1985	Derived	4.91E+05	5.12E+04	5.53E+05	5.92E+04
R-1986	Derived	9.09E+05	8.47E+04	9.76E+05	1.06E+05
R-1987	Derived	8.75E+05	1.07E+05	1.12E+06	1.42E+05
R-1988	Derived	8.82E+05	1.04E+05	1.12E+06	1.47E+05
R-1989	Derived	1.75E+06	2.15E+05	2.38E+06	3.20E+05
R-1990	Derived	2.87E+06	3.25E+05	3.81E+06	4.73E+05
R-1991	Derived	1.78E+06	2.67E+05	2.56E+06	3.86E+05
R-1992	Derived	5.19E+06	6.47E+05	7.34E+06	9.26E+05
R-1993	Derived	7.82E+06	9.39E+05	1.13E+07	1.34E+06
R-1994	Derived	3.07E+06	3.93E+05	4.37E+06	5.62E+05
R-1995	Derived	3.97E+06	4.93E+05	5.56E+06	6.95E+05
R-1996	Derived	7.84E+06	1.05E+06	1.14E+07	1.48E+06
R-1997	Derived	1.64E+07	1.95E+06	2.45E+07	2.84E+06
R-1998	Derived	3.65E+06	4.35E+05	5.19E+06	6.32E+05
R-1999	Derived	1.90E+06	2.36E+05	2.59E+06	3.31E+05
R-2000	Derived	7.09E+06	7.53E+05	9.64E+06	1.04E+06
R-2001	Derived	1.08E+06	2.05E+05	1.55E+06	2.70E+05
R-2002	Derived	1.41E+07	2.12E+06	1.64E+07	2.19E+06
R-2003	Derived	7.16E+06	1.18E+06	5.13E+06	8.00E+05
R-2004	Derived	9.82E+06	1.62E+06	5.23E+06	9.10E+05
R-2005	Derived	2.30E+06	4.37E+05	1.01E+06	2.67E+05
R-2006	Derived	2.60E+06	6.79E+05	3.66E+06	2.90E+06
R-2007	Derived	2.10E+06	1.69E+06	6.24E+06	4.82E+06
R-2008	Derived	3.61E+06	2.81E+06	6.94E+06	5.37E+06

Table 9. Likelihood components and derived quantities of interest for the update model (PS08_J14), the projection model (PS08_a), and a range of cases illustrating sensitivity to stepwise addition of new data.

New Data: Landings (EN, CA, NW)									
CA Length Comps '07-08									
NW Length Comps '07-08									
CA Age Comps '07-08									
NW Age Comps '07-08									
DEPM Survey '08									
Description:	**2007 FINAL**	**---- SENSITIVITY TO INCREMENTAL ADDITION OF NEW DATA ----**							**TUNED UPDATE**
Likelihood Component \ Model:	**PS07_J14**	**PS08_a**	**PS08_b**	**PS08_c**	**PS08_d**	**PS08_e**	**PS08_f**	**PS08_g**	**PS08_J14**
DEPM Index	-0.181	-0.194	-0.217	-2.077	-2.194	-1.985	2.045	-0.360	0.049
TEP Index	-0.958	-0.954	-0.965	-0.480	-0.167	-0.656	-1.281	-0.585	-0.603
Indices Subtotal	**-1.139**	**-1.148**	**-1.181**	**-2.557**	**-2.361**	**-2.641**	**0.764**	**-0.944**	**-0.554**
CA-len	2122.54	2122.29	2202.56	2132.48	2203.91	2238.06	2233.36	2237.37	2211.10
EN-len	842.57	842.59	843.82	861.14	876.25	877.61	846.18	878.26	861.26
NW-len	436.06	436.08	434.57	653.49	639.36	647.84	434.02	647.50	644.12
Length Comp Subtotal	**3401.17**	**3400.96**	**3480.96**	**3647.11**	**3719.52**	**3763.52**	**3513.56**	**3763.12**	**3716.49**
CA-age	2939.34	2939.55	2943.93	2967.74	2950.50	3077.72	3083.71	3079.66	2994.76
EN-age	684.19	684.18	687.25	697.34	704.95	710.23	692.43	710.38	704.36
NW-age	279.92	279.91	279.77	286.08	285.84	316.99	291.03	317.11	316.67
Age Comp Subtotal	**3903.44**	**3903.64**	**3910.95**	**3951.16**	**3941.30**	**4104.93**	**4067.16**	**4107.15**	**4015.80**
Recruitment	143.83	143.70	143.38	134.10	153.23	160.06	150.91	158.36	131.53
Penalties	0.0172	0.0175	0.0364	0.1215	1.9394	2.0255	0.0512	2.0353	0.1026
Forecast_Recruitment	-1.6081	-1.6081	-1.6081	-1.6081	-1.6081	-1.6081	-1.6081	-1.6081	-1.3401
TOTAL LIKELIHOOD	**7445.72**	**7445.56**	**7532.54**	**7728.33**	**7812.02**	**8026.29**	**7730.83**	**8028.12**	**7862.02**
Derived Quantities									
Steepness (*h*) (Ricker)	2.592	2.593	2.601	2.743	2.990	2.941	2.597	2.951	2.708
SSB-virgin (mt)	928,165	924,167	908,154	595,711	441,757	532,878	1,116,850	510,078	615,573
SSB-peak (mt)	1,462,240	1,456,100	1,427,840	792,570	586,166	705,611	1,751,240	681,348	817,219
R-virgin (billions)	5.006	4.985	4.906	3.283	2.458	2.973	6.049	2.848	3.411
R-peak (billions)	24.583	24.501	24.185	15.759	13.194	14.900	28.764	14.565	16.351
Biomass (1+) peak	1,713,280	1,706,520	1,676,290	974,993	745,729	878,371	2,029,490	851,542	1,002,330
Biomass (1+) - 2007	832,706	832,546	836,477	905,925	497,690	750,013	1,283,640	689,956	867,100
Biomass (1+) - 2008	---	**586,369**	582,246	666,302	415,770	561,477	921,606	502,999	**662,886**
HG - 2009	---	**56,946**	56,408	67,377	34,683	53,698	100,695	46,066	**66,932**

Table 10a. Pacific sardine biomass and population number-at-age (1,000s) from the update model (PS08_J14).

			Population numbers-at-age (1,000s of fish)								
Year	B1+ (mt)	SSB (mt)	0 (R)	1	2	3	4	5	6	7	8+
1981	1,315	1,257	22,460	15,055	2,832	1,010	332	185	134	545	1,109
1982	1,944	1,871	51,899	15,053	9,982	1,815	630	205	114	82	1,015
1983	2,904	2,803	92,817	34,725	9,396	5,194	818	268	86	47	457
1984	5,292	2,902	105,845	62,206	22,839	5,566	2,757	415	134	43	251
1985	5,919	5,193	137,075	70,837	33,539	5,130	382	154	23	7	16
1986	9,029	8,891	491,492	91,826	44,439	15,385	1,718	112	44	6	7
1987	19,674	18,480	909,451	328,776	56,692	21,719	6,189	640	41	16	5
1988	42,191	41,784	875,346	609,172	204,311	25,302	6,994	1,734	172	11	5
1989	70,887	60,375	882,228	586,570	398,877	119,887	13,325	3,524	863	85	8
1990	88,376	75,604	1,750,710	590,952	374,607	214,866	56,337	5,970	1,561	381	41
1991	117,160	92,485	2,868,990	1,171,950	373,759	200,777	101,795	25,603	2,686	701	190
1992	170,236	119,235	1,779,310	1,922,270	741,116	182,290	78,319	36,739	9,076	948	314
1993	170,178	153,156	5,193,670	1,159,590	852,797	277,971	81,513	41,041	21,116	5,458	778
1994	271,031	247,078	7,816,220	3,428,820	660,623	458,666	159,866	49,735	25,930	13,574	4,044
1995	437,942	389,916	3,067,160	5,112,020	1,835,900	342,460	260,356	97,034	31,303	16,606	11,387
1996	531,859	449,743	3,968,530	2,035,040	3,022,680	1,046,910	206,307	163,810	62,506	20,392	18,353
1997	559,613	415,710	7,840,520	2,634,600	1,203,720	1,714,080	628,608	129,624	105,448	40,701	25,402
1998	589,564	503,942	16,350,700	5,146,960	1,317,840	536,749	879,606	360,493	78,873	65,982	42,035
1999	887,809	778,204	3,648,960	10,794,800	2,763,760	673,113	301,732	531,079	226,102	50,371	69,710
2000	1,002,330	817,219	1,903,300	2,383,610	6,081,810	1,619,710	427,108	197,839	351,721	150,194	79,874
2001	878,841	676,213	7,085,900	1,222,280	1,248,710	3,421,320	996,695	271,521	126,987	226,395	148,253
2002	785,200	572,520	1,076,480	4,423,300	512,776	600,971	1,983,810	616,686	171,147	80,476	237,935
2003	610,683	471,793	14,062,800	681,624	1,938,160	241,322	337,694	1,193,160	378,467	105,656	197,091
2004	730,489	591,628	7,157,810	9,044,090	332,613	964,555	134,893	199,379	717,315	228,772	183,449
2005	847,585	688,977	9,820,410	4,688,740	4,979,150	170,758	535,835	78,903	118,727	429,491	247,390
2006	949,717	754,290	2,299,320	6,416,260	2,619,330	2,672,650	97,852	320,018	47,804	72,249	412,635
2007	867,100	625,704	2,602,900	1,468,360	3,341,290	1,408,500	1,574,410	60,179	199,587	29,940	304,295
2008	662,886	479,519	2,101,190	1,584,160	578,672	1,540,910	797,679	950,914	36,963	123,165	206,748

Table 10b. Pacific sardine biomass and population number-at-age (1,000s) from the projection model (PS08_a).

			Population numbers-at-age (1,000s of fish)								
Year	B1+ (mt)	SSB (mt)	0 (R)	1	2	3	4	5	6	7	8+
1981	1,403	1,352	21,754	14,582	2,985	1,063	360	202	147	619	1,259
1982	2,012	1,947	48,078	14,579	9,663	1,917	667	224	126	91	1,166
1983	2,890	2,858	99,419	32,157	9,060	5,051	887	296	98	55	549
1984	5,443	3,136	115,928	66,627	21,101	5,355	2,706	458	151	50	308
1985	6,417	5,879	147,239	77,559	35,171	4,587	414	154	26	9	20
1986	10,048	10,299	552,966	98,623	48,577	16,531	1,666	137	50	8	9
1987	22,606	22,296	975,907	369,864	61,083	24,552	7,181	686	56	20	7
1988	48,299	49,554	1,120,040	653,669	230,994	28,966	9,169	2,455	230	19	9
1989	84,517	75,679	1,119,960	750,535	428,622	138,170	15,978	4,912	1,306	122	15
1990	111,365	100,733	2,382,450	750,207	481,322	238,304	69,280	7,760	2,370	629	66
1991	158,487	137,366	3,813,570	1,595,040	478,643	269,775	122,422	34,682	3,864	1,179	346
1992	242,564	193,407	2,564,460	2,555,320	1,021,080	254,369	124,356	54,059	15,184	1,689	666
1993	271,728	256,587	7,343,470	1,681,800	1,276,140	469,244	133,255	72,451	33,355	9,615	1,511
1994	429,242	412,409	11,258,800	4,867,060	1,009,410	746,689	288,060	84,934	47,132	21,902	7,338
1995	700,286	652,947	4,368,680	7,410,790	2,806,360	578,522	455,484	183,195	55,156	30,893	19,254
1996	861,326	758,935	5,561,380	2,906,060	4,561,960	1,703,370	364,989	295,264	120,373	36,458	33,252
1997	914,794	740,950	11,398,100	3,700,310	1,784,820	2,751,550	1,071,070	236,252	193,858	79,525	46,213
1998	999,175	901,075	24,500,900	7,522,510	2,029,290	929,464	1,582,400	660,387	150,763	125,585	82,110
1999	1,490,210	1,363,330	5,185,020	16,243,900	4,359,370	1,157,370	565,335	1,004,980	428,450	98,734	136,709
2000	1,706,520	1,456,100	2,594,140	3,409,580	9,716,770	2,704,110	754,560	375,160	670,059	286,035	157,268
2001	1,542,430	1,245,470	9,637,800	1,681,920	1,931,440	5,859,070	1,731,000	492,422	246,065	440,082	291,301
2002	1,391,310	1,082,650	1,547,160	6,112,340	817,211	1,056,670	3,628,190	1,114,060	320,042	160,344	477,066
2003	1,132,110	908,239	16,372,400	992,551	3,064,700	442,186	643,982	2,302,690	714,641	205,887	410,559
2004	1,204,150	991,002	5,125,670	10,613,900	533,806	1,715,390	269,037	405,332	1,463,550	455,427	393,303
2005	1,211,420	966,117	5,231,430	3,358,960	6,034,630	299,217	1,037,190	168,476	256,388	928,288	538,921
2006	1,093,800	823,679	1,008,990	3,381,930	1,830,150	3,338,710	180,289	648,294	106,402	162,382	930,252
2007	832,546	562,754	3,658,360	608,481	1,438,460	914,870	1,968,420	112,484	410,611	67,664	696,100
2008	586,369	426,110	6,244,380	1,988,440	115,054	467,359	480,472	1,169,070	68,691	252,534	471,338

Table 11. Harvest guideline (ABC) for Pacific sardine for the 2009 management year based on the update and projection models. See 'Harvest Guideline' section for methods used to derive the harvest guideline.

Model	Stock biomass (age 1+, mt)	Cutoff (mt)	Fraction	Distribution	ABC for 2009 (mt)
Update	662,886	150,000	0.15	0.87	66,932
Projection	586,369	150,000	0.15	0.87	56,946

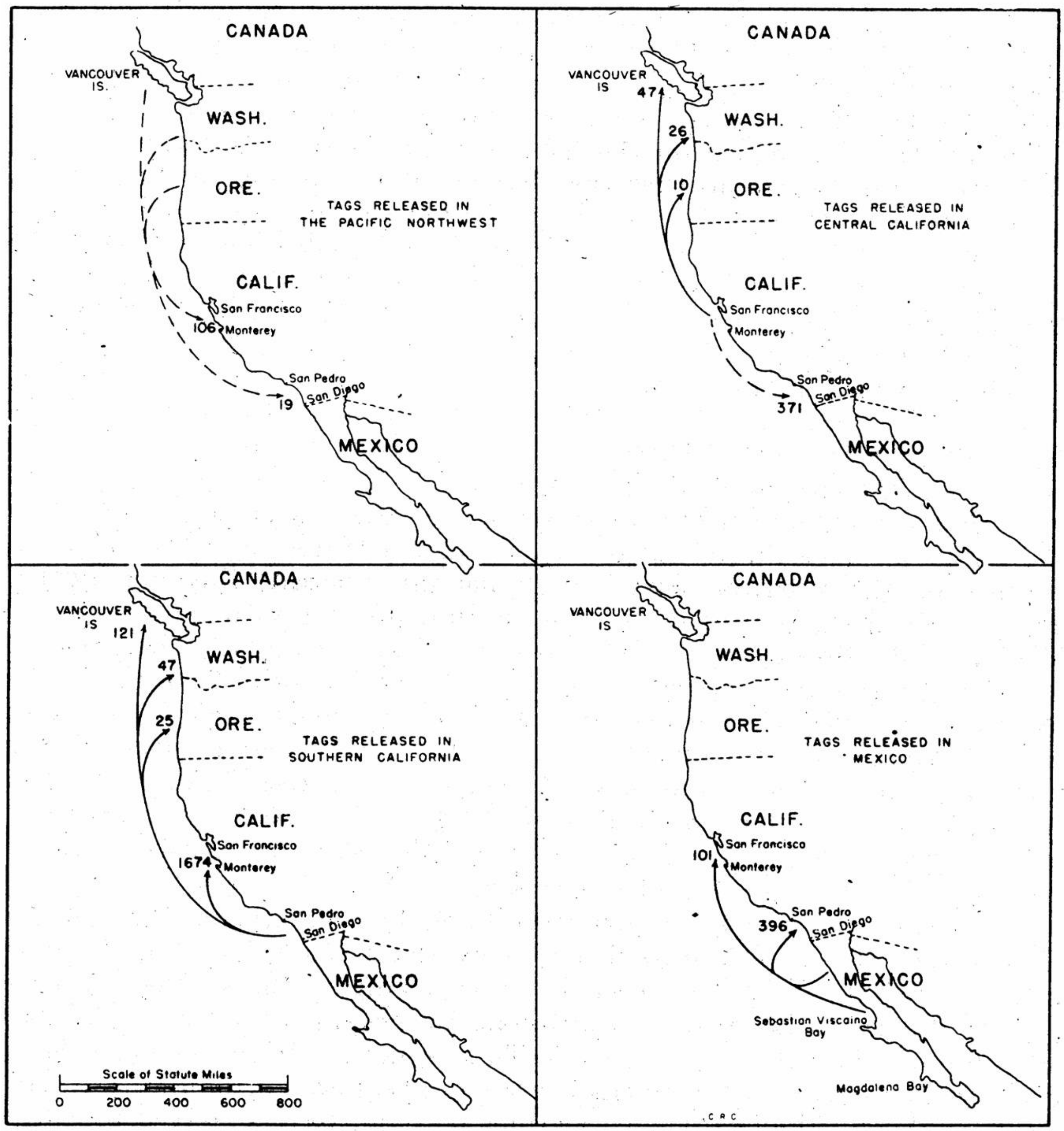


Figure 1. Sections of the Pacific Coast of North America showing the major movements of tagged sardines as indicated by recoveries from June 1935 to May, 1944 (reproduced from Clark and Janssen, 1945).

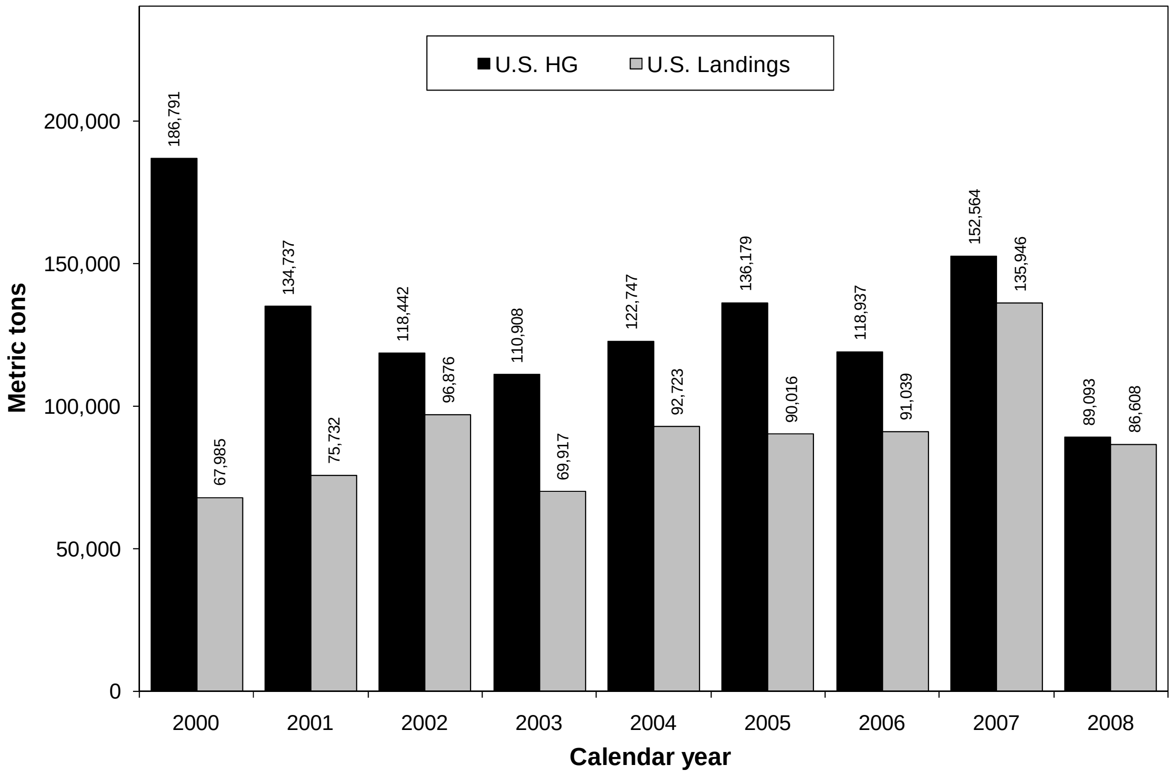


Figure 2a. Performance of the U.S. Pacific sardine fishery since calendar year 2000.

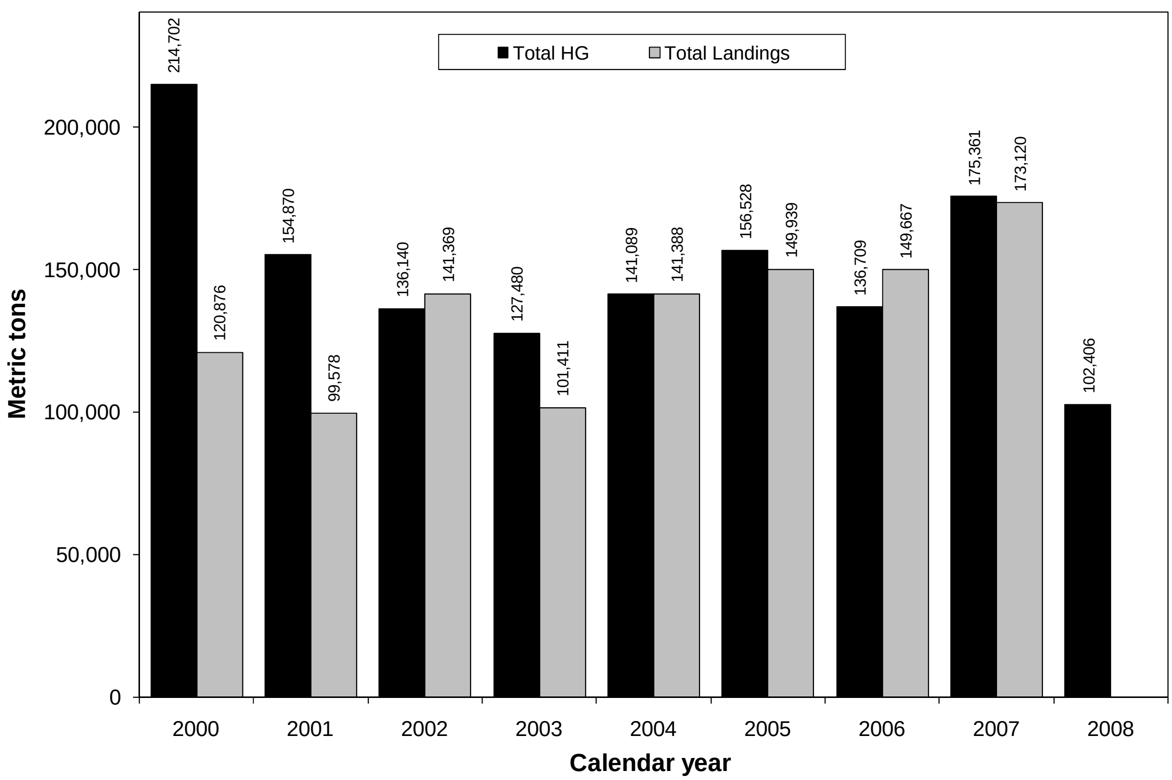


Figure 2b. Coast-wide harvest (Ensenada to British Columbia) and theoretical HGs since 2000.

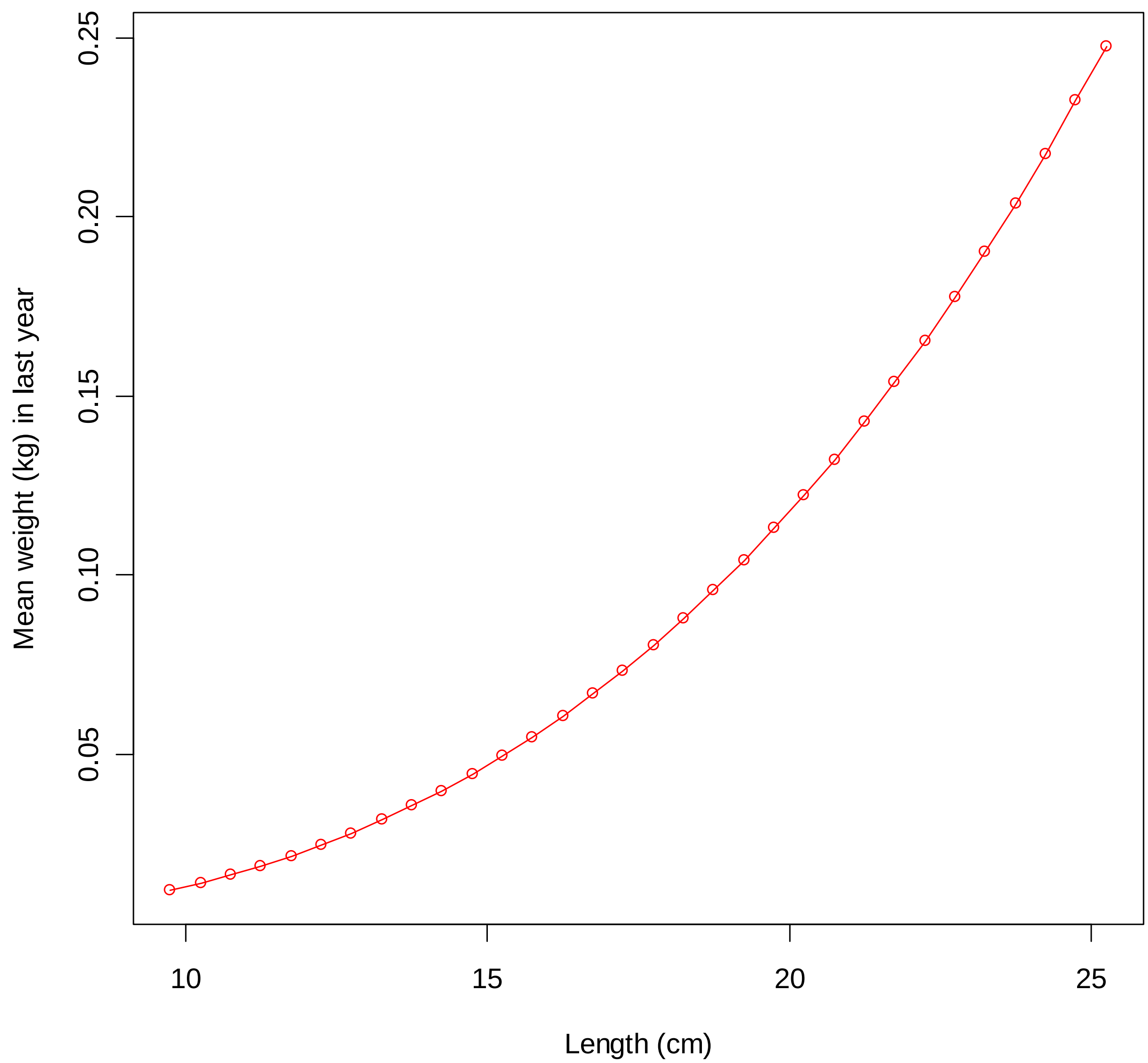


Figure 3. Weight-at-length as applied in the base model.

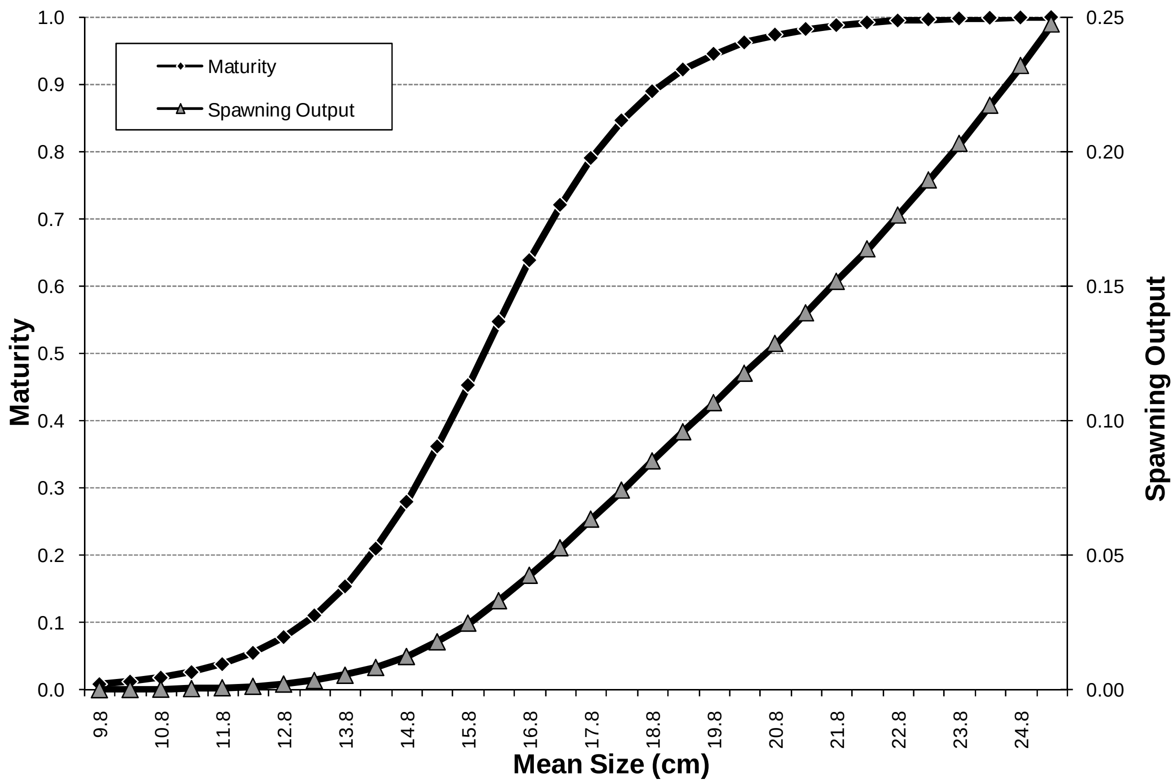


Figure 4a. Maturity and spawning output as a function of length in base model.

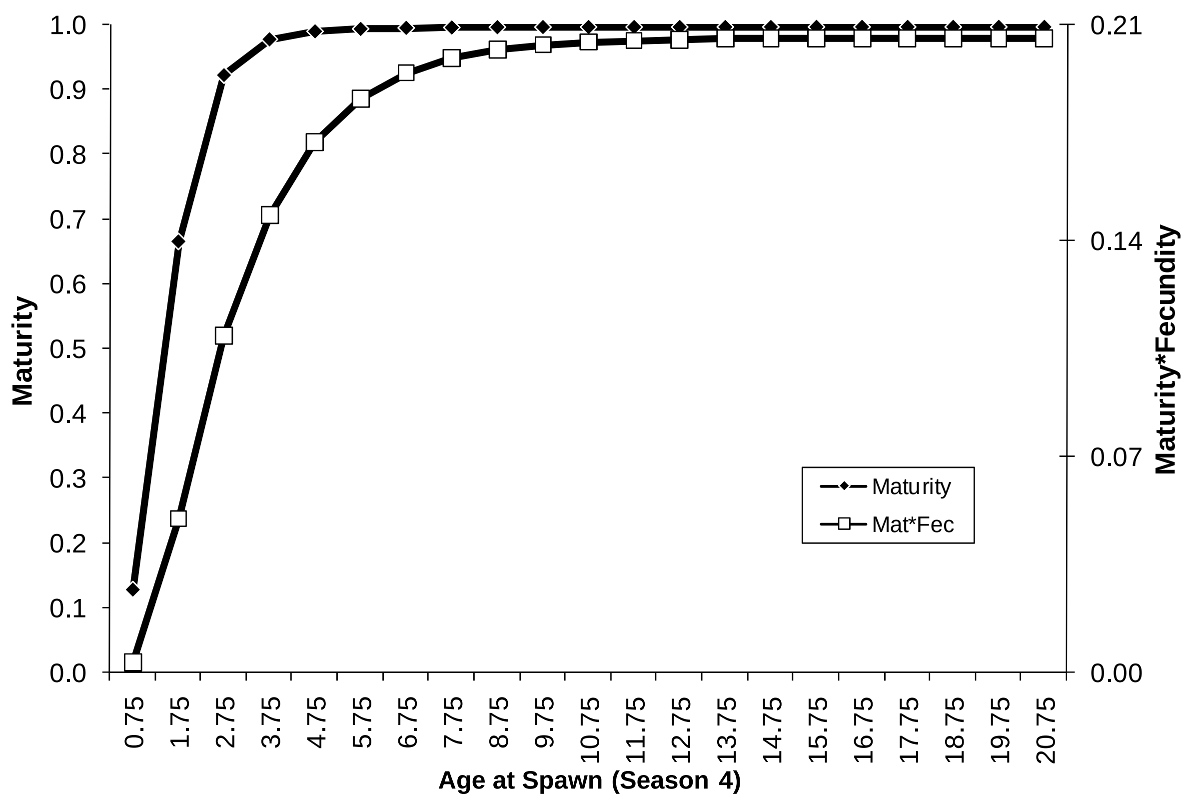


Figure 4b. Maturity and fecundity as a function of age in base model.

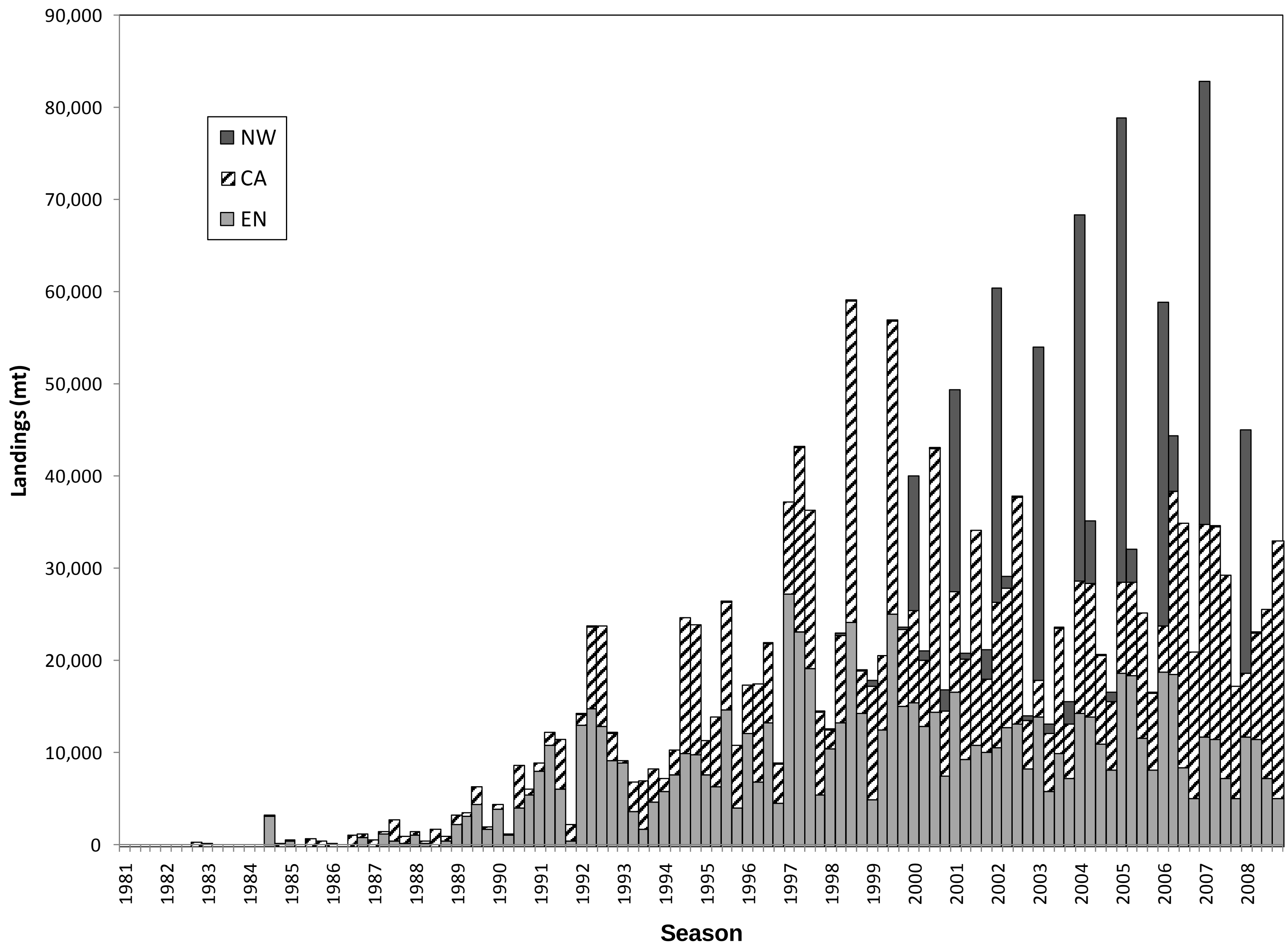


Figure 5. Pacific sardine landings (mt) by fishery and season used in the base model.

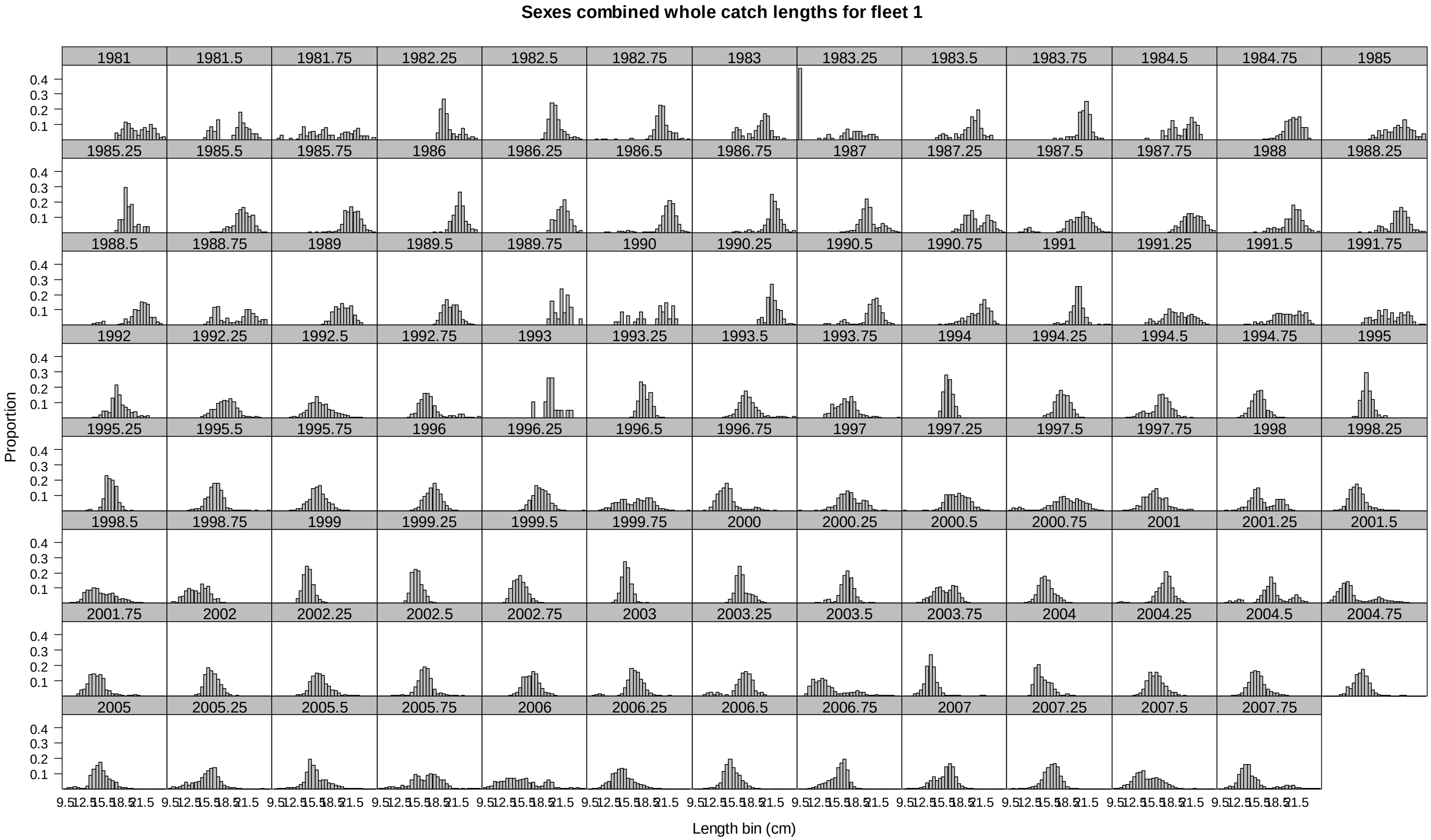


Figure 6. Length-composition data for the California fishery, 1981-2007. The projection model excludes 2007 data.

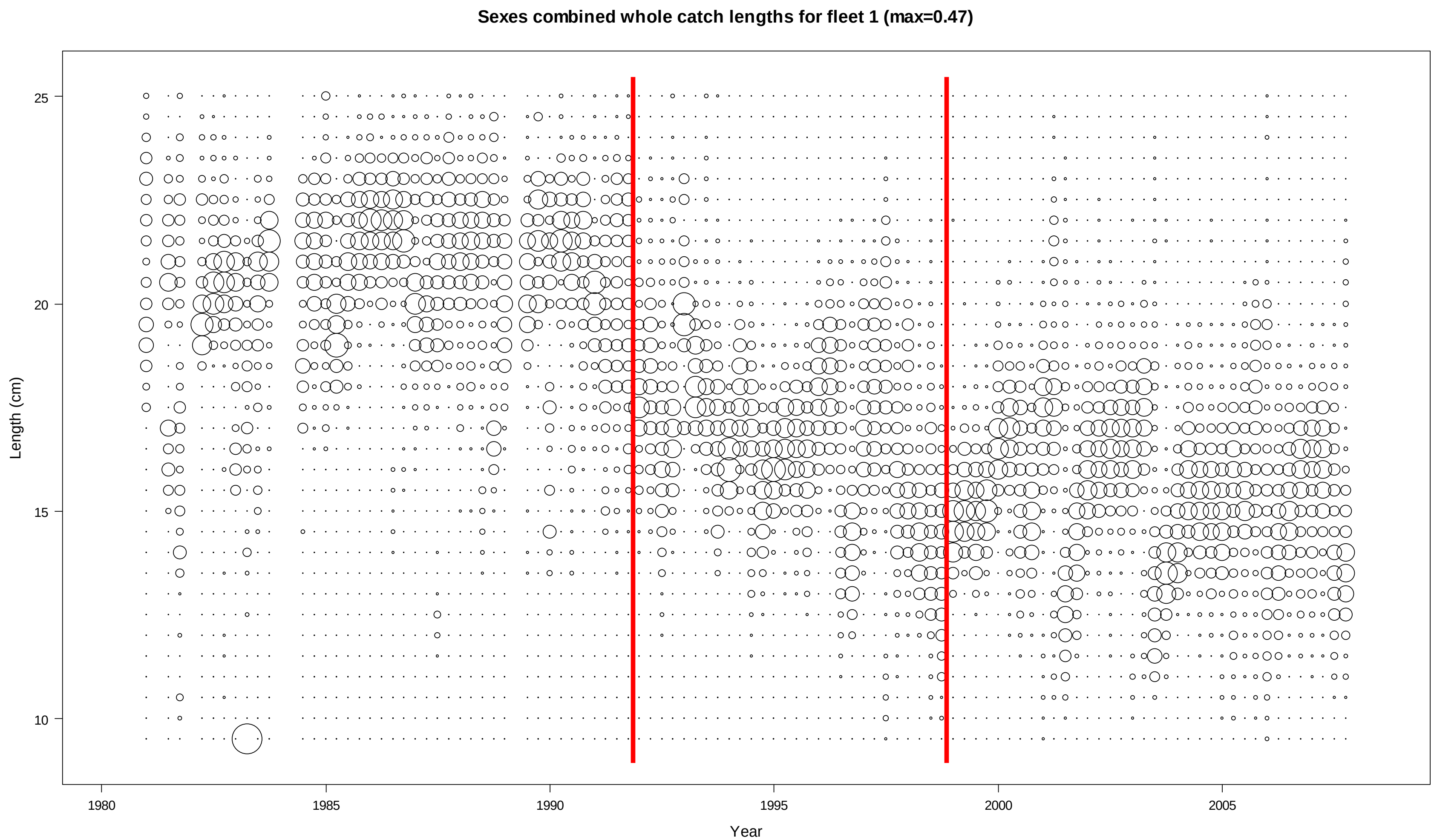


Figure 7. Length-composition data for the California fishery, 1981-2007. The projection model excludes 2007 data. Vertical line indicates selectivity period change.

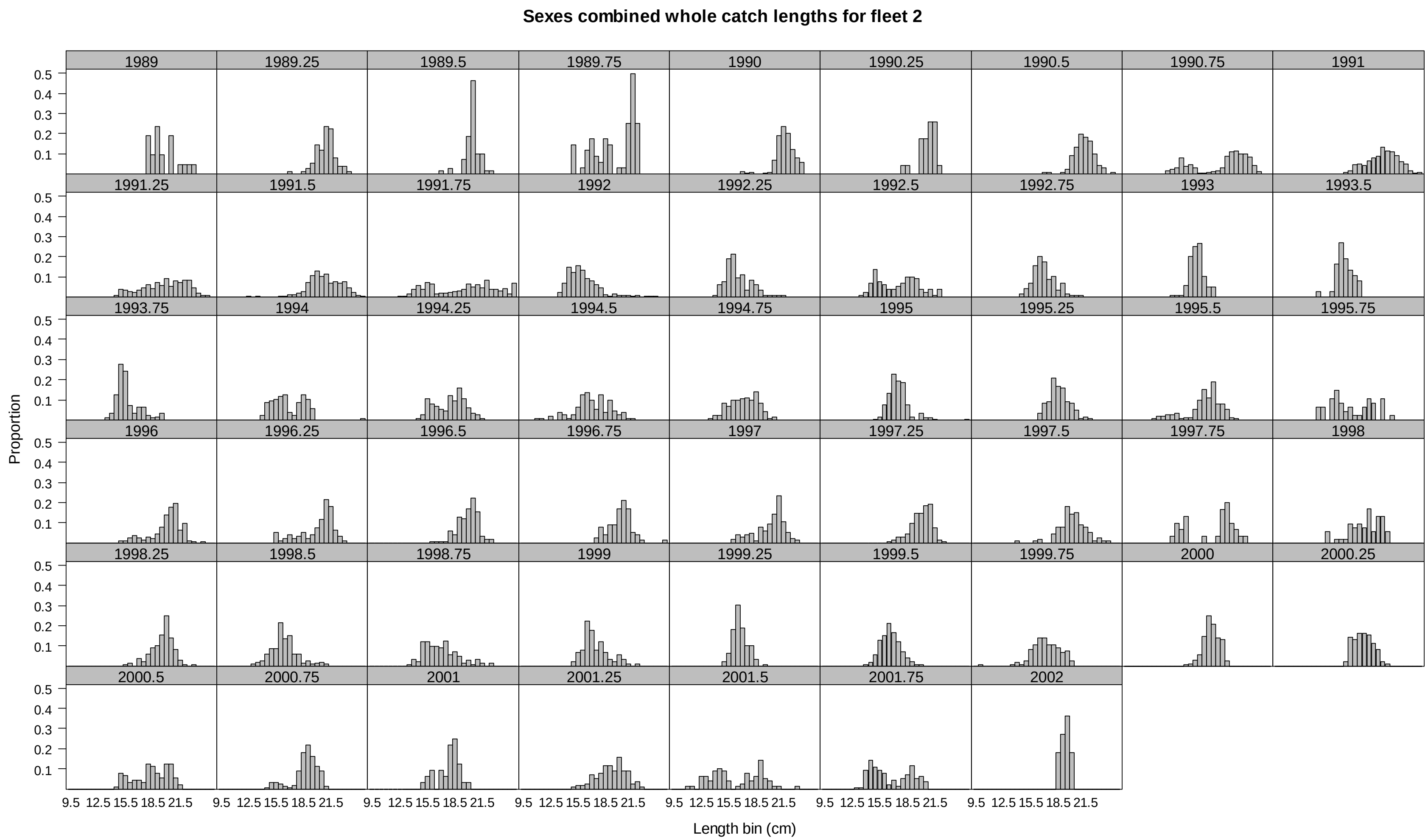


Figure 8. Length-composition data for the Ensenada fishery, 1989-2002.

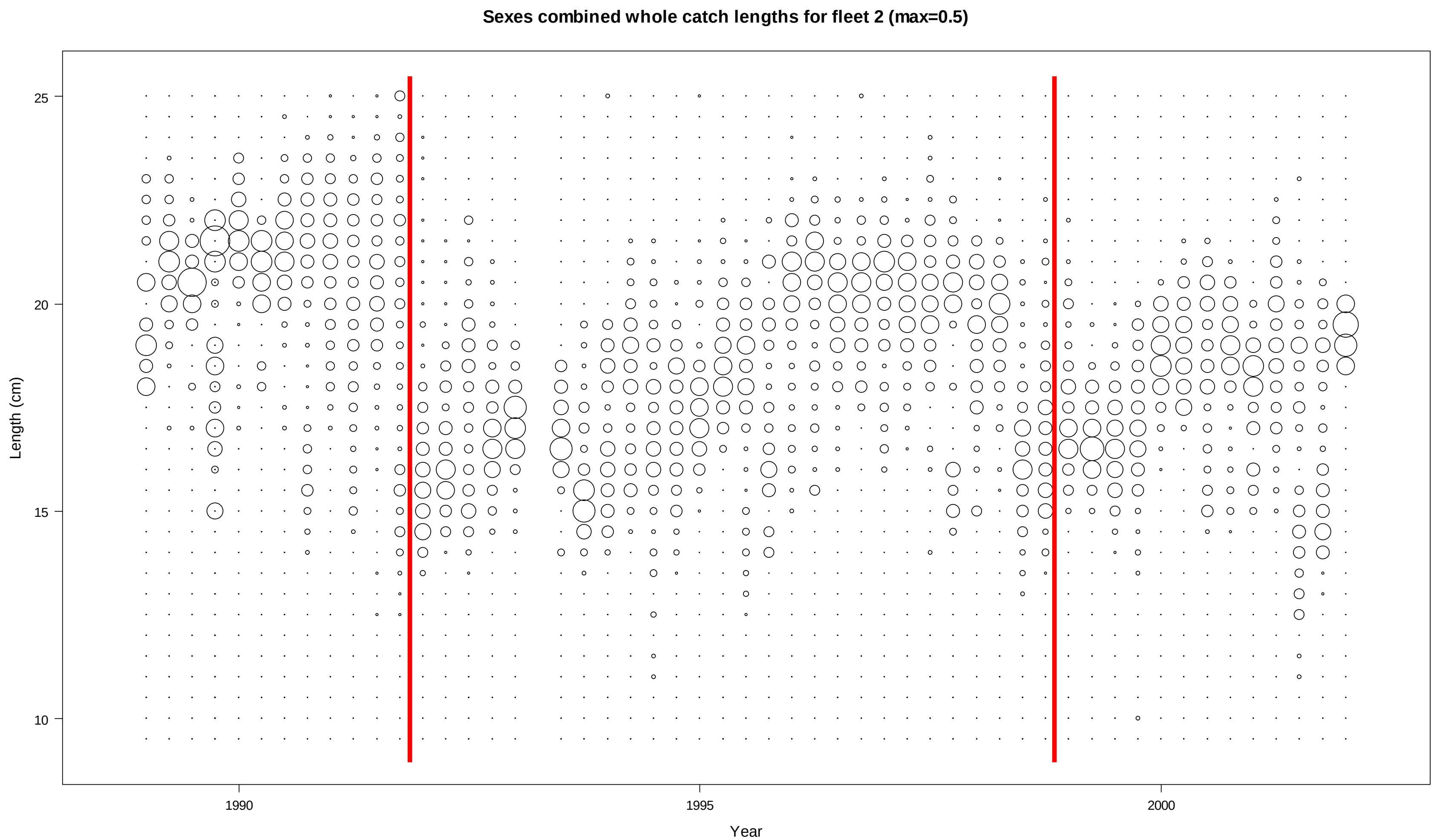


Figure 9. Length-composition data for the Ensenada fishery, 1989-2002. Vertical line indicates selectivity period change.

