

# NOAA Technical Memorandum NMFS



DECEMBER 2009

## ASSESSMENT OF THE PACIFIC SARDINE RESOURCE IN 2009 FOR U.S. MANAGEMENT IN 2010

Kevin T. Hill  
Nancy C.H. Lo  
Beverly J. Macewicz  
Paul R. Crone  
Roberto Felix-Uraga

NOAA-TM-NMFS-SWFSC-452

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

The National Oceanic and Atmospheric Administration (NOAA), organized in 1970, has evolved into an agency that establishes national policies and manages and conserves our oceanic, coastal, and atmospheric resources. An organizational element within NOAA, the Office of Fisheries is responsible for fisheries policy and the direction of the National Marine Fisheries Service (NMFS).

In addition to its formal publications, the NMFS uses the NOAA Technical Memorandum series to issue informal scientific and technical publications when complete formal review and editorial processing are not appropriate or feasible. Documents within this series, however, reflect sound professional work and may be referenced in the formal scientific and technical literature.



## **NOAA Technical Memorandum NMFS**

This TM series is used for documentation and timely communication of preliminary results, interim reports, or special purpose information. The TMs have not received complete formal review, editorial control, or detailed editing.

**DECEMBER 2009**

# **ASSESSMENT OF THE PACIFIC SARDINE RESOURCE IN 2009 FOR U.S. MANAGEMENT IN 2010**

Kevin T. Hill<sup>1</sup>, Nancy C.H. Lo<sup>1</sup>, Beverly J. Macewicz<sup>1</sup>,  
Paul R. Crone<sup>1</sup>, Roberto Felix-Uraga<sup>2</sup>

<sup>1</sup>NOAA National Fisheries Service  
Southwest Fisheries Science Center  
8604 La Jolla Shores Drive  
La Jolla, California, USA 92037

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

**NOAA-TM-NMFS-SWFSC-452**

### **U.S. DEPARTMENT OF COMMERCE**

Gary F. Locke, Secretary

**National Oceanic and Atmospheric Administration**

Jane Lubchenco, Undersecretary for Oceans and Atmosphere

**National Marine Fisheries Service**

James W. Balsiger, Acting Assistant Administrator for Fisheries



## TABLE OF CONTENTS

ACRONYMS, ABBREVIATIONS, AND DEFINITIONS .....	3
ACKNOWLEDGMENTS .....	5
PREFACE .....	6
EXECUTIVE SUMMARY .....	7
INTRODUCTION .....	10
Scientific Name, Distribution, Stock Structure, Management Units .....	10
Important Features of Life History that Affect Management .....	11
Relevant History of the Fishery .....	13
Early Management History .....	14
Management Performance Under the CPS-FMP (2000-present) .....	15
ASSESSMENT .....	15
Biological Data .....	15
Stock Structure .....	15
Weight-at-length .....	16
Age and growth .....	16
Maturity .....	16
Natural mortality .....	16
Fishery Data .....	17
Overview .....	17
Landings .....	17
Length composition .....	18
Age composition .....	18
Fishery-Independent Data .....	19
Overview .....	19
Daily Egg Production Method .....	19
Total Egg Production .....	20
NWFSC Predator-Forage Fish Survey .....	20
West Coast Vancouver Island Trawl Survey .....	21
West Coast Aerial Sardine Survey of 2009 .....	22
History of Modeling Approaches .....	