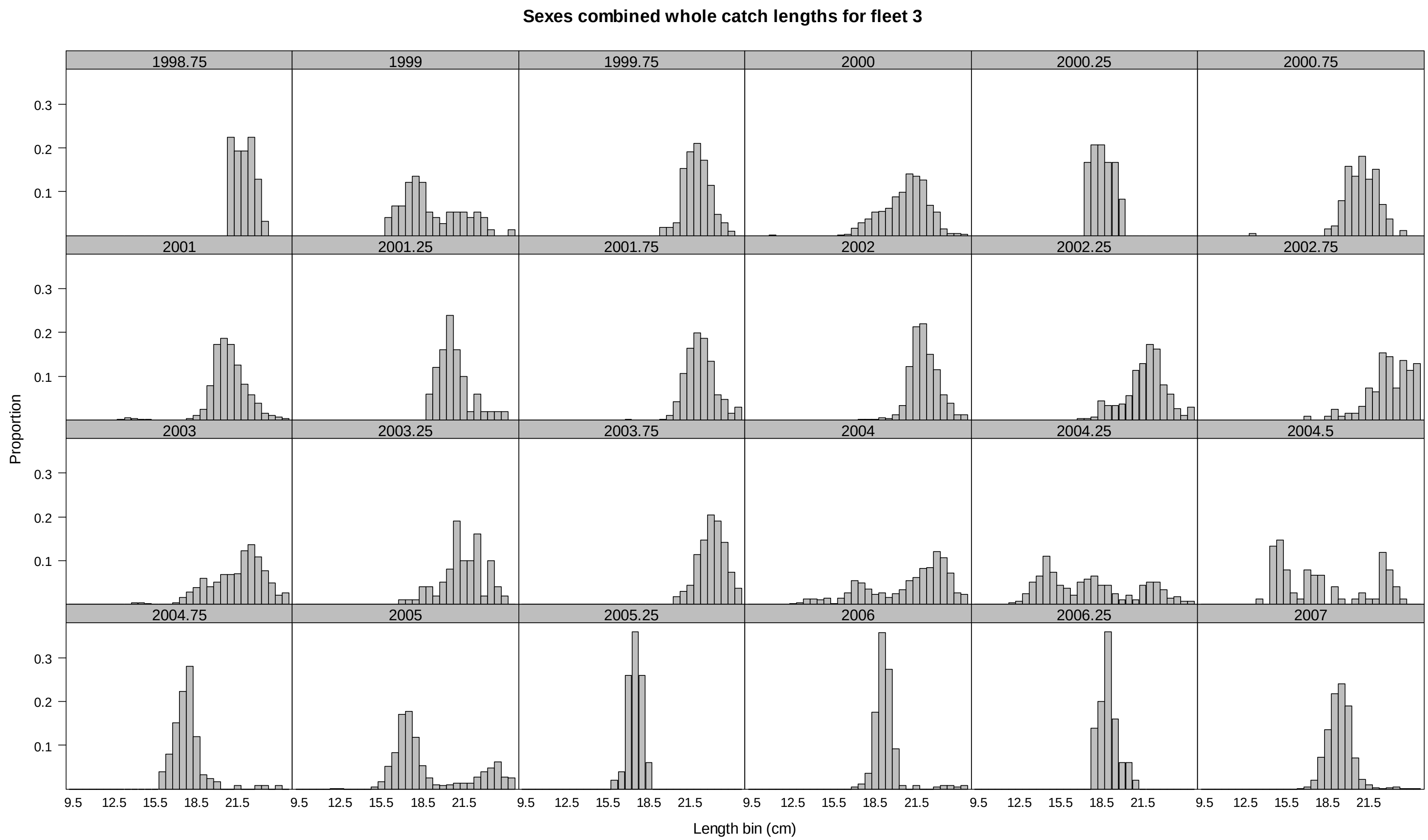


Figure 10. Length-composition data for the Pacific Northwest fishery, 1998-2007. The projection model excludes 2007 data.

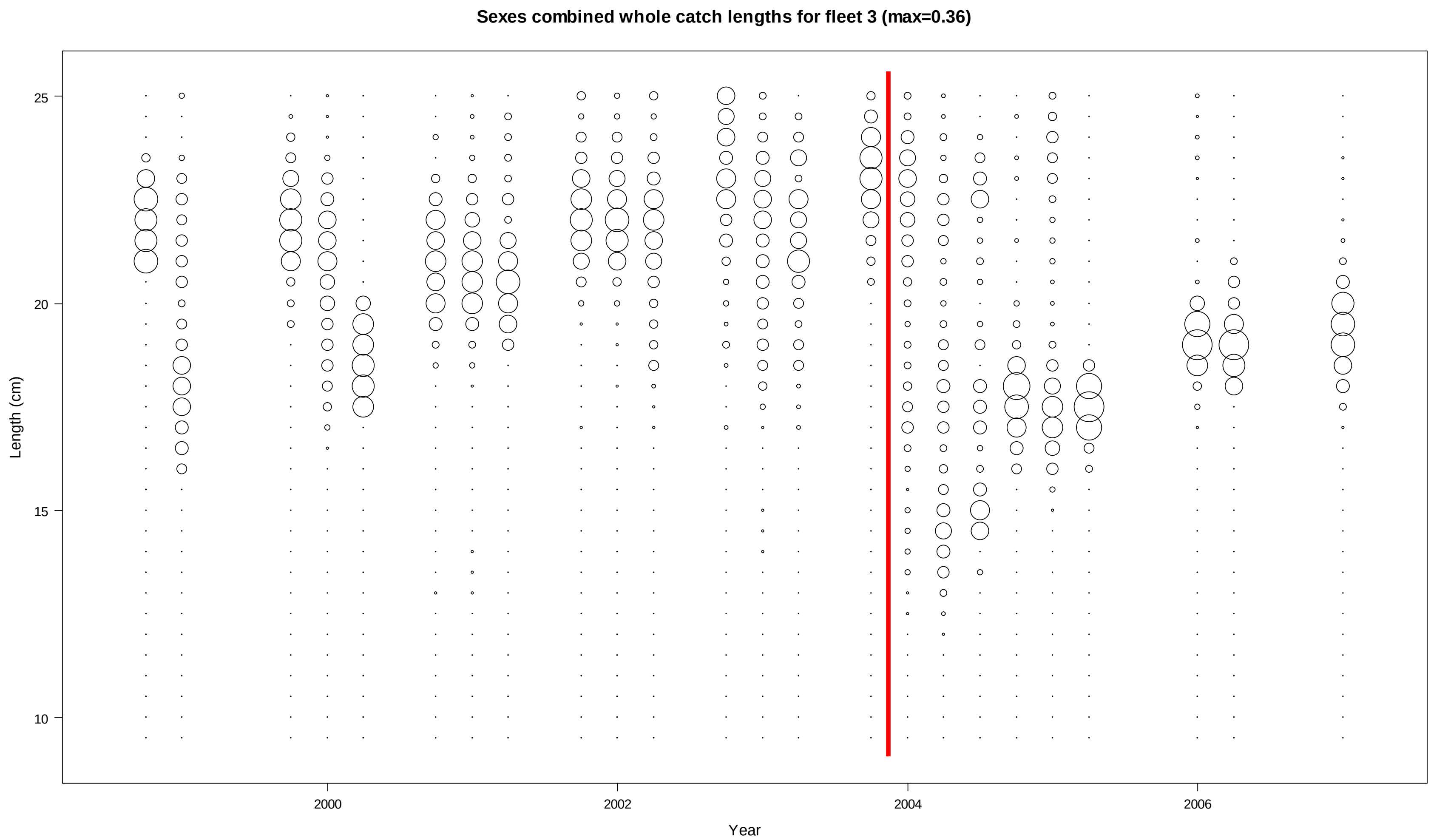


Figure 11. Length-composition data for the Pacific Northwest fishery, 1999-2007. The projection model excludes 2007 data. Vertical line indicates selectivity period change.

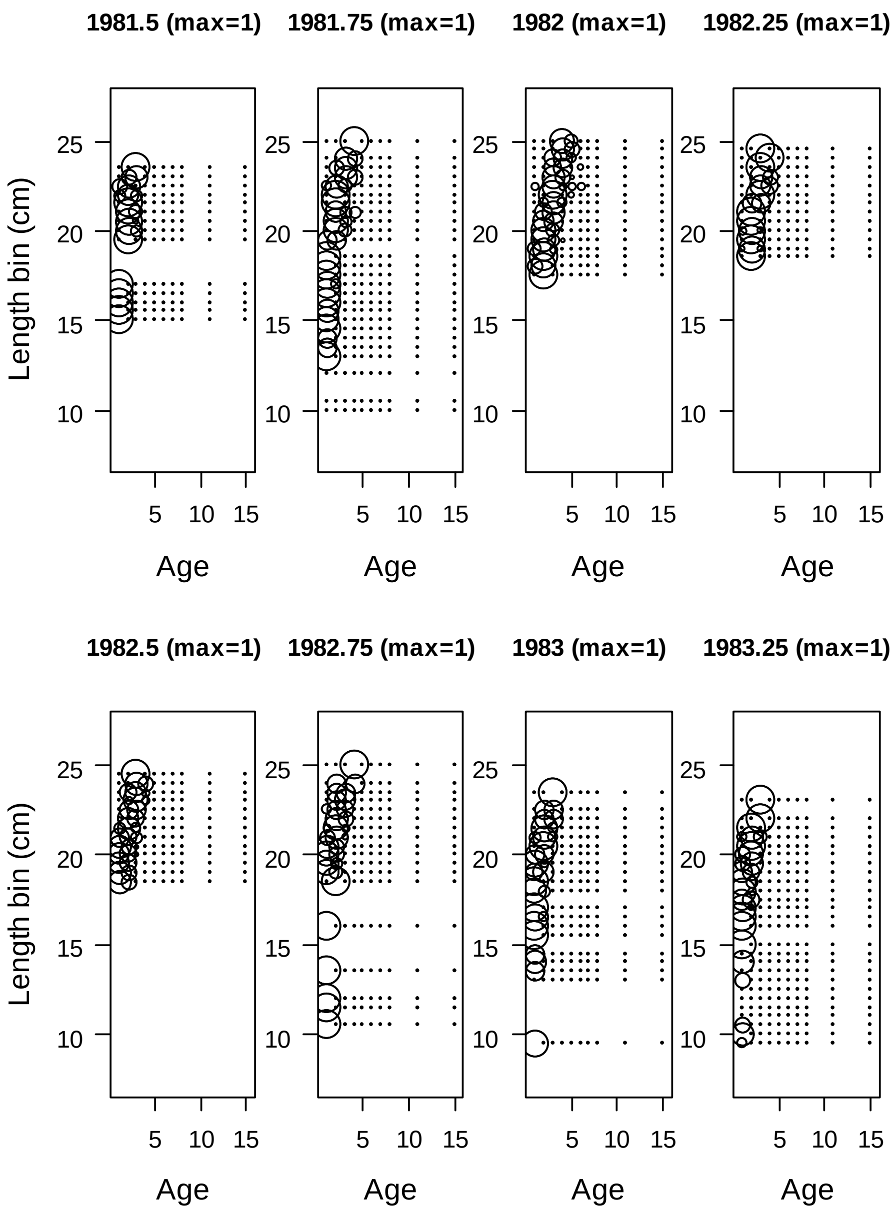


Figure 12. Conditional age-at-length data for the California fishery.

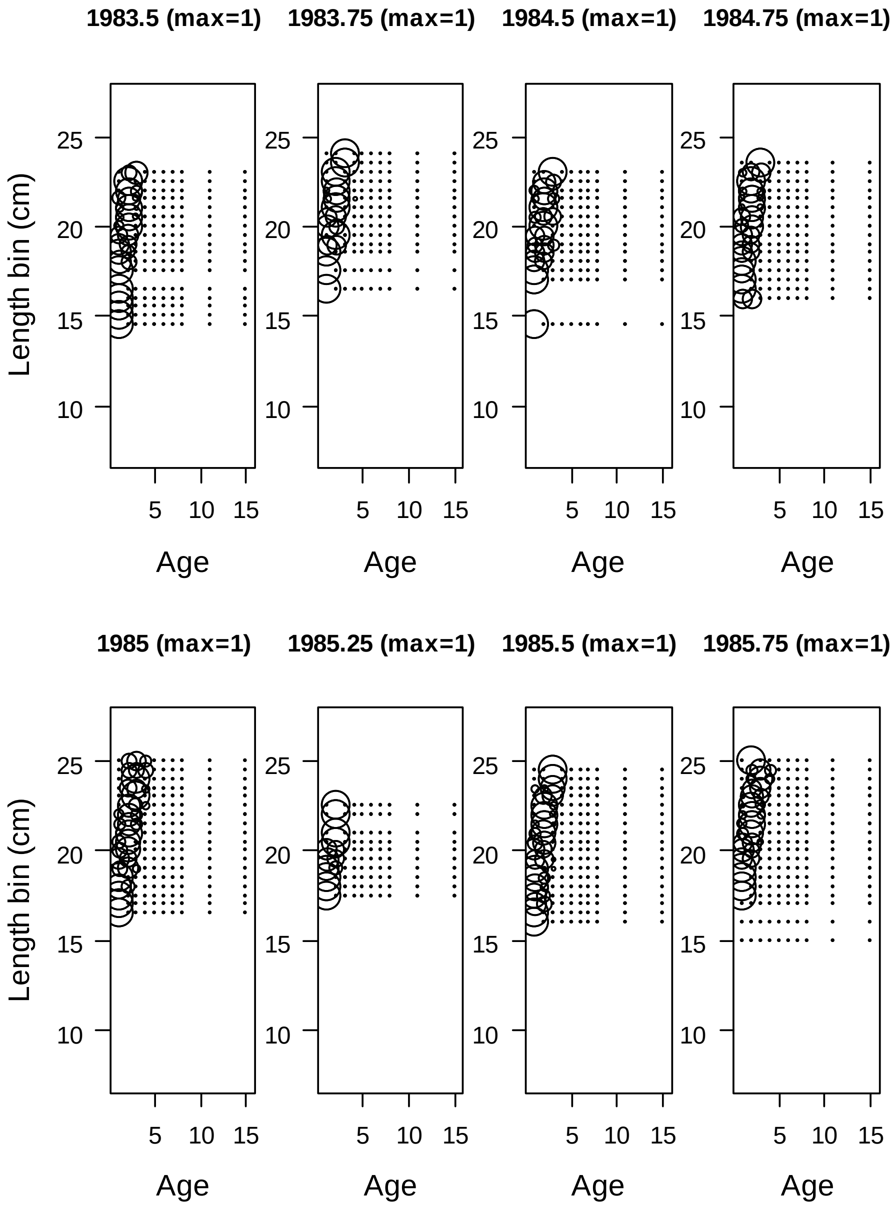


Figure 12 cont. Conditional age-at-length data for the California fishery.

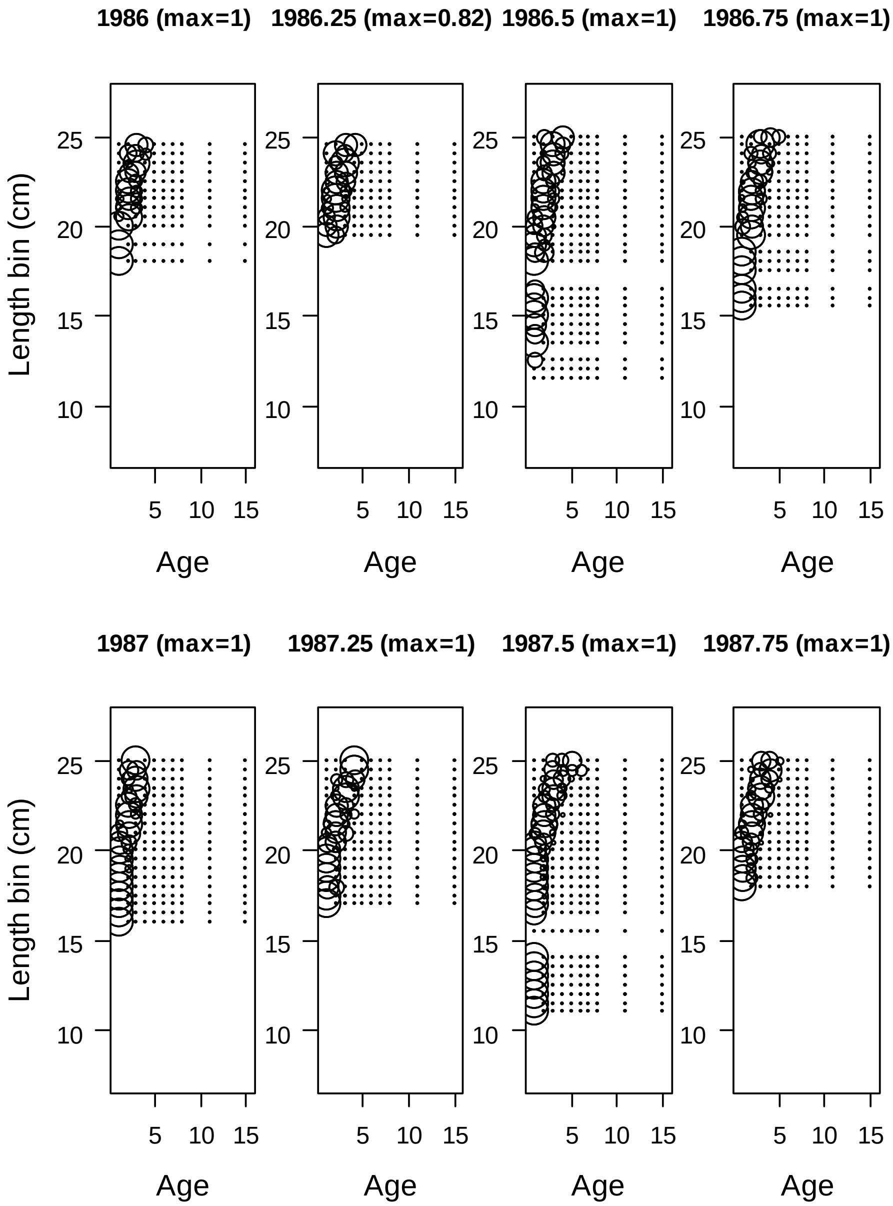


Figure 12 cont. Conditional age-at-length data for the California fishery.

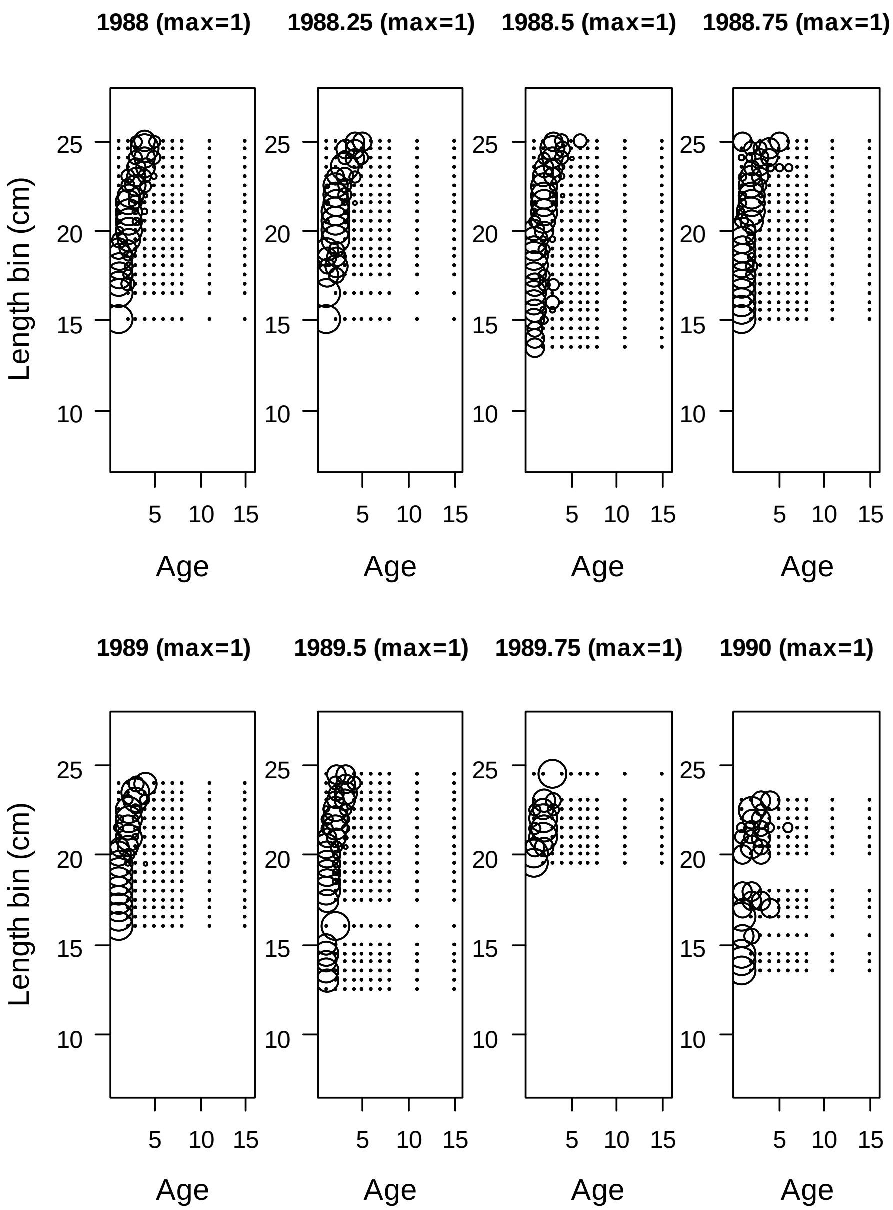


Figure 12 cont. Conditional age-at-length data for the California fishery.

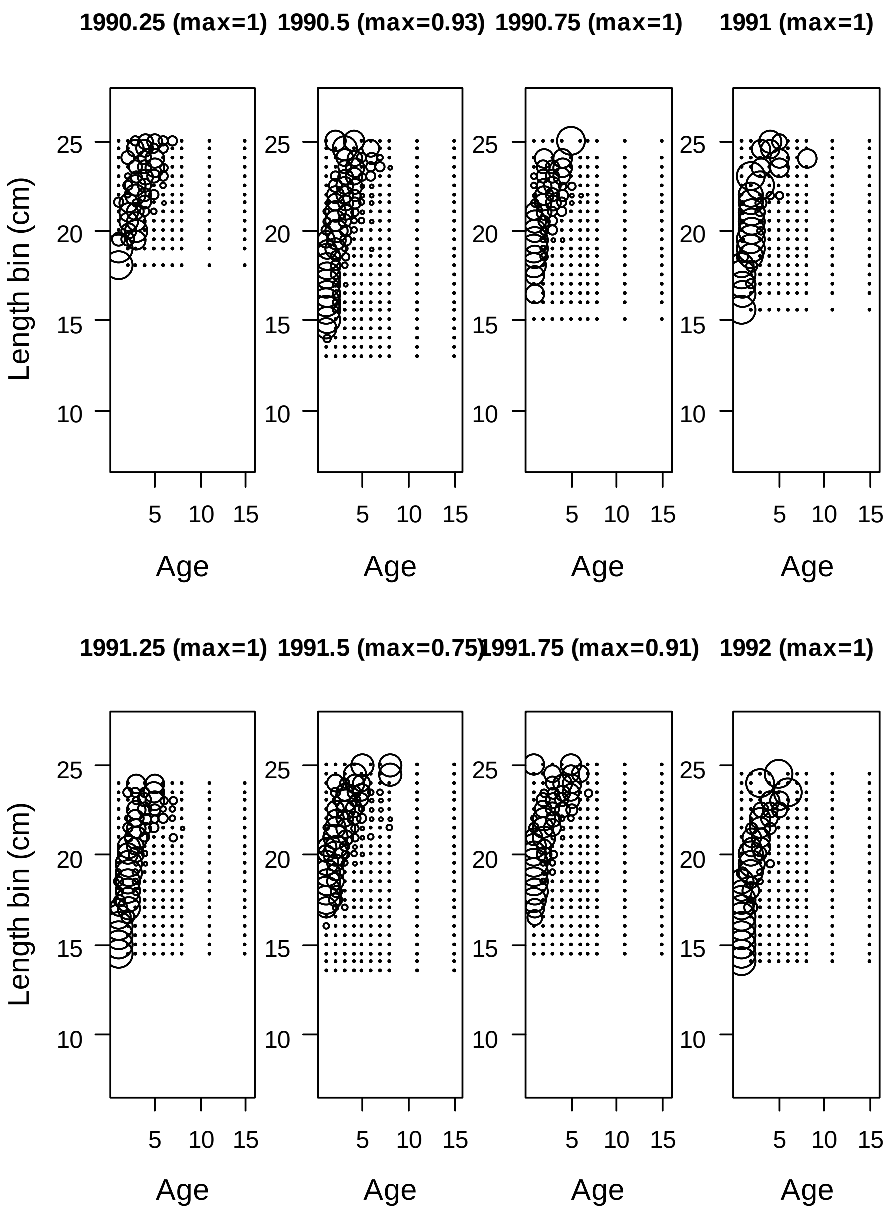


Figure 12 cont. Conditional age-at-length data for the California fishery.

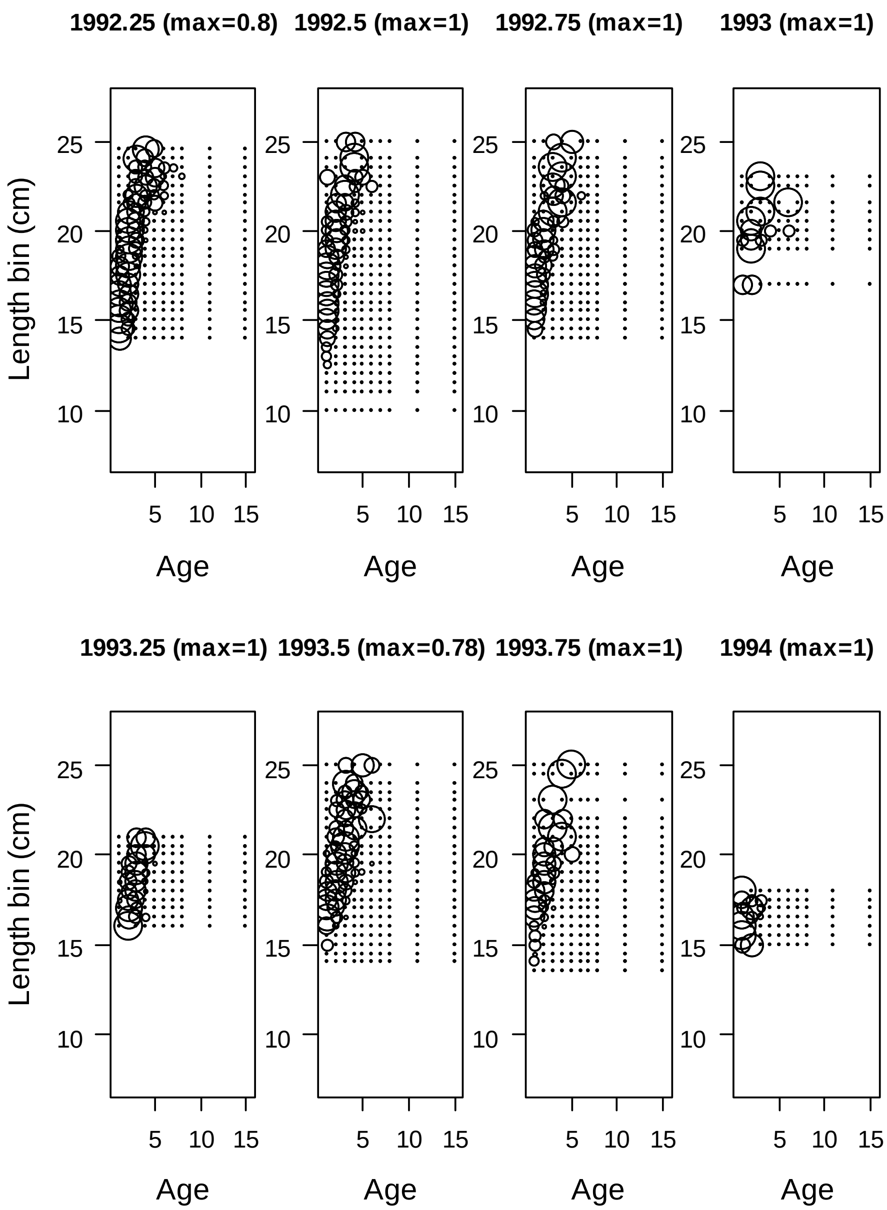


Figure 12 cont. Conditional age-at-length data for the California fishery.

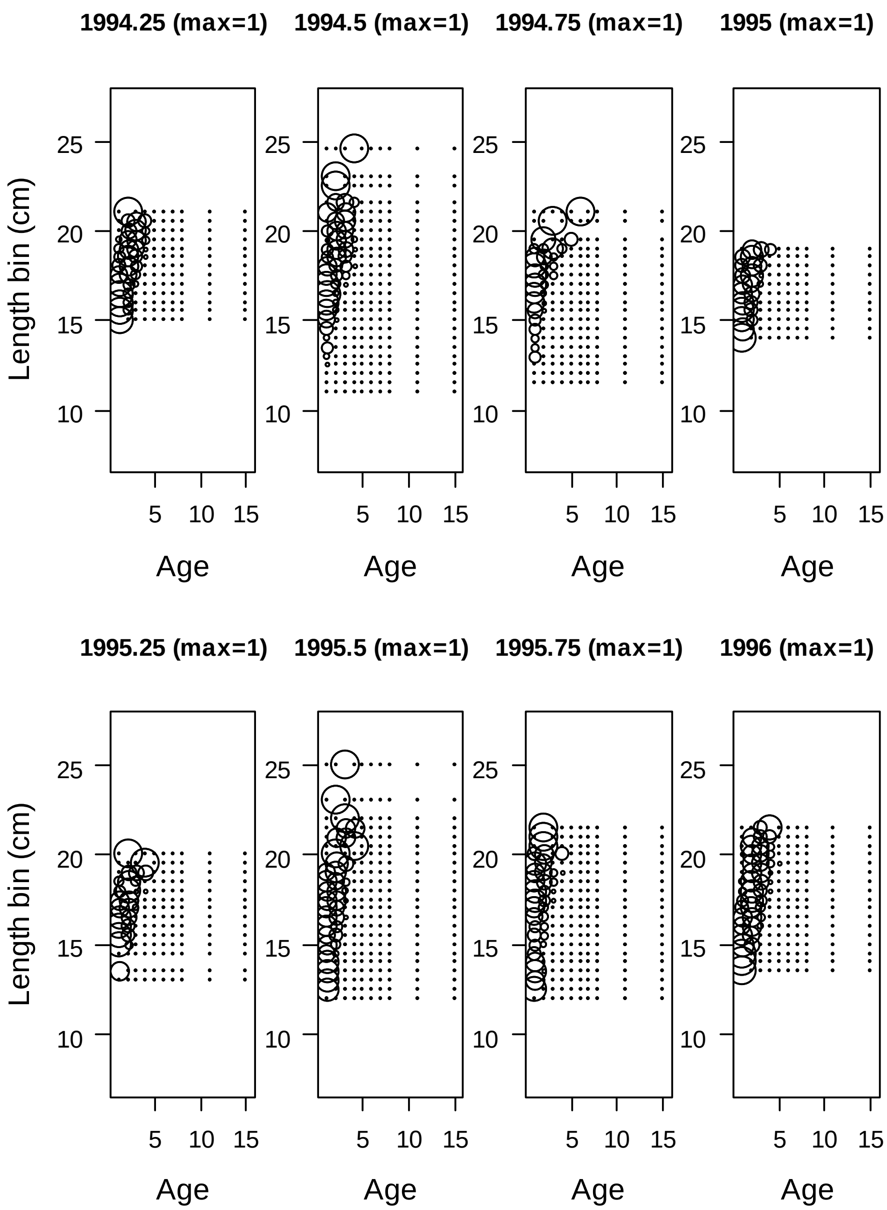


Figure 12 cont. Conditional age-at-length data for the California fishery.

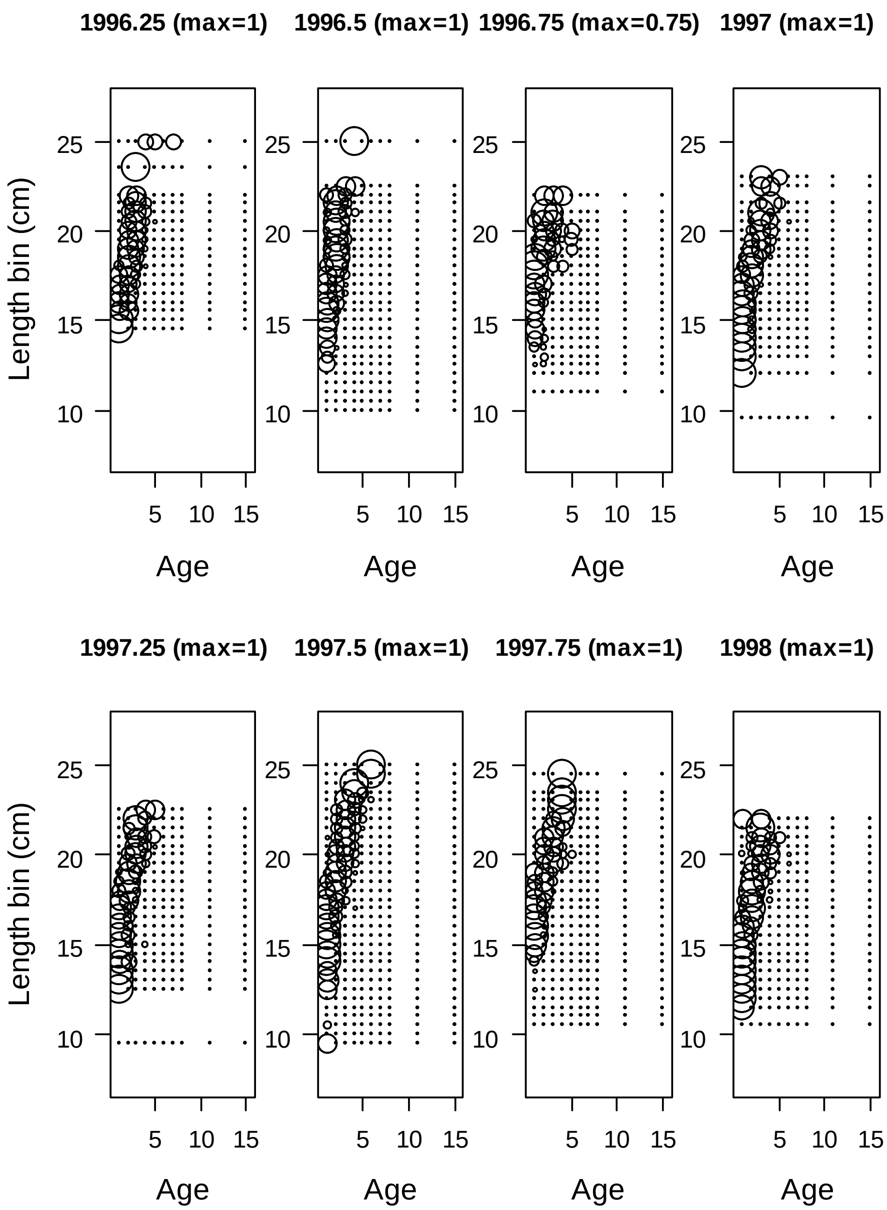


Figure 12 cont. Conditional age-at-length data for the California fishery.

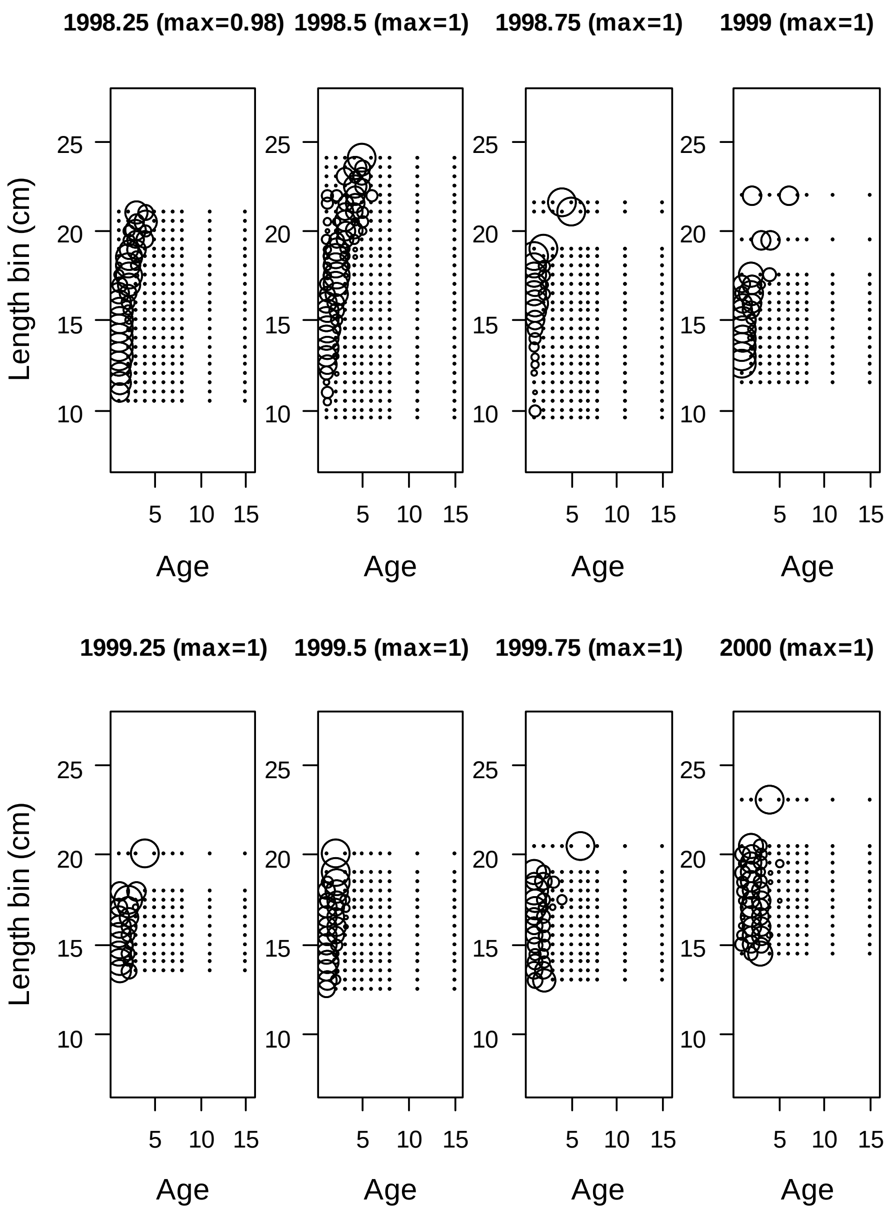


Figure 12 cont. Conditional age-at-length data for the California fishery.

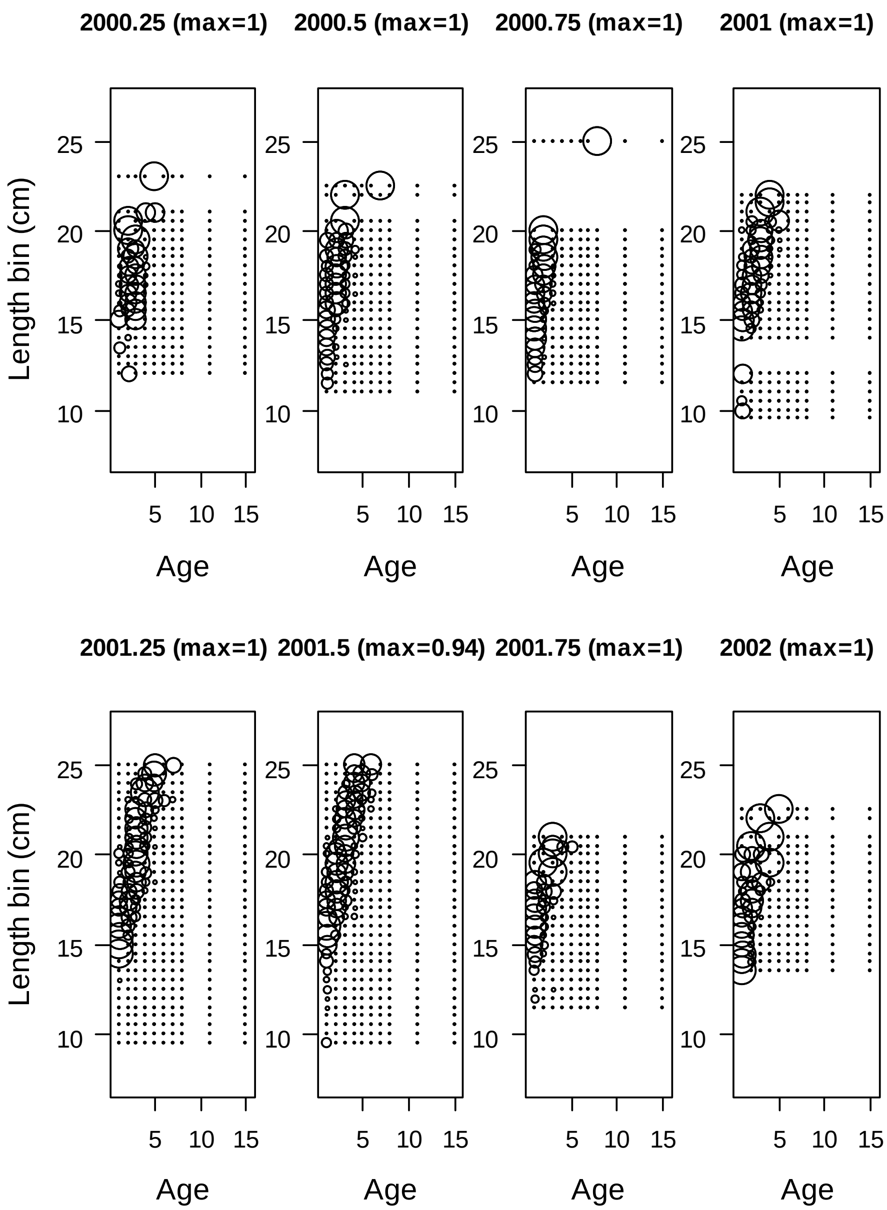


Figure 12 cont. Conditional age-at-length data for the California fishery.

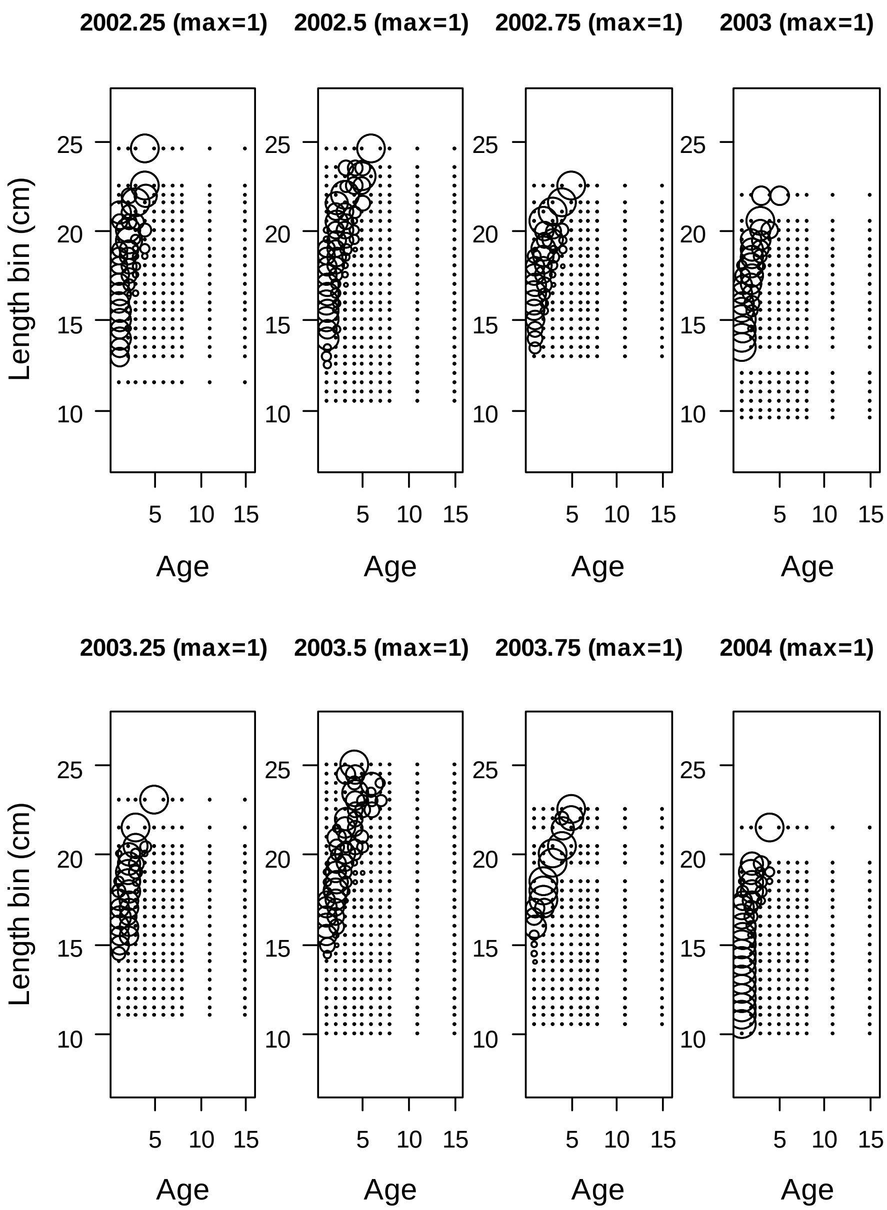


Figure 12 cont. Conditional age-at-length data for the California fishery.

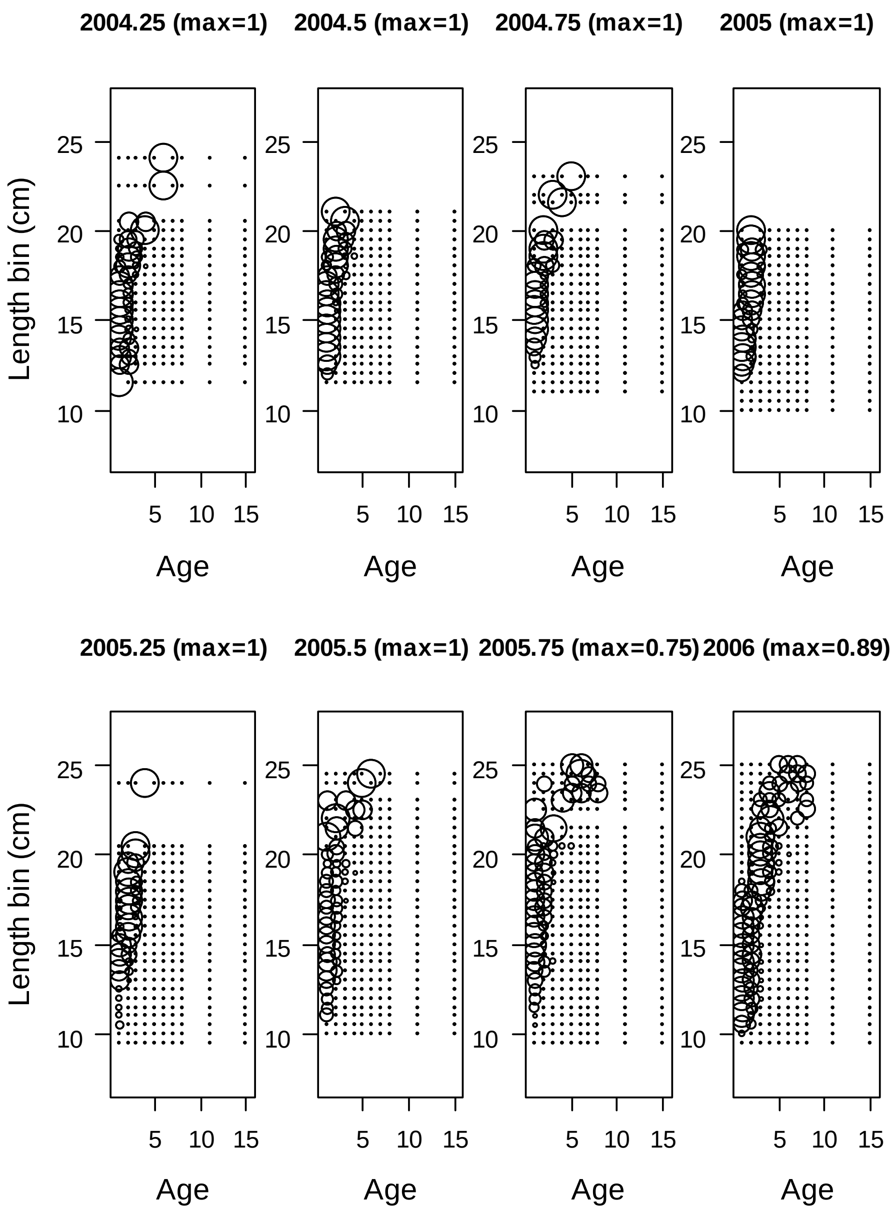


Figure 12 cont. Conditional age-at-length data for the California fishery.

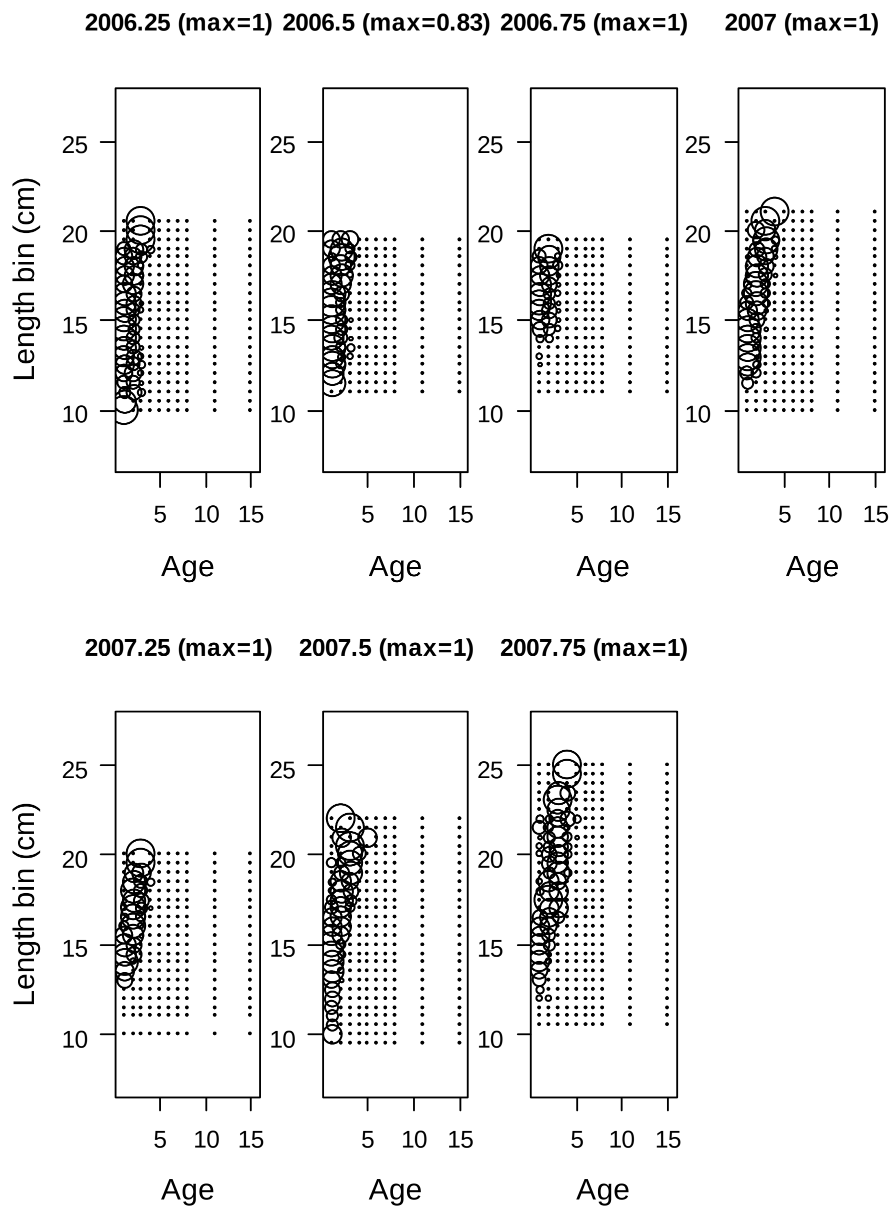


Figure 12 cont. Conditional age-at-length data for the California fishery. The projection model excludes 2007 data.

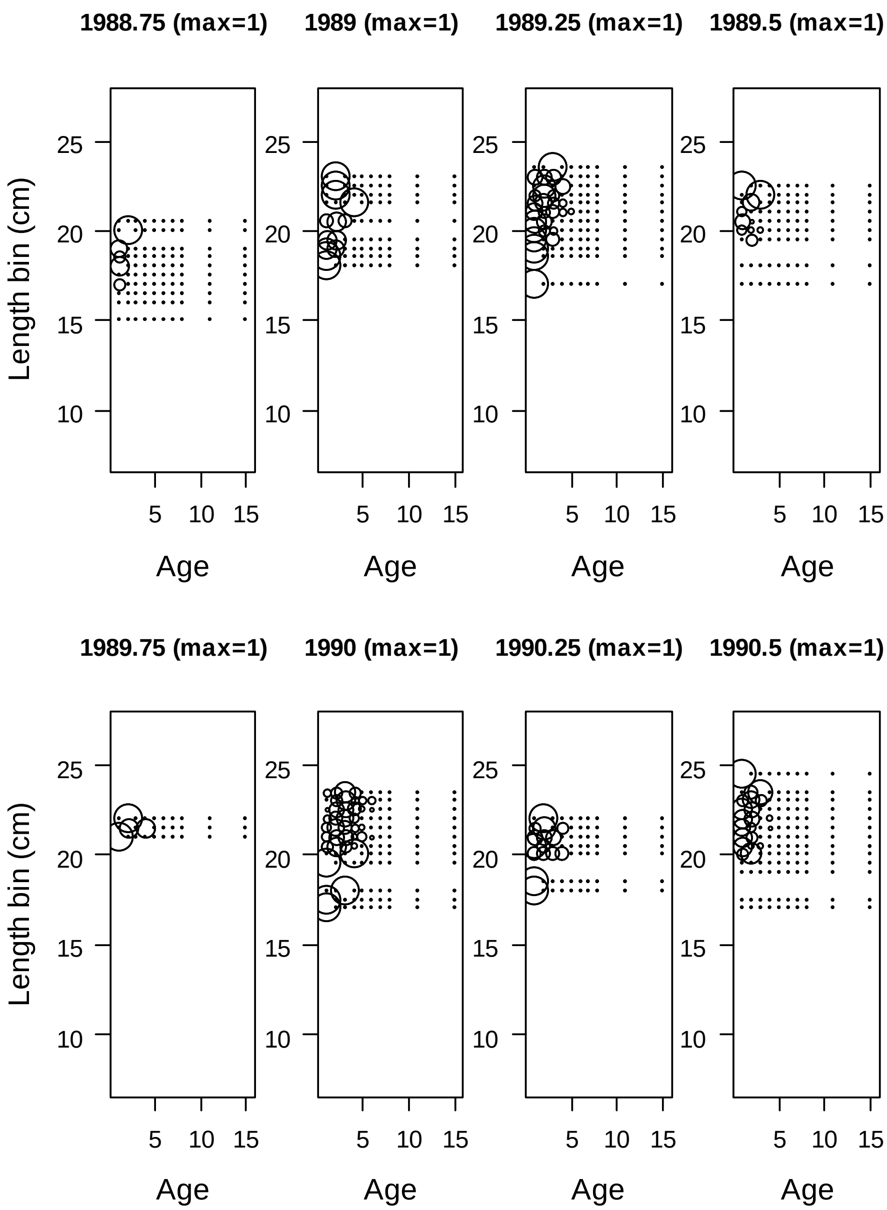


Figure 13. Conditional age-at-length data for the Ensenada fishery.

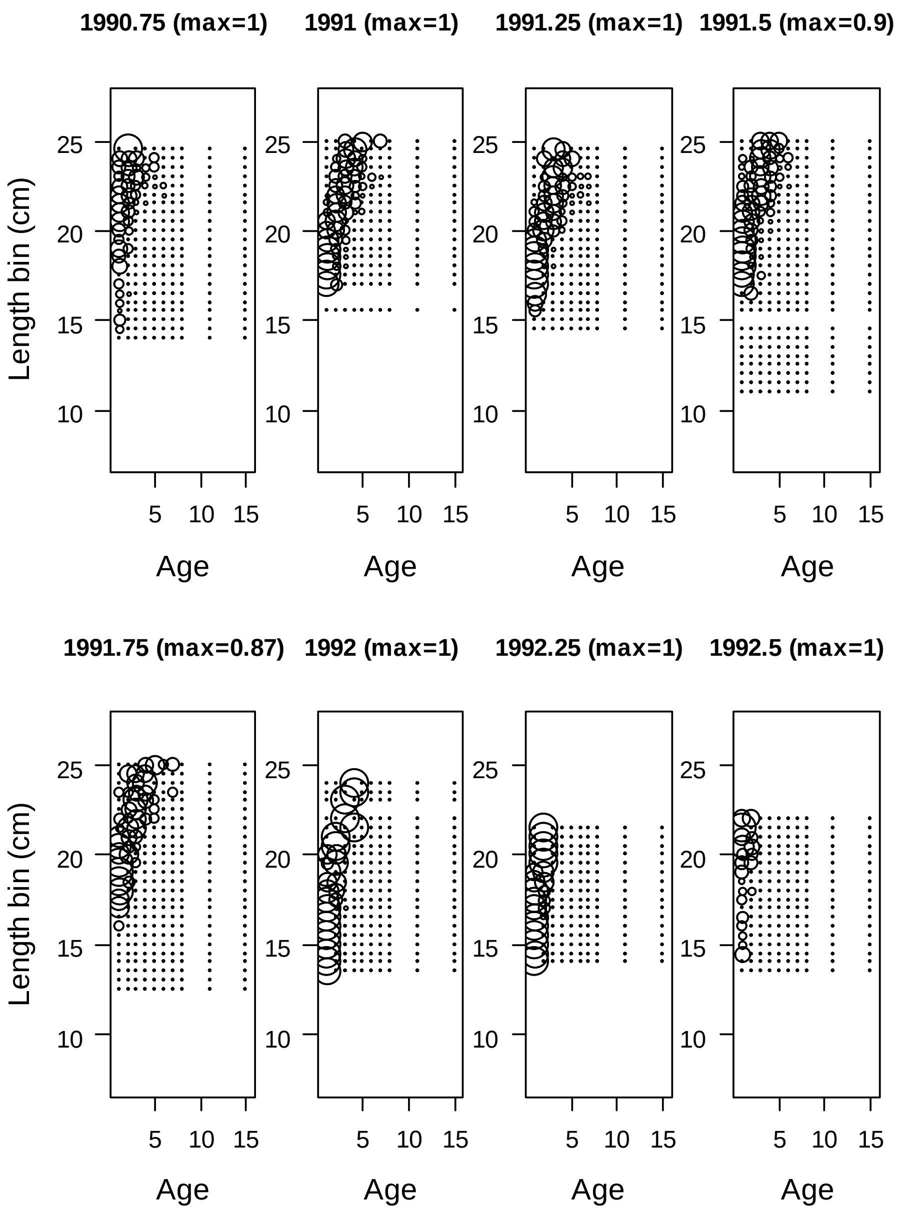


Figure 13 cont. Conditional age-at-length data for the Ensenada fishery.

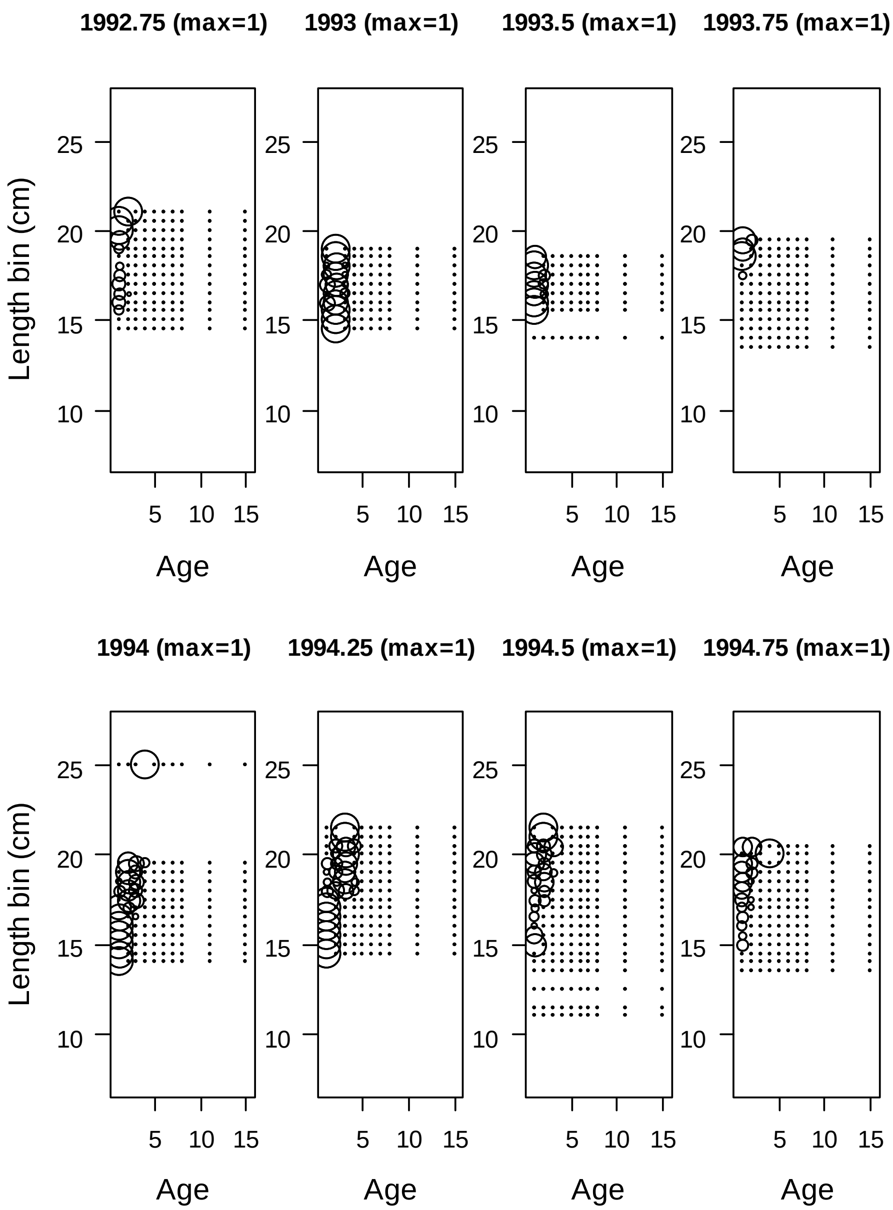


Figure 13 cont. Conditional age-at-length data for the Ensenada fishery.

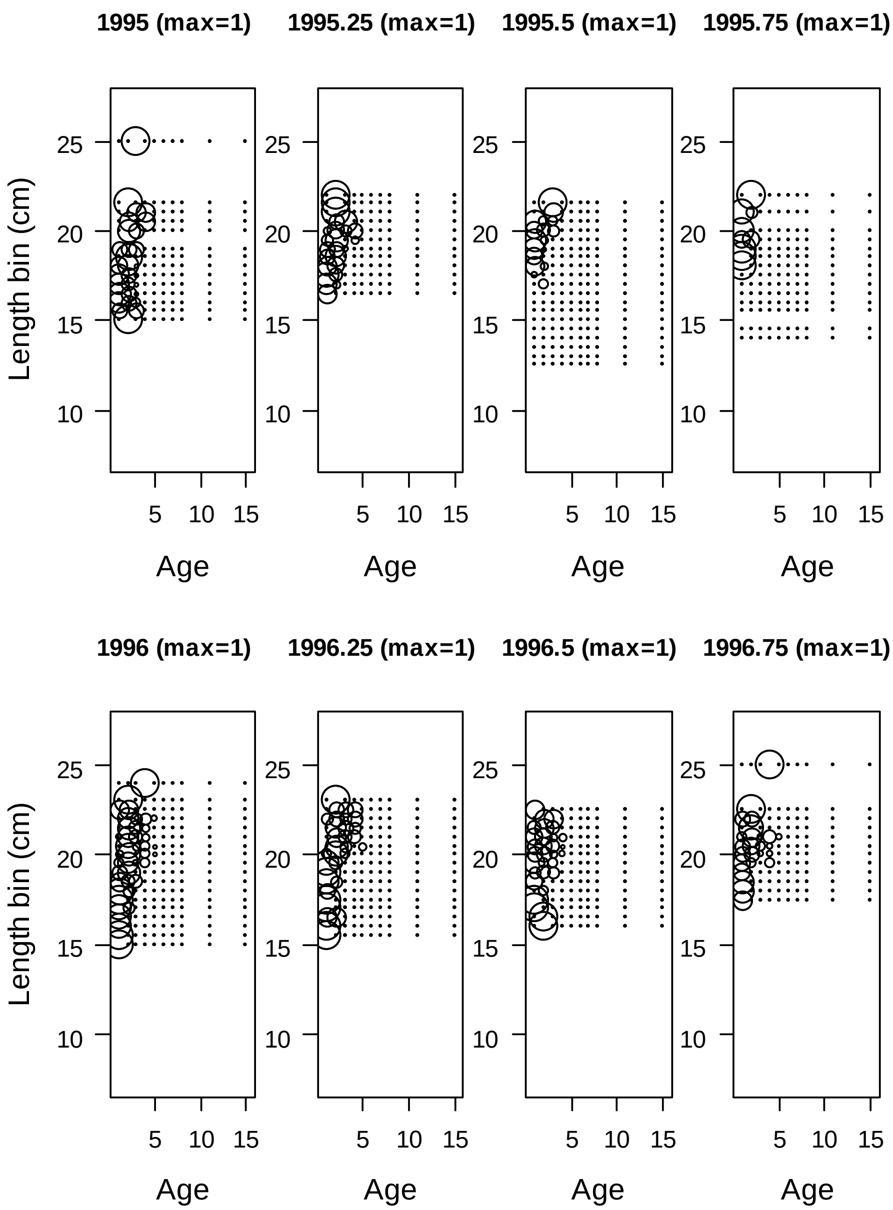


Figure 13 cont. Conditional age-at-length data for the Ensenada fishery.

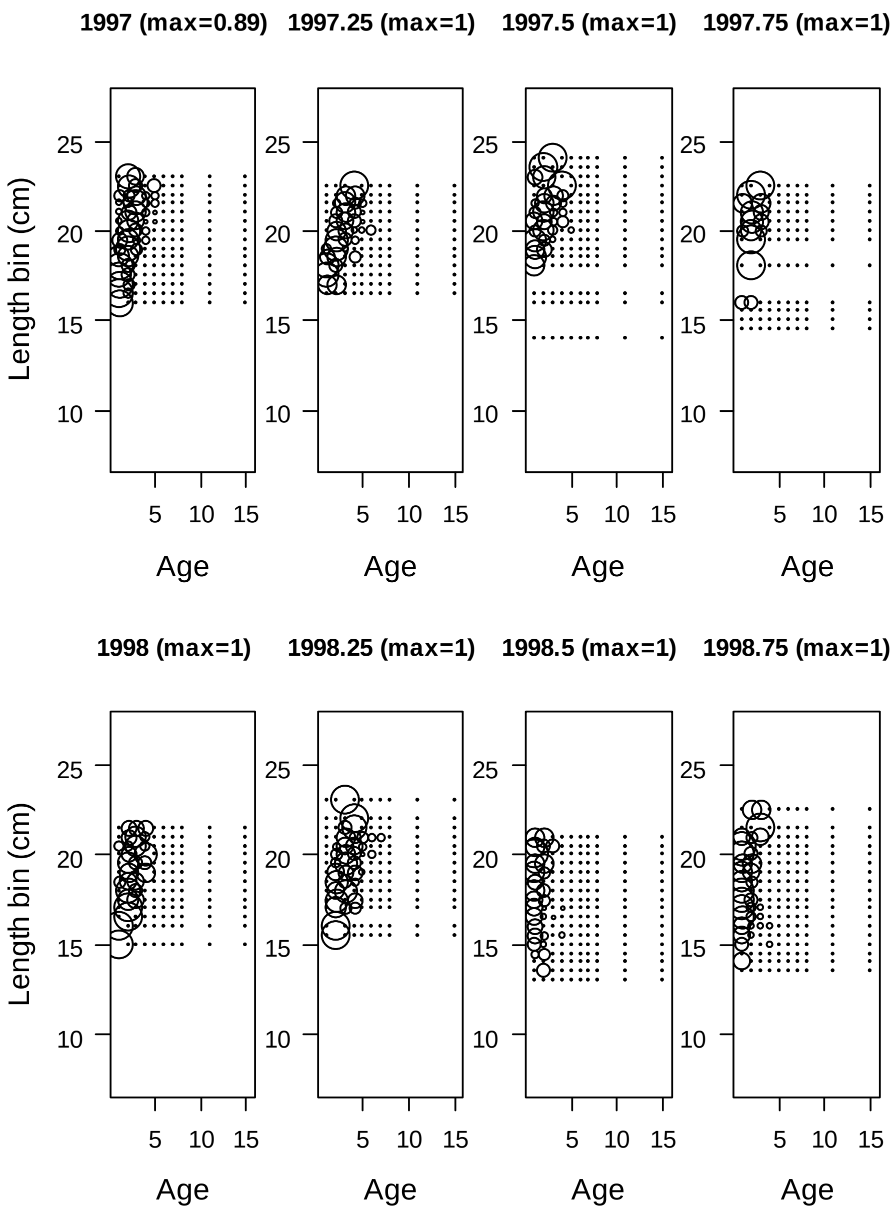


Figure 13 cont. Conditional age-at-length data for the Ensenada fishery.

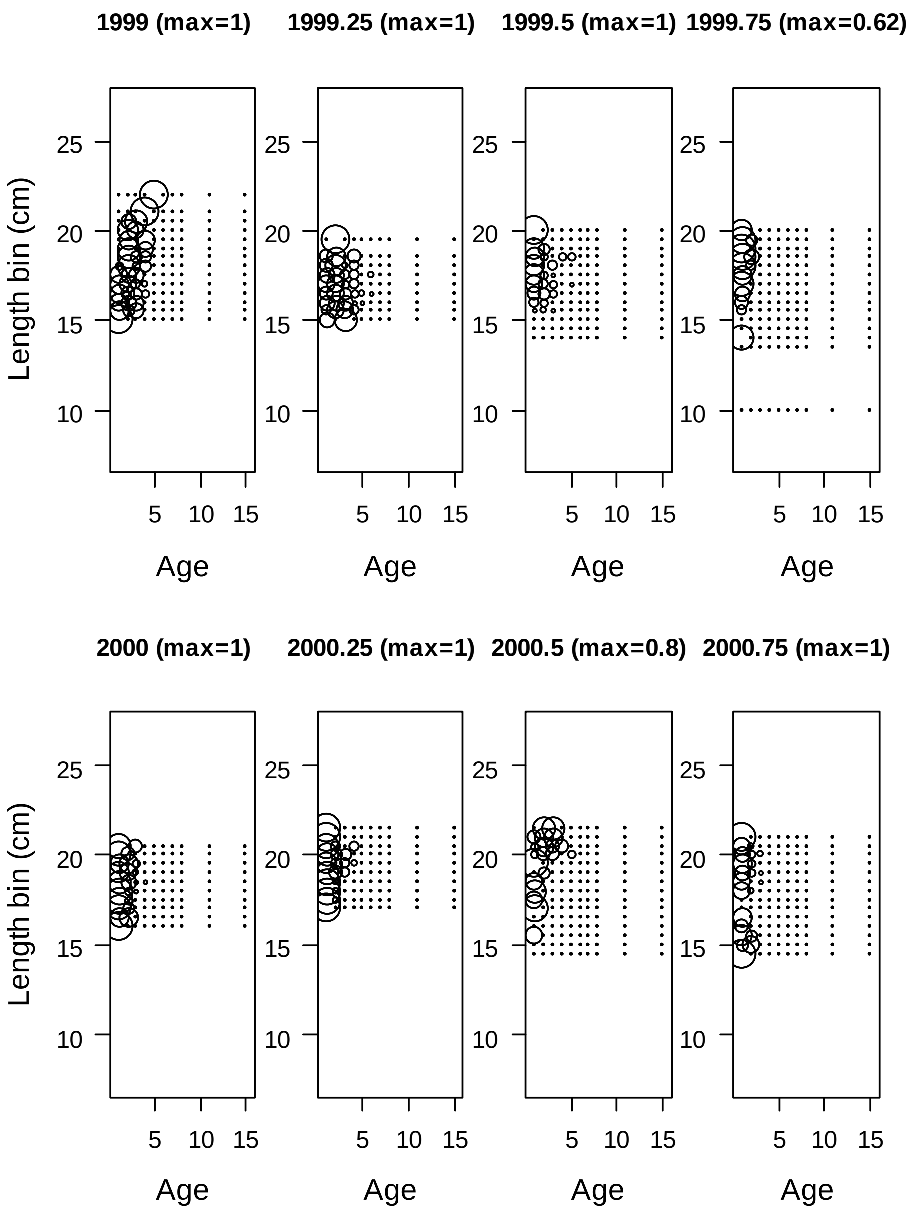


Figure 13 cont. Conditional age-at-length data for the Ensenada fishery.

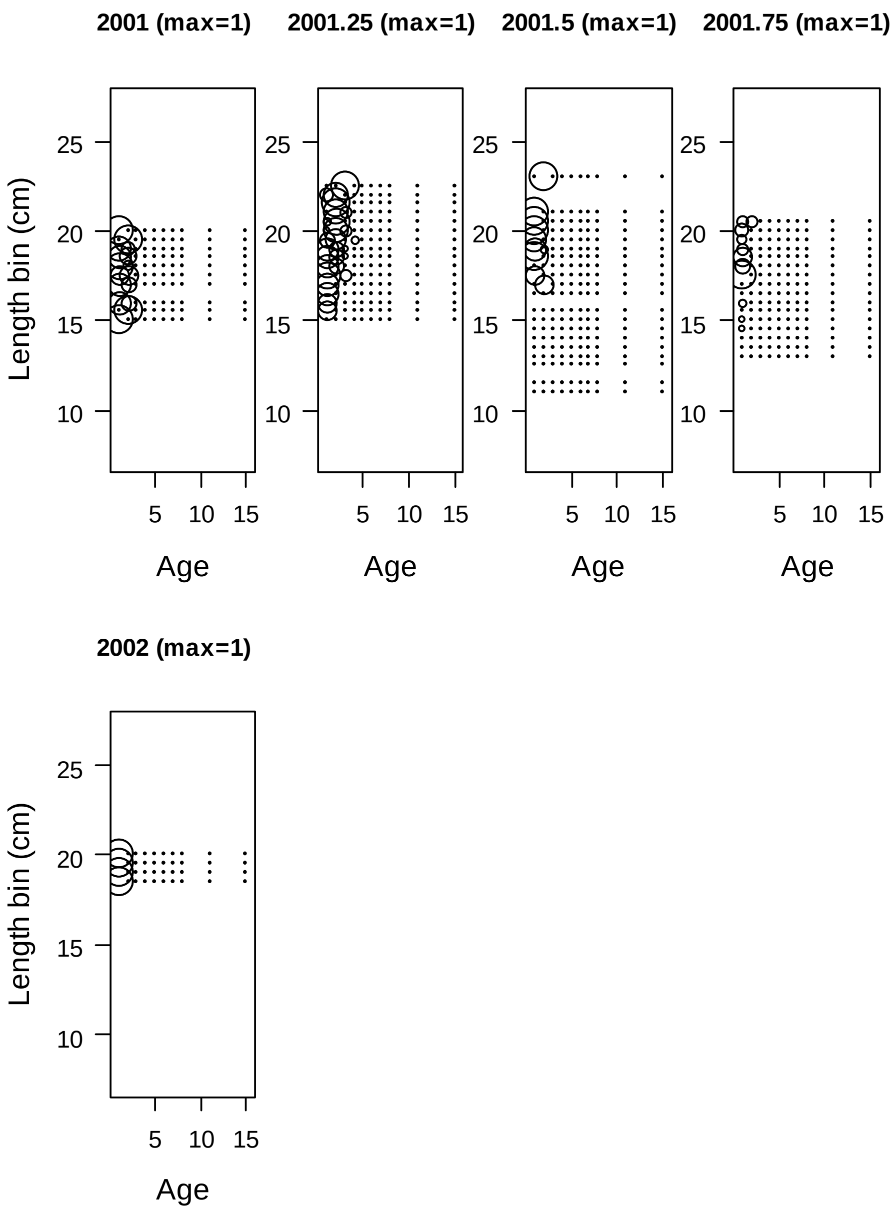


Figure 13 cont. Conditional age-at-length data for the Ensenada fishery.

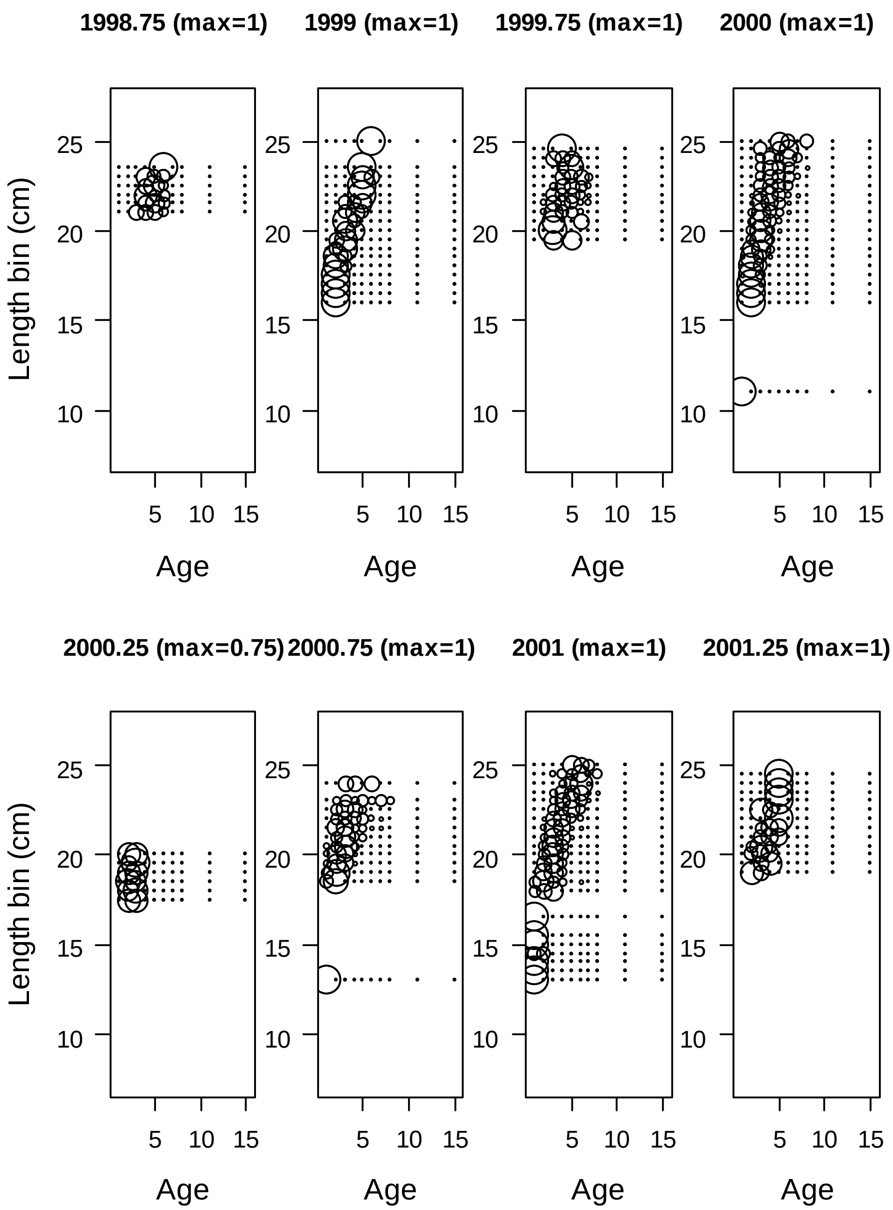


Figure 14. Conditional age-at-length data for the Pacific Northwest fishery.

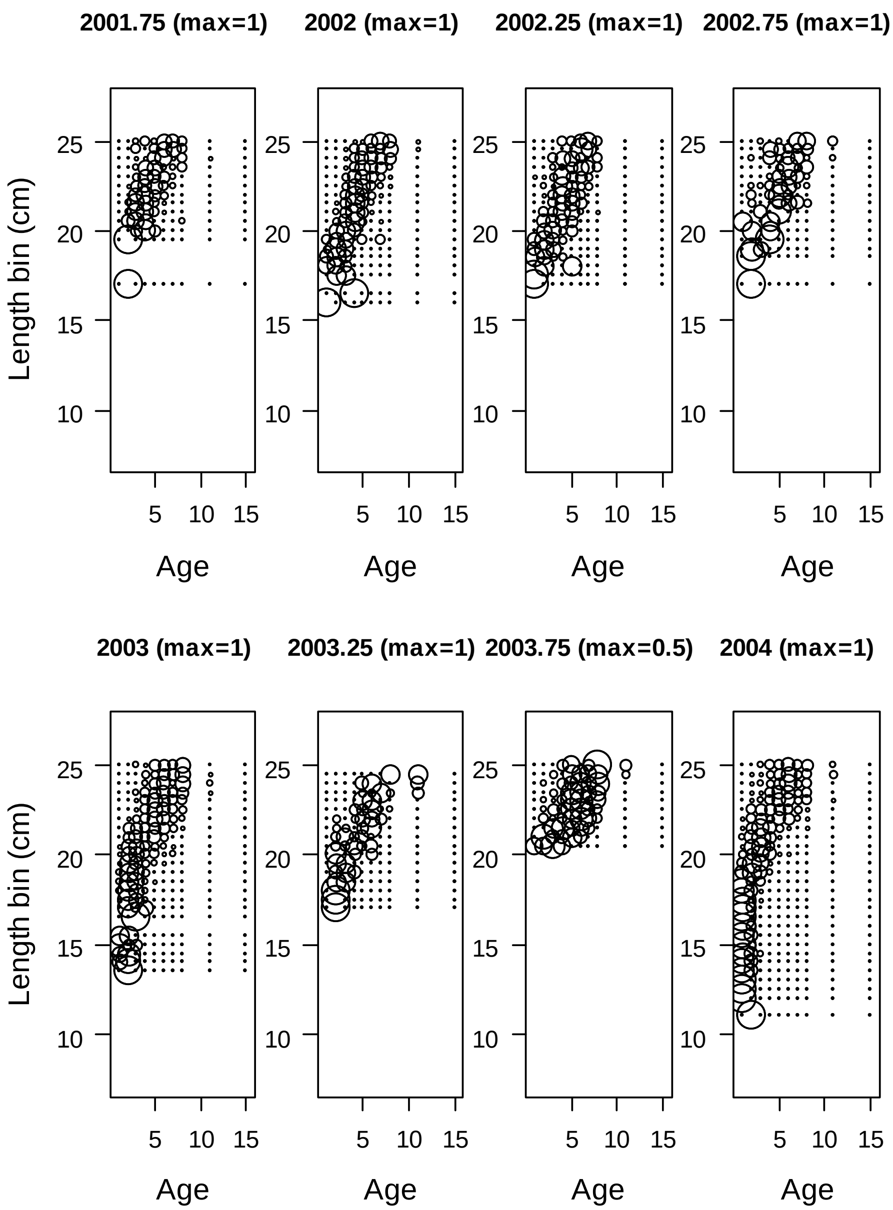


Figure 14 cont. Conditional age-at-length data for the Pacific Northwest fishery.

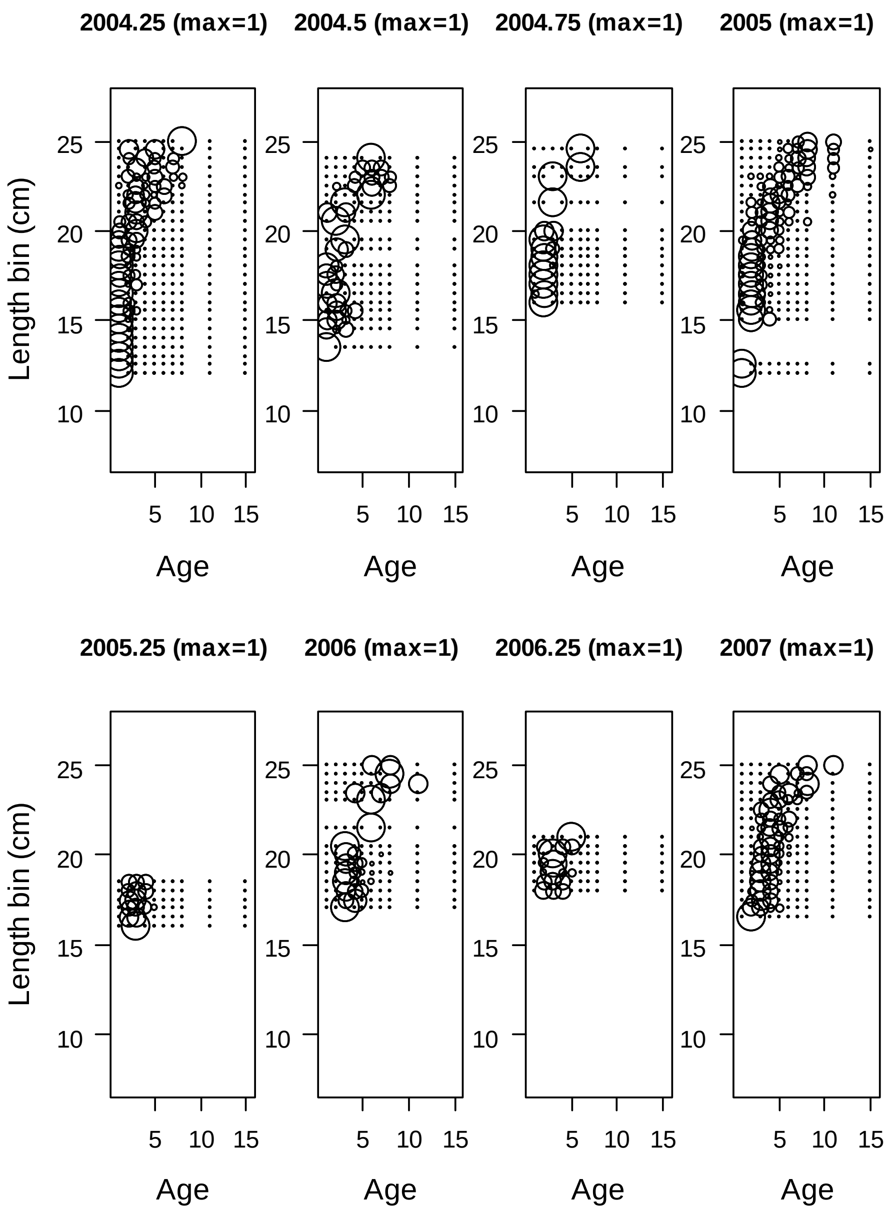


Figure 14 cont. Conditional age-at-length data for the Pacific Northwest fishery. The projection model excludes 2007 data.

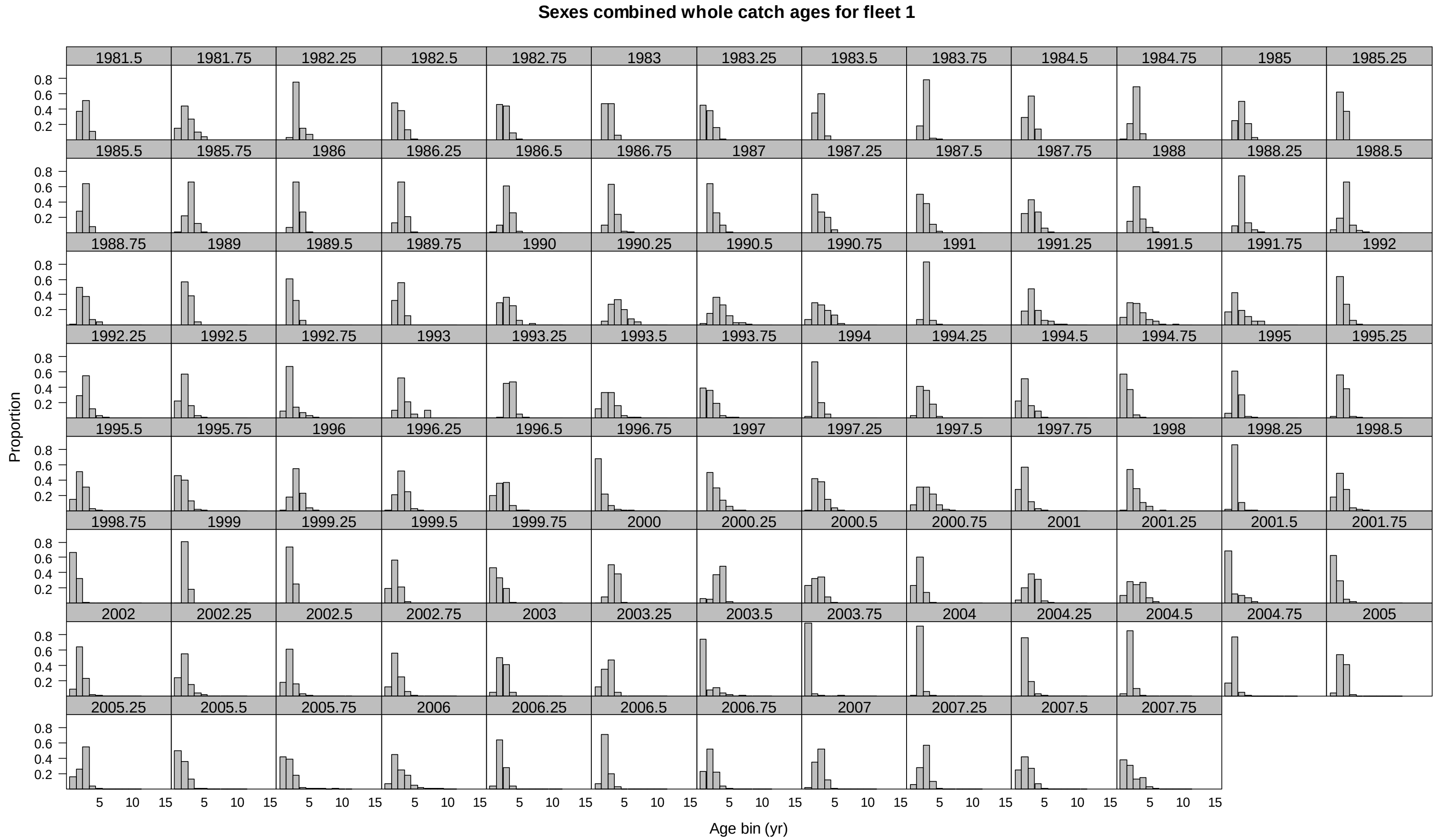


Figure 15. Implied age-composition data for the California fishery, 1981-2007. The projection model excludes 2007 data.

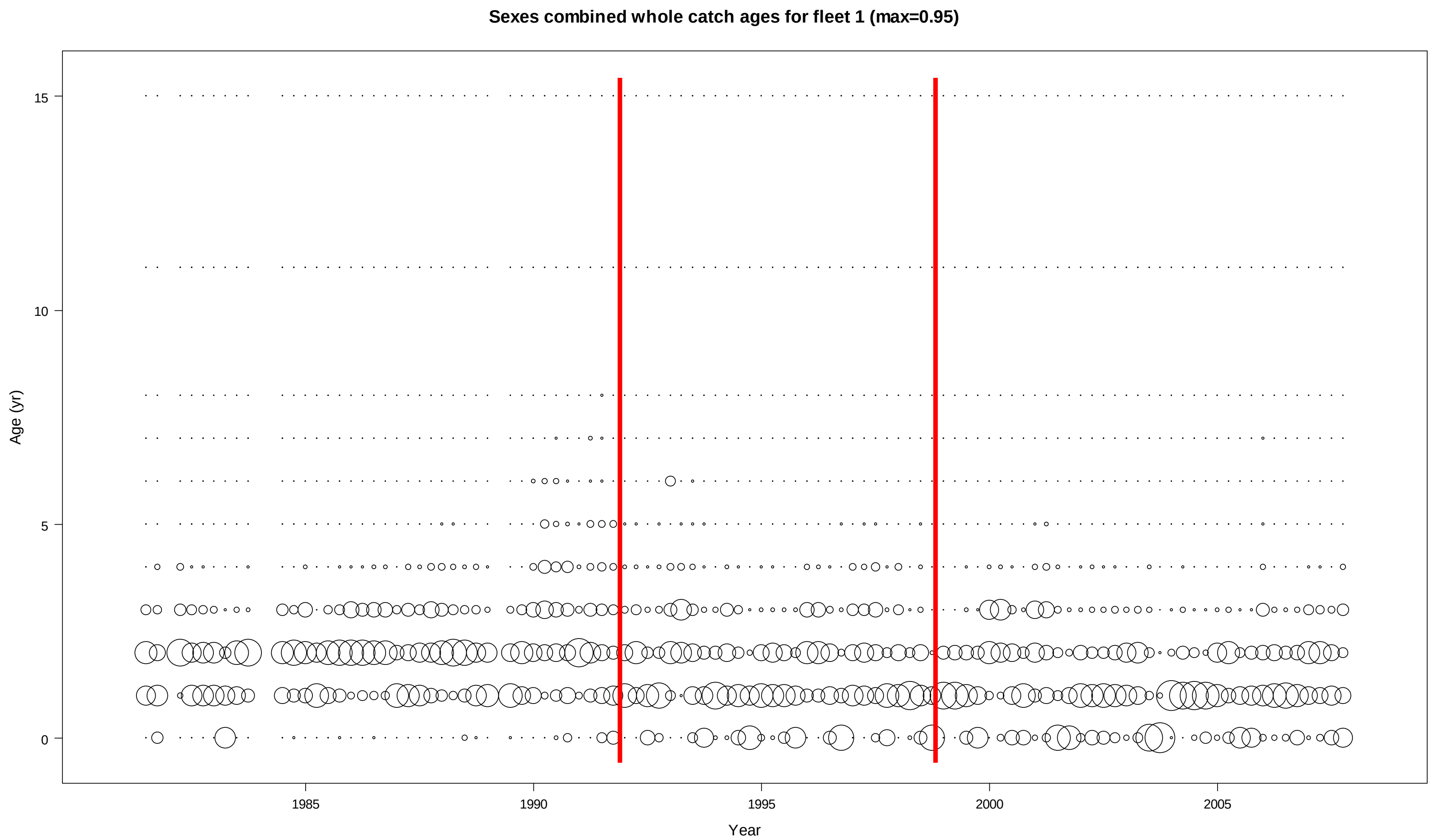


Figure 16. Implied age-composition data for the California fishery, 1981-2007. The projection model excludes 2007 data. Vertical line indicates selectivity period change.

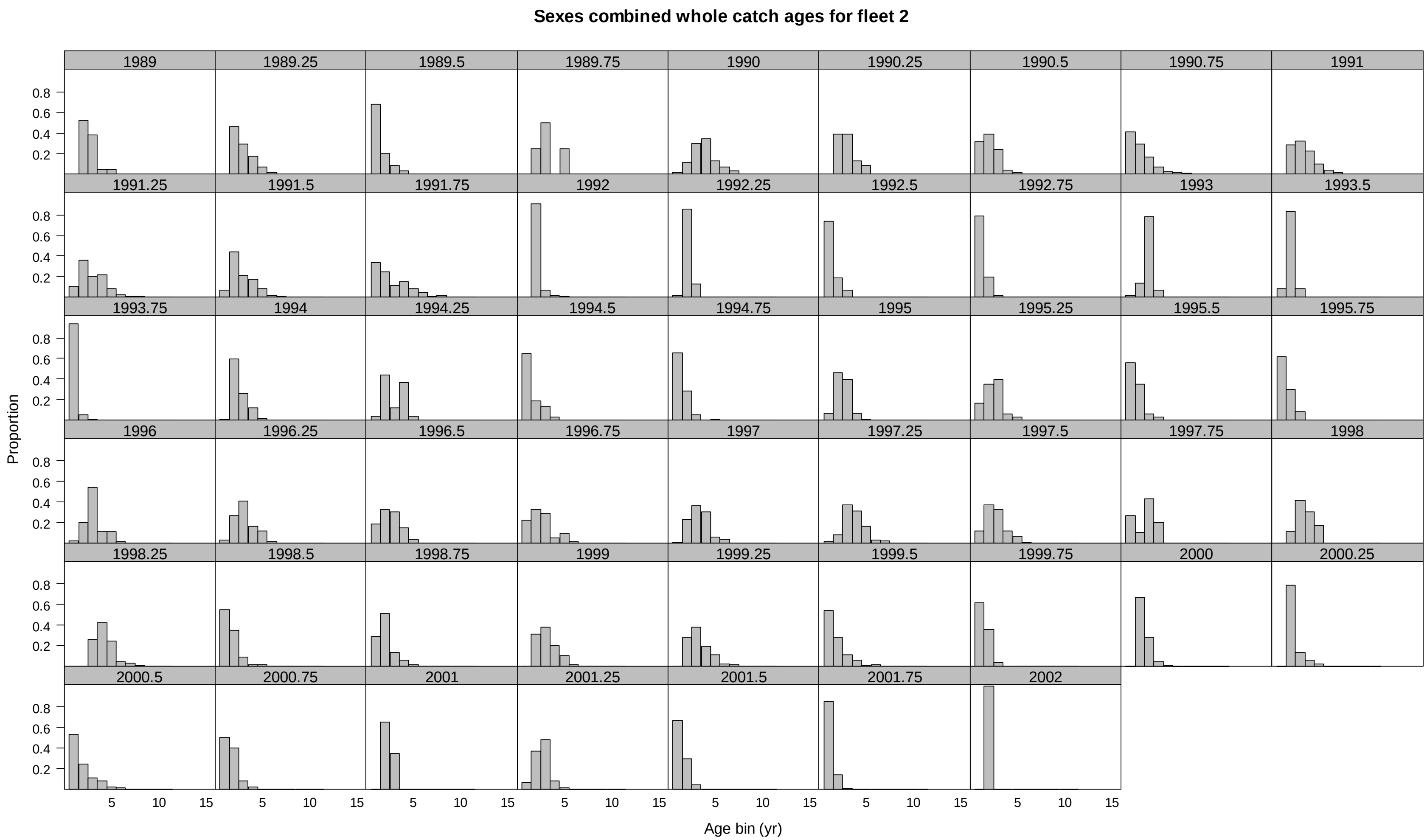


Figure 17. Implied age-composition data for the Ensenada fishery, 1989-2002.

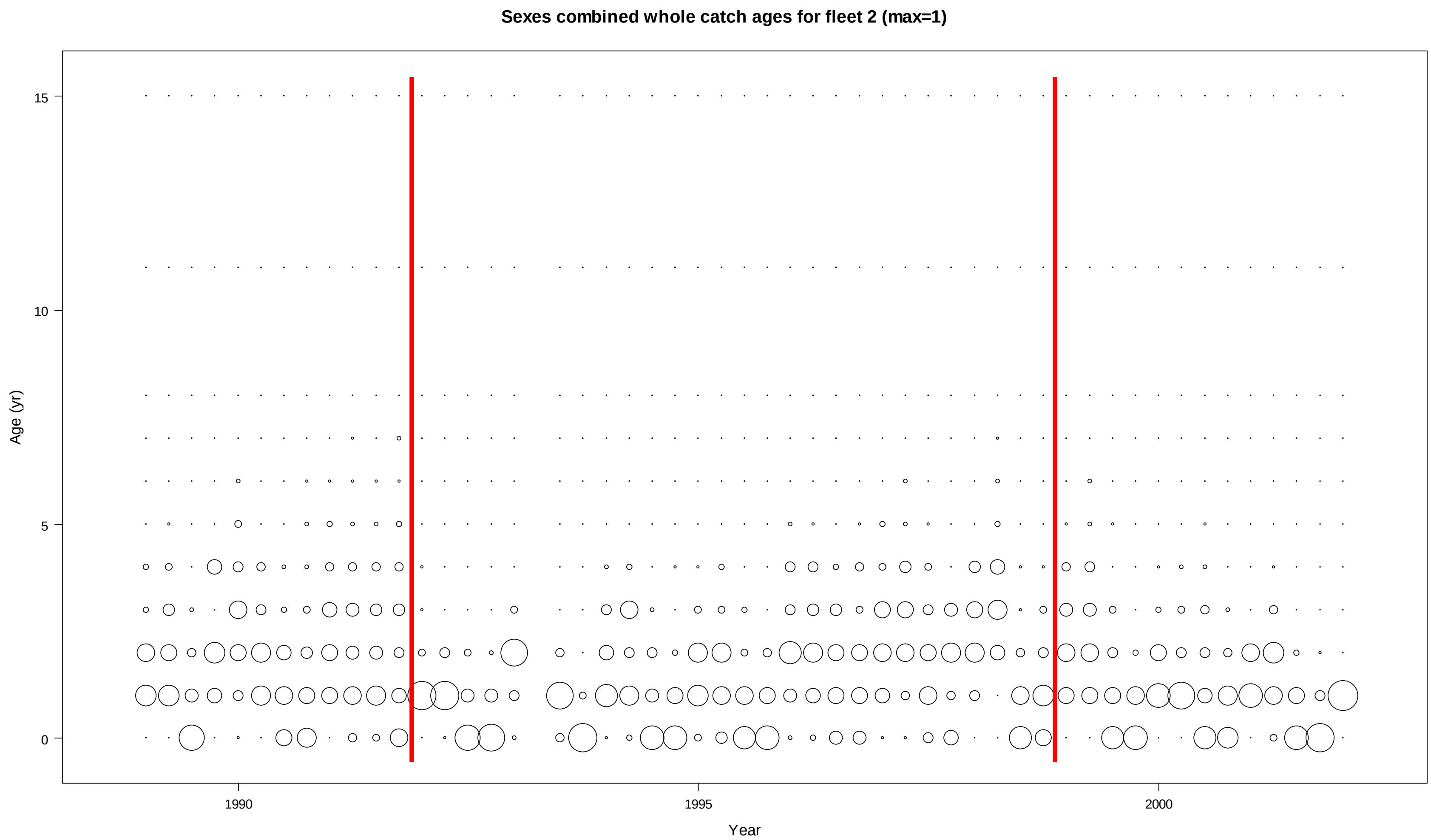


Figure 18. Implied age-composition data for the Ensenada fishery, 1989-2002. Vertical line indicates selectivity period change.

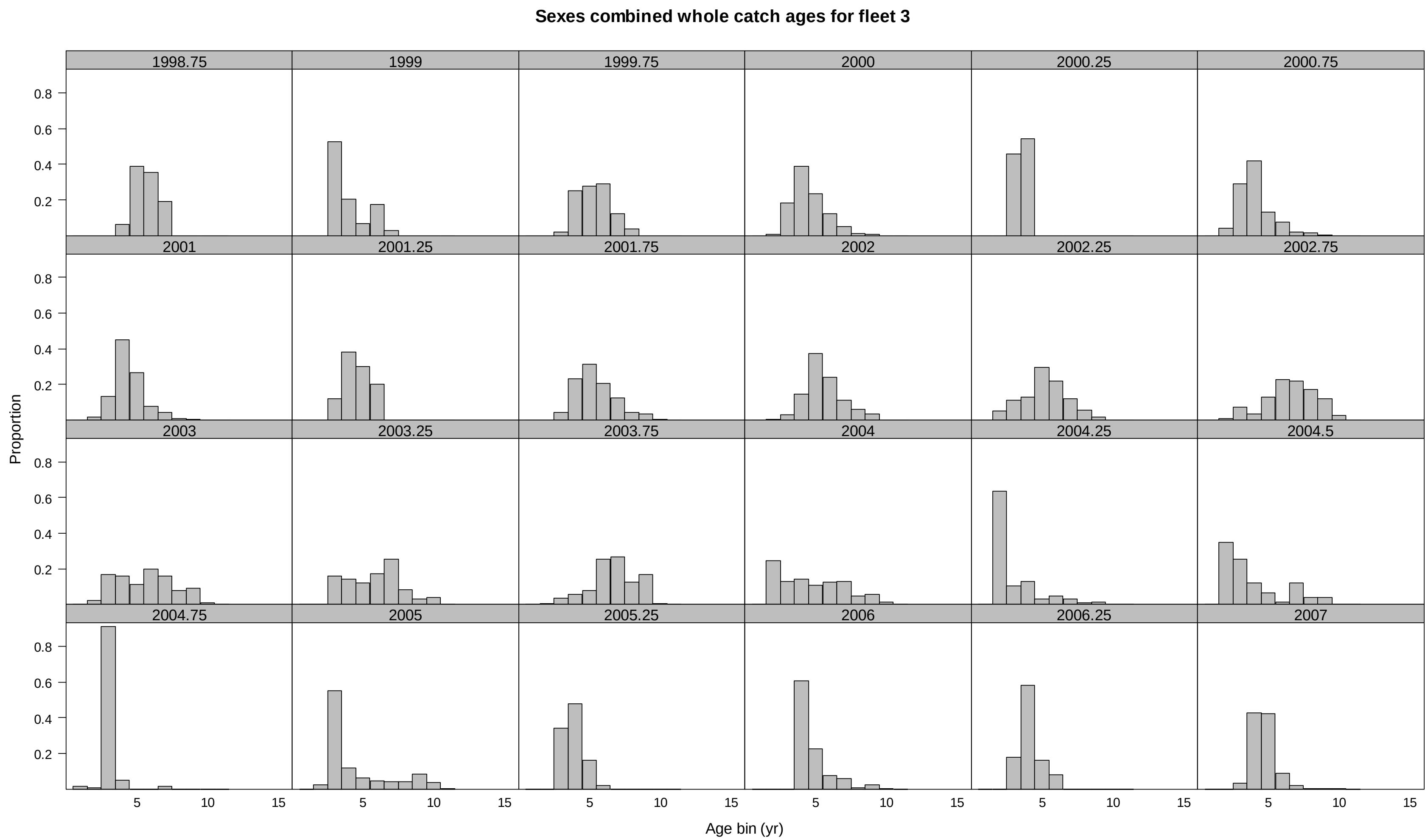


Figure 19. Implied age-composition data for the Pacific Northwest fishery, 1998-2007. The projection model excludes 2007 data.

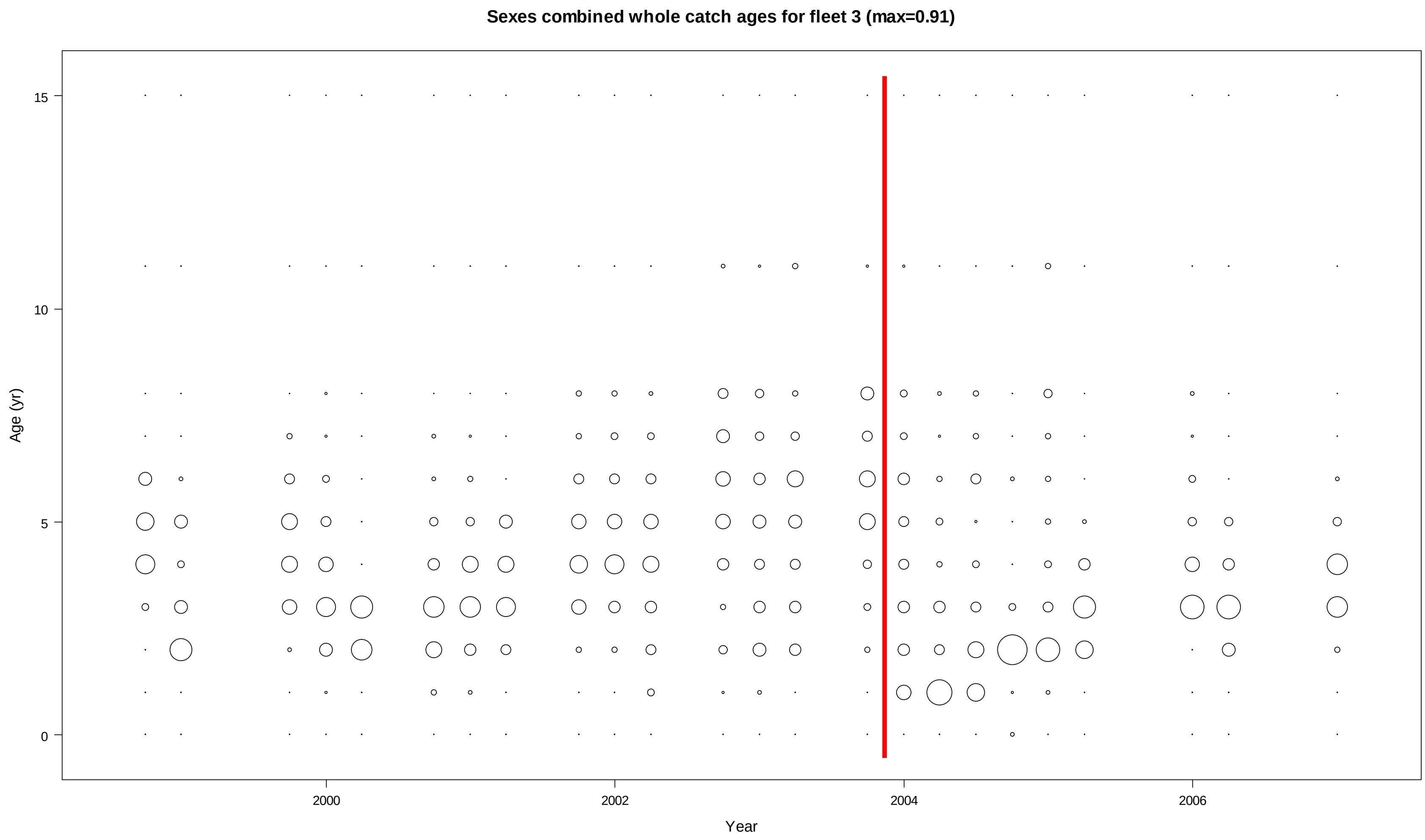


Figure 20. Implied age-composition data for the Pacific Northwest fishery, 1998-2007. The projection model excludes 2007 data. Vertical line indicates selectivity period change.

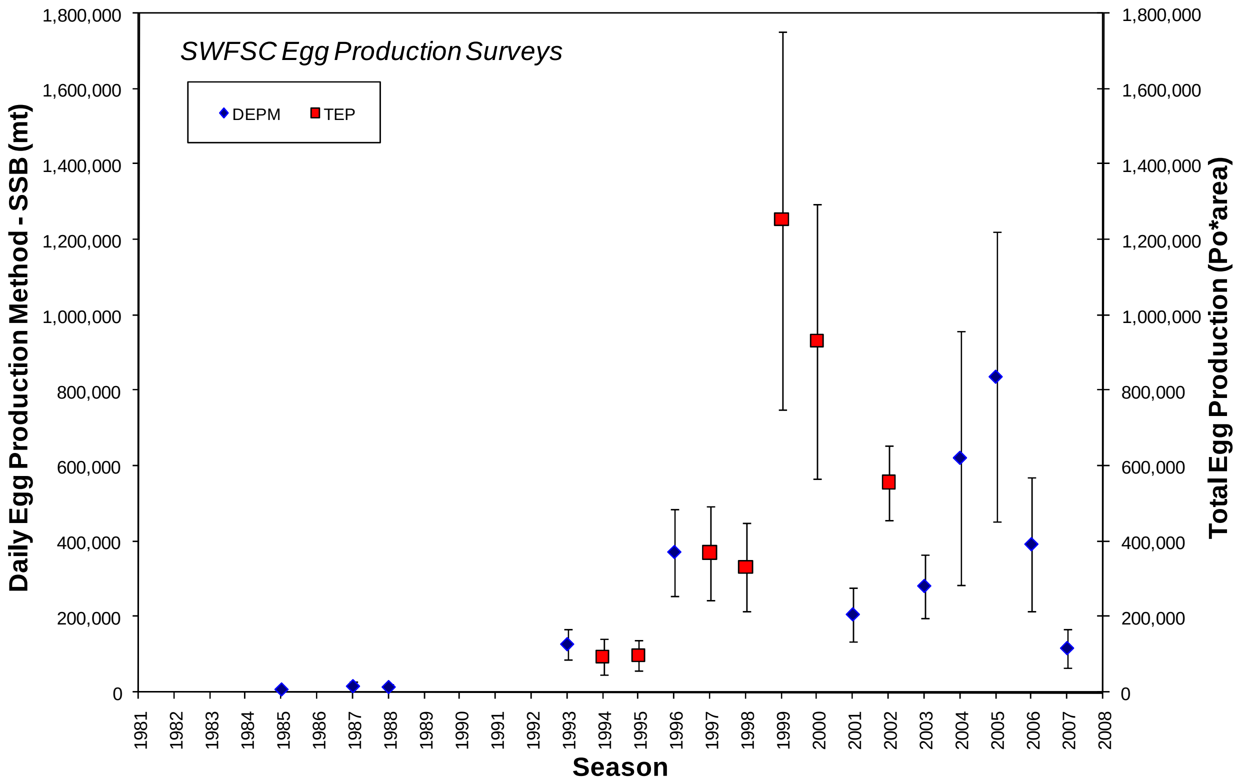


Figure 21. Estimates of Pacific sardine egg production from SWFSC surveys. The projection model excludes the 2007 DEPM estimate (based on the April 2008 survey).

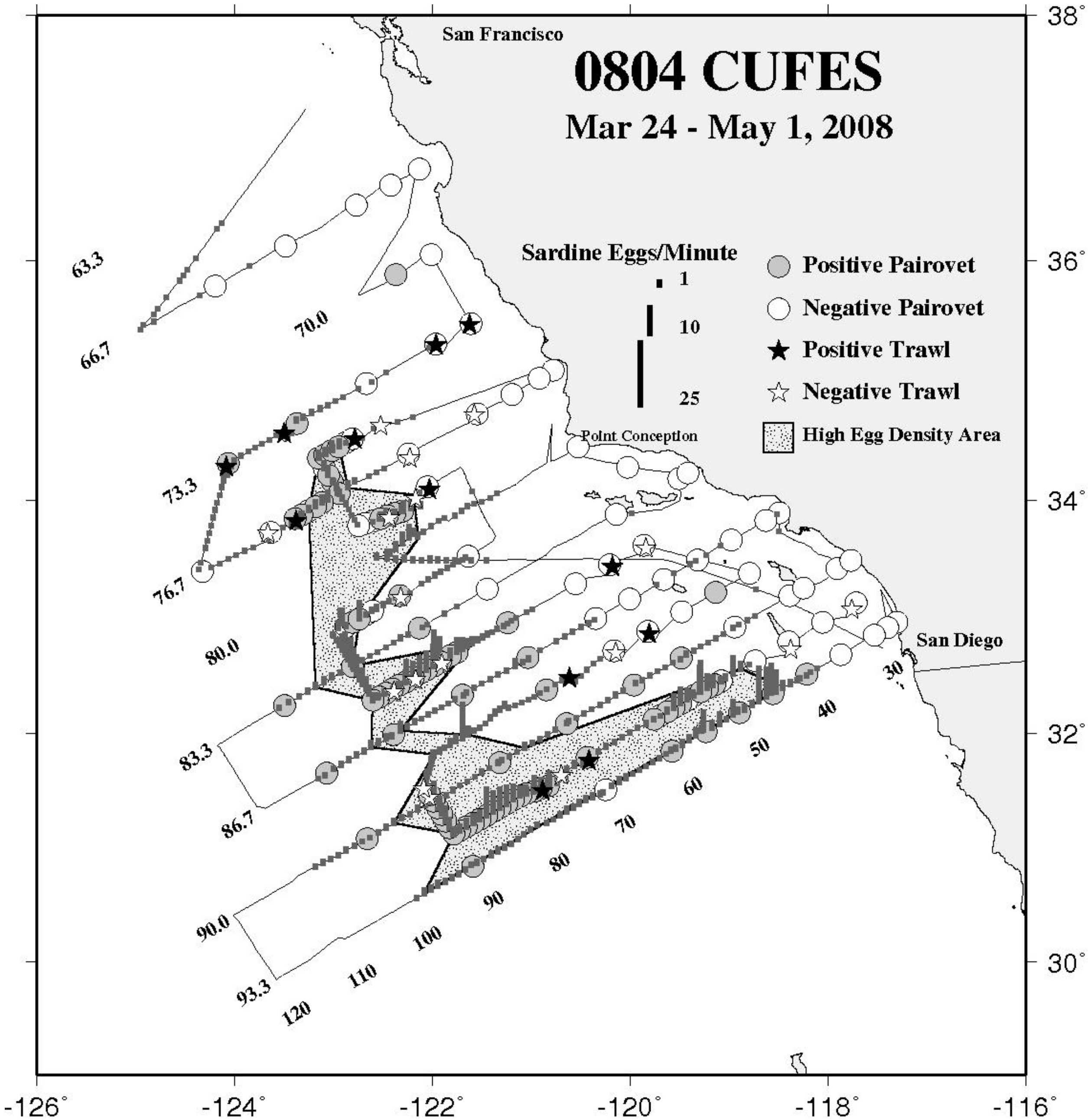


Figure 22. Sardine egg distribution from the SWFSC annual survey, March 24 to May 1, 2008. Coast-wide details for this survey are provided in Figure 25.

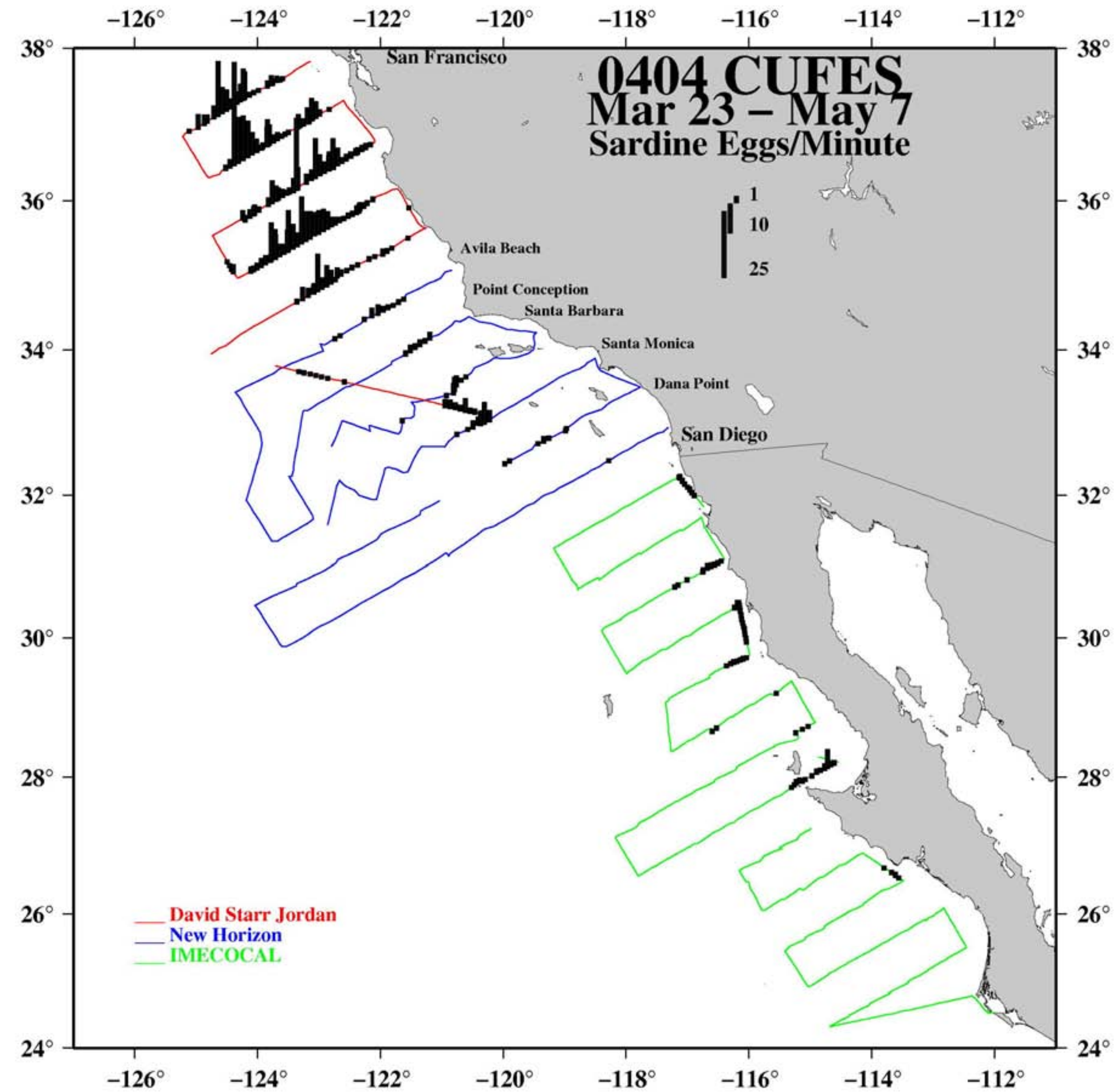


Figure 23. Distribution of Pacific sardine eggs collected by CUFES, between San Francisco and northern Baja California, from March to May, 2004. Northern Baja California egg data, collected during an IMECOCAL cruise, were provided courtesy Dr. Timothy Baumgartner (CICESE Ensenada).

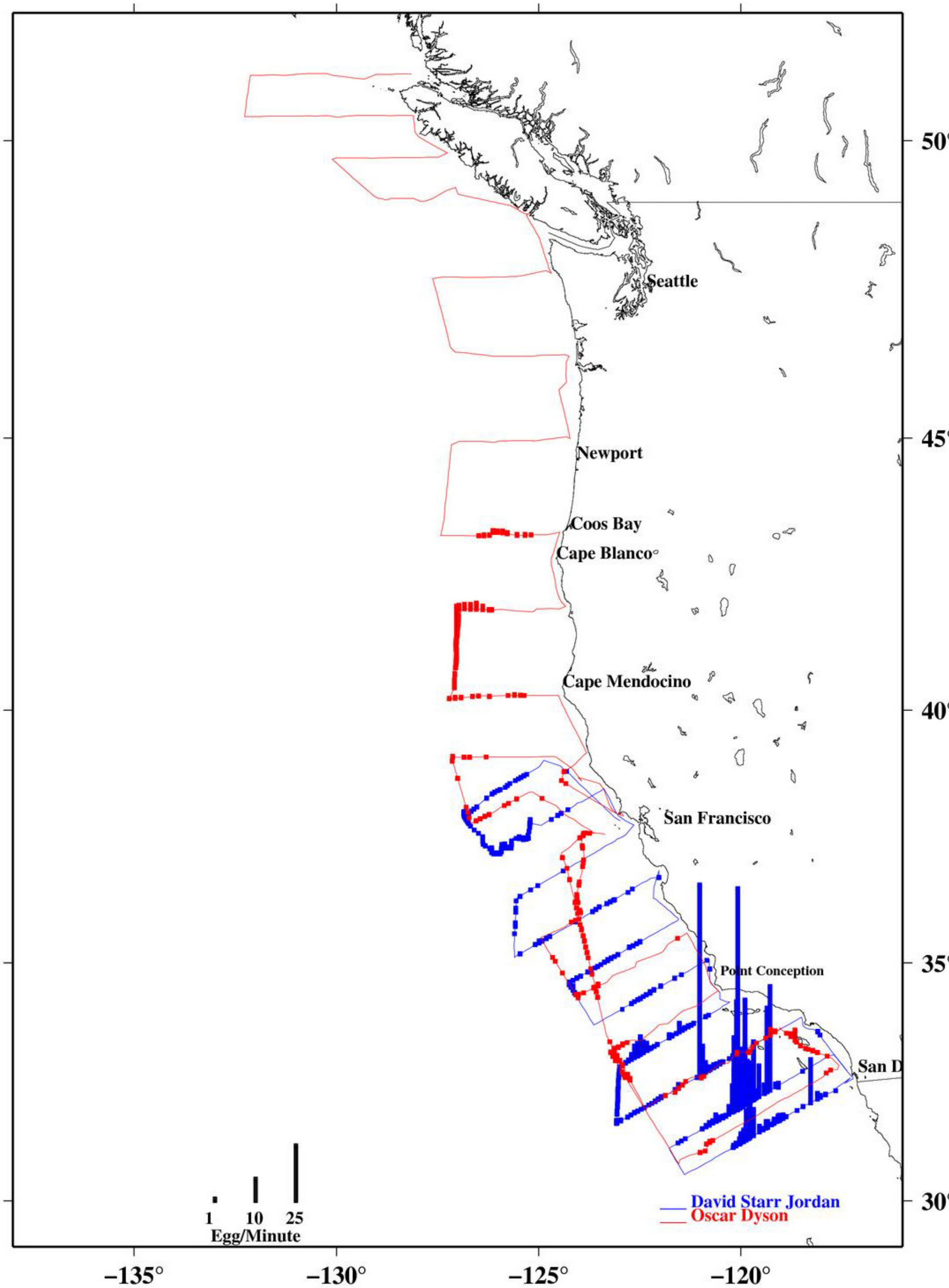


Figure 24. Distribution of Pacific sardine eggs collected by CUFES, between British Columbia and San Diego during April-May, 2006.

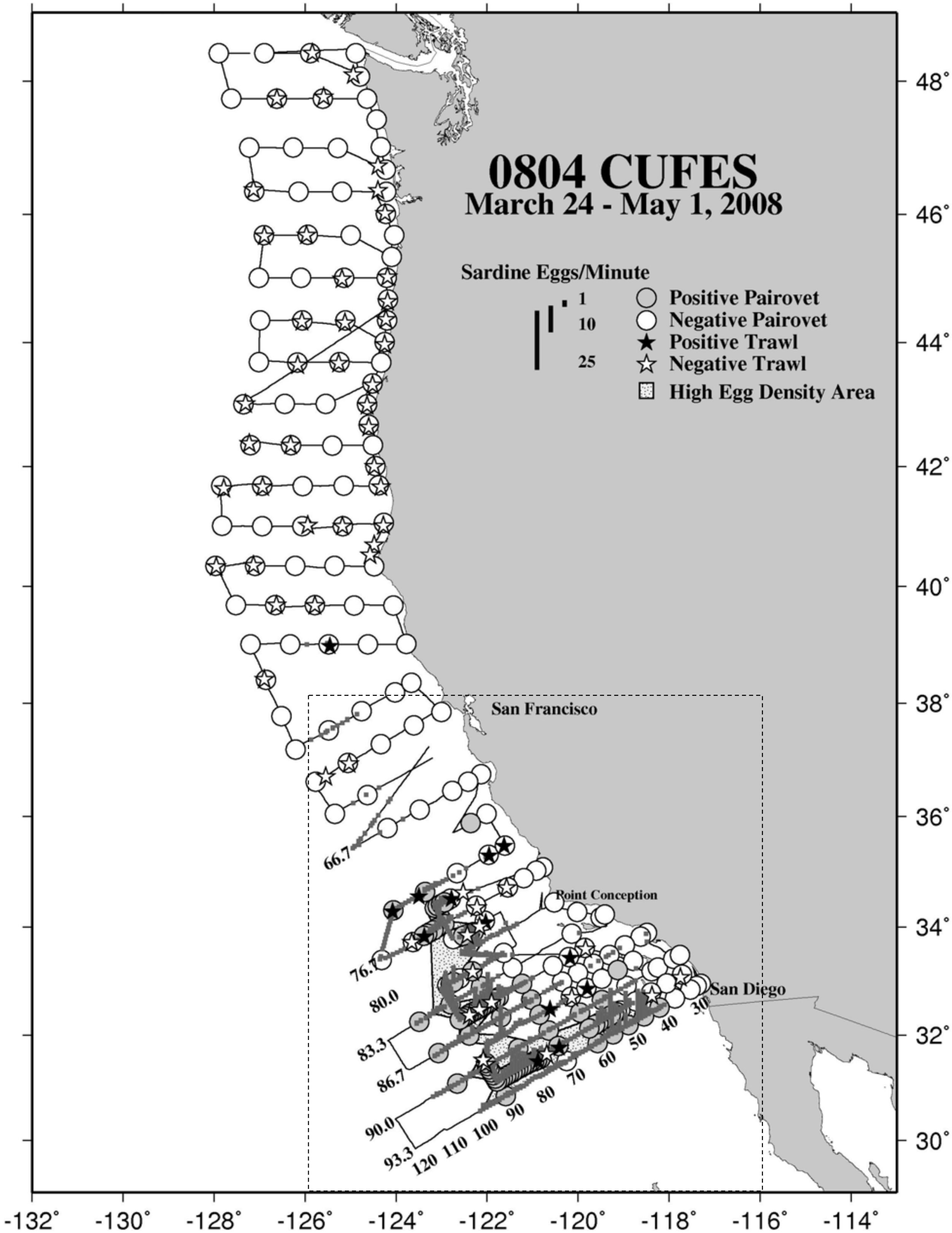


Figure 25. Sardine egg distribution from the SWFSC coast-wide survey, March 24 to May 1, 2008. Detailed map of standard survey area (outlined) is provided in Figure 22.

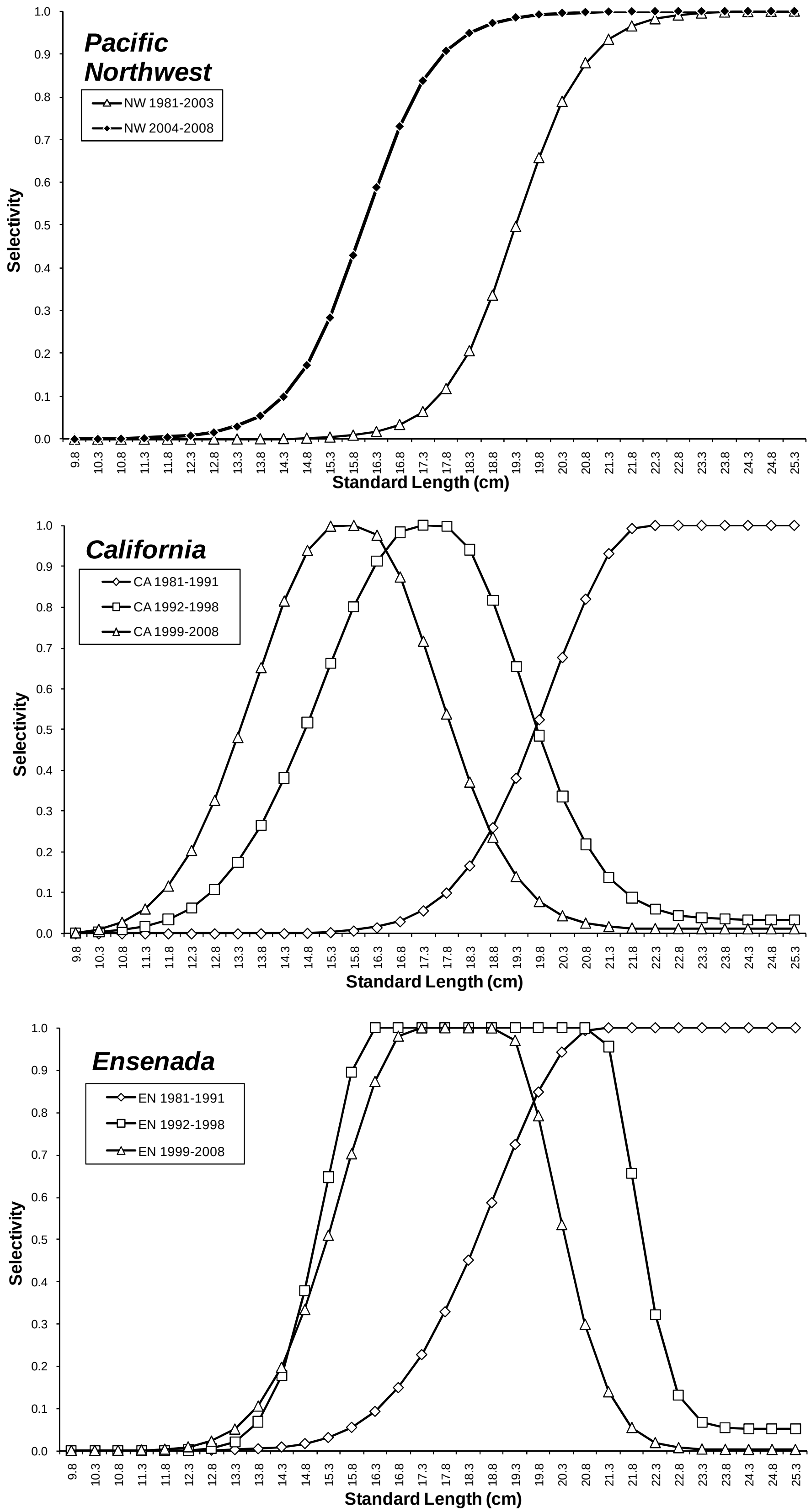


Figure 26. Length-based selectivity estimated for each fleet (projection model).

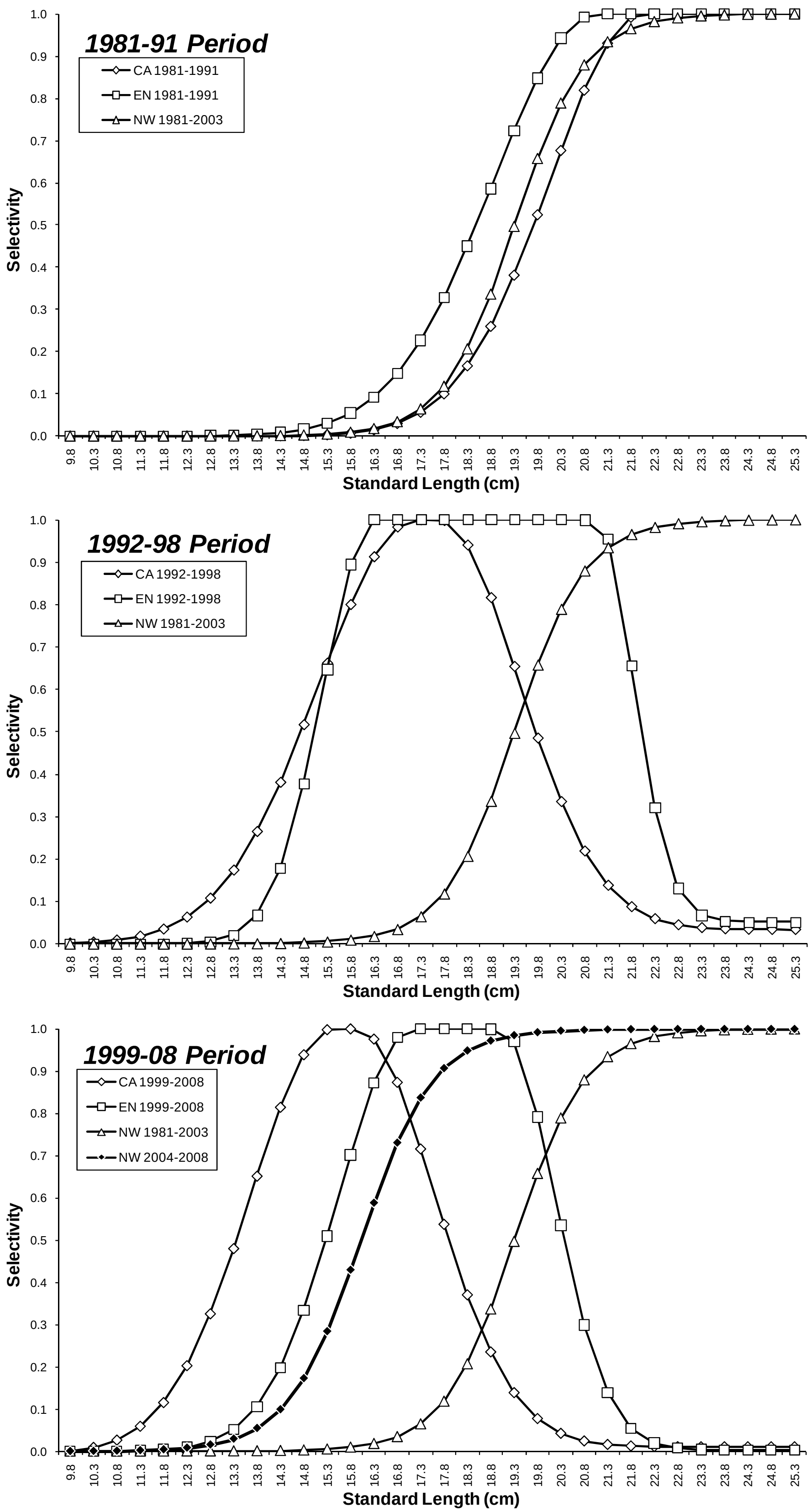


Figure 27. Length-based selectivity estimated for each time period (projection model).

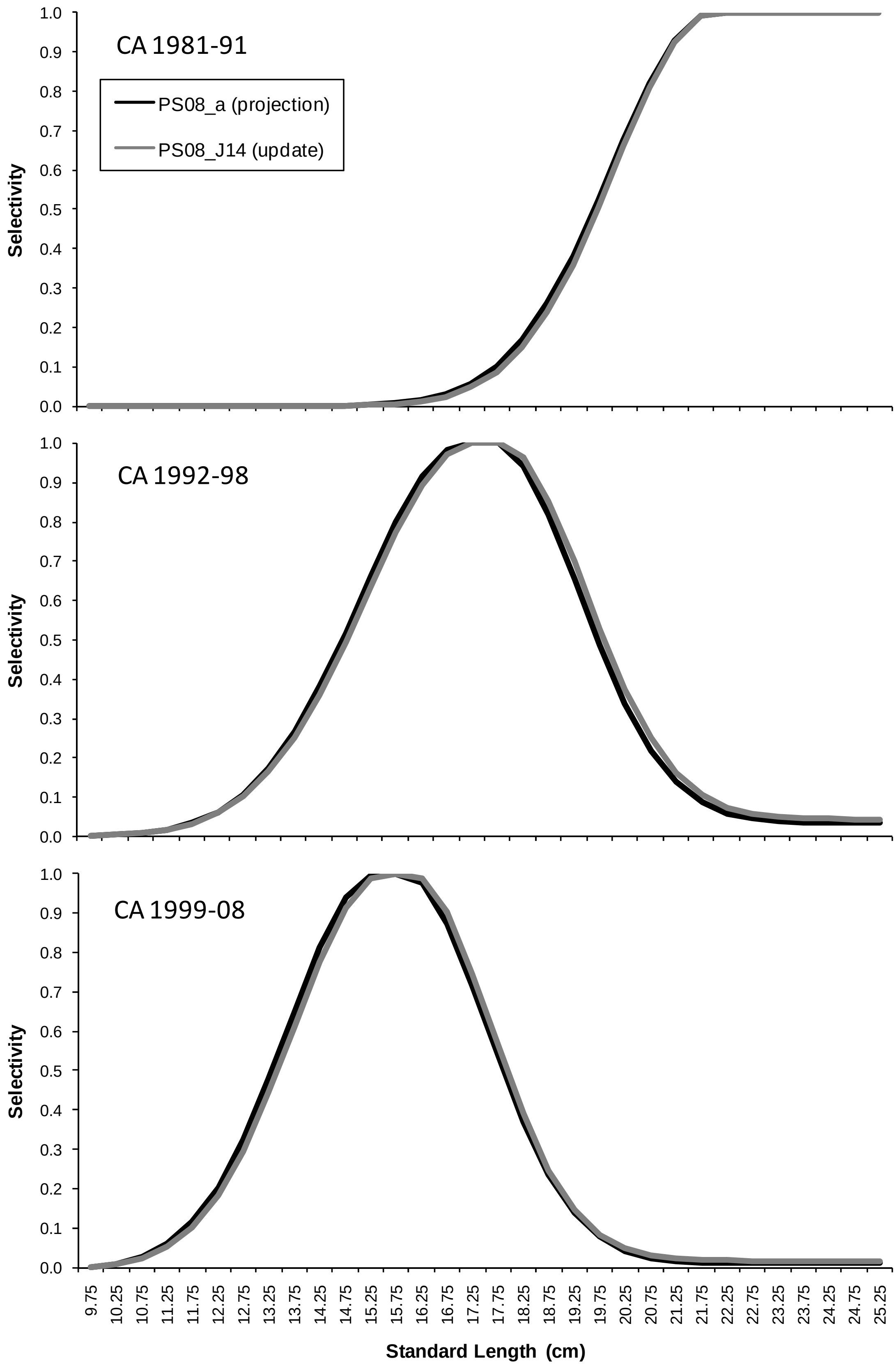


Figure 28a. CA fishery selectivities for the update and projection models.

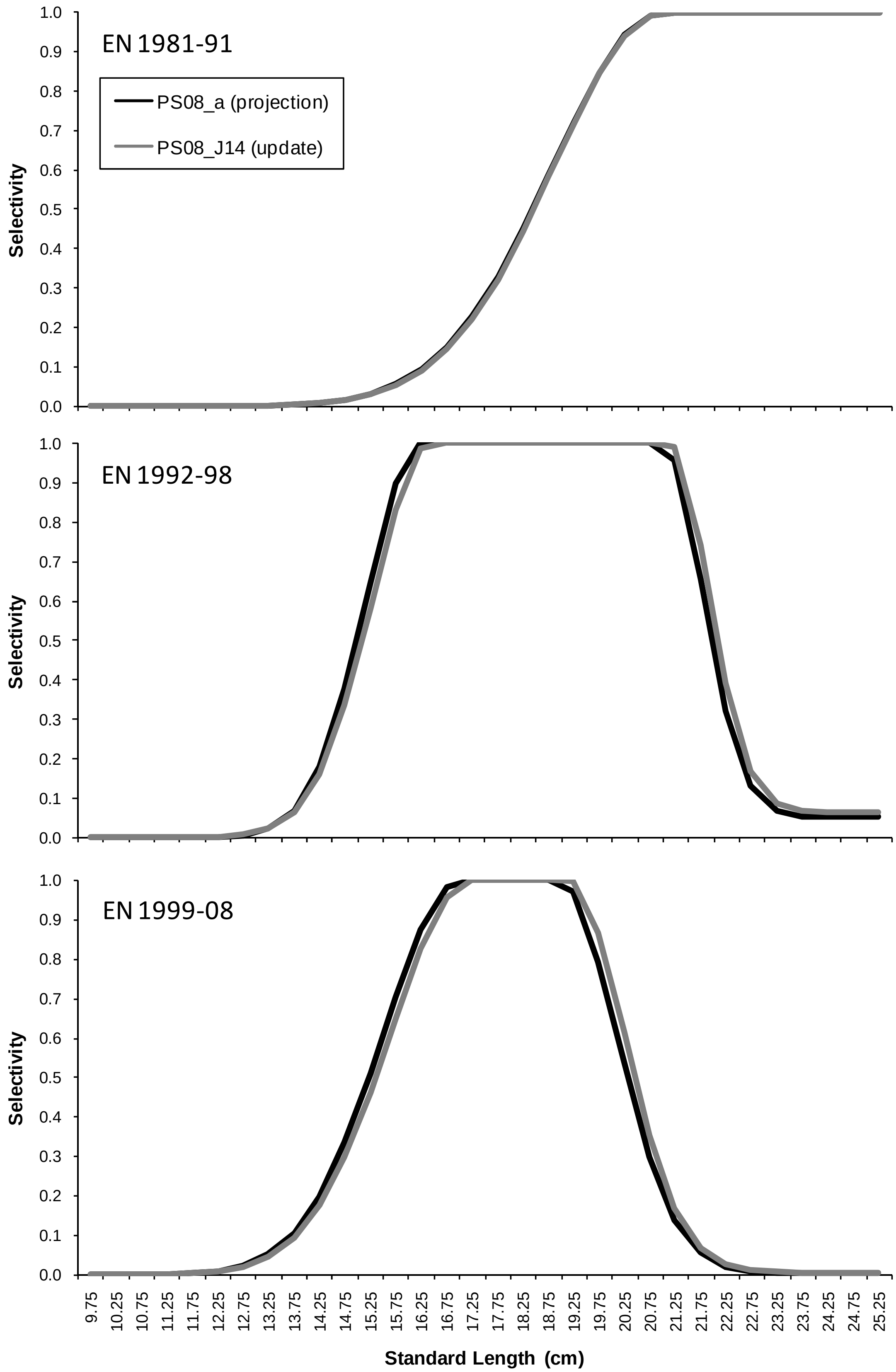


Figure 28b. EN fishery selectivities for the update and projection models.

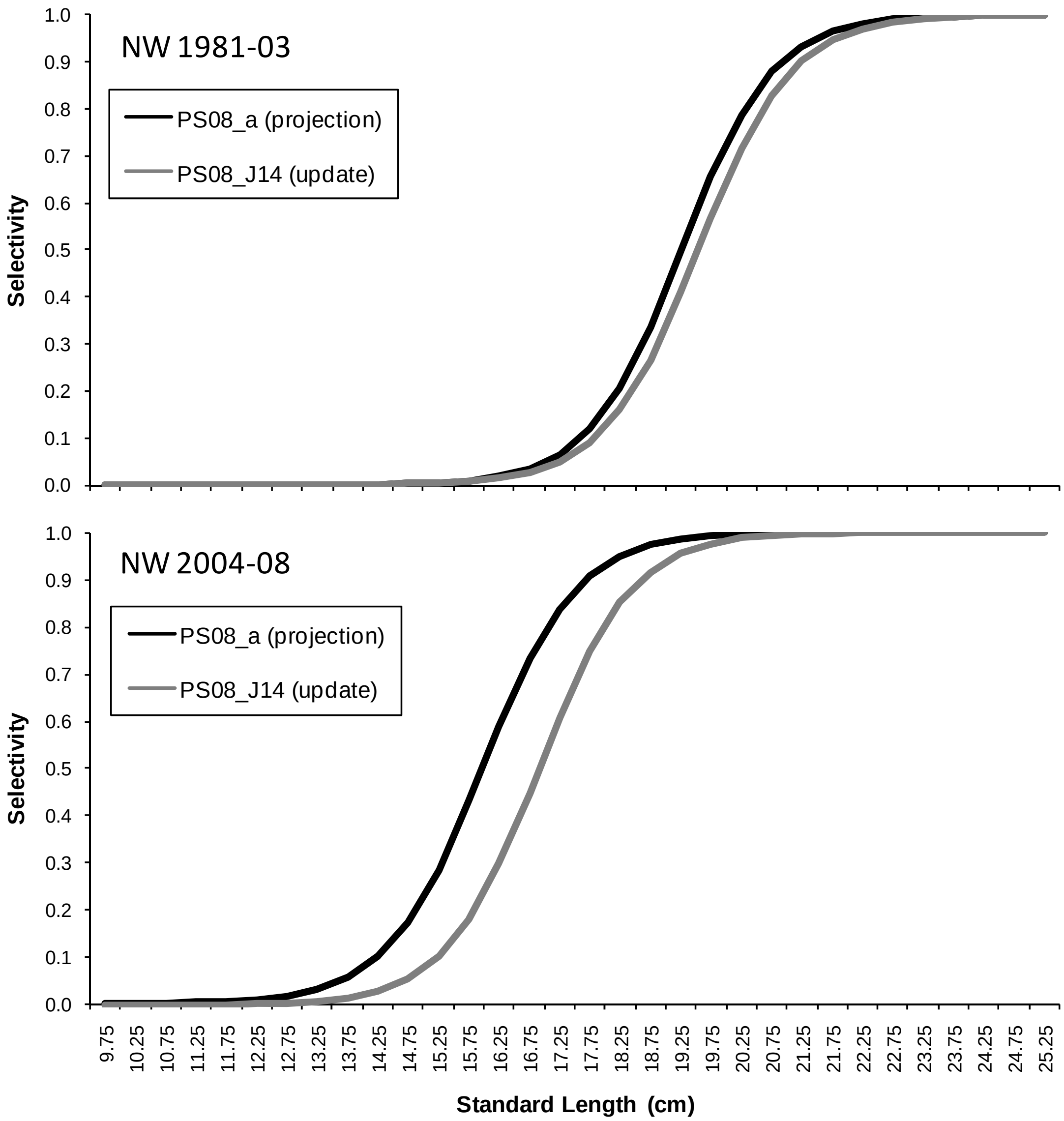


Figure 28c. NW fishery selectivities for the update and projection models.

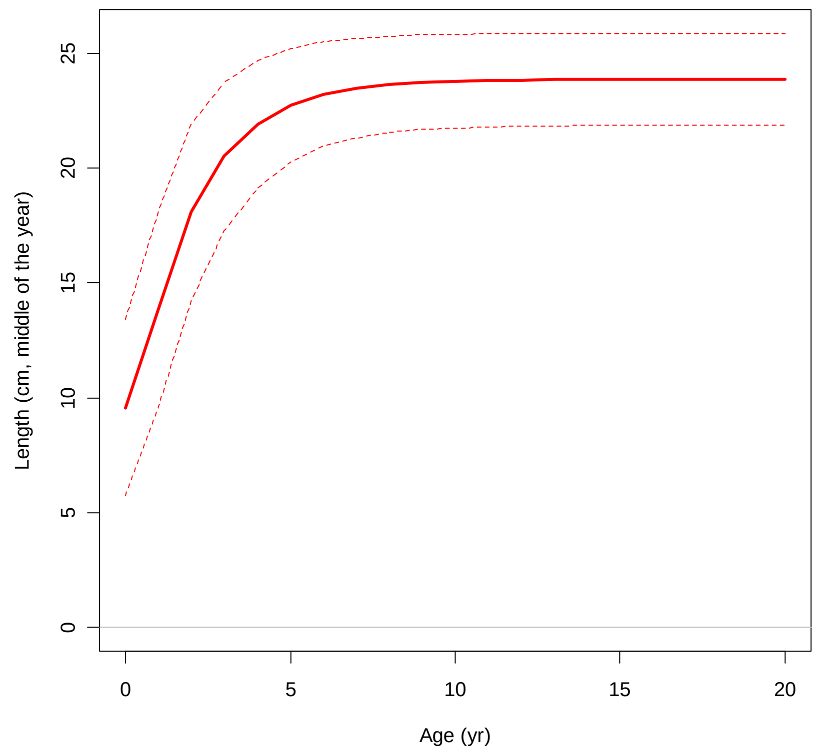


Figure 29a. Growth curve for Pacific sardine estimated in the update model (*K*=0.548).

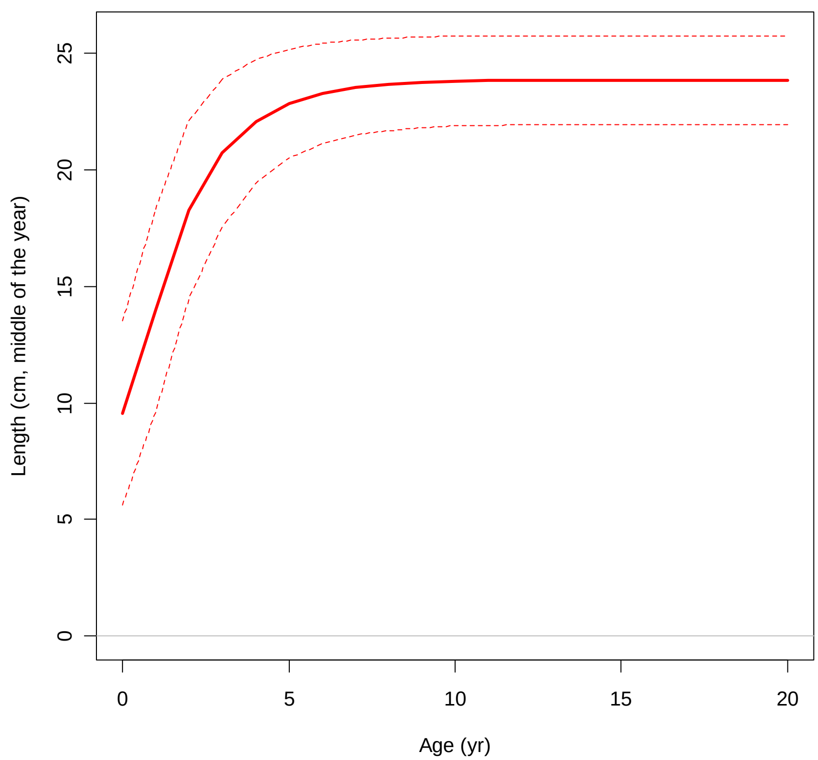


Figure 29b. Growth curve for Pacific sardine estimated in the projection model (*K*=0.572).

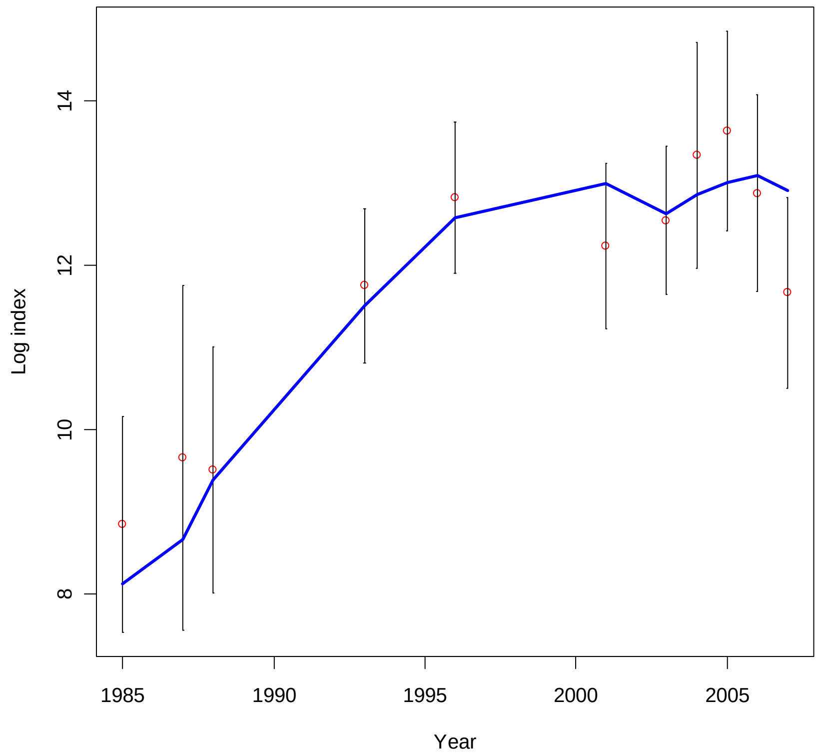


Figure 30a. Update model fit to the Daily Egg Production Method series (*Q*=0.649).

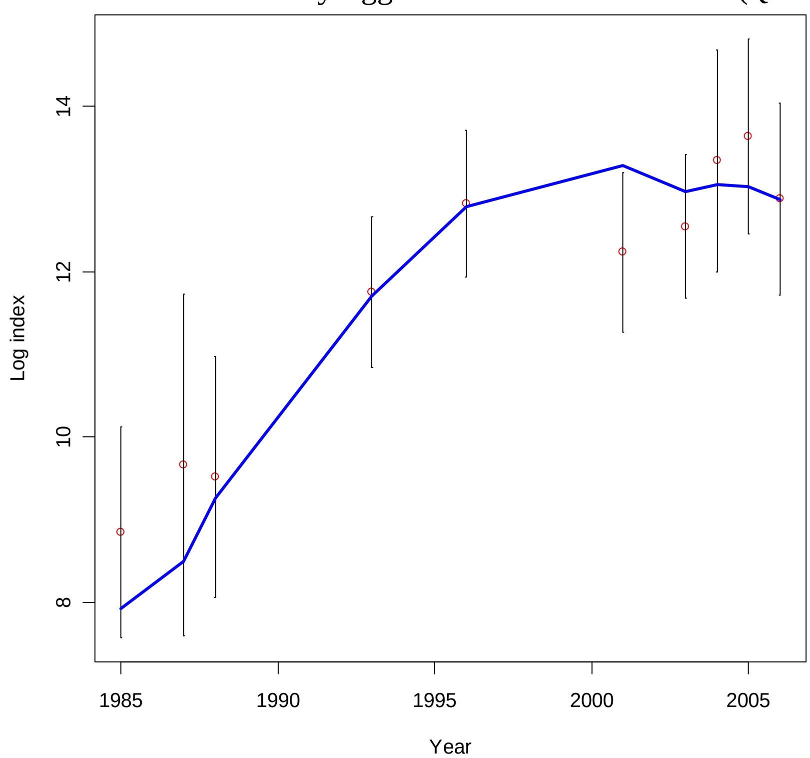


Figure 30b. Projection model fit to the Daily Egg Production Method series (*Q*=0.471) (excludes 2008 survey).

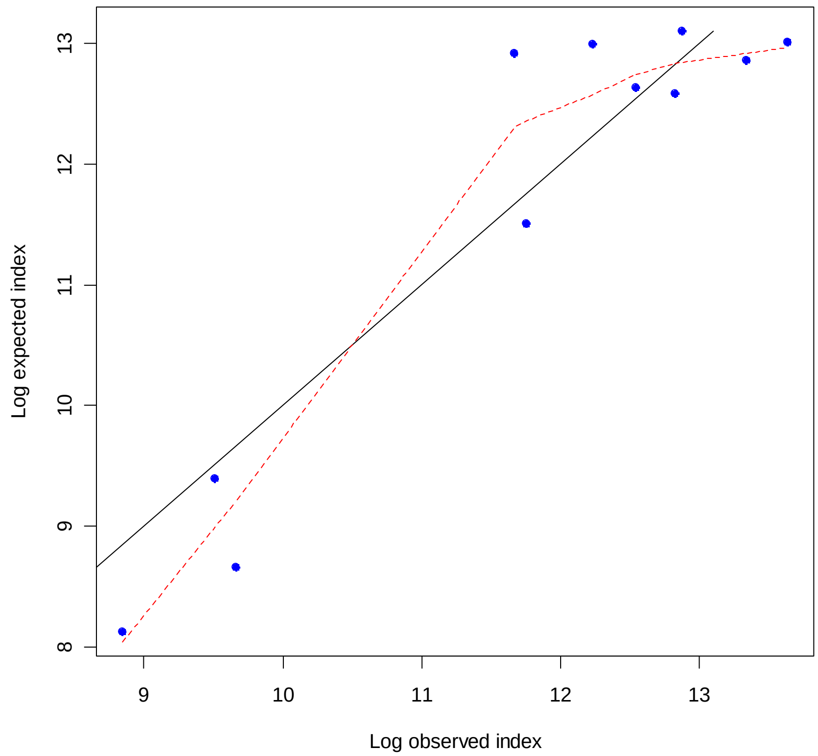


Figure 31a. Relationship between observed and expected values (log scale) for the Daily Egg Production survey (update model). Straight line is 1 to 1 relationship; dashed is LOESS fit.

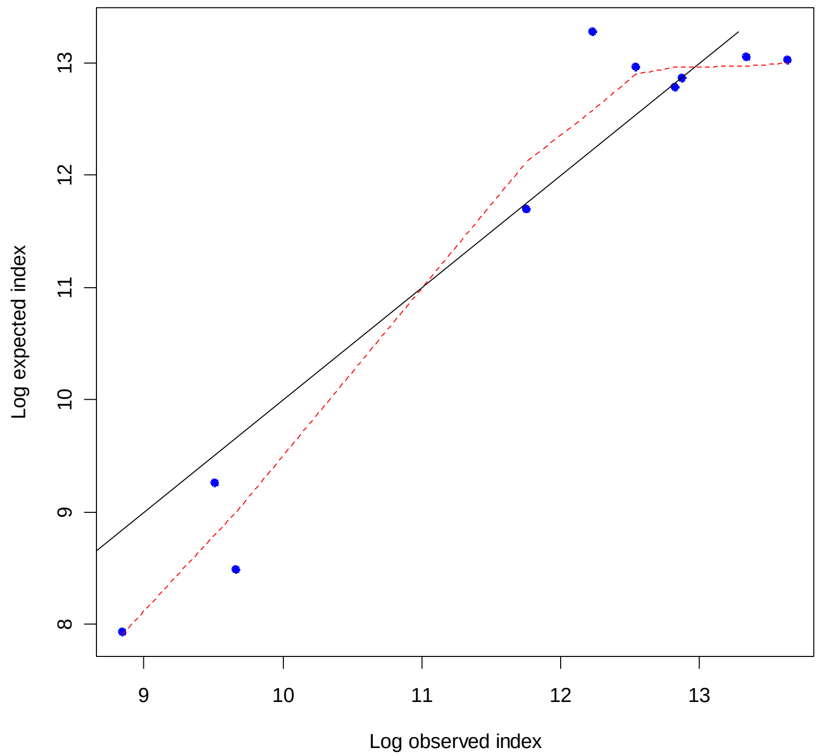


Figure 31b. Relationship between observed and expected values (log scale) for the Daily Egg Production survey (projection model). Straight line is 1 to 1 relationship; dashed is LOESS fit.

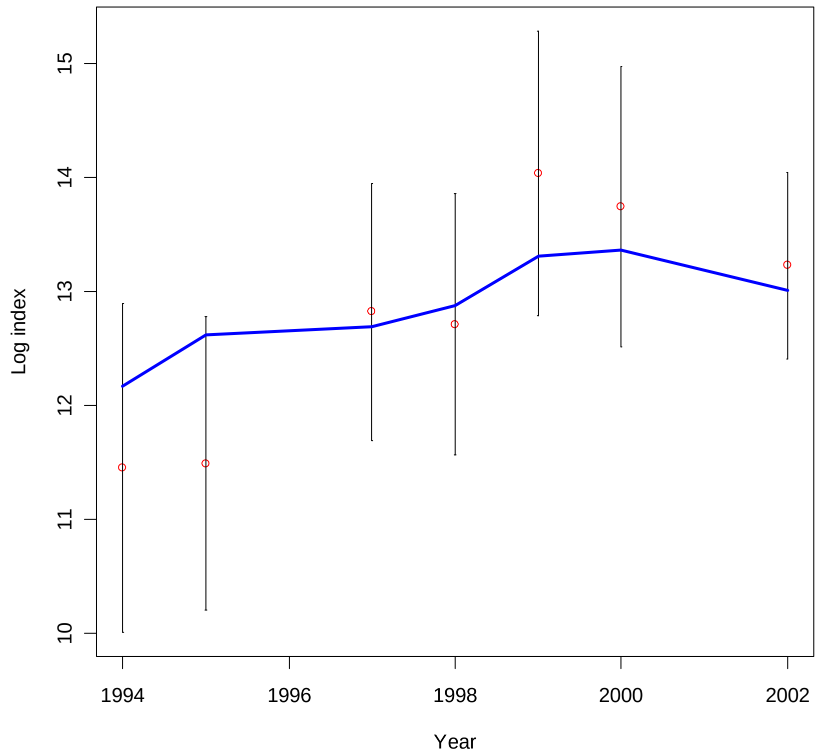


Figure 32a. Update model fit to the Total Egg Production series (Q=0.779).

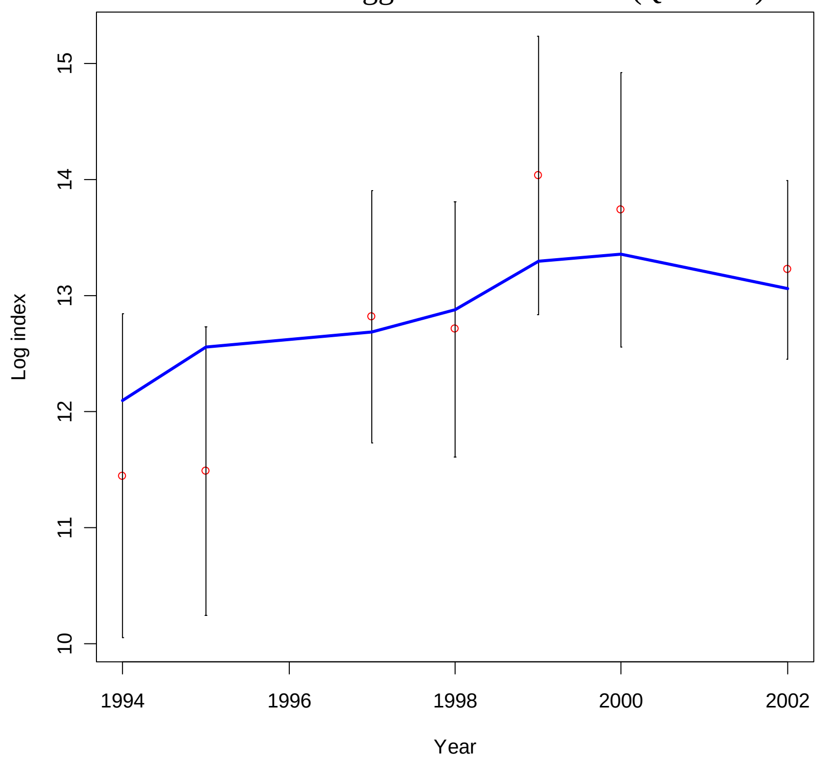


Figure 32b. Projection model fit to the Total Egg Production series (Q=0.437).

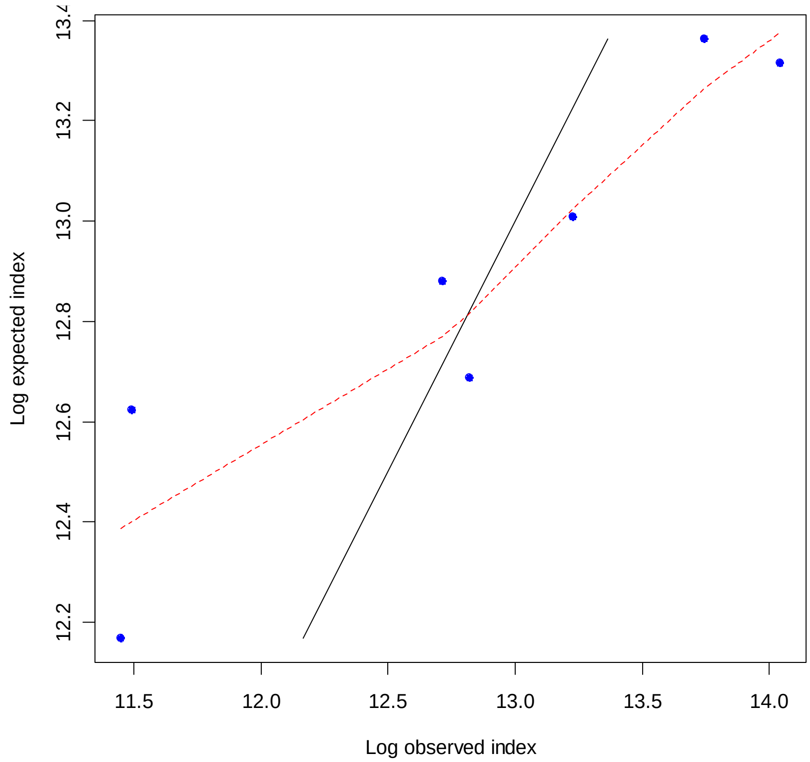


Figure 33a. Relationship between observed and expected values (log scale) for the Total Egg Production survey (update model). Straight line is 1 to 1 relationship; dashed is LOESS fit.

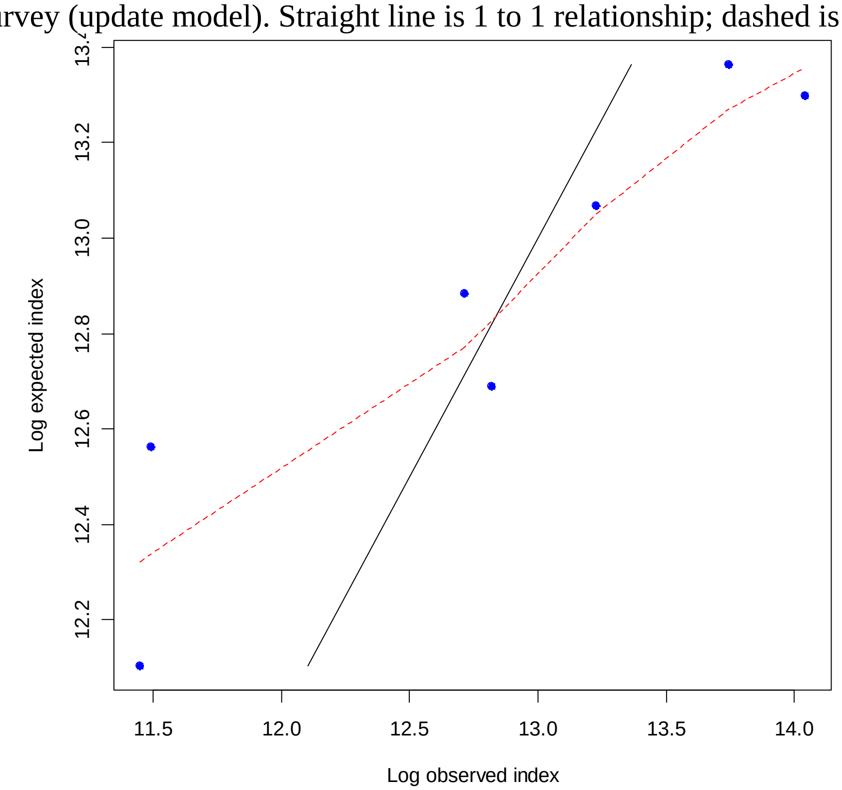


Figure 33b. Relationship between observed and expected values (log scale) for the Total Egg Production survey (projection model). Straight line is 1 to 1 relationship; dashed is LOESS fit.

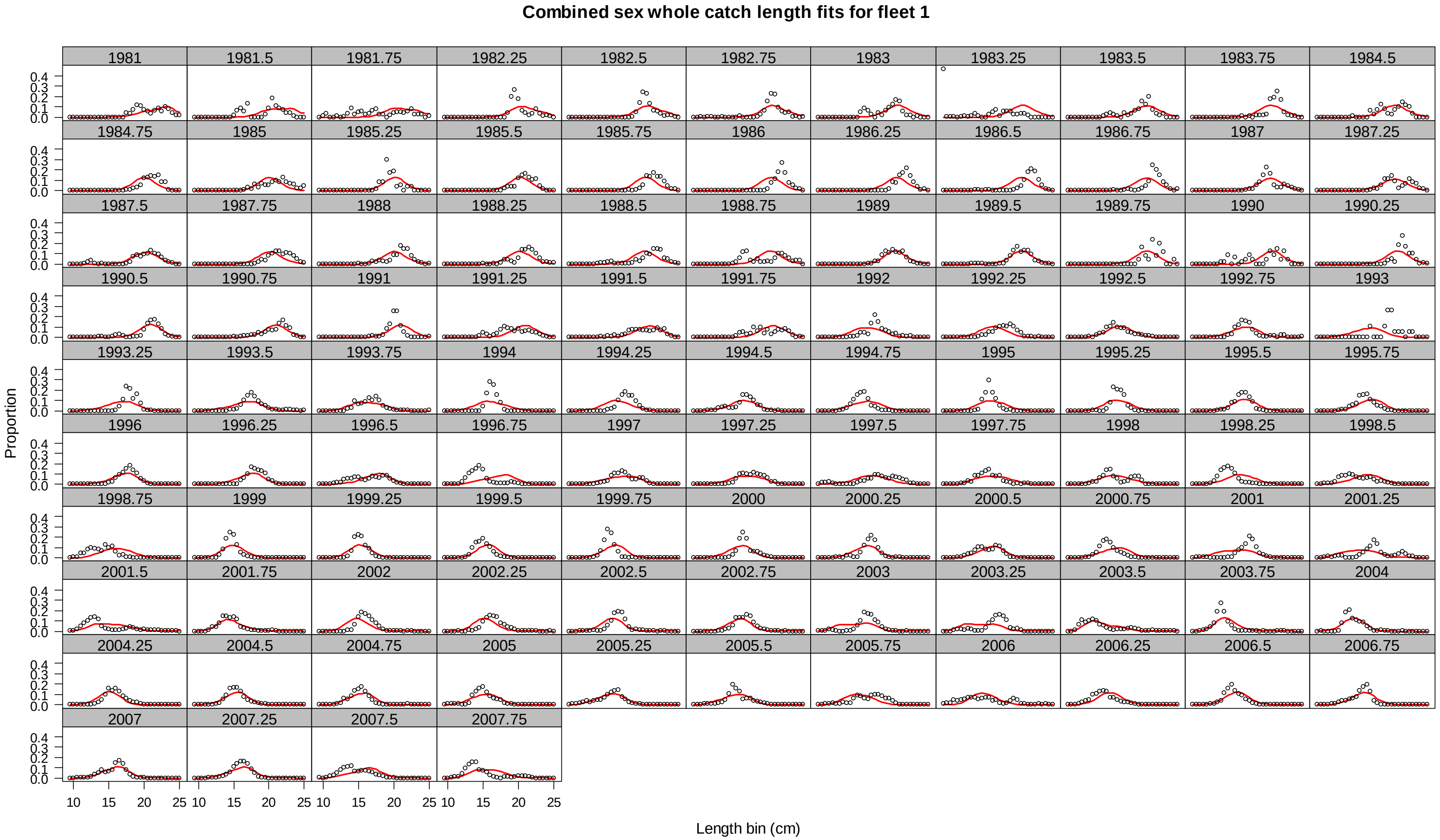


Figure 34a. Update model fits to length-frequency data for the California fishery.

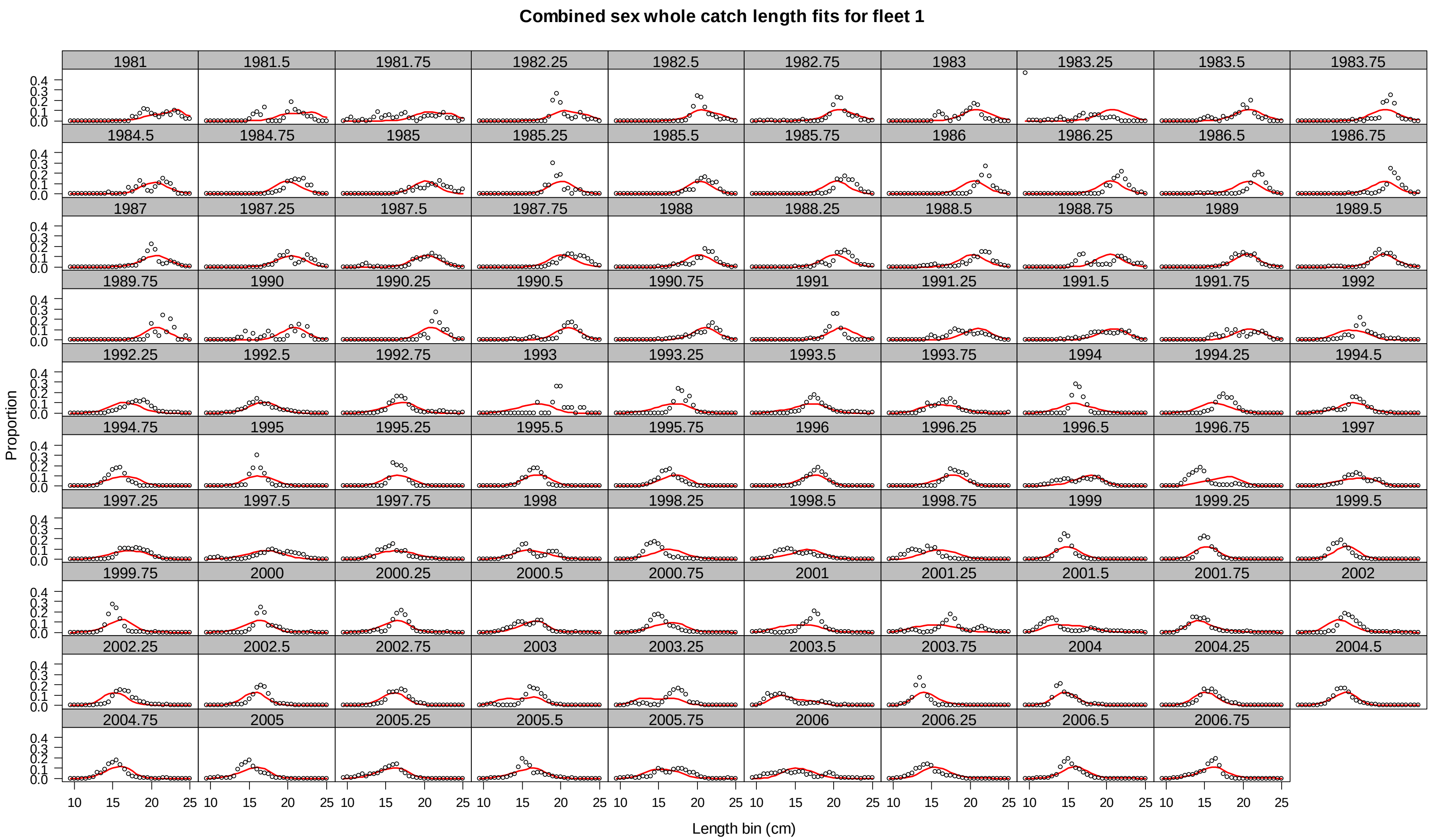


Figure 34b. Projection model fits to length-frequency data for the California fishery.

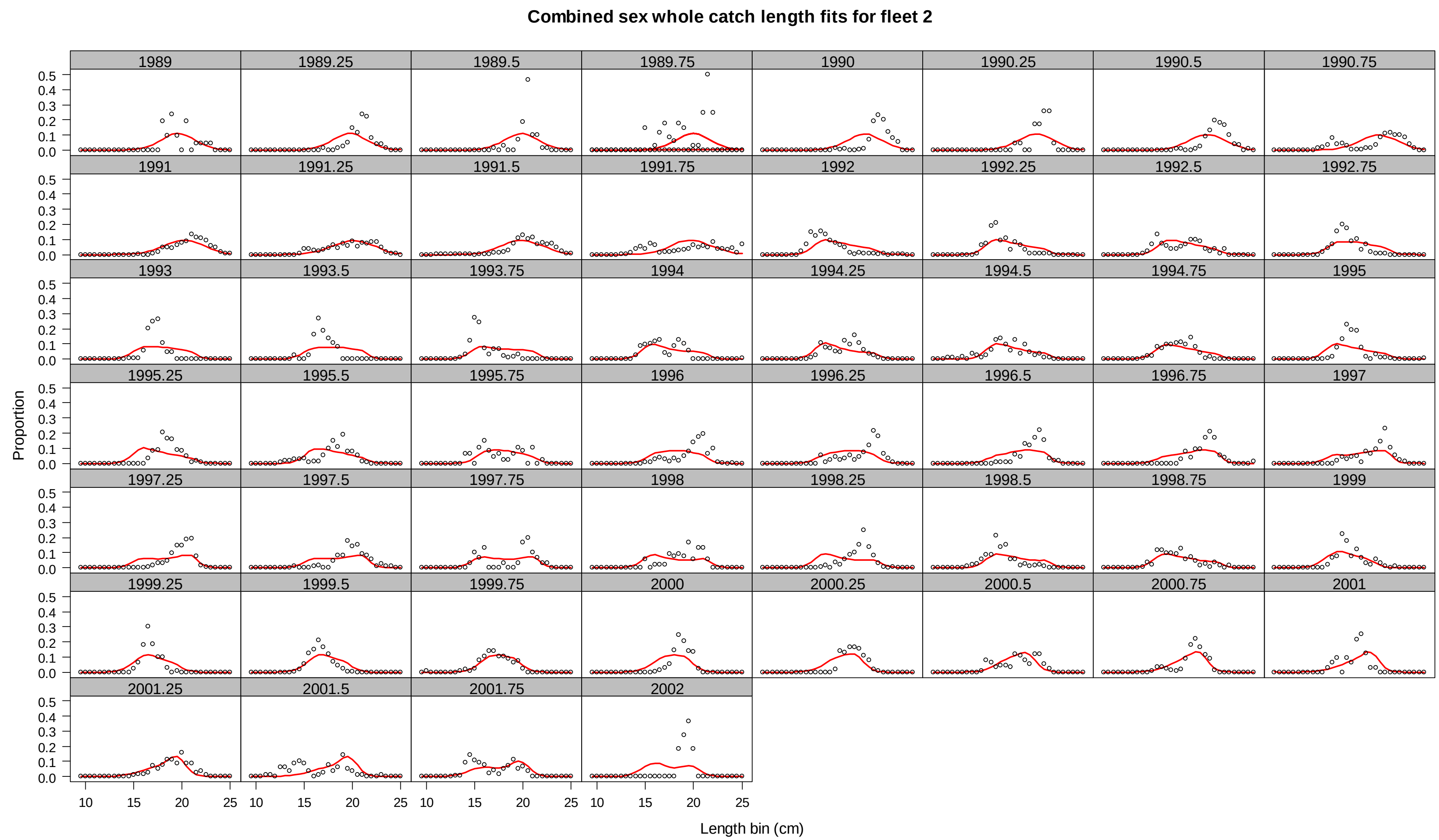


Figure 35a. Update model fits to length-frequency data for the Ensenada fishery.

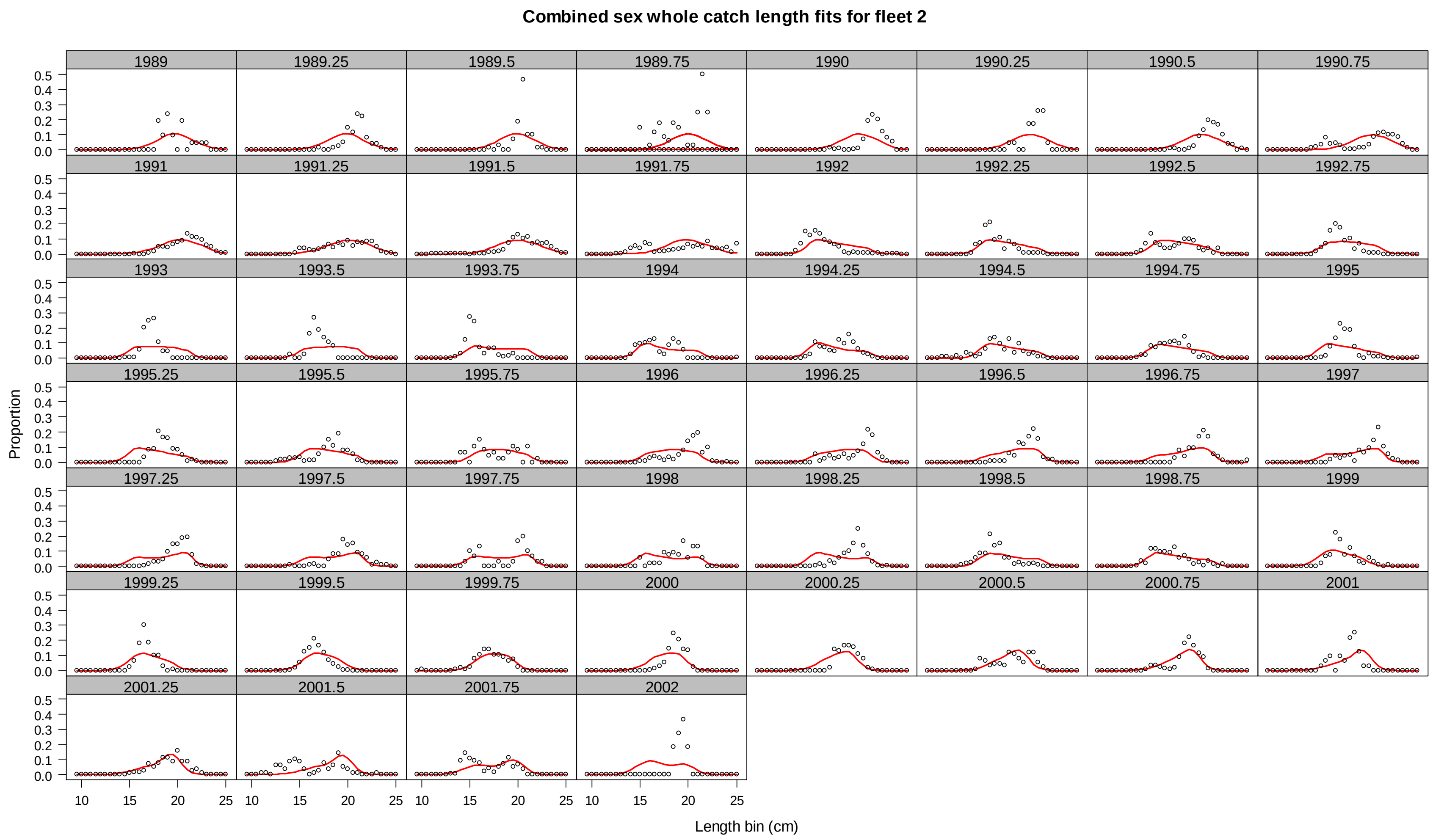


Figure 35b. Projection model fits to length-frequency data for the Ensenada fishery.

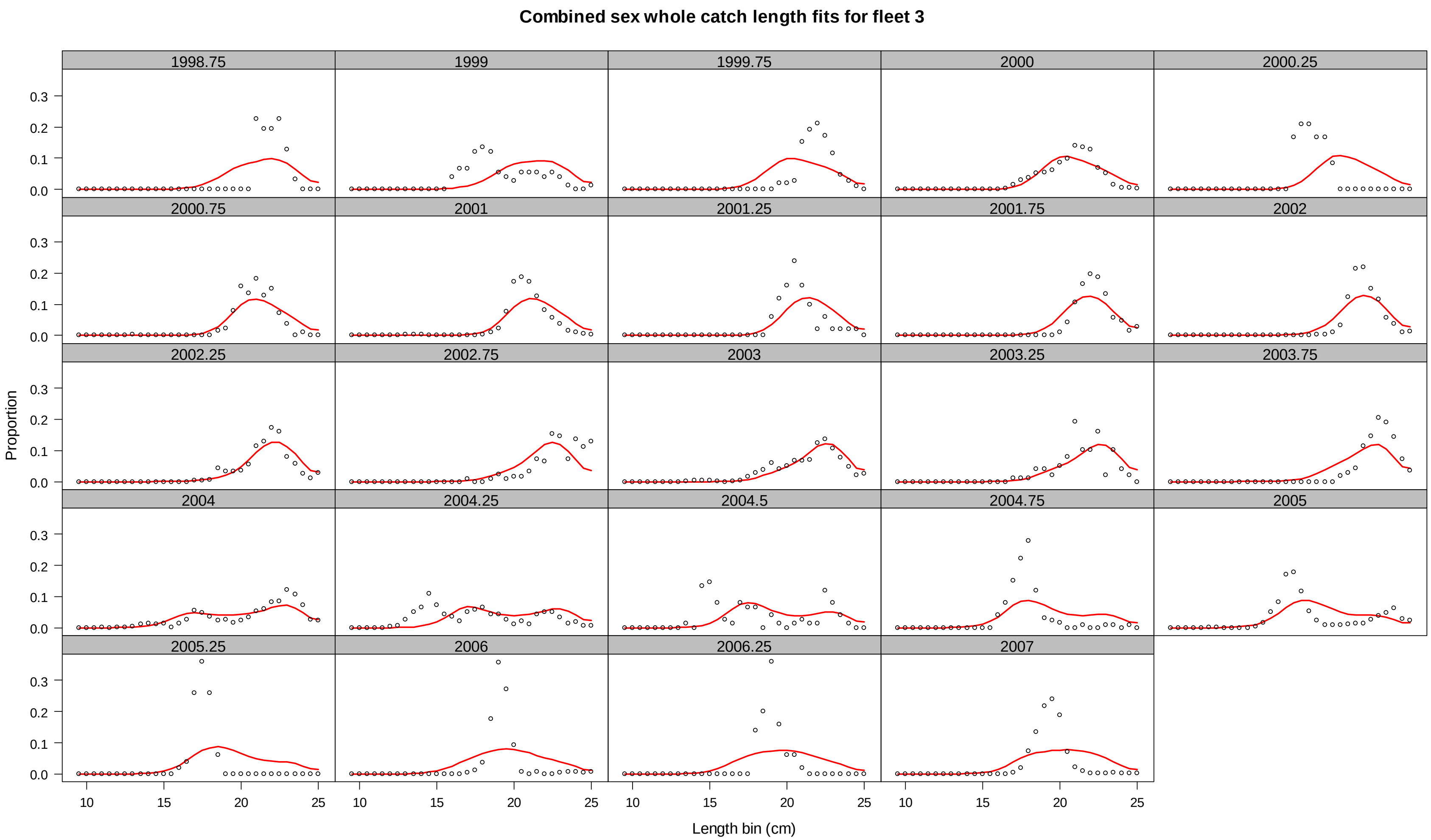


Figure 36a. Update model fits to length-frequency data for the Pacific northwest fishery.

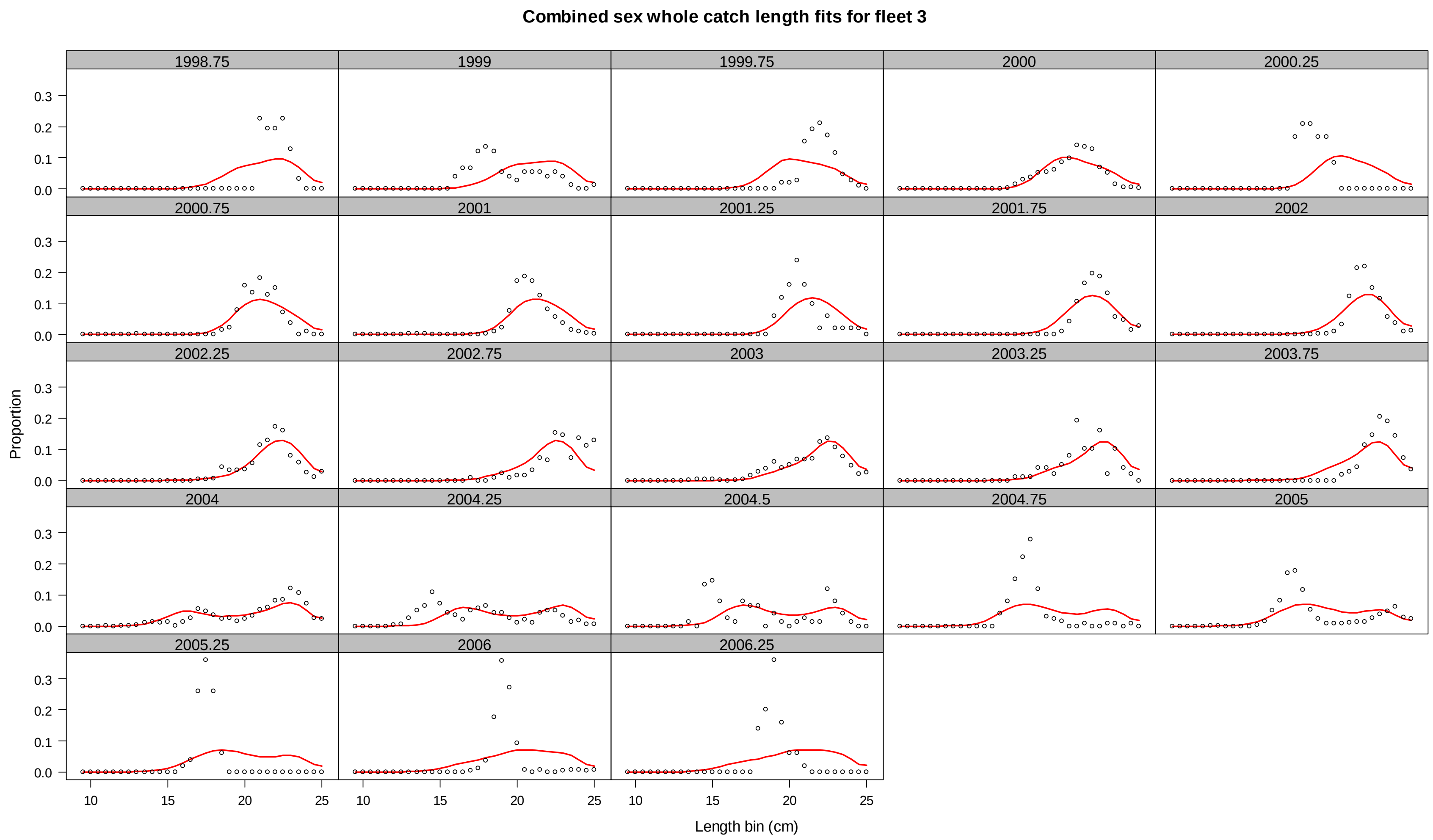


Figure 36b. Projection model fits to length-frequency data for the Pacific northwest fishery.

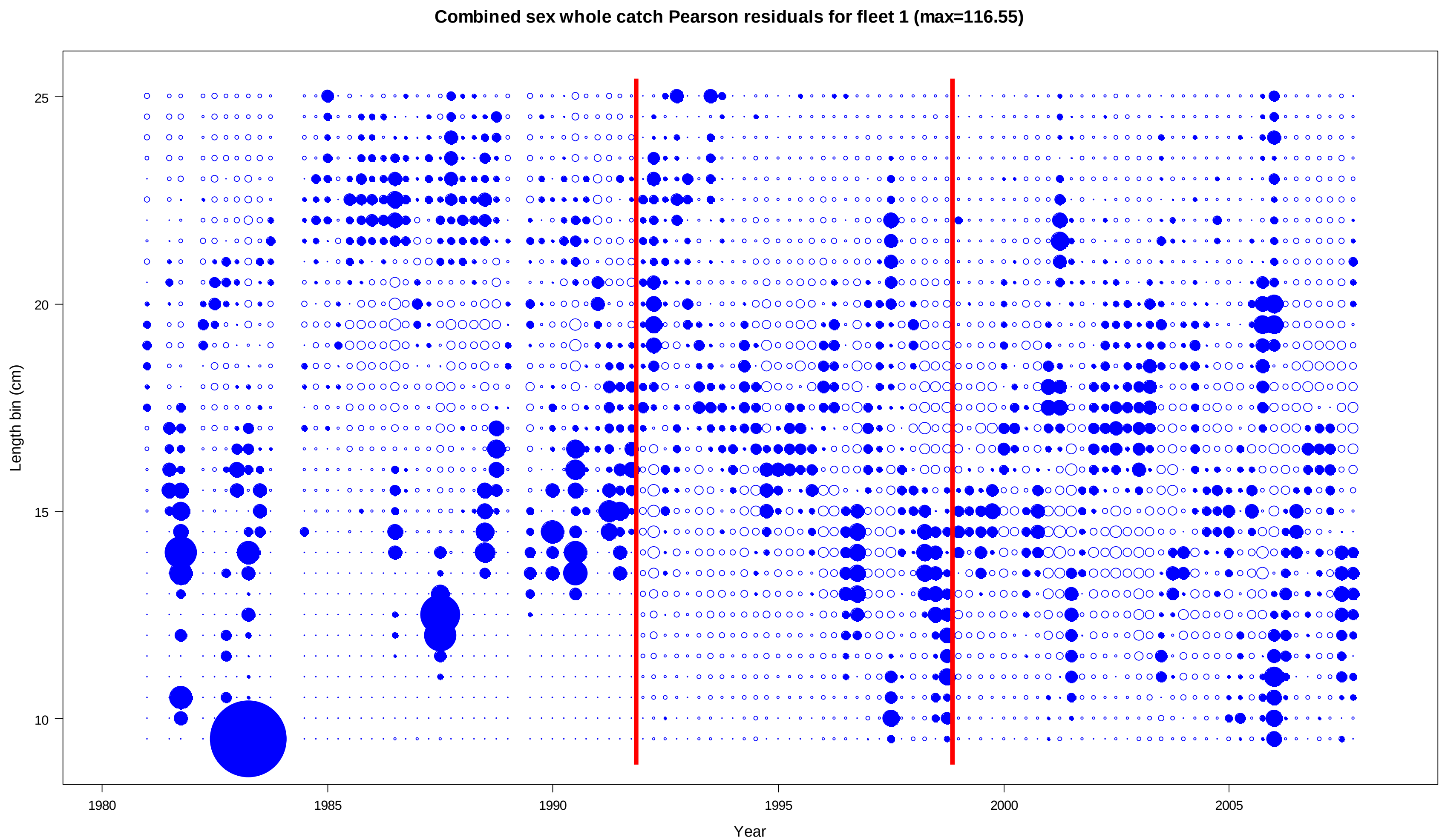


Figure 37a. Pearson residuals for the update model fit to length-frequency data for the California fishery. Vertical line indicates selectivity period change.

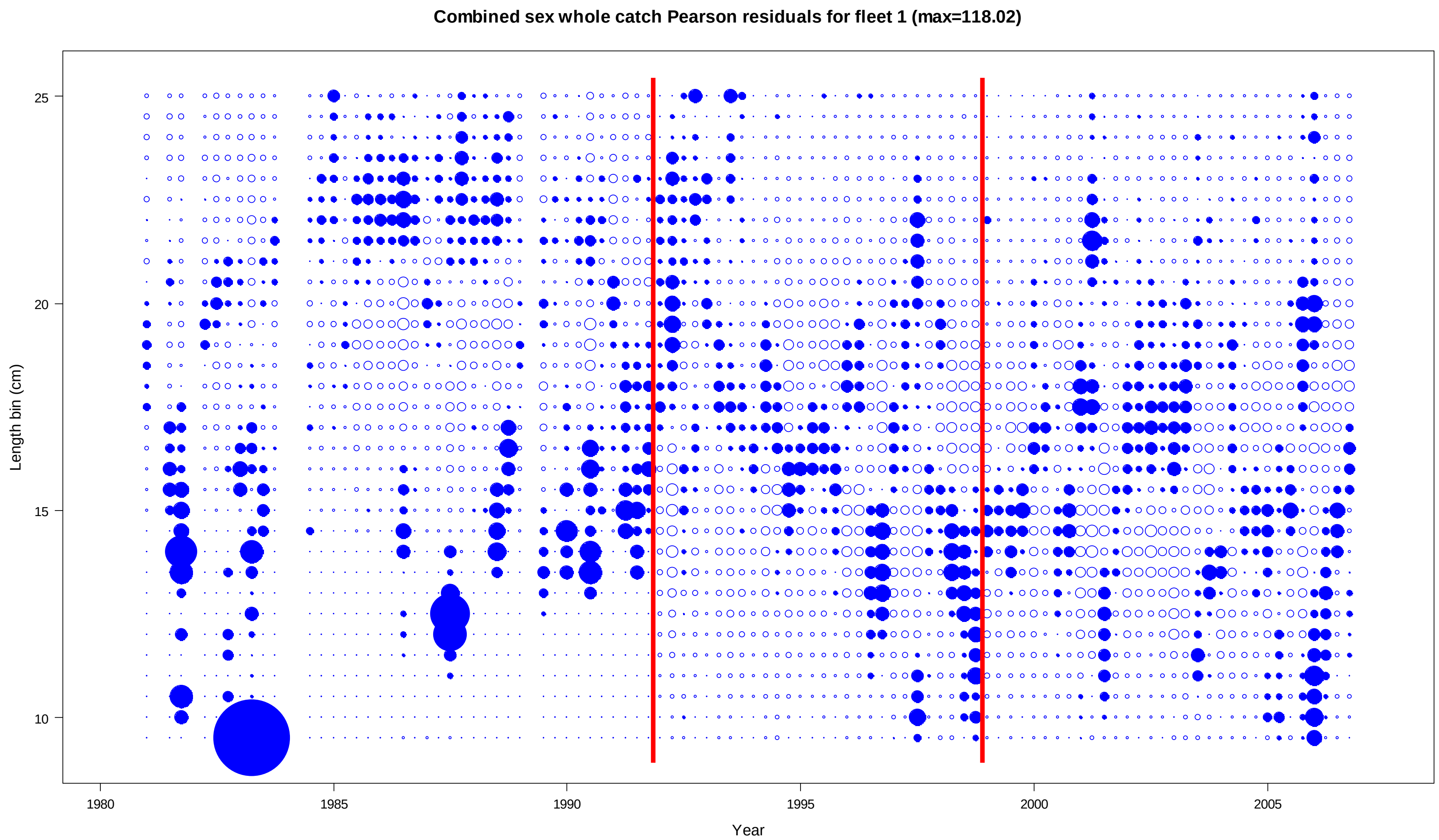


Figure 37b. Pearson residuals for the projection model fit to length-frequency data for the California fishery. Vertical line indicates selectivity period change.

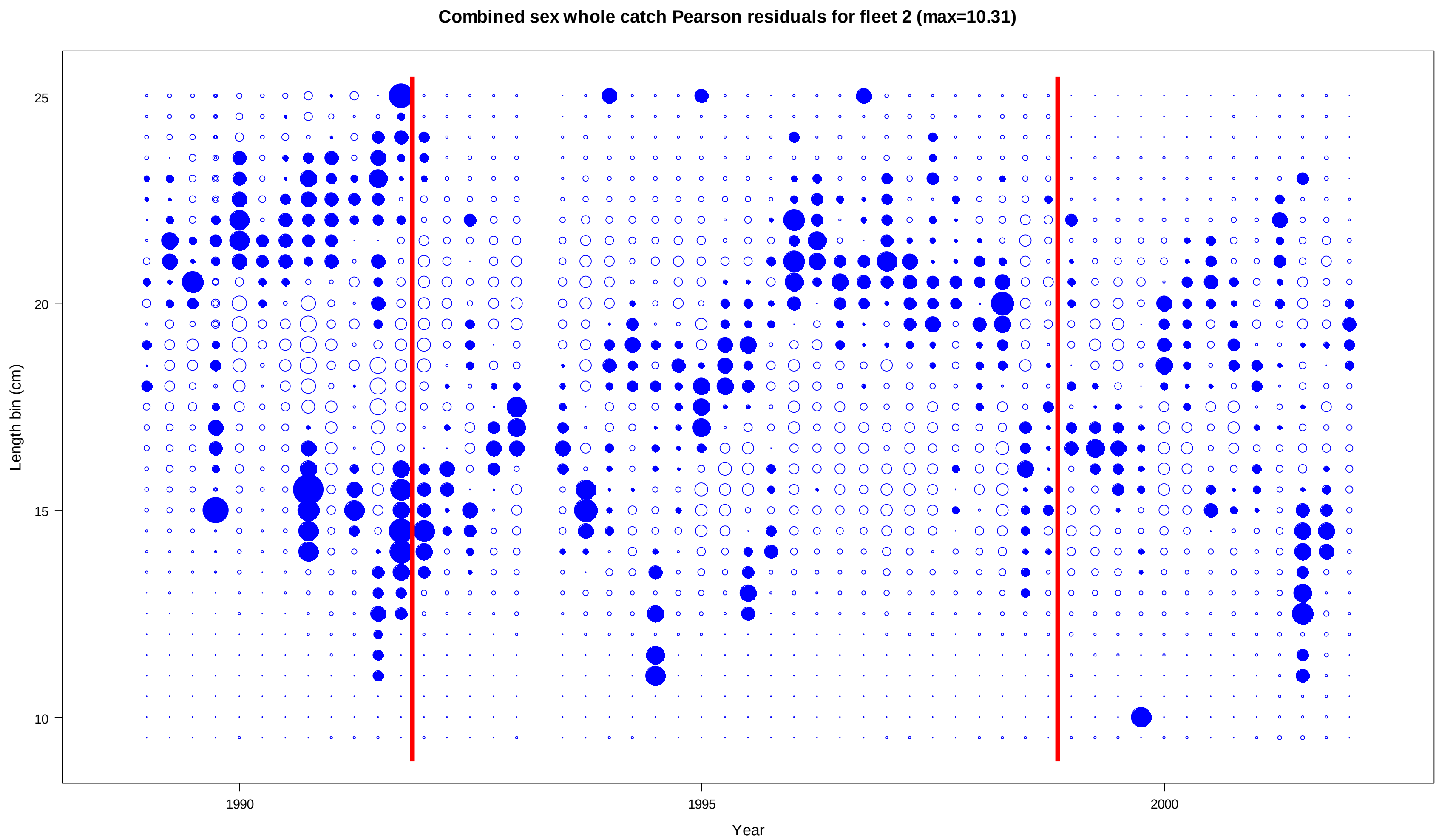


Figure 38a. Pearson residuals for the update model fit to length-frequency observations for the Ensenada fleet. Vertical line indicates selectivity period change.

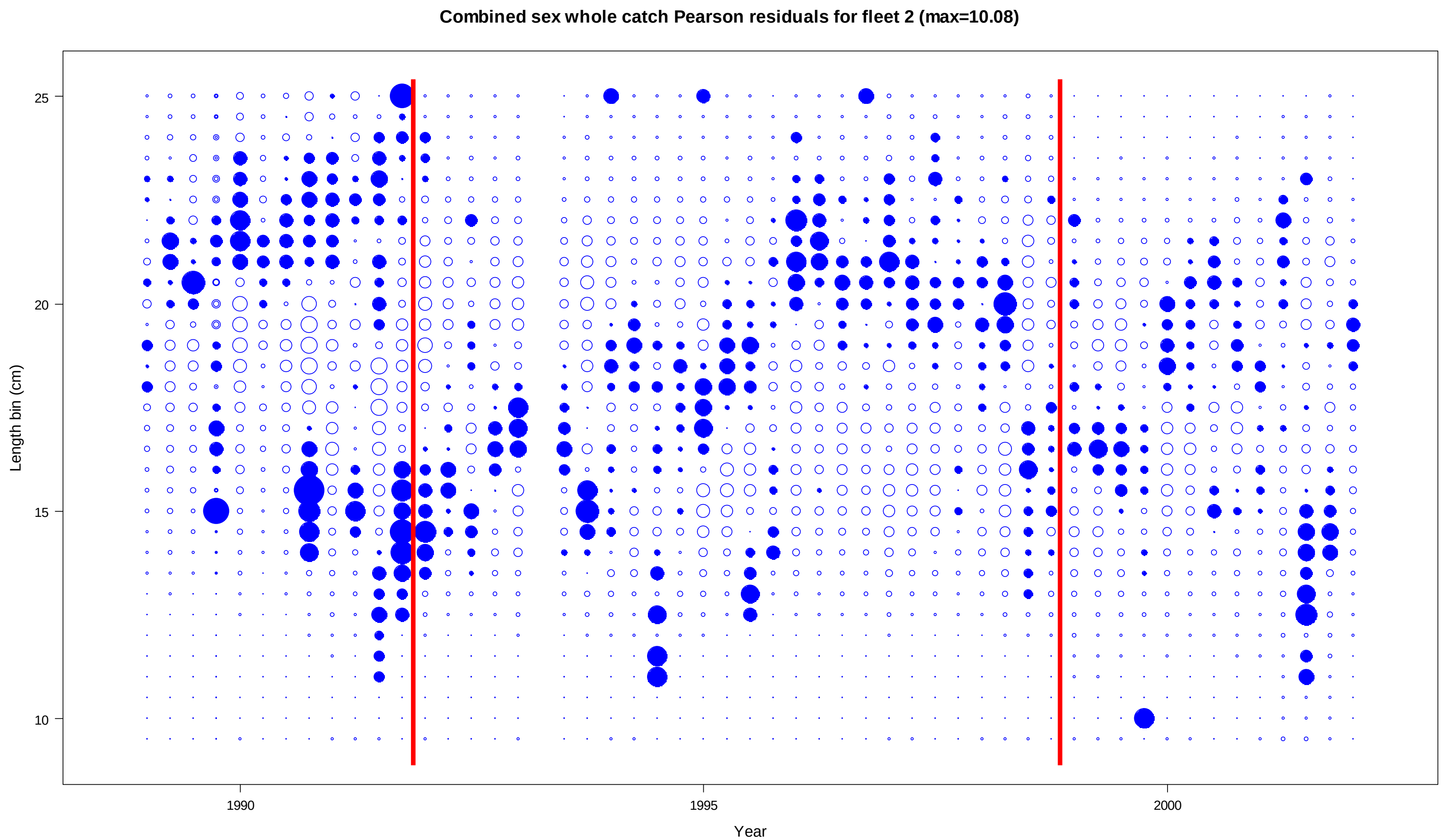


Figure 38b. Pearson residuals for the projection model fit to length-frequency observations for the Ensenada fleet. Vertical line indicates selectivity period change.

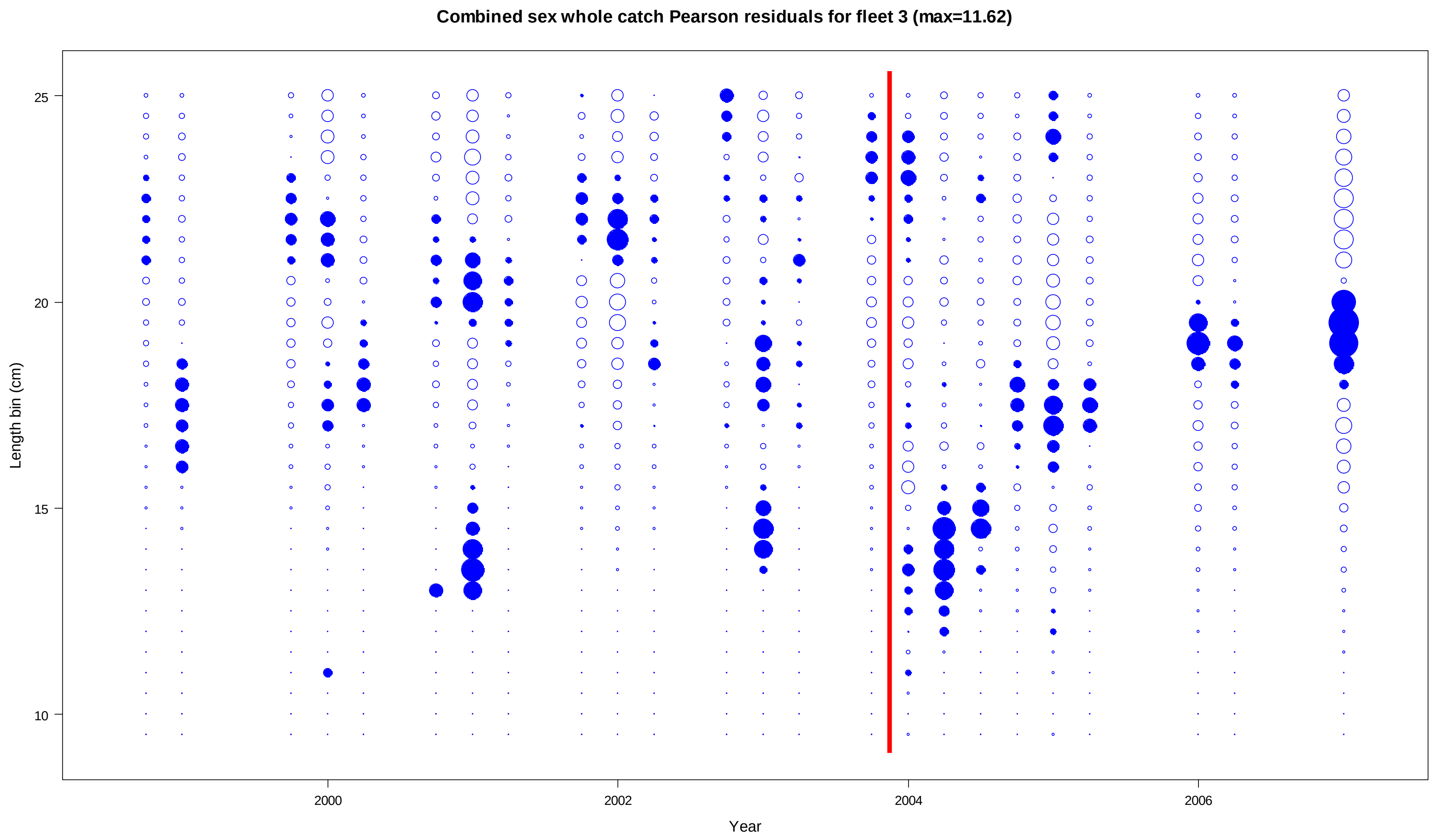


Figure 39a. Pearson residuals for the update model fit to length-frequency data for the Pacific Northwest fishery. Vertical line indicates selectivity period change.

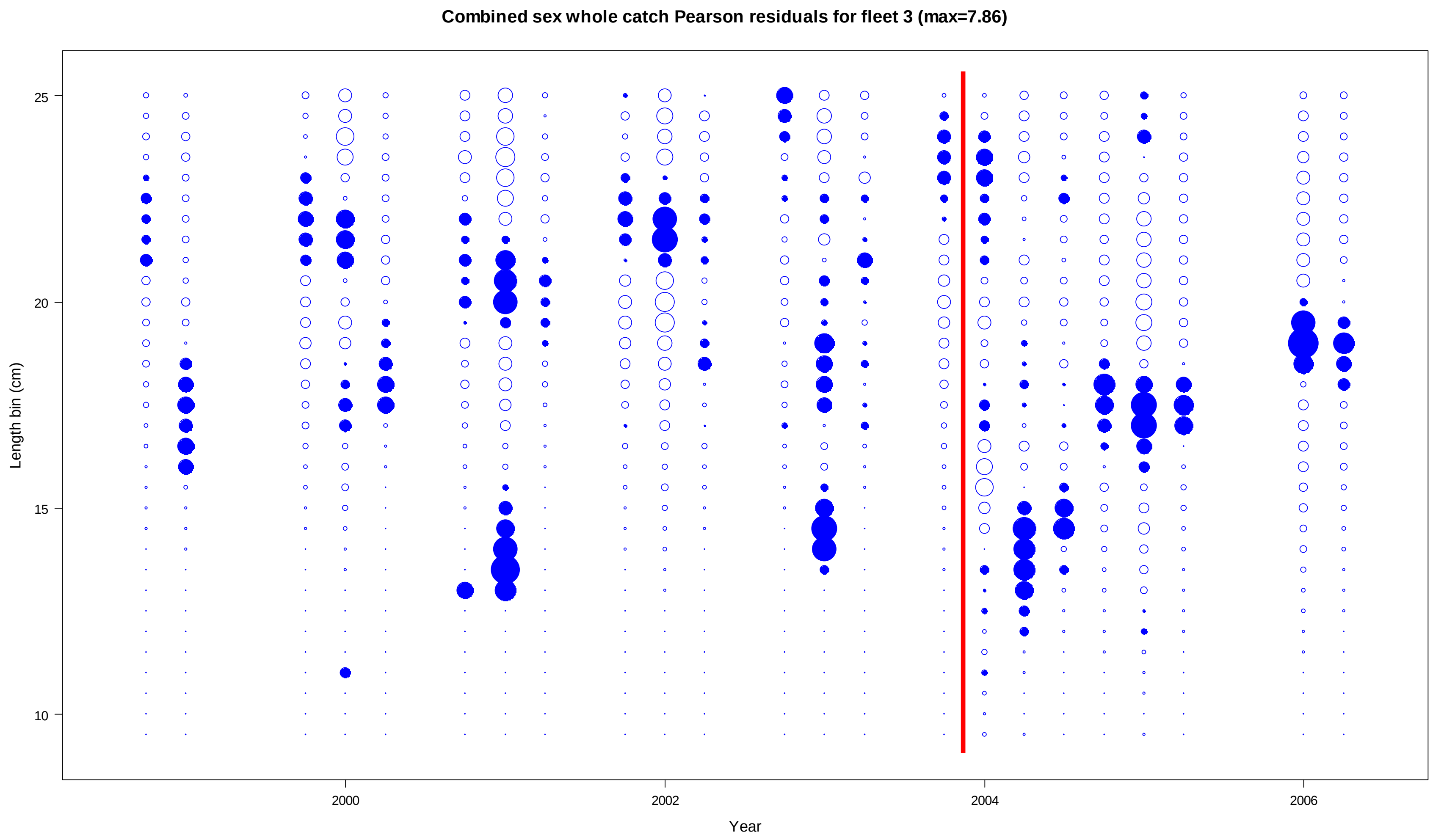


Figure 39b. Pearson residuals for the projection model fit to length-frequency data for the Pacific Northwest fishery. Vertical line indicates selectivity period change.

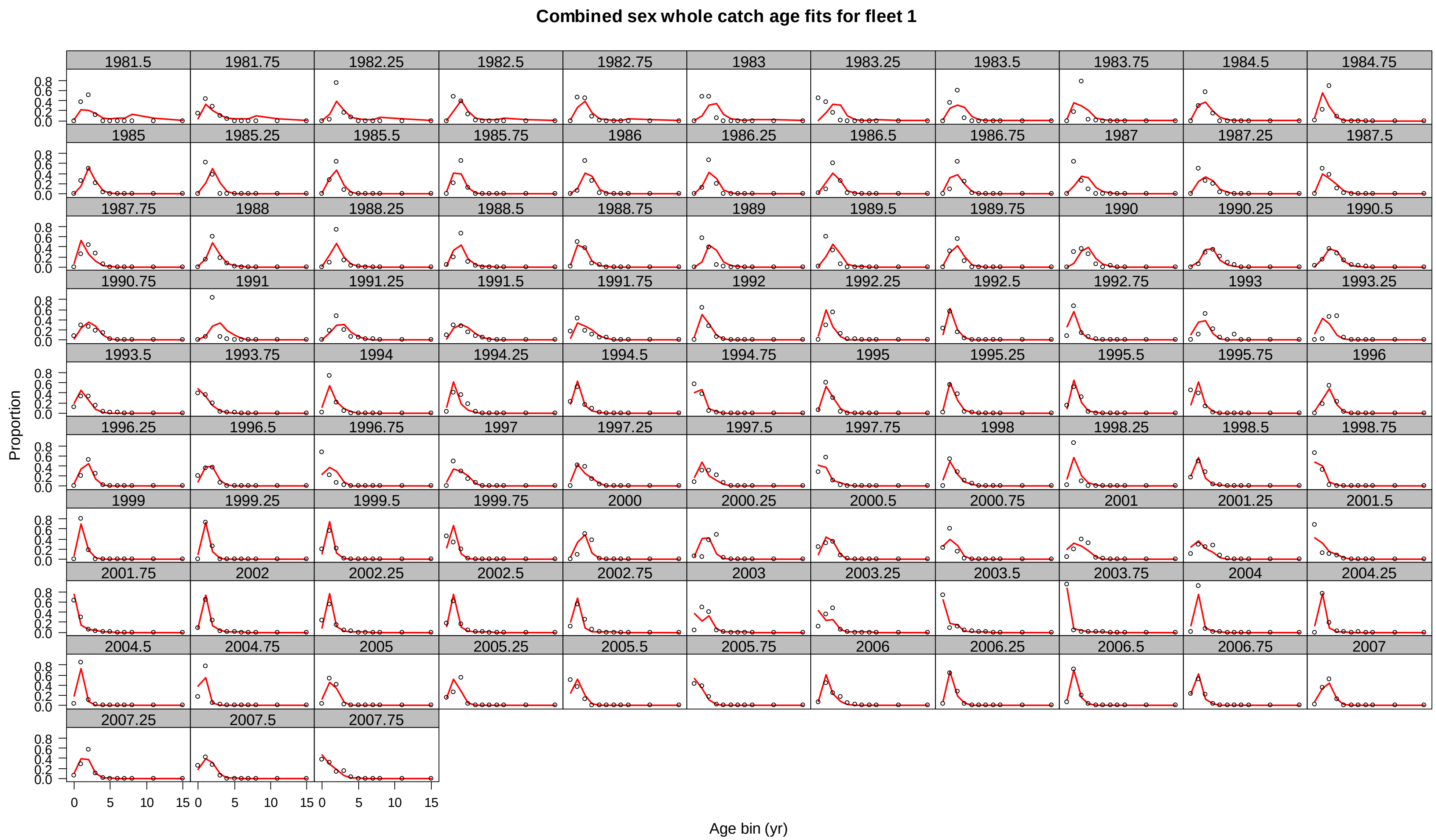


Figure 40a. Update model fit to the (implied) age-frequency data for the California fishery.

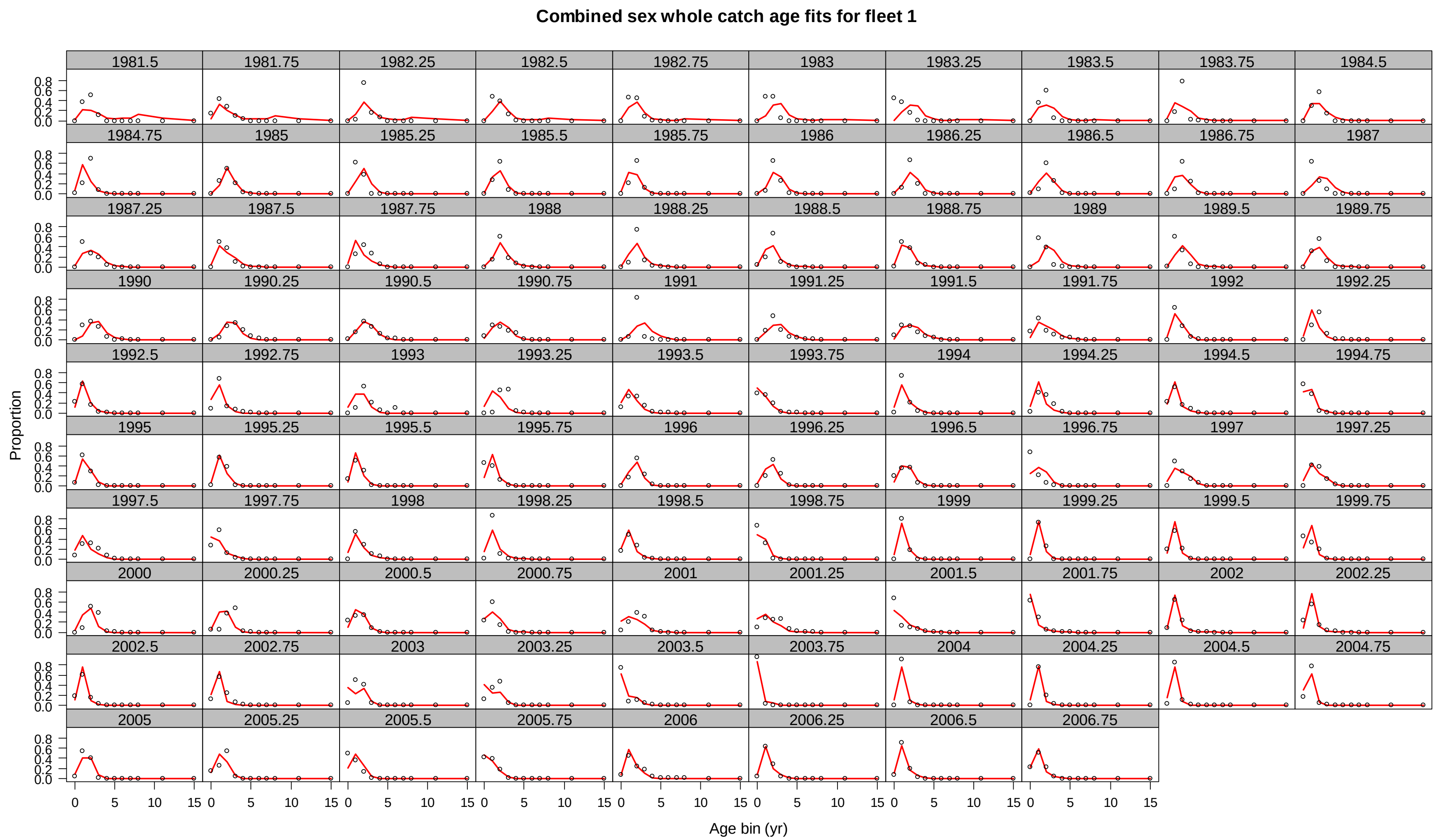


Figure 40b. Projection model fit to the (implied) age-frequency data for the California fishery.

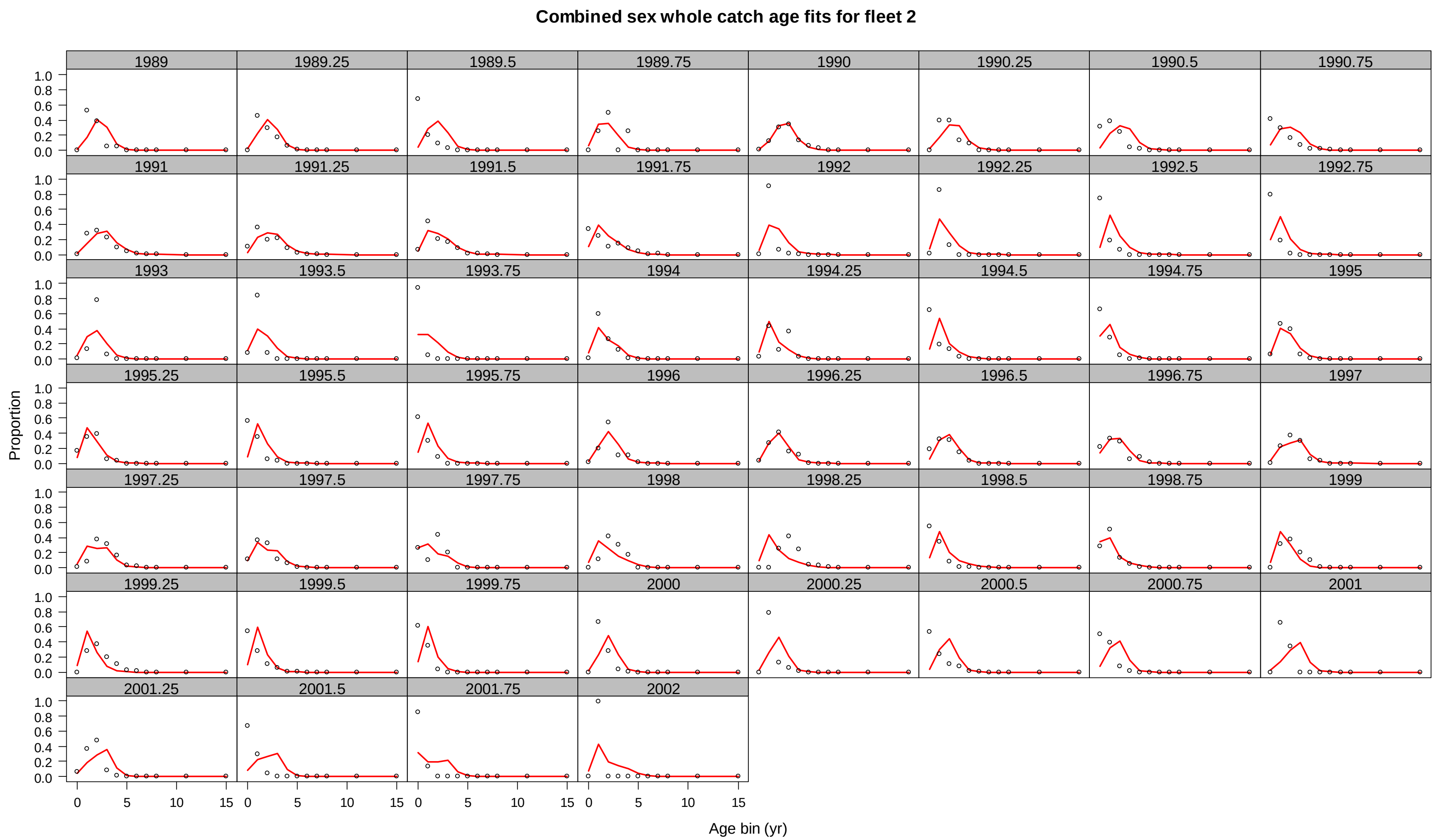


Figure 41a. Update model fit to the (implied) age-frequency data for the Ensenada fishery.

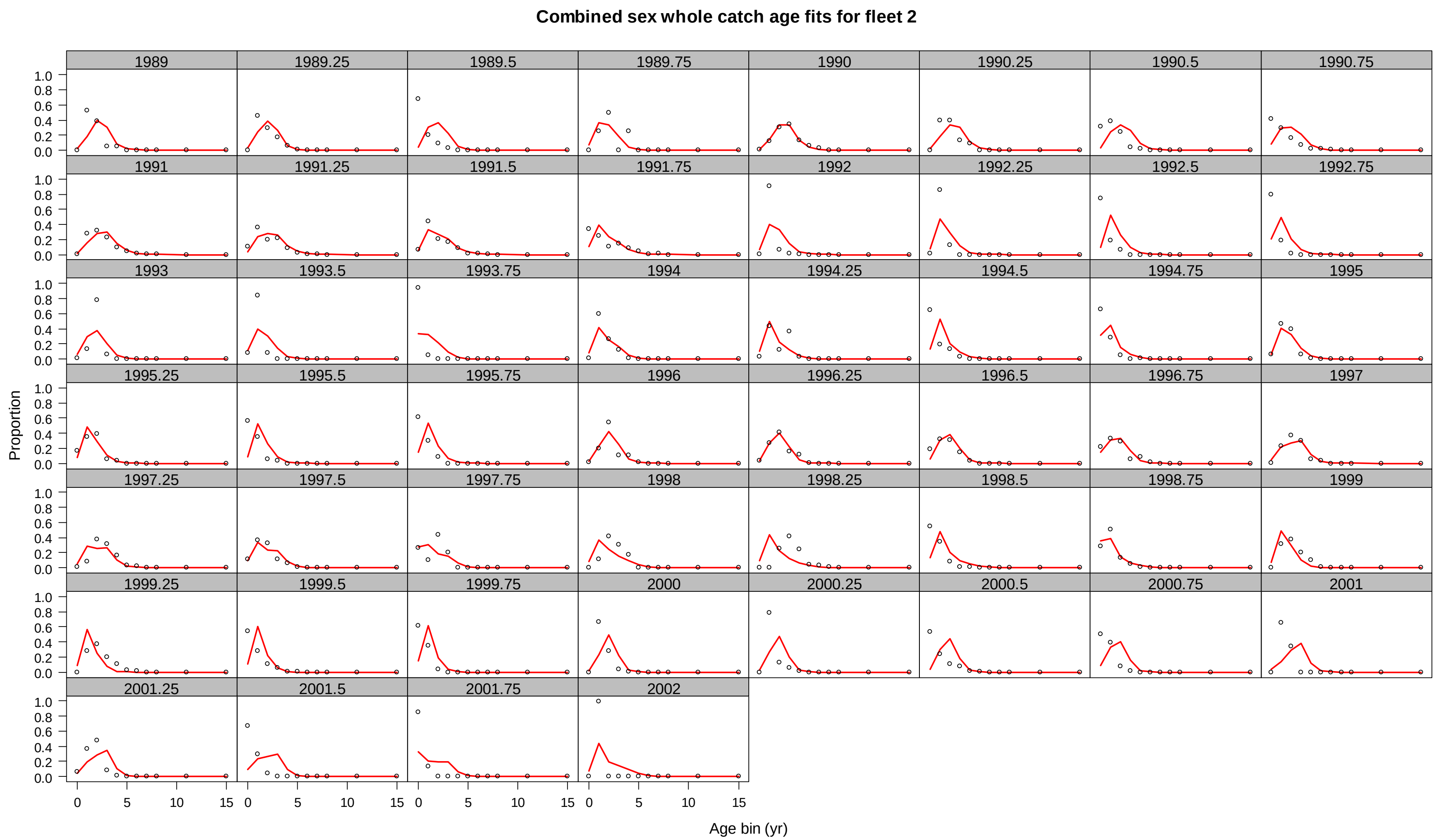


Figure 41b. Projection model fit to the (implied) age-frequency data for the Ensenada fishery.

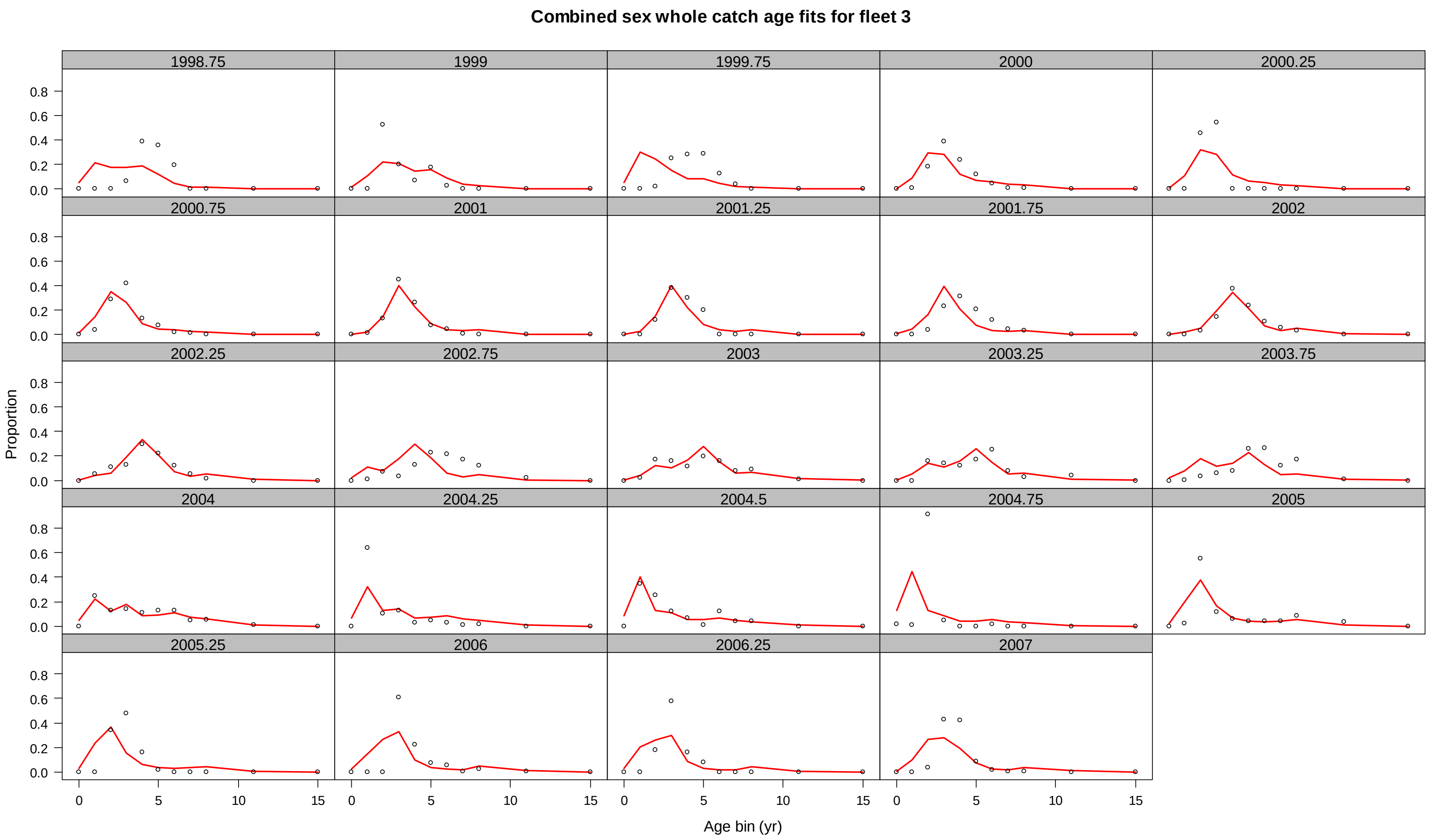


Figure 42a. Update model fit to the (implied) age-frequency data for the Pacific Northwest fishery.

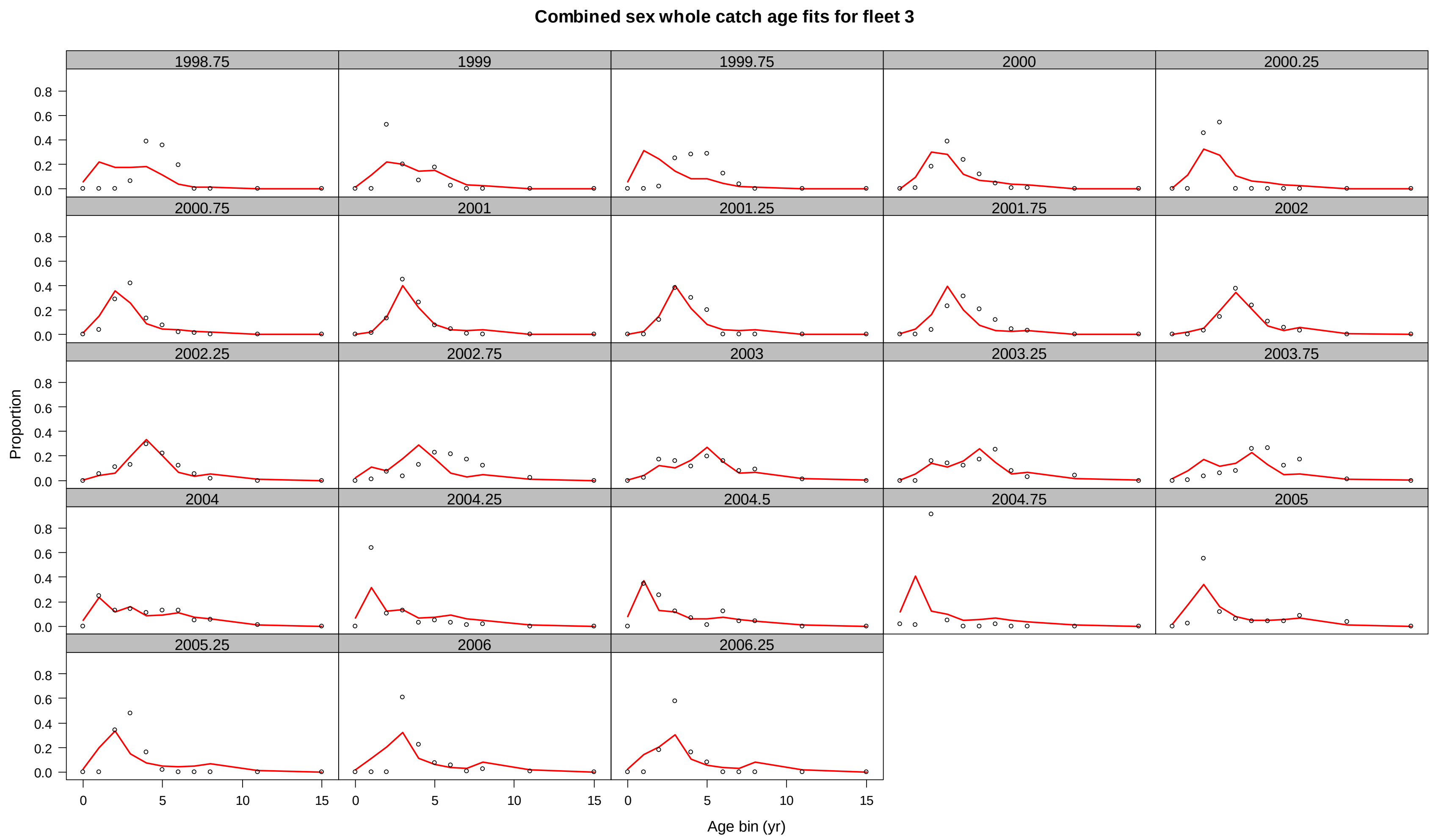


Figure 42b. Projection model fit to the (implied) age-frequency data for the Pacific Northwest fishery.

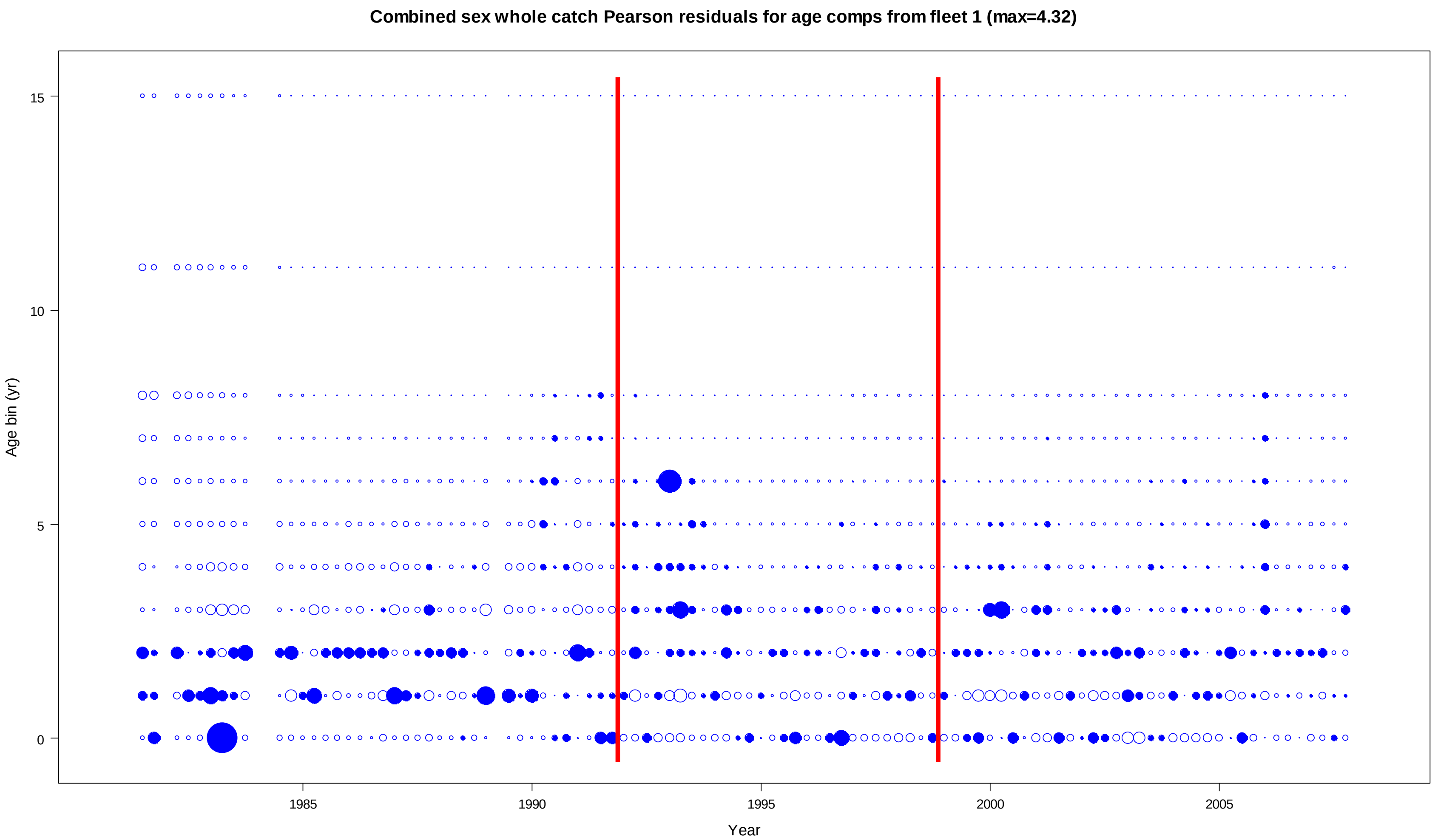


Figure 43a. Pearson residuals for update model fit to the (implied) age-frequency data for the California fishery. Vertical line indicates selectivity period change.

Combined sex whole catch Pearson residuals for age comps from fleet 1 (max=4.09)

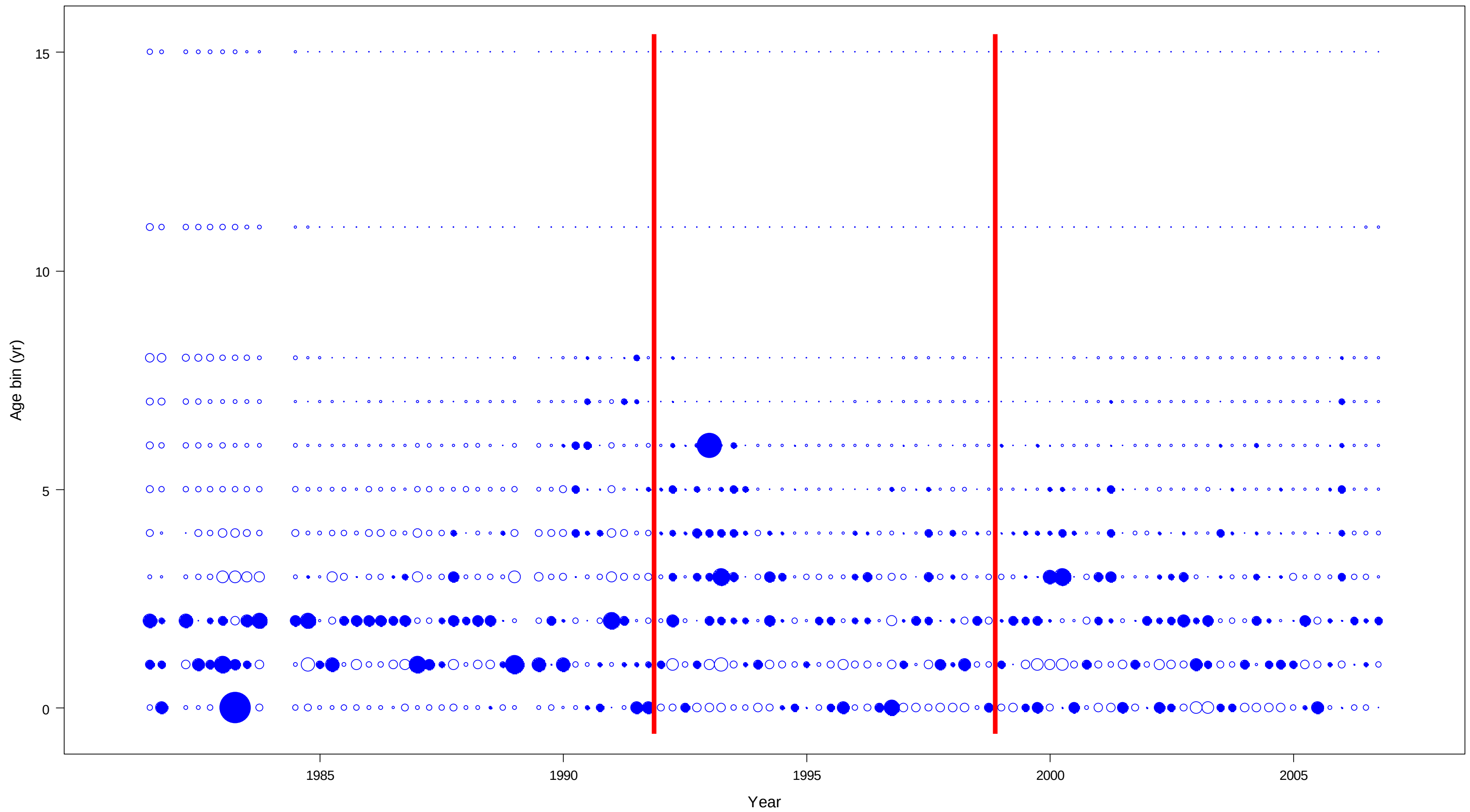


Figure 43b. Pearson residuals for projection model fit to the (implied) age-frequency data for the California fishery. Vertical line indicates selectivity period change.

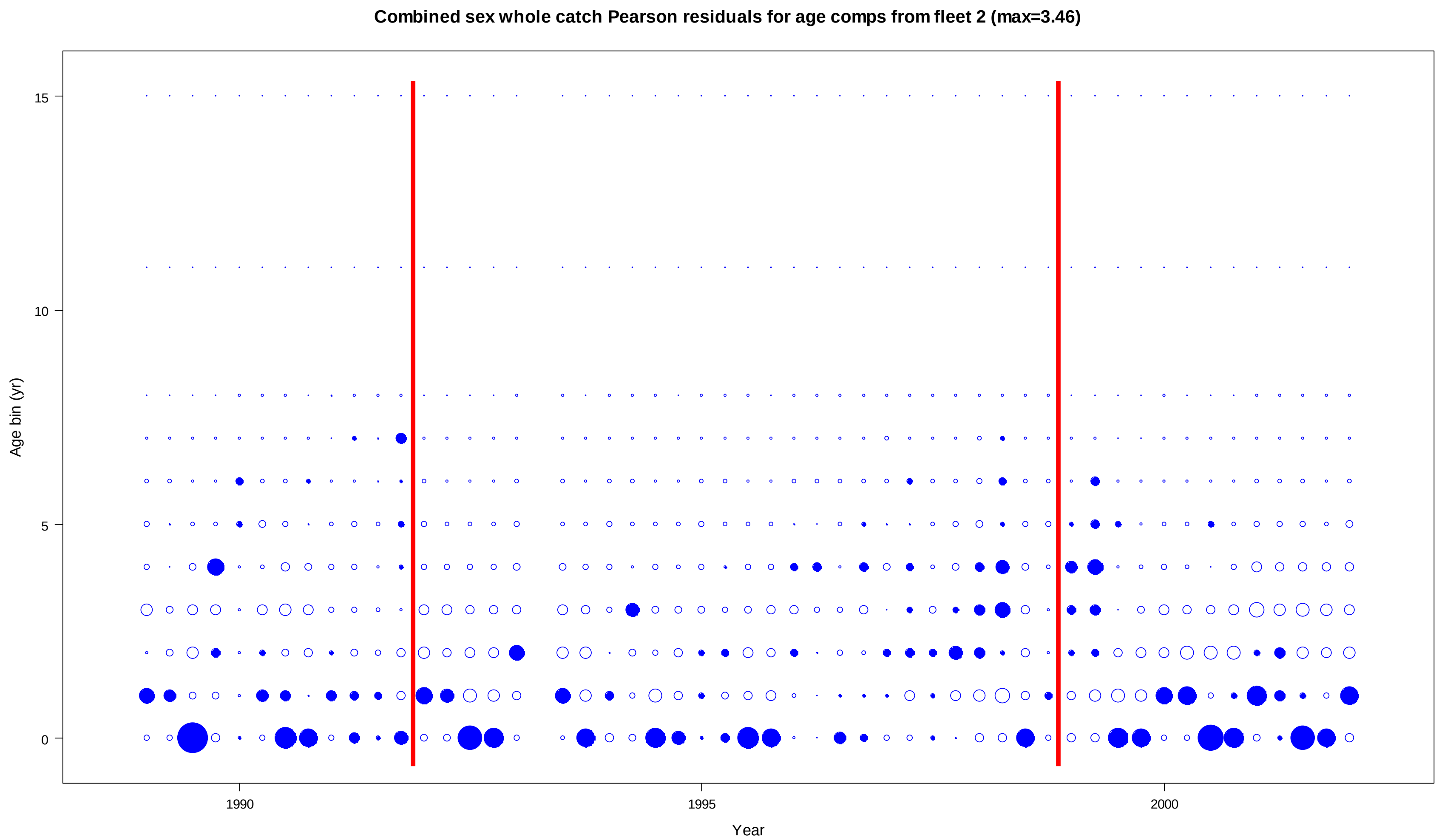


Figure 44a. Pearson residuals for update model fit to the (implied) age-frequency data for the Ensenada fishery. Vertical line indicates selectivity period change.

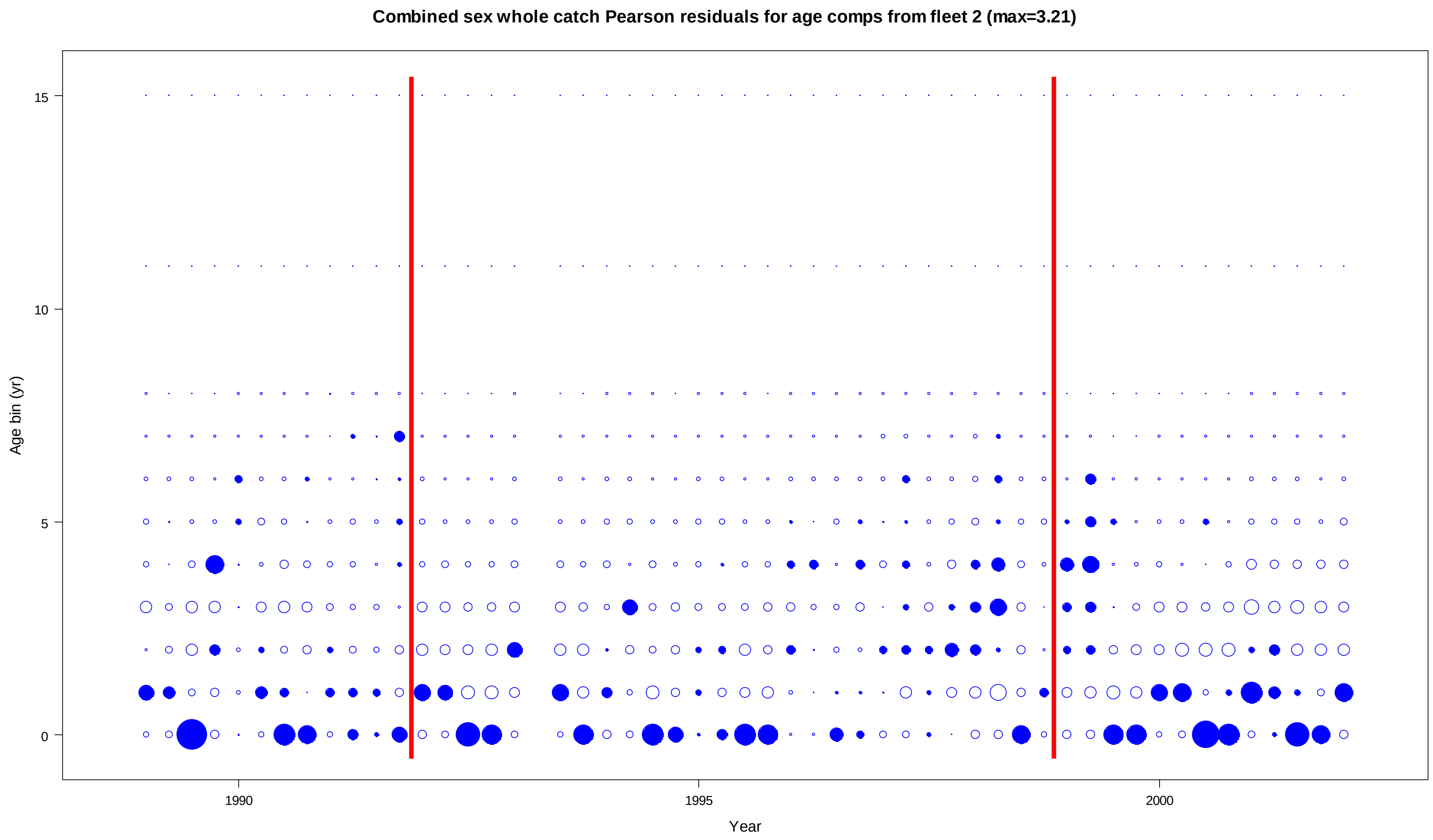


Figure 44b. Pearson residuals for projection model fit to the (implied) age-frequency data for the Ensenada fishery. Vertical line indicates selectivity period change.

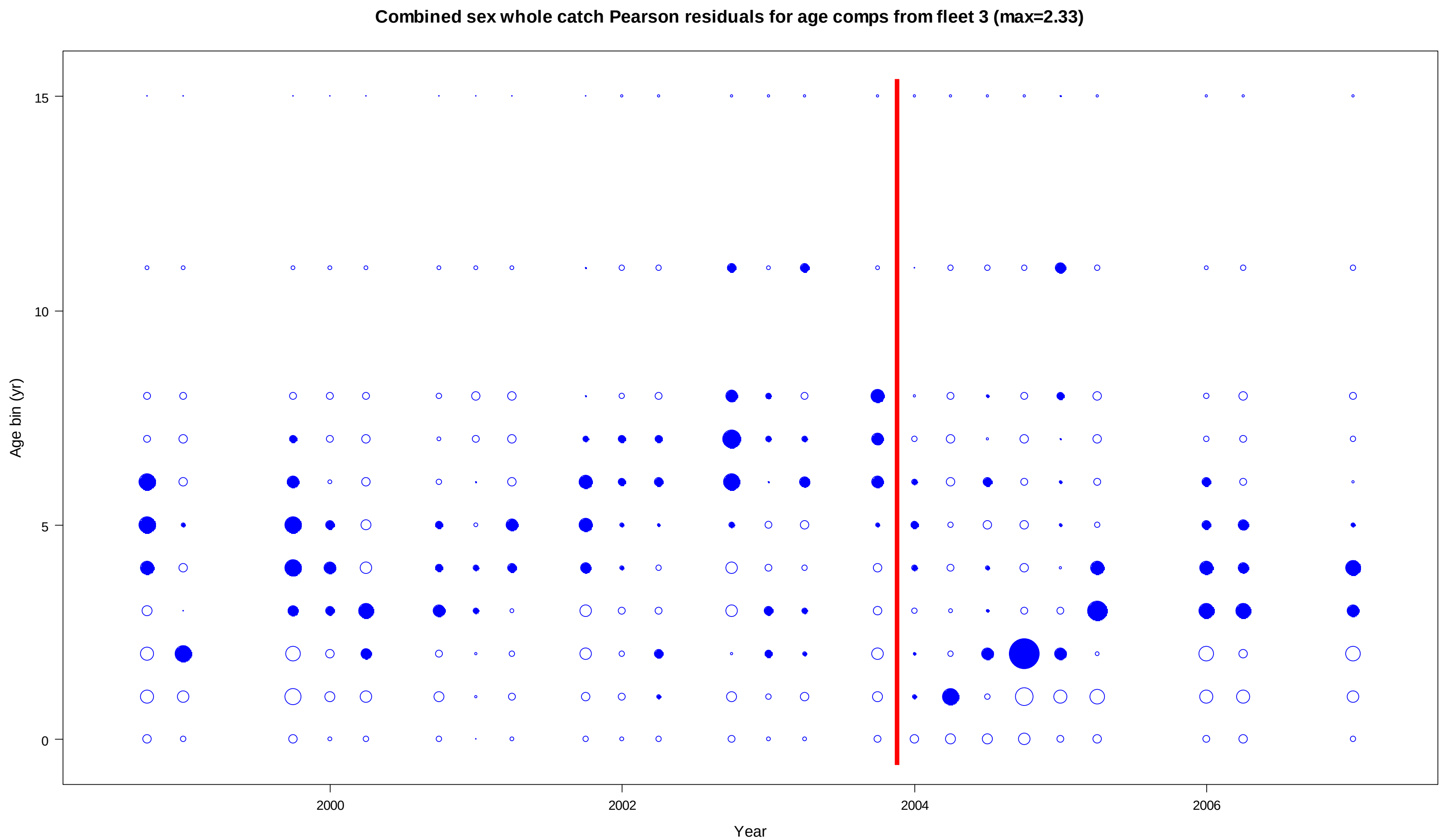


Figure 45a. Pearson residuals for update model fit to the (implied) age-frequency data for the Pacific northwest fishery. Vertical line indicates selectivity period change.

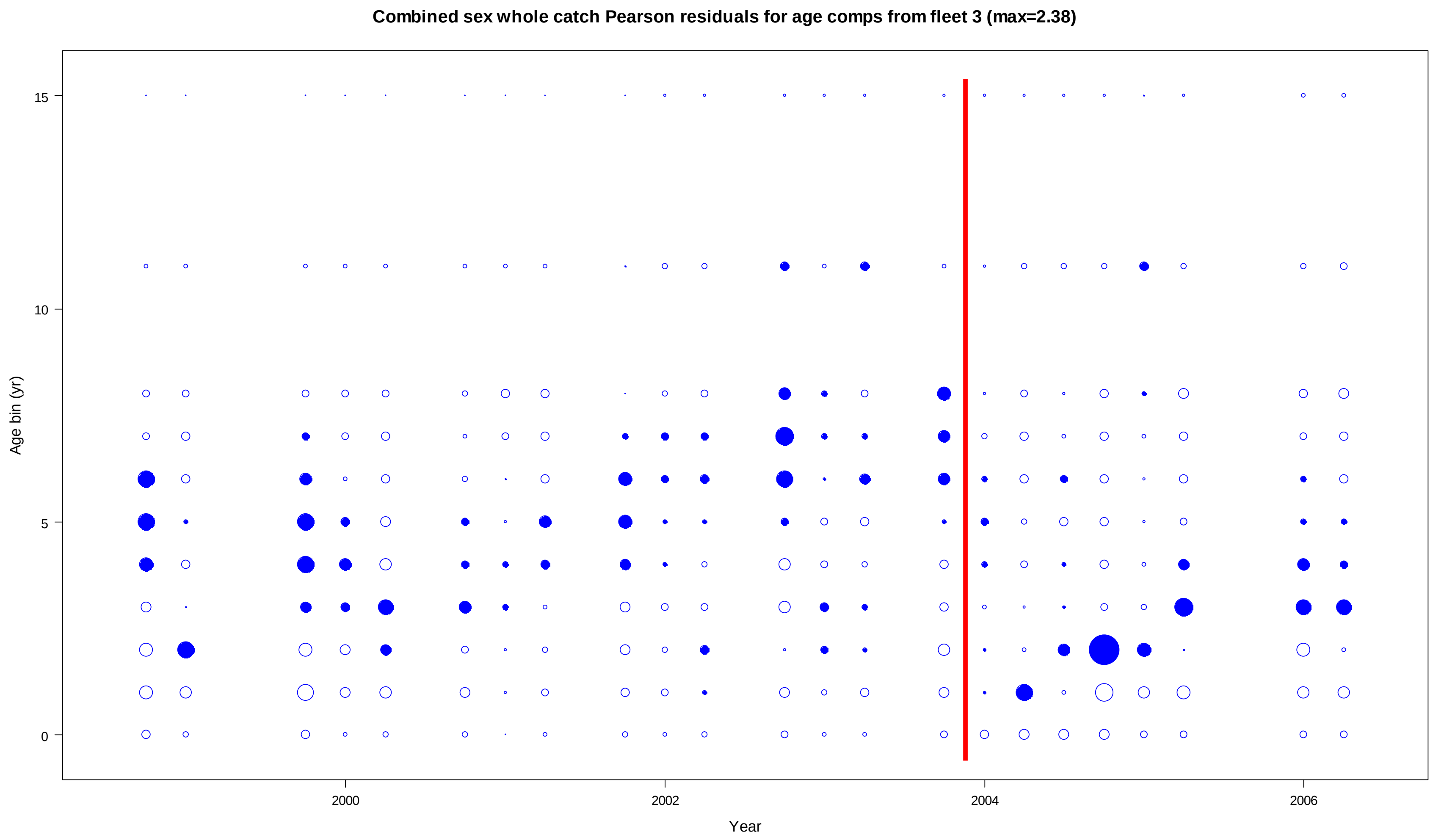


Figure 45b. Pearson residuals for projection model fit to the (implied) age-frequency data for the Pacific northwest fishery. Vertical line indicates selectivity period change.

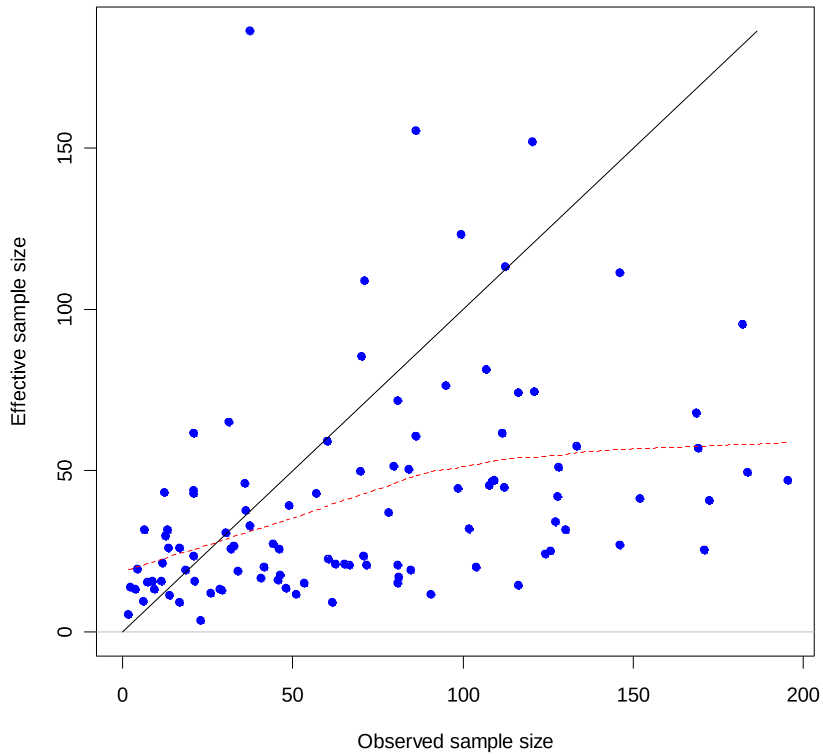


Figure 46a. Observed and effective samples sizes (update model) for CA length data.

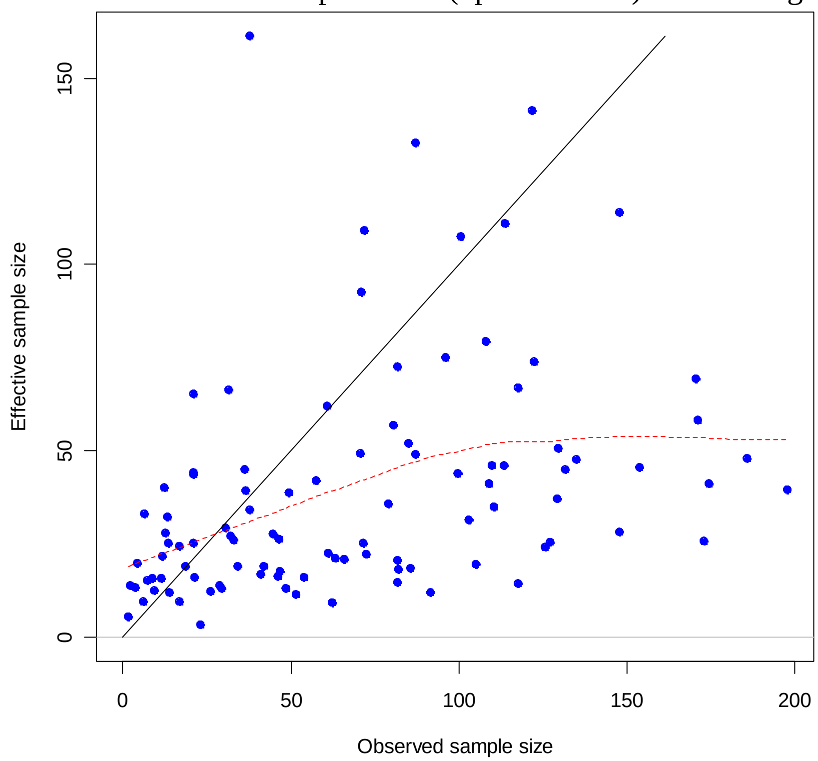


Figure 46b. Observed and effective samples sizes (projection model) for CA length data.

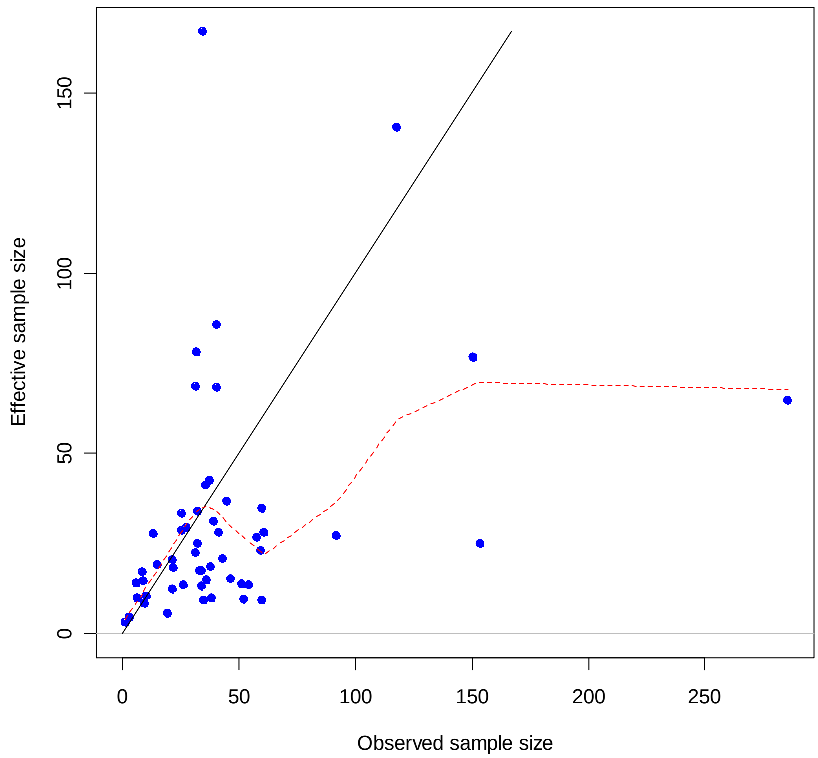


Figure 47a. Observed and effective samples sizes (update model) for EN length data.

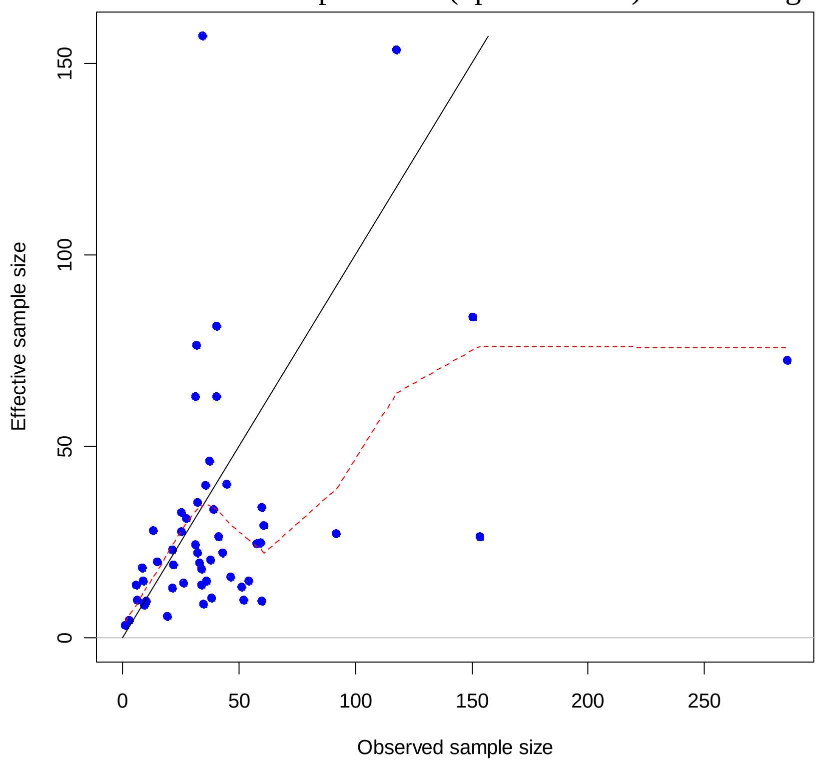


Figure 47b. Observed and effective samples sizes (projection model) for EN length data.

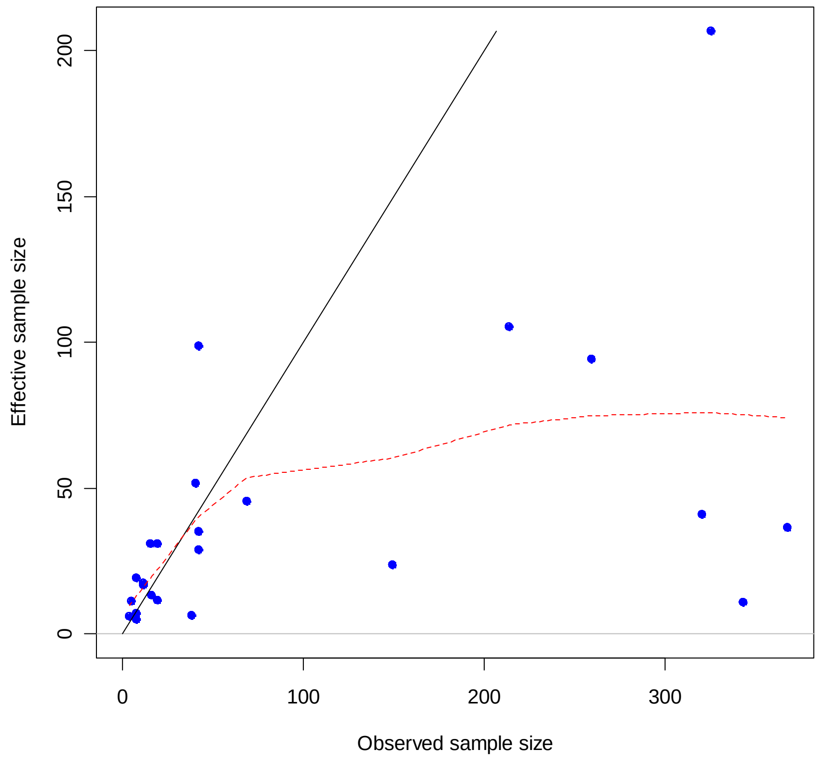


Figure 48a. Observed and effective samples sizes (update model) for NW length data.

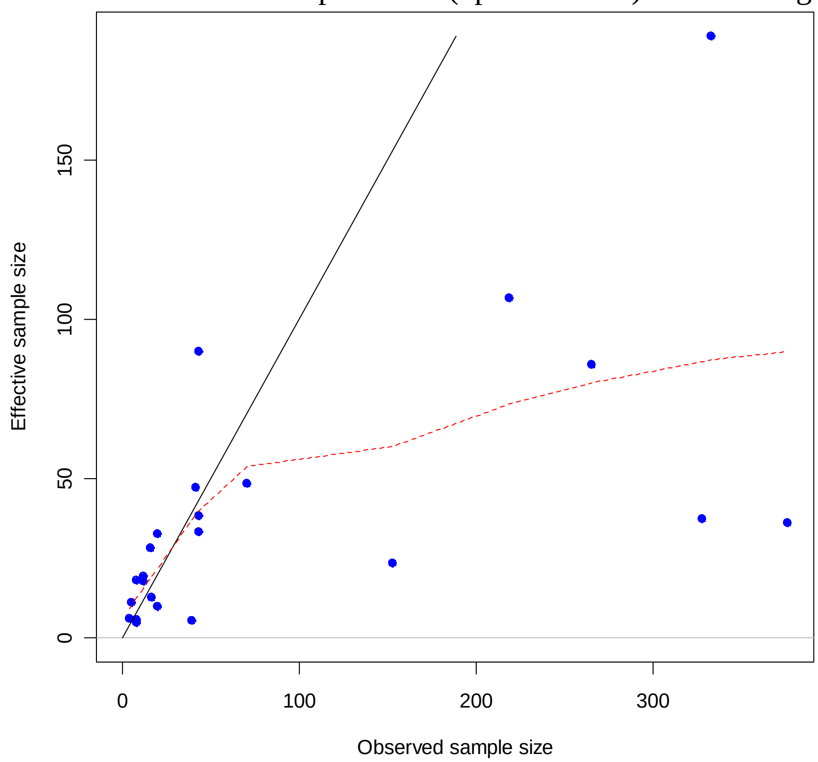


Figure 48b. Observed and effective samples sizes (projection model) for NW length data.

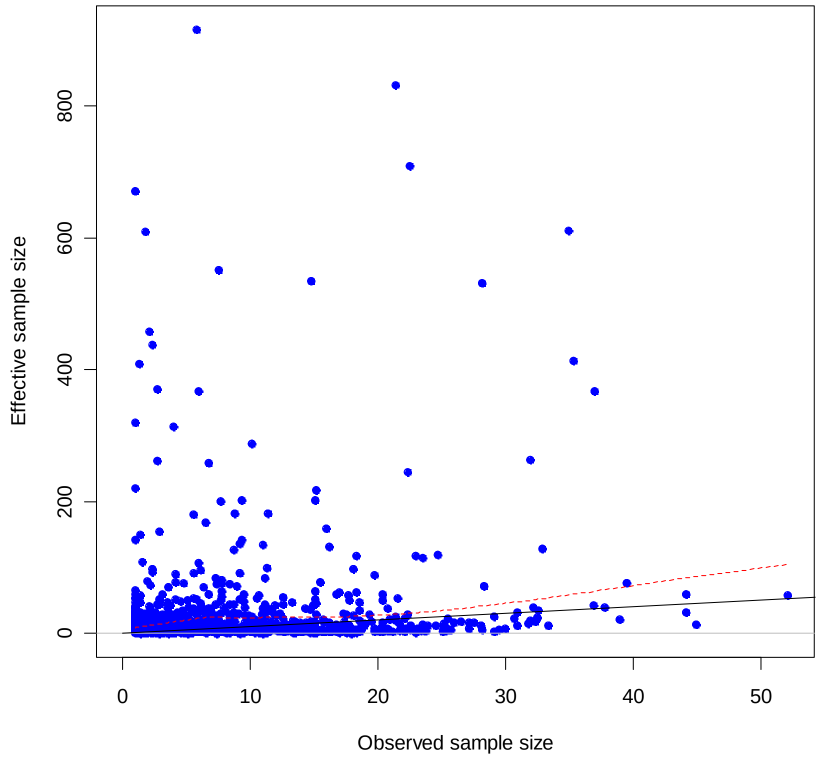


Figure 49a. Observed and effective samples sizes (update model) for CA age data.

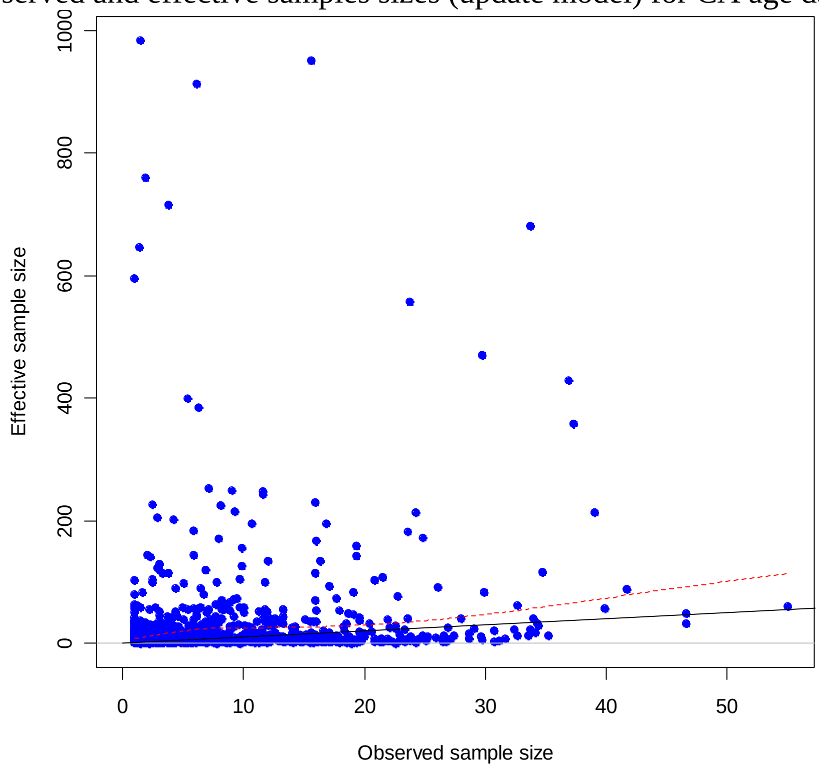


Figure 49b. Observed and effective samples sizes (projection model) for CA age data.

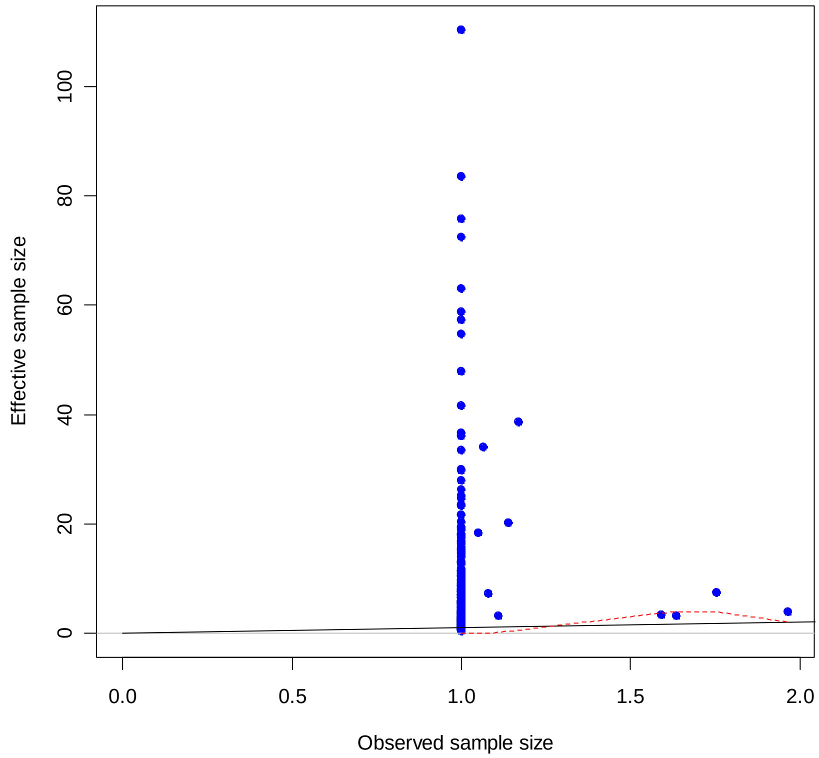


Figure 50a. Observed and effective samples sizes (update model) for EN age data.

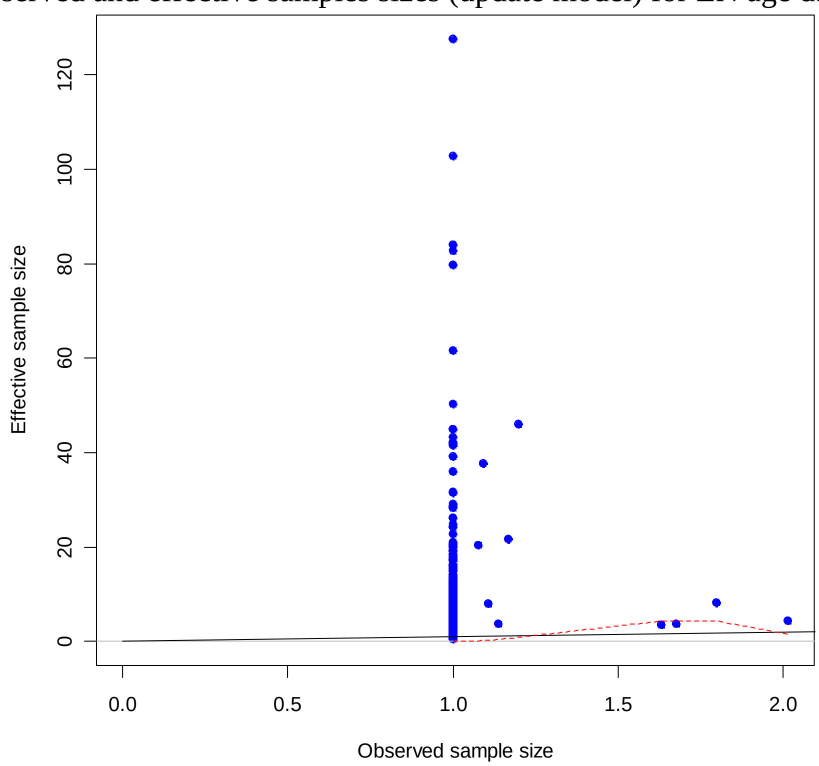


Figure 50b. Observed and effective samples sizes (projection model) for EN age data.

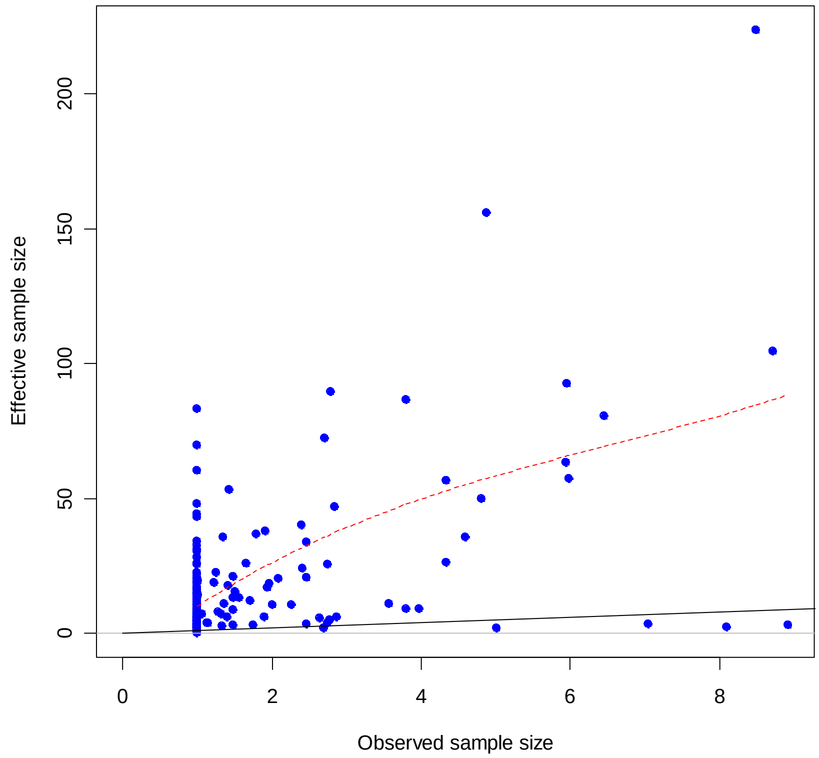


Figure 51a. Observed and effective samples sizes (update model) for NW age data.

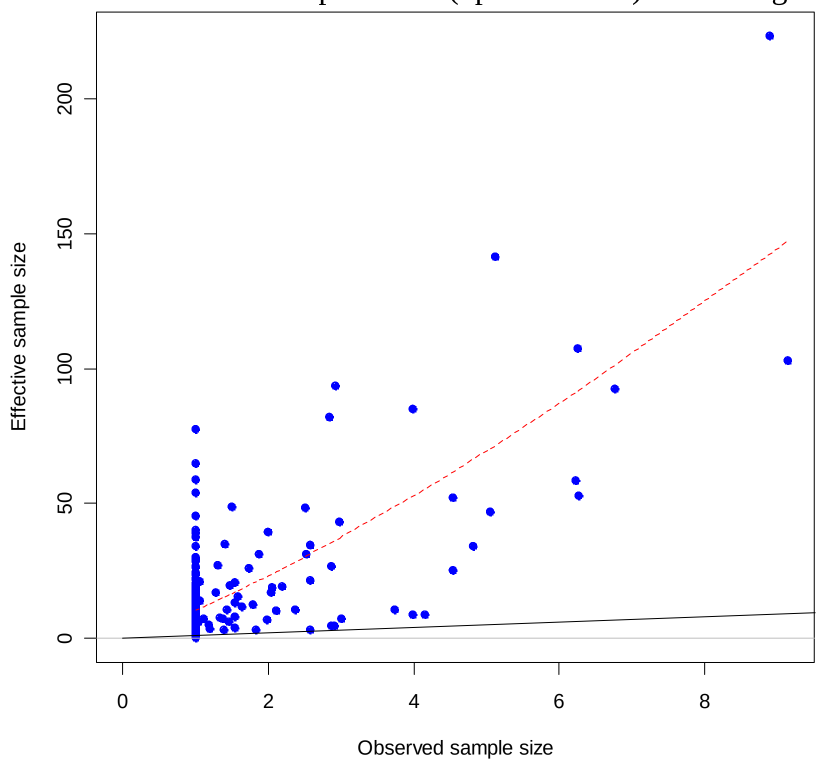


Figure 51b. Observed and effective samples sizes (projection model) for NW age data.

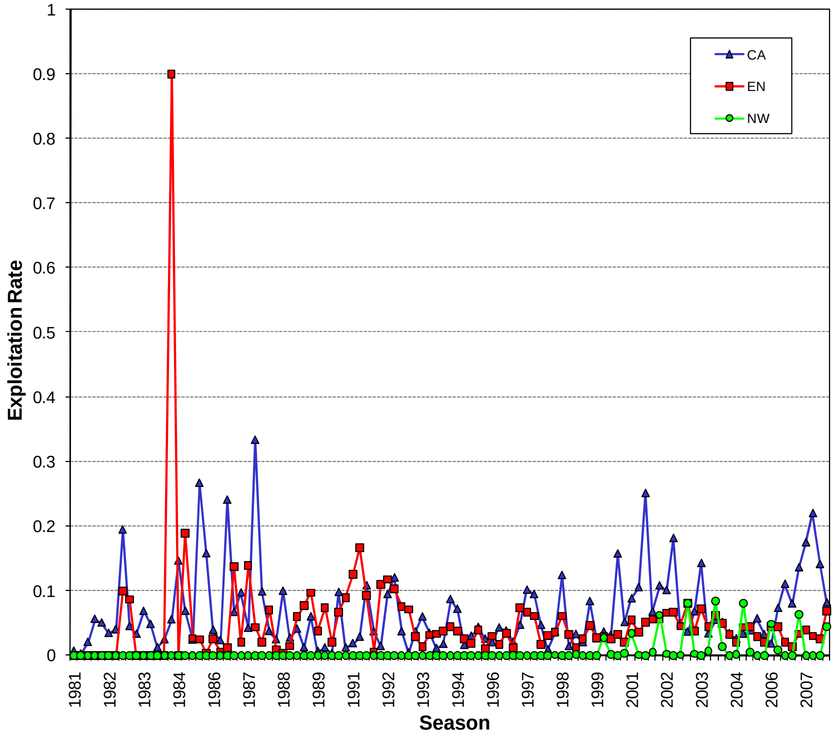


Figure 52a. Harvest rates (landings/selected biomass) through 2008-1 from the update model.

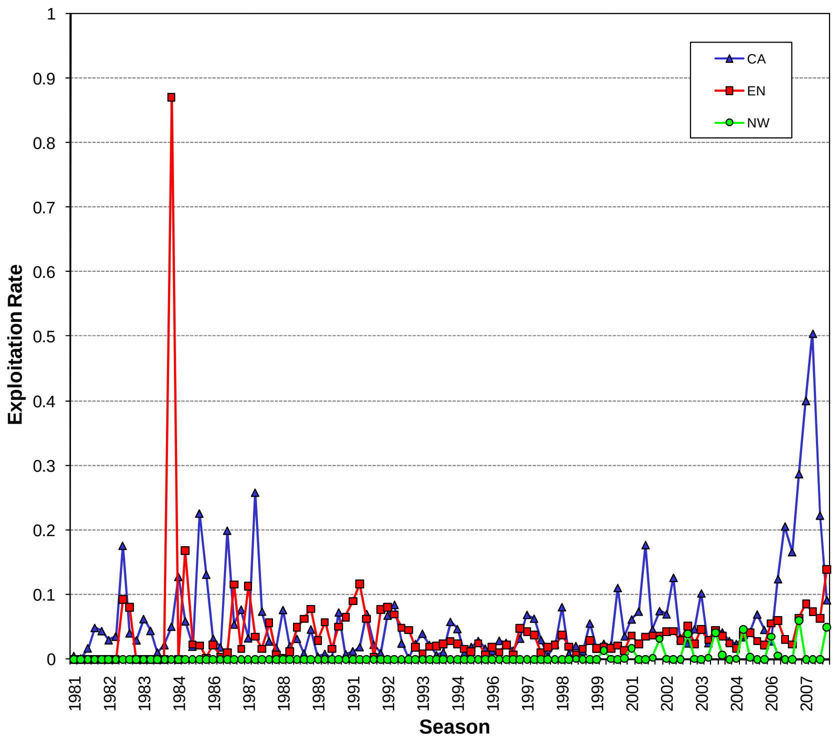


Figure 52b. Harvest rates (landings/selected biomass) through 2008-1 from the projection model.

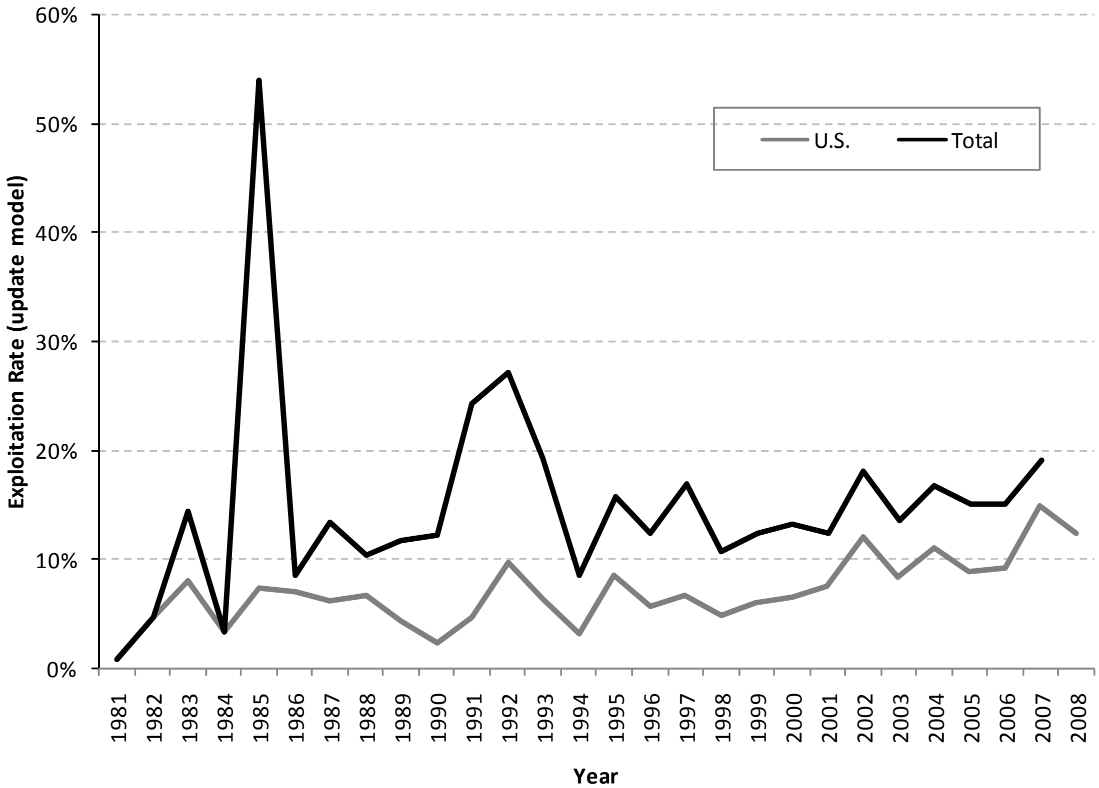


Figure 53a. Exploitation rates (landings/total biomass) from the update model.

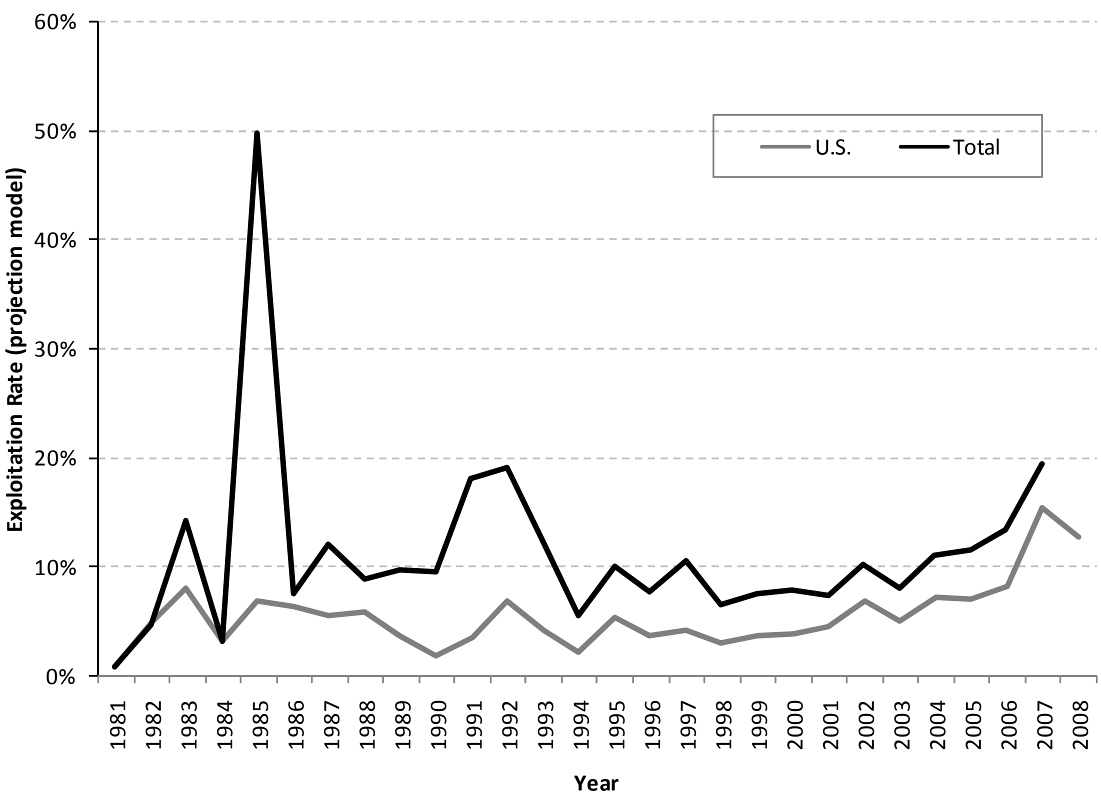


Figure 53b. Exploitation rates (landings/total biomass) from the projection model.

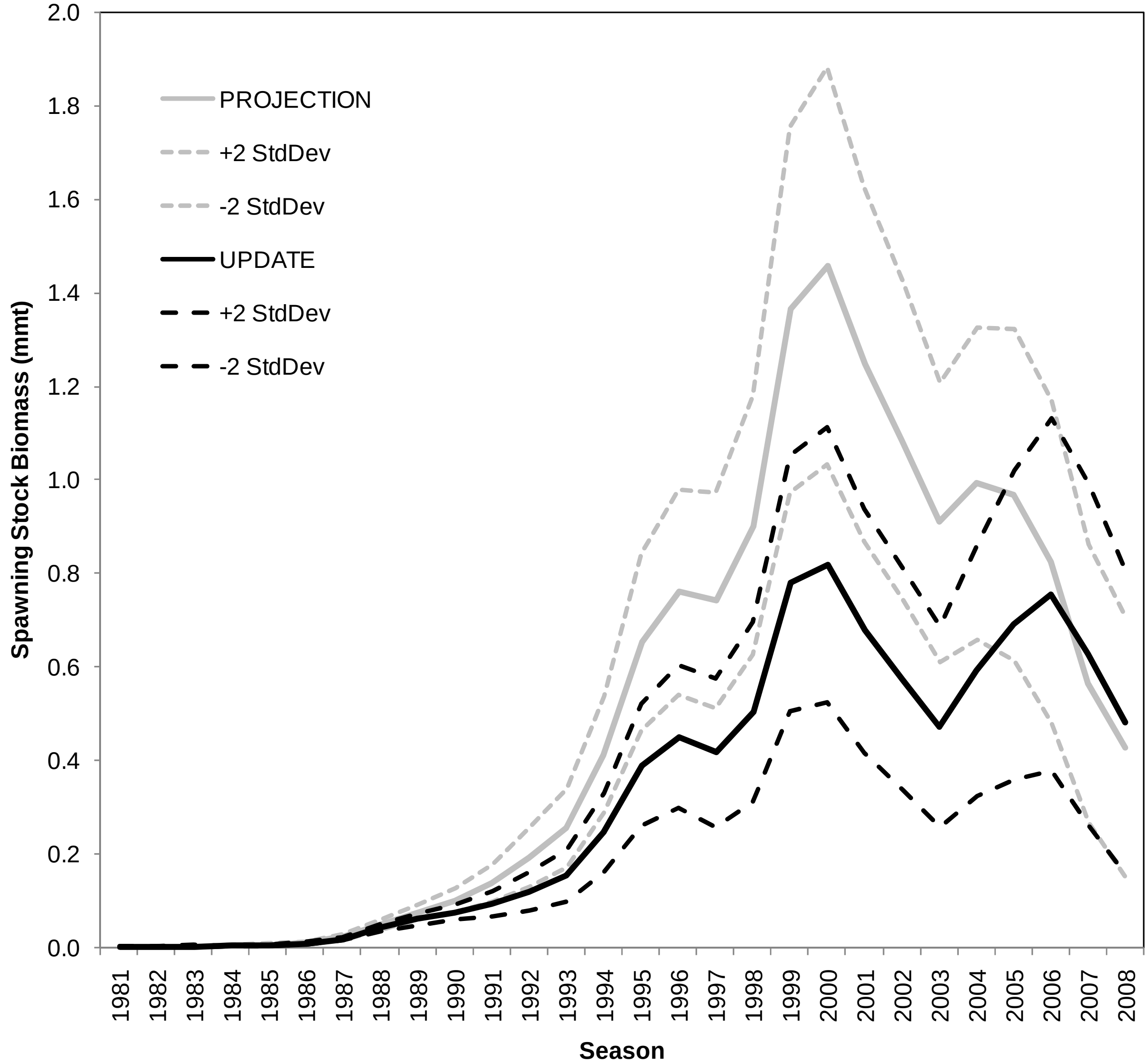


Figure 54. Spawning stock biomass from the update and projection models.

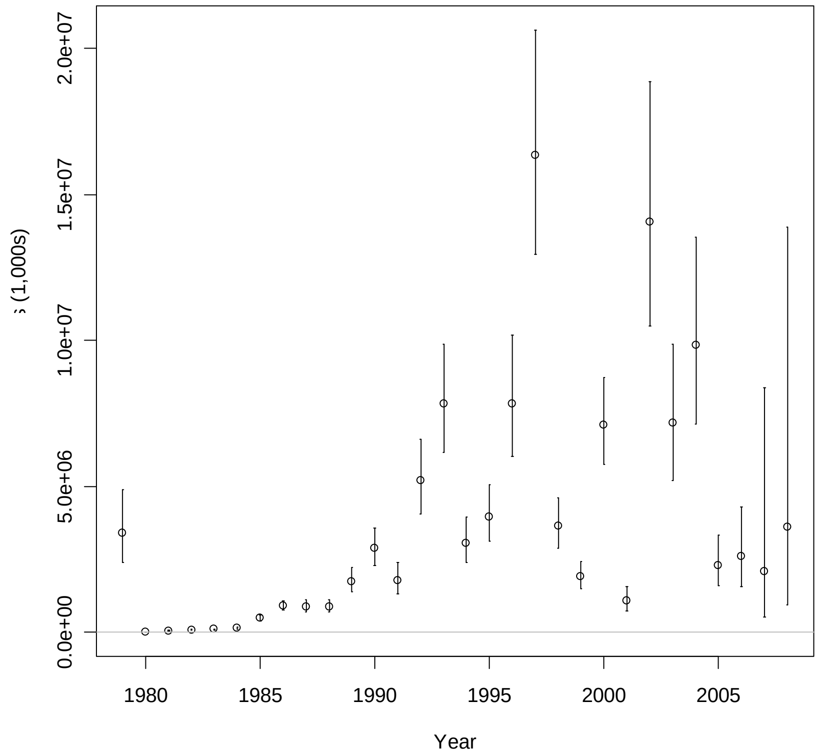


Figure 55a. Recruitments and ~95% asymptotic confidence intervals from the update model.

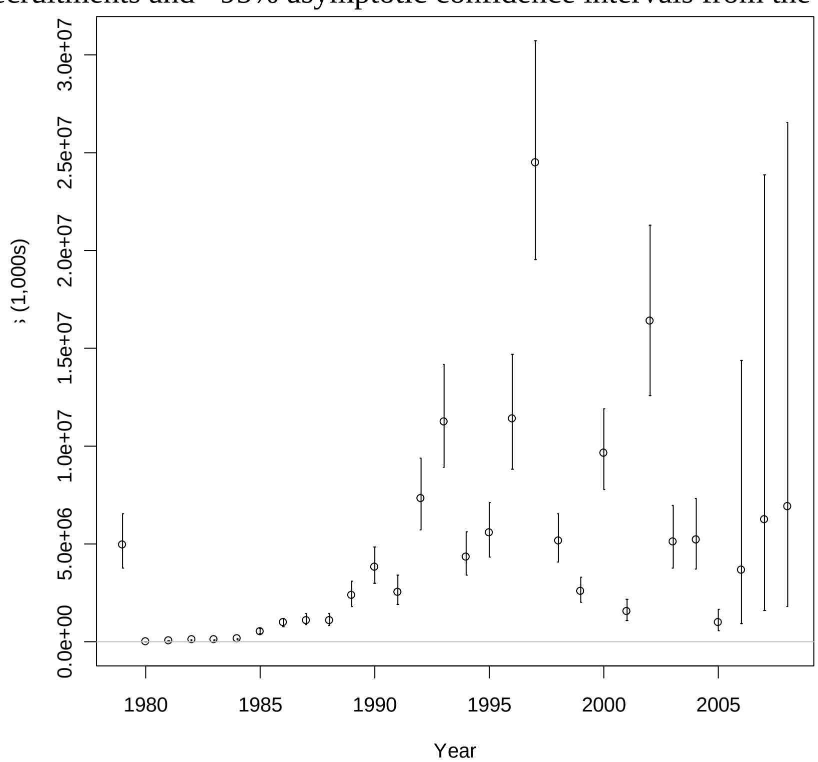


Figure 55b. Recruitments and ~95% asymptotic confidence intervals from the projection model.

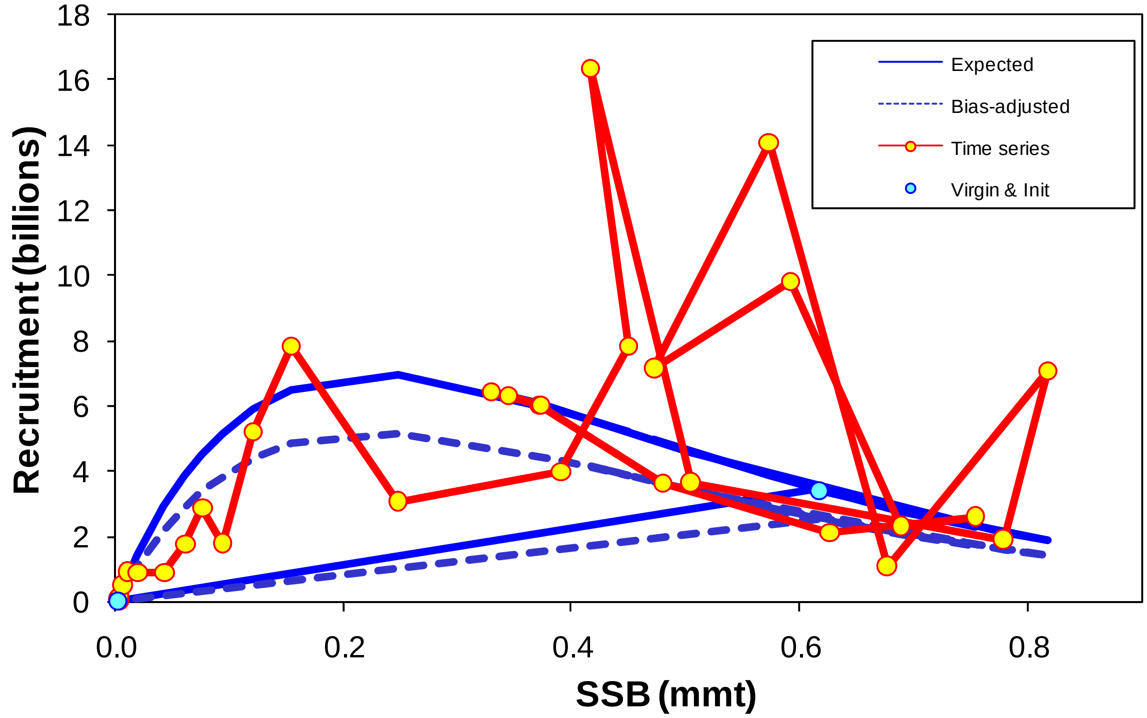


Figure 56a. Spawner-recruitment relationship for the update model, showing Ricker function fit.

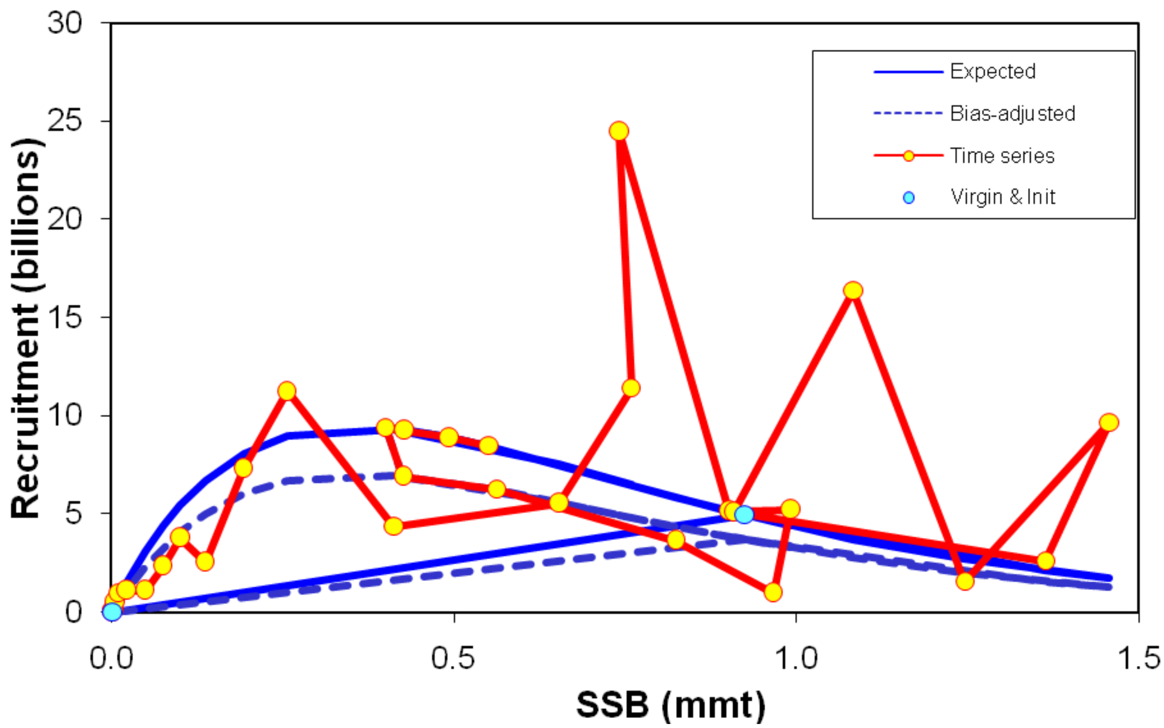


Figure 56b. Spawner-recruitment relationship for the projection model, showing Ricker function fit.

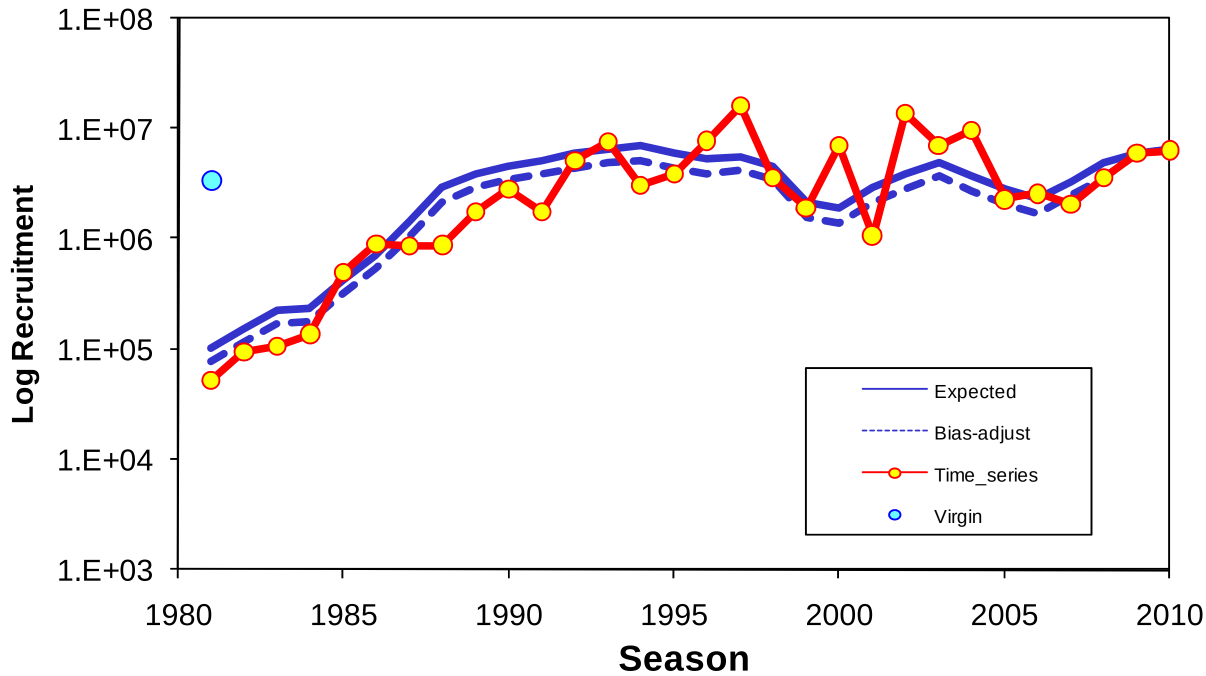


Figure 57a. Ricker model fit to the recruitment time series in the update model.

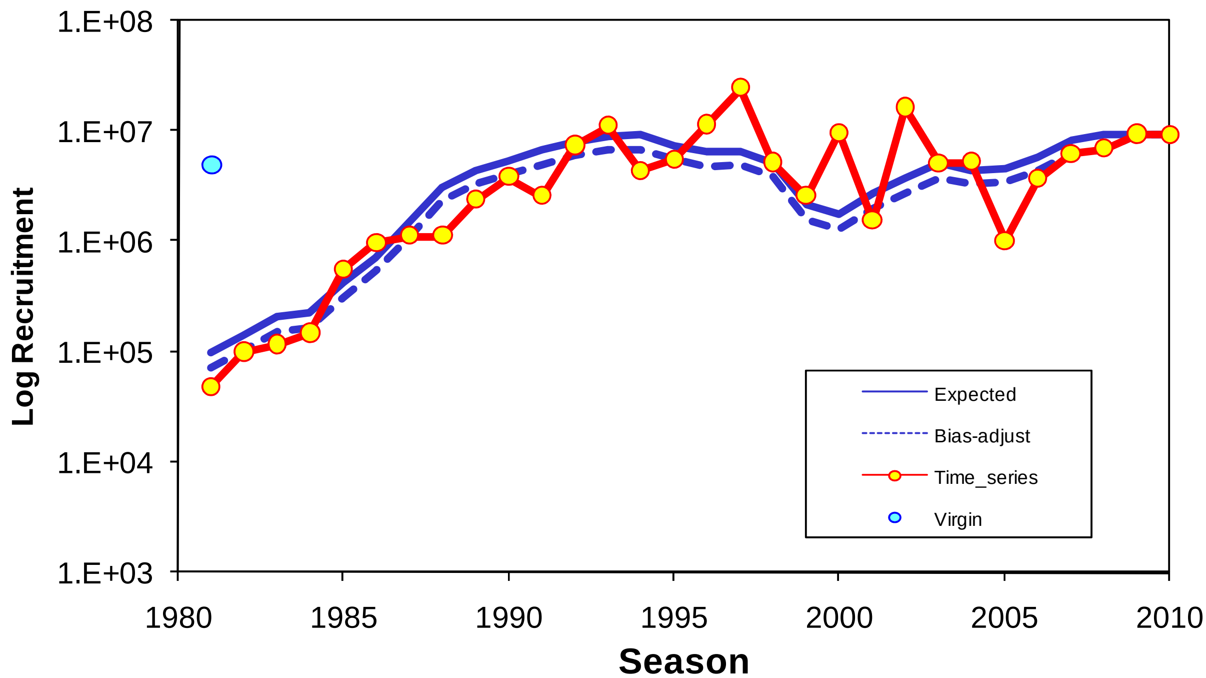


Figure 57b. Ricker model fit to the recruitment time series in the projection model.

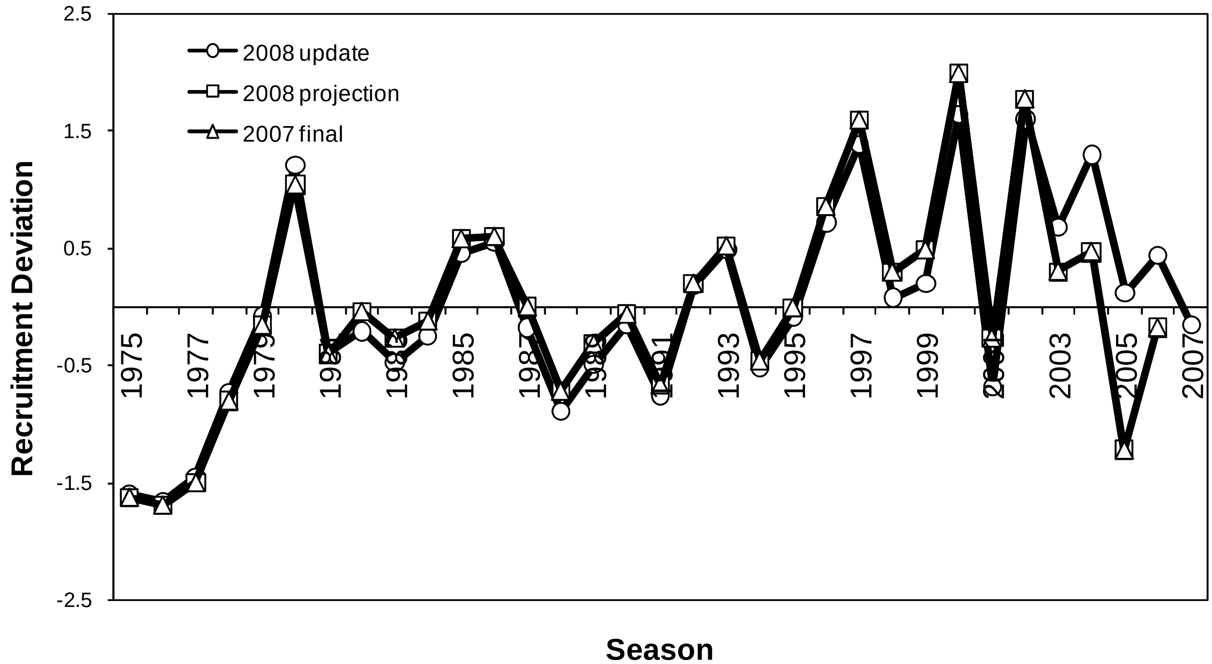


Figure 58a. Recruitment deviations estimated in the 2007 final and 2008 update and projection models.

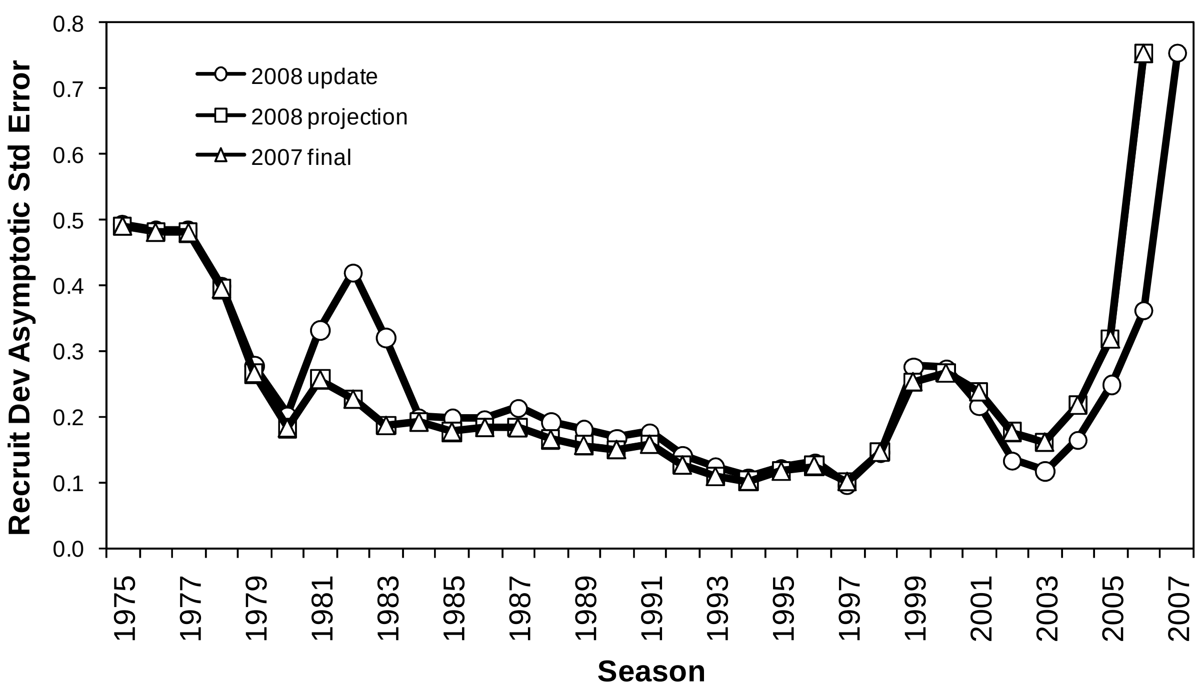


Figure 58b. Asymptotic standard errors for estimated recruitment deviations in the 2007 final and 2008 update and projection models.

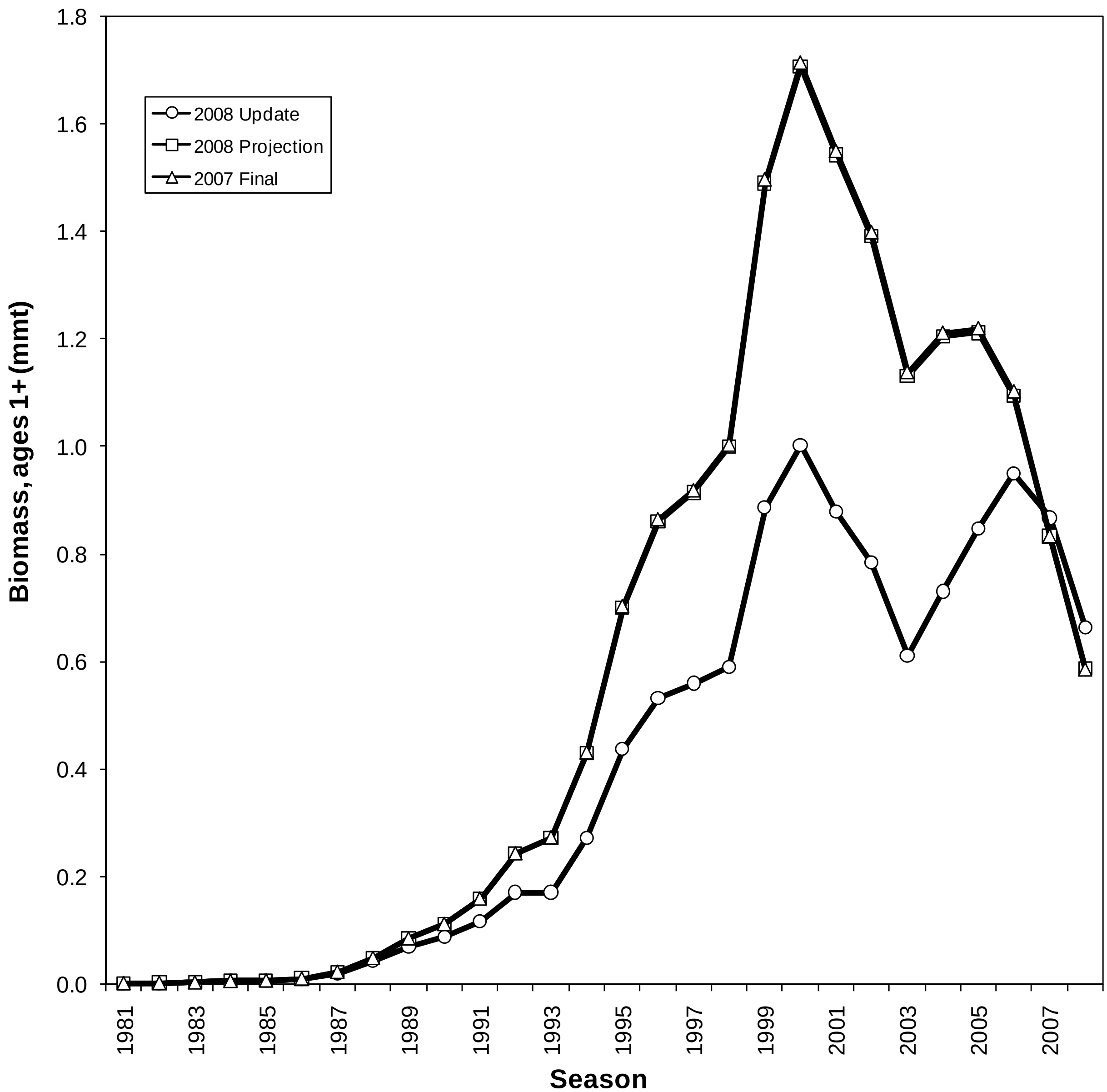


Figure 59. Pacific sardine stock biomass (ages 1+) for the 2007 final and 2008 update and projection models.

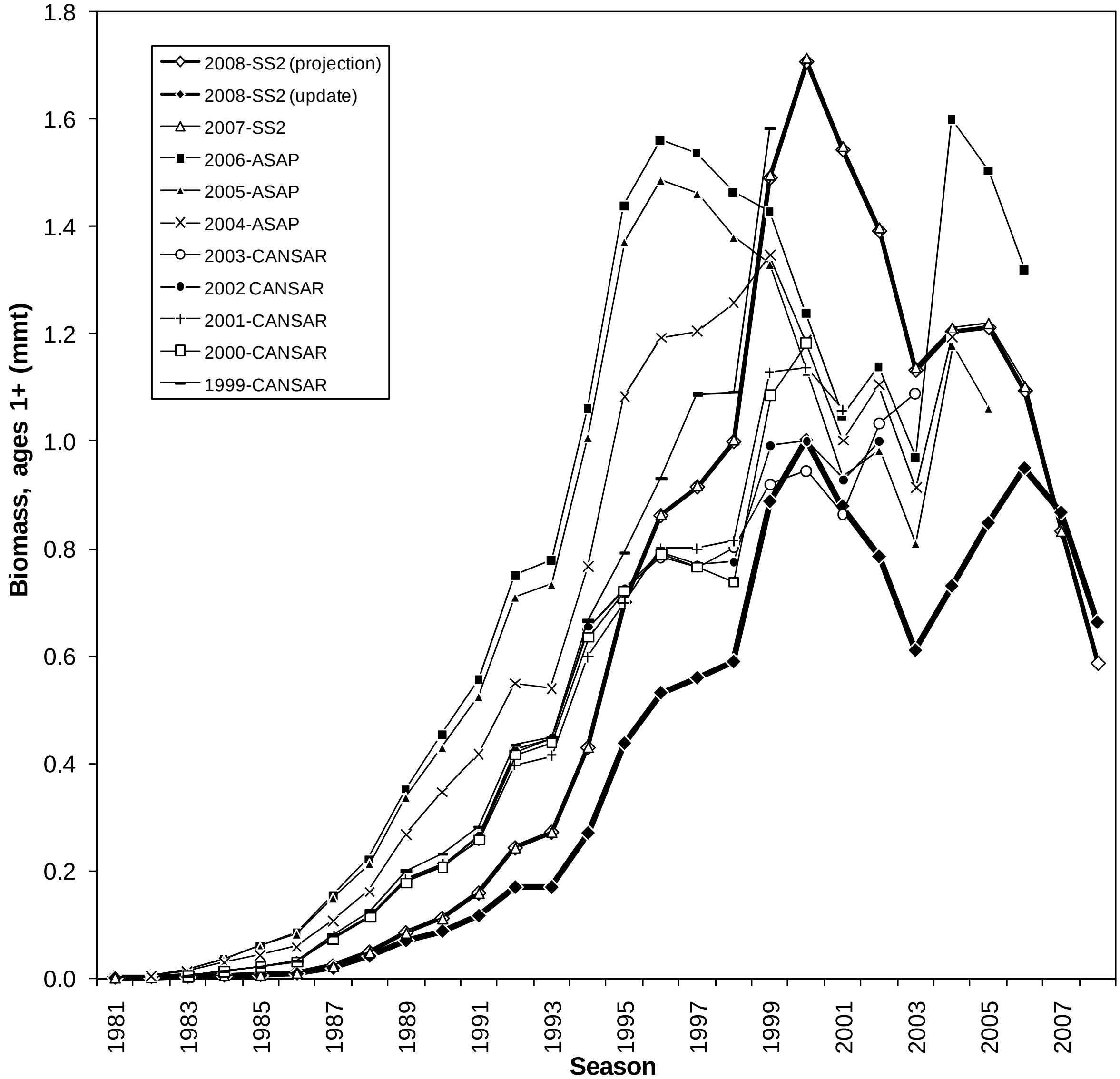


Figure 60. Pacific sardine stock biomass (ages 1+) from the 2008 update and projection models compared to previous assessments used for PFMC management.

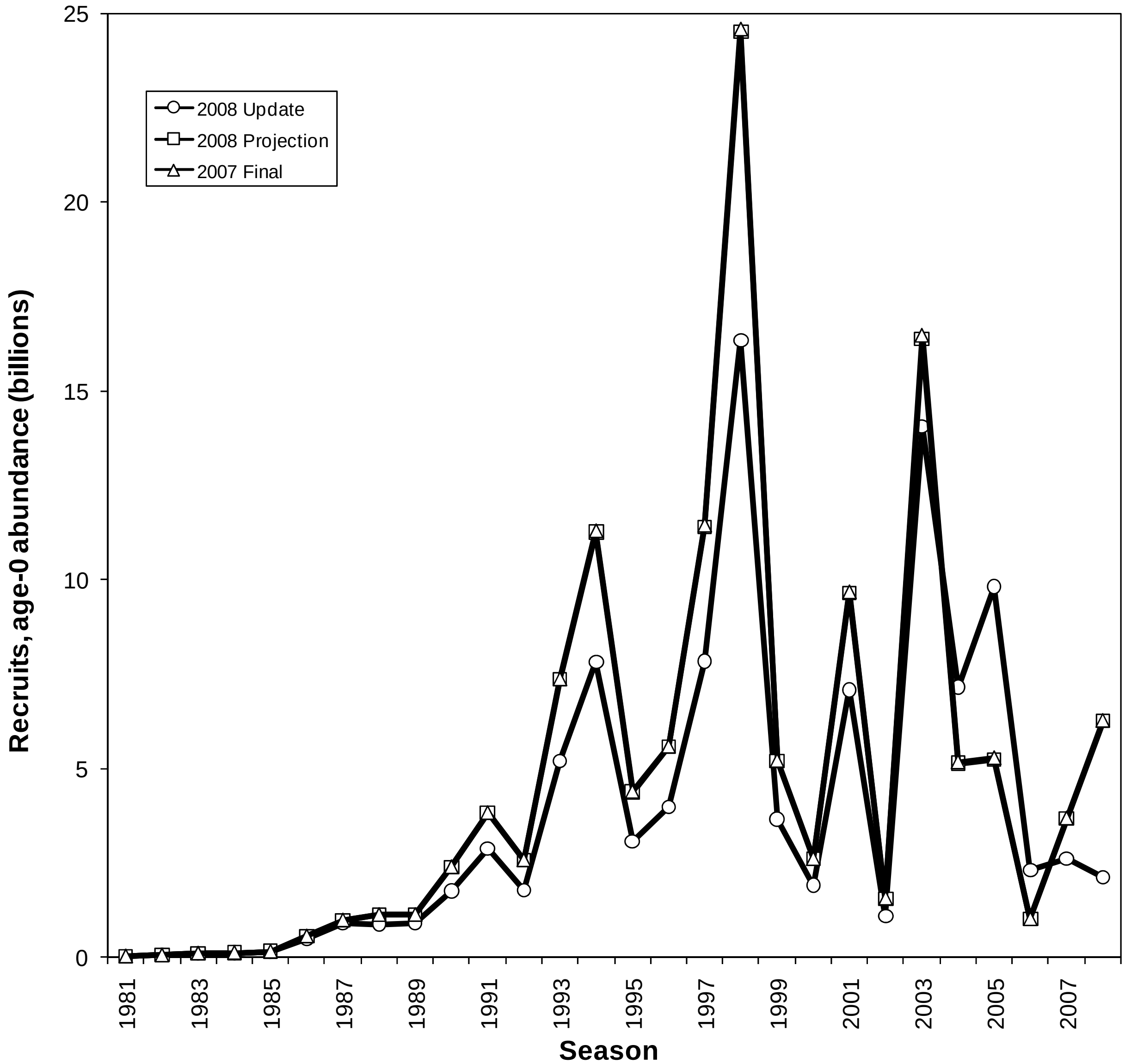


Figure 61. Pacific sardine recruit (age-0) abundance for the 2007 final and 2008 update and projection models.

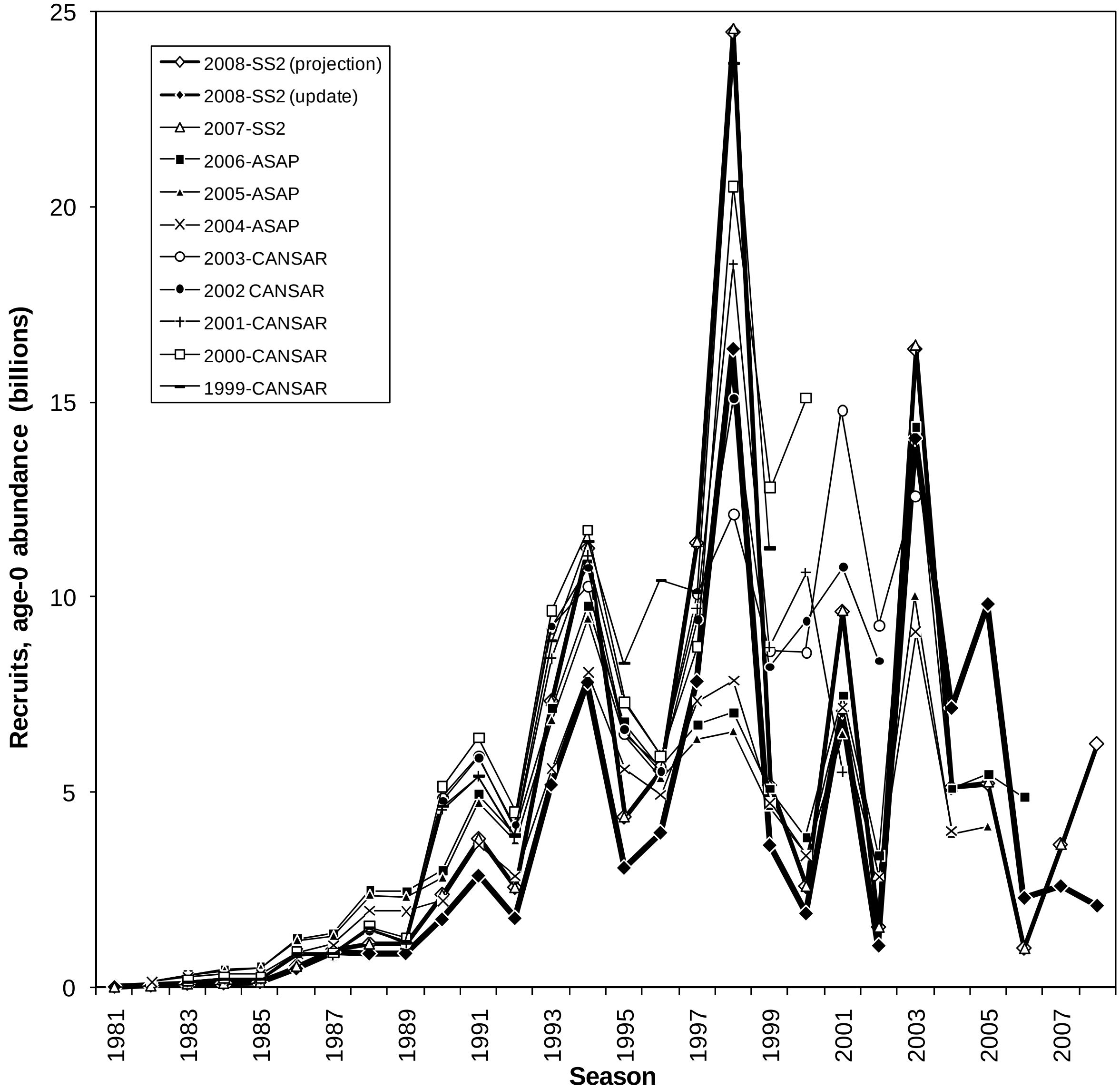


Figure 62. Pacific sardine recruit (age-0) abundance from the 2008 update and projection models compared to previous assessments used for PFMC management.

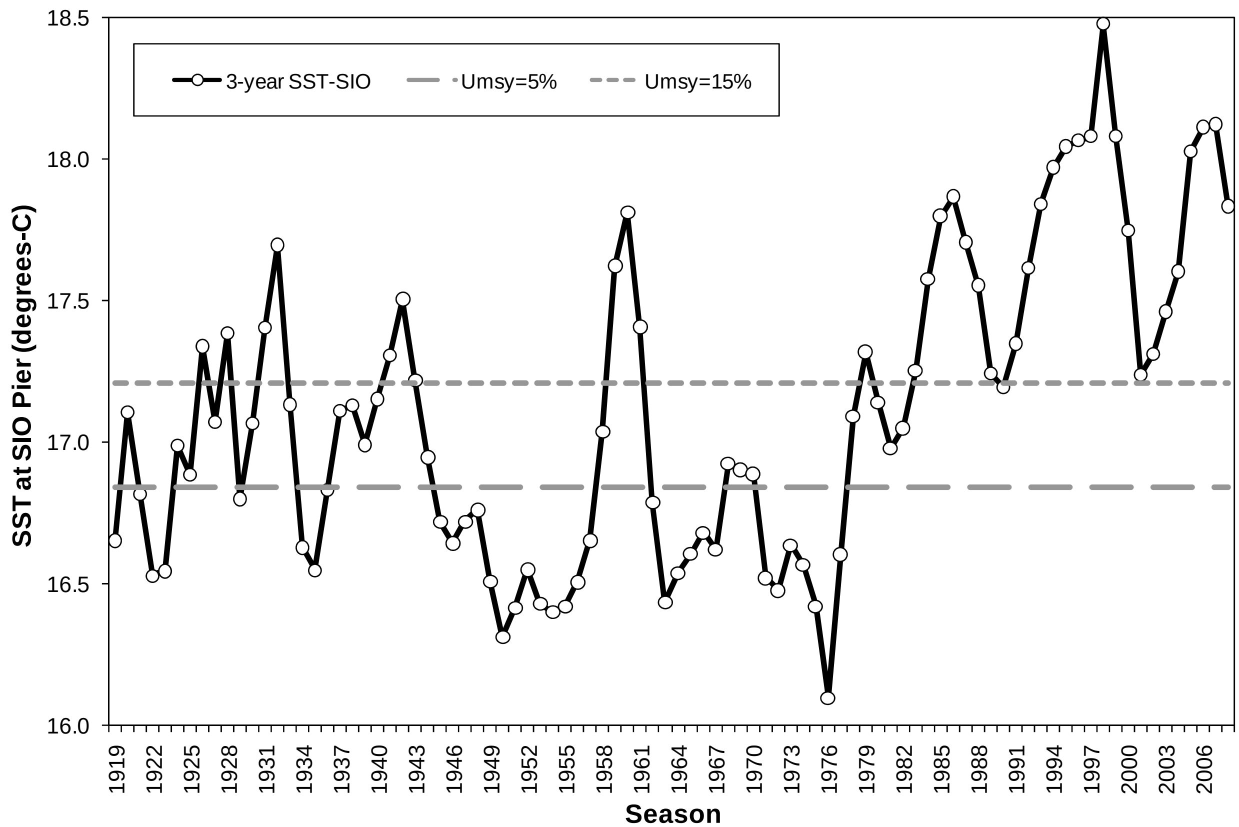


Figure 63. Three-season running average of sea surface temperature (SST) data collected daily at Scripps Institution of Oceanography pier since 1916. For any given season, SST is the running average temperature during the preceding three seasons (July-June), e.g. the 2008 estimate is the average from July 1, 2005 through June 30, 2008. The 2008 value used for management in 2009 was calculated to be 17.83 °C, so a 15% exploitation fraction (F_{msy}) should be applied in the harvest control rule.

COASTAL PELAGIC SPECIES SUBCOMITTEE OF THE SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON PACIFIC SARDINE STOCK ASSESSMENT AND MANAGEMENT MEASURES

Please note, this is a report of the Scientific and Statistical Committee's (SSC) coastal pelagic species (CPS) Subcommittee that is intended, primarily, to convey findings from their October 7, 2008 meeting to the full SSC. ***This report does not represent the position of the full SSC.*** *The full SSC is scheduled to review this topic under Agenda Item G.2 on Sunday, November 2, 2008 (see Ancillary A, SSC Agenda) at which time an SSC statement will be developed.*

Members of the Scientific and Statistical Committee's (SSC) coastal pelagic species (CPS) subcommittee met on October 7^{th} at the Pacific Fishery Management Council (Council) office in Portland, Oregon to review the recently completed stock assessment for Pacific sardine. The review occurred during a joint session that also included members of the CPS Management Team (CPSMT) and the CPS Advisory Subpanel (CPSAS). Results of the sardine stock assessment were presented by Dr. Kevin Hill, the lead member of the Stock Assessment Team (STAT), while Dr. André Punt chaired the meeting, and Dr. Stephen Ralston rapporteured.

The sardine assessment was conducted as an update to a stock assessment that had undergone a full stock assessment review (STAR) in 2007. Updates are appropriate in situations where no alterations to a stock assessment model have occurred, other than to incorporate recent data. In this case the newly incorporated data included: (1) 2007-08 catches from the Pacific Northwest (PNW), California, and northern Baja fisheries, (2) 2007-08 compositional information (lengths and age-at-length data) from the PNW and California fisheries, and (3) a daily egg production method (DEPM) estimate of spawning biomass from a survey conducted during the spring of 2008. In addition the STAT made minor corrections to the 2006-07 catch statistics.

As specified in the "Terms of Reference for Coastal Pelagic Species Stock Assessment Review Process," the review focused on two central questions: (1) did the update maintain complete fidelity to the last full stock assessment, and (2) are the new input data and model results sufficiently consistent with previous data and results that the updated assessment can form the basis for Council decision-making. The subcommittee determined that, although the update closely followed the exact structure of the 2007 model, results from the update were inconsistent with those from the previous assessment. For example, the new assessment results in a major drop in the estimate of the peak age-1+ biomass that the sardine stock reached, dropping from 1,713,280 mt in last year's assessment to 1,002,330 mt in the updated model, i.e., a 41 percent reduction. Dr. Hill showed by incrementally adding the new data (see Table 9 of the assessment document) that the principal reason for this was the inclusion of the 2007-08 length composition data from the PNW fishery. It was not possible to fully understand why adding one new length-frequency sample should impact the results of the assessment so markedly, although a significant change to the selectivity curves estimated for PNW fishery for 2004-08 appeared to affect the estimates of recruitment for the entire period considered in the assessment.

The subcommittee considered a number of ways of proceeding, including: (a) accepting the substantial change in results and recommending that the update assessment represents the best available science, (b) requesting that a new full assessment be conducted and reviewed prior to setting the sardine harvest guideline, (c) developing a model that incorporates only a portion of the new data, and (d) using the accepted 2007 assessment model and projecting this forward using only the updated catch information. The subcommittee concluded that Option A was an inappropriate course of action due to the unexplained and unexpected changes in model results (use of this model would require much more review than was possible during the meeting), Option B was not feasible given the timeframe concerned, and Option C was undesirable because it would involve incorporating data for use in the assessment simply because the data concerned had not impacted the assessment outcomes. The subcommittee therefore requested that Dr. Hill conduct a run that used the 2007-STAR approved model (without any model tuning or variance adjustments), with a simple update of the 2006-08 catches. The results from this run were virtually identical to those from the 2007 base model (as expected) and the subcommittee therefore concluded that it represented the best available scientific information on the current status of the sardine stock and recommended that it be used by the Council for setting the harvest guideline. In particular, the model estimated 586,369 mt of age-1+ biomass in 2008, which results in a harvest guideline of 56,946 mt when the control rule for Pacific sardine is applied.

Given that a formal "update" could not be completed with the data collected during the last year, the subcommittee recommends that the sardine assessment model be evaluated by a full STAR Panel in September 2009. That Panel should explore the possibility of cohort targeting in the Pacific Northwest fishery, as well as consider using the results of the Pacific Northwest Sardine Survey. However, use of the survey results can only occur if the methodology on which it is based has been previously reviewed, for example during the Pacific mackerel STAR Panel scheduled for May 2009.

The subcommittee wishes to emphasize that, although it was able to select a model for Council decision making, the considerable sensitivity of the outcomes from the model to what should be minor changes to the data inputs highlights the substantial uncertainty regarding sardine stock status. Moreover, it notes that although considerable progress has been made to collect data on abundance by the Pacific Northwest Sardine Survey, it is not yet possible to include these data in the assessment, owing to: (1) the lack of formal review of the survey methodology, (2) the fact that the 2008 effort was a localized pilot survey, and (3) constraints imposed on update assessments with respect to including new types of data. Finally, the subcommittee notes that inclusion of the DEPM estimate for 2008 in the assessment leads to a slightly lower estimate of age-1+ biomass than the run in which just the catches are updated.

The subcommittee would like to compliment Dr. Hill for his thorough documentation and his willingness to conduct supplemental analyses during the meeting, which allowed the subcommittee to quickly identify a model which represents the best available science concerning the status of Pacific sardine.

PFMC
10/16/08

SCIENTIFIC AND STATISTICAL COMMITTEE REPORT ON PACIFIC SARDINE STOCK ASSESSMENT AND MANAGEMENT MEASURES

Dr. Kevin Hill, the lead member of the Stock Assessment Team (STAT), presented the results of the sardine stock assessment update. Dr. André Punt provided a summary of the review conducted on October 7th, 2008 by members of the Scientific and Statistical Committee's (SSC) coastal pelagic species (CPS) subcommittee in a joint session with members of the CPS Management Team (CPSMT) and the CPS Advisory Subpanel (CPSAS). Dr. Samuel Herrick presented the viewpoint of the CPSMT.

The sardine assessment was conducted as an update to a stock assessment that had undergone a full stock assessment review (STAR) in 2007. Updates are appropriate in situations where no alterations to a stock assessment model have occurred, other than to incorporate recent data from sources already used in the full assessment. In this case the newly incorporated data included: (1) 2007-08 catches from the Pacific Northwest (PNW), California, and northern Baja fisheries, (2) 2007-08 compositional information (lengths and age-at-length data) from the PNW and California fisheries, and (3) a daily egg production method (DEPM) estimate of spawning biomass from a survey conducted during the spring of 2008. In addition the STAT made minor corrections to the 2006-07 catch statistics.

As specified in the "Terms of Reference for Coastal Pelagic Species Stock Assessment Review Process," the review focused on two central questions: (1) did the update maintain complete fidelity to the last full stock assessment, and (2) are the new input data and model results sufficiently consistent with previous data and results that the updated assessment can form the basis for Council decision-making? Although the update closely followed the exact structure of the 2007 model, results from the update were inconsistent with those from the previous assessment. For example, the peak biomass in the update model was only 59 percent of that in the 2007 model. This volatility in reconstruction of past dynamics affects interpretation of stock status and is unexpected for an assessment update. Due to these factors, the update assessment failed to meet the acceptance criteria specified in the terms of reference (TOR).

The subcommittee, and subsequently the SSC, considered a number of ways of proceeding, including: (a) accepting the substantial change in results and recommending that the update assessment represents the best available science, (b) requesting that a new full assessment be conducted and reviewed prior to setting the sardine harvest guideline, (c) developing a model that incorporates only a portion of the new data, and (d) using the accepted 2007 assessment model and projecting this forward using only the updated catch information. In addition, the SSC also considered not recommending any of the assessment models.

After lengthy discussion the SSC concluded that it was not possible to identify a single model representing the "best available science," although two results were identified that the Council could consider as reasonable scientific representations of Pacific sardine stock status. A selection between these choices, however, is viewed by the SSC as a policy, not scientific, decision.

(1) If it is the intention of the Council to adhere as closely as possible to the TOR, the SSC agrees with the subcommittee that the most appropriate course of action is option (d), i.e., a run that used the 2007-STAR approved model without any model tuning or variance adjustments but with a simple update of the 2006-08 catches. The results from this run are virtually identical to those from the 2007 base model (as expected). In particular, this model estimates 586,369 mt of age-1+ biomass in 2008, which results in a harvest guideline of 56,946 mt when the control rule for Pacific sardine is applied. However, the SSC could not strictly endorse this option as best available science, due to an absence of specificity in the TOR about what to do when an update failed to meet the acceptance criteria.

(2) If the Council wishes to incorporate all of the new data collected in the preceding year in making their decision it should use the results of the strict update, i.e., option (a). In particular, that model estimates 662,886 mt of age-1+ biomass in 2008, which results in a harvest guideline of 66,932 mt when the control rule for Pacific sardine is applied. However, the SSC could not strictly endorse this option as best available science because of substantial changes in the model output that could not be thoroughly reviewed in the available time.

Regardless of which option the Council elects, the CPS terms of reference should be updated to clarify the appropriate course of action in situations where an update fails to meet the existing acceptance criteria.

It should also be noted that the DEPM, the only index of abundance for sardine, was quite low in 2008. However, the index DEPM is influenced by environmental factors as well as abundance.

Given that a formal "update" could not be completed, the SSC recommends that the sardine assessment model be evaluated by a full STAR Panel in September 2009. The new assessment should explore the possibility of cohort targeting in the Pacific Northwest fishery, as well as consider using the results of the Pacific Northwest Sardine Survey. However, use of the survey results can only occur if the methodology on which it is based has been previously reviewed, for example during the Pacific mackerel STAR Panel scheduled for May 2009. The SSC further recommends that a spatial model with separate areas off of California and the Northwest be developed.

The SSC emphasizes that the considerable sensitivity of the model to what should be minor changes in the data inputs underscores the substantial uncertainty regarding sardine stock status and relative recruitment across years. The development of new indices of abundance would likely help to reduce this uncertainty, while the development of spatial models might resolve the apparent conflict in data between the southern and northern portions of the stock. In any case, full assessments should be conducted more frequently than the current three year timeframe until there is improvement in these issues.

The SSC would like to compliment Dr. Hill for his thorough documentation and his willingness to conduct supplemental analyses during the review meeting.

PFMC
11/03/08

COASTAL PELAGIC SPECIES MANAGEMENT TEAM REPORT ON PACIFIC SARDINE STOCK ASSESSMENT AND MANAGEMENT MEASURES

The Coastal Pelagic Species Management Team (CPSMT), along with the Scientific and Statistical Committee's Coastal Pelagic Species Subcommittee (Subcommittee), received a presentation on the 2008 Pacific Sardine stock assessment update from Dr. Kevin Hill. The CPSMT recommends the assessment update (noted as the "Strict Update" in the assessment and the remainder of this report) that uses all of the available data and most strictly adheres to the 2007 CPS terms of reference (TOR). This update resulted in a biomass (ages 1+) estimate of 662,886 mt and from the harvest control rule, an acceptable biological catch (ABC) for the 2009 fishery of 66,932 mt. This ABC is 25 percent less than the 2008 ABC/harvest guideline (HG) adopted by the Council (November 2007).

The CPSMT disagrees with the Subcommittee concerning the degree of consistency that the Strict Update has with respect to the 2007 stock assessment data and modeling results. In particular, the CPSMT-recommended Strict Update includes all new available data (i.e., 2007-08 landings, 2007-08 age/length distributions, and the Daily Egg Production Method estimate produced from the California Cooperative Oceanic Fisheries Investigation survey in April 2008), whereas the Subcommittee-proposed 2007 update projection includes only new landings (2007-08) data. Further, evaluating consistency in results in ongoing assessments is inherently difficult, given model uncertainty. For example: (1) parameterization of a single length distribution (2007-08 Pacific Northwest (PNW) fishery) indicates that the overall model, both current and future, is highly sensitive; and, (2) estimated biomass from each of the updates must necessarily be evaluated on a past, current, and future basis. Finally, the above issues are related to the current TOR, and are addressed in the CPSMT statement on revised TOR for CPS stock assessment updates (Agenda Item C.1.c).

The CPSMT also considered an assessment update proposed by Dr. Hill in which the parameterization of the 2007-08 PNW length composition was adjusted to more closely reflect model-estimated (effective) sample sizes. This modification to the model, when using all the new available data, resulted in improved consistency with the 2007 assessment. Although such model tuning is a common practice in stock assessments that are based on integrated statistical methods, it did not comply with the TOR for an assessment update, and therefore the CPSMT is not recommending it for further consideration by the Council.

The CPSMT notes that all three of the assessment updates that it considered would result in nearly the same age 1+ biomass estimates for the 2009 fishing season, follow generally similar trajectories, and are well within all projected confidence intervals. Moreover, 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.

Given this situation, the CPSMT does not see the need to unnecessarily reduce fishing opportunity. Therefore its decision to recommend the strict assessment update over the Subcommittee projected update is further supported on the basis that all else being equal, this update would result in a lesser negative economic impact in terms of potential revenues to industry from harvesting the resulting HG.

Management Measures

As has happened in 2008, there is a high probability that each directed seasonal allocation of the recommended 2009 HG, 66,932 mt, could be reached prematurely. The CPSMT agrees with the CPSAS on the need for (1) a total incidental catch set aside of 6,500 mt for the 2009 fishing season and, (2) a set aside of 1,200 mt for industry research -- to be deducted from the HG before it is allocated (Table 1).

Further, the CPSMT feels that the first two incidental catch amounts should each be set to 1,000 mt and that the last incidental amount should be set to 4,500 mt to account for management uncertainty in addition to incidental sardine catch in other fisheries (Table 1). This means that any overage in the directed sardine fishery in the third period would be deducted from the 4,500 mt incidental set aside in the third period. The CPSMT is in agreement with the CPS Advisory Subpanel regarding the inseason automatic actions that should be taken to deal with surpluses or shortages that may occur for the direct and incidental seasonal allocations, and that the incidental landing allowance be no more than 20 percent Pacific sardine by weight. The CPSMT recommends that if both the adjusted seasonal allocation and the seasonal incidental/management uncertainty set-asides are reached or exceeded in any period, the retention of Pacific sardine be prohibited.

Table 1. Allocation scheme for the 2009 Pacific Sardine HG.

HG = 66,932 mt Research set aside = 1,200 mt Adjusted HG = 65,732 mt				
	Jan 1- Jun 30	Jul 1- Sep 14	Sep 15 – Dec 31	Total
Seasonal Allocation (mt)	23,006	26,293	16,433	65,732
Incidental Set Aside (mt)	1,000	1,000	4,500	6,500
Adjusted Allocation (mt)	22,006	25,293	11,933	59,232

The CPSMT recommends the Council encourage National Marine Fisheries Service (NMFS) to continue to fund comprehensive coastwide annual CPS research, including the survey off the PNW to fully evaluate the contribution of PNW sardine to the spawning biomass as a whole, and encourage similar cooperative surveys in Canada and Mexico. The CPSMT also encourages cooperative research with the fishing industry and other interest groups as in the case of the industry-supported sardine aerial survey in the PNW and possible expansion off California to develop a coastwide index. The CPSMT continues to believe strongly that coordinated international management of CPS fisheries is essential to avoid the potential for coastwide overfishing. The CPSMT encourages the Council, NMFS and the State Department to continue working to achieve timely receipt of biological research data from Mexico.

PFMC
10/16/08

COASTAL PELAGIC SPECIES MANAGEMENT TEAM REPORT ON PACIFIC SARDINE STOCK ASSESSMENT AND MANAGEMENT MEASURES

Alternate Allocation scheme for the 2009 Pacific Sardine HG based on the Projection Model (PS08_a).

Acceptable Biological Catch = 56,946 mt Research set aside = 1,200 mt Adjusted HG = 55,746 mt				
	Jan 1- Jun 30	Jul 1- Sep 14	Sep 15 – Dec 31	Total
Seasonal Allocation (mt)	19,511	22,298	13.937	55,746
Incidental Set Aside (mt)	1,000	1,000	4,500	6,500
Adjusted Allocation (mt)	18,511	21,298	9,437	49,246

PFMC
11/03/08

COASTAL PELAGIC SPECIES ADVISORY SUBPANEL REPORT ON THE PACIFIC SARDINE STOCK ASSESSMENT AND MANAGEMENT MEASURES

Recent years have seen our November Coastal Pelagic Species Advisory Subpanel (CPSAS) statement echoing the same message—the stock assessment models are underestimating sardine abundance, especially in the Pacific Northwest (PNW). Each year we have thanked the Coastal Pelagic Species Management Team (CPSMT) and the Scientific and Statistical Committee (SSC) for their work in calculating the annual stock biomass and each year we begrudgingly have accepted the resulting harvest guideline (HG) recommendations.

This year the CPSAS cannot accept the recommended HG.

We note (albeit for different reasons) that the SSC Coastal Pelagic Species (CPS) Subcommittee (Subcommittee) also rejected the 2008 sardine stock assessment. We appreciate the efforts of the CPSMT to resolve the problems manifested by one 'outlier' data point that changed the history of both sardine biomass and recruitment. Unfortunately, the rigid Terms of Reference, now in place for Pacific sardine, tied the hands of both the CPSMT and Subcommittee. The Pacific Fishery Management Council (Council) must act on whatever 'best available science' the scientists recommend, but the fundamental point remains – the stock assessment does not reflect the reality reported by fishermen and spotter pilots over the last eight years. It is clear that a second index of abundance is absolutely necessary. At the very least it is required to gain perspective on the accuracy and validity of the assumptions and enormous uncertainty inherent in the current stock assessment methodology.

We ask in the face of this uncertainty, "Does it not make sense – is it not time – to count actual numbers of fish?" In view of our observations we have asked this question now for eight years. It is time for something to change in this equation. The same old answers are no longer sufficient.

Our disappointment in past years was masked by an overriding consideration—the annual HG still allowed for an economically viable fishery – at least it did until 2008. Unfortunately, next year's Subcommittee recommended HG, which is dramatically reduced from the 2008 level and only 37 percent of the 2007 HG, will cause further major economic disruption to our fishing communities.

The CPSAS is largely comprised of commercial and recreational fishing representatives—laymen if you will—and clearly not scientists. With that said, we are now nearly 10 years into a resurgent fishery and in recent years we have observed sardine abundance in the Northwest and California that belies current biomass estimates. Meanwhile the scientific committee has recommended successive cuts in the HG, declining from 152,000 mt in 2007 to 89,000 mt in 2008 and only 66,932 mt (recommended by the CPSMT) or 56,946 mt (proposed by the Subcommittee) for 2009. Intuitively, in light of the major uncertainties in the current assessment, and echoing concerns voiced by the scientists, who agree that one data point should not have such a dramatic affect on the past history of the resource, we cannot accept this precipitous decline in predicted abundance.

The CPSAS will be the first to admit that a growing world demand for Pacific sardines and higher ex-vessel prices are now driving increased fishing effort in California and the PNW. This, coupled with a fully developed harvesting and processing sector in the PNW, allows for greater utilization of Pacific sardine quota. However, our objection to the recommended HG is not predicated on a "what the industry needs in 2009" argument. Rather, we regrettably maintain that the SSC continues to work within the confines of historic assumptions untested in today's environment, and a narrowly constructed stock assessment model driven by incomplete data. Further stock assessments have been unable to quantify on-the-water observations or the upward trending harvest rates and catches per unit of effort for all harvest areas. Consequently, we must conclude that the National Oceanic and Atmospheric Administration (NOAA) and, by implication, the Council, have relegated the Pacific sardine fishery to a second tier status that does not warrant the same level of resources and attention directed to other Council-managed fisheries, this notwithstanding the growing economic importance of the Pacific sardine fishery on the west coast.

Frustrated by eight years of disregard for our observations, this year we sought to validate our "layman" opinion. Industry employed respected scientists to design and implement, through industry funding, an aerial-based sardine abundance survey for the PNW coast. This study, which included a systematic sampling design, was developed in consultation with an expert panel and took into consideration that the Pacific sardine stock assessment review (STAR) panel had until recently utilized a California aerial spotter index in the base model. The industry-sponsored study concluded that aerial surveys can provide a scientifically valid approach for Pacific sardine stock assessment. Further, when combined with adequate sampling, this approach provides for an accurate biomass estimate. Not surprising from our perspective, when the 225,000 mt found in 91 nautical miles of the PNW coast is extrapolated, the aerial survey study projects a sardine biomass far in excess of any of the SSC's present or recent estimates In fact, one 30 mile transect identified sardine biomass equal to one-third of the entire 2009 biomass estimate.

The Subcommittee and CPSMT found the aerial survey methodology promising and saw potential for further development as an absolute or relative index of abundance. However, under the current Terms of Reference, any new data collection methodology must be reviewed by a STAR panel prior to its use in the stock assessment model. A STAR panel to review mackerel and sardine assessment methodology is now being considered for May 2009, but it is unclear at this time if this new, quantifiable, aerial survey methodology will be accepted. The industry would like to mount a synoptic survey in the summer of 2009, but we need help to fund such a synoptic effort. This survey would be intended to cover the PNW and extend at a minimum to Monterey. We ask for the Council's support in this effort, by emphasizing the importance of this work and requesting that NOAA provide an adequate allocation for cooperative research in 2009, specifically for this purpose.

We are troubled by the lack of substantive forward progress in addressing the uncertainty surrounding the Pacific sardine stock(s). This is a research need that has been identified for many years. It is apparent that the present egg production collection methodology is inadequate to measure the full extent of the resource, and a second index of abundance is necessary. This need has been identified in the past by the SSC and CPSMT, but to date has not been addressed, except through the actions of industry and the independent scientists they employed.

Perhaps most troubling: recent scientific recommendations come on top of a maximum sustainable yield-proxy control rule that is the gold standard for sustainable fisheries management. What other management plan comes anywhere close to the conservation, environmental and forage considerations built into the CPS Fishery Management Plan?

Except for the legal obligations of the Magnuson-Stevens Fishery Conservation and Management Act and strict process nightmare inherent in the Terms of Reference regarding addressing uncertainty in the stock assessment update, the CPSAS sees nothing in available science or management that would preclude the SSC and Council from recommending a 2009 HG of 100,000 mt. This harvest level would promote stability in both the California and PNW fishing communities, and most importantly, provide ample protection to a coastwide Pacific sardine population that fishermen on the grounds believe is expanding—and not contracting. The conservation representative on CPSAS, Ben Enticknap (Oceana), disagrees with the notion of setting a harvest guideline in excess of the allowable biological catch that is determined by the most recent stock assessment and harvest control rule.

Regarding 2009 sardine management measures, the CPSAS provides the following recommendations:

A research set-aside of 1,200 mt is recommended for continuing and expanding the 2008 pilot aerial survey sponsored by the PNW sardine industry. The CPSAS recommends that the research set-aside is taken "off the top" before the HG is allocated seasonally because the results of the research would have coastwide benefits and there are tentative plans to extend the survey into California. Any of the research set-aside that is not used in the second allocation period will be rolled into the third seasonal period's directed HG.

Seasonal Allocation Period	**Period 1 Jan 1-June 30**	**Period 2 July 1- Sept 14**	**Period 3 Sept 15-Dec31**	**Total**
Seasonal Incidental Set-Aside (mt)	1,000	1,000	4,500	6,500

The Seasonal Incidental Set-Asides are intended to allow CPS fisheries targeting species other than Pacific sardine to continue if a seasonal allocation to the directed fishery is reached or exceeded in any period. Under these circumstances, the CPSAS anticipates that National Marine Fisheries Service (NMFS) would close the directed sardine fishery and the fishery would revert to an incidental fishery with an incidental landing allowance of no more that 20 percent Pacific sardine by weight. The larger Seasonal Incidental Set-Aside in Period 3 is intended to protect the winter market squid fishery and to minimize the chance of exceeding the allowable biological catch.

Under this proposal, the CPSAS recommends NMFS take the following inseason automatic actions:

- Any unused seasonal allocation to the directed fishery from Period 1 or Period 2 rolls into the next period's directed fishery.
- Any overage of a seasonal allocation to the directed fishery from Period 1 or Period 2 is deducted from the next Period's directed fishery.
- Any unused Seasonal Incidental Set-Aside from Period 1 or Period 2 rolls into the next period's directed fishery.
- If both the seasonal allocation to the directed fishery and the Seasonal Incidental Set-Aside are reached or exceeded in any period, the retention of Pacific sardine will be prohibited.

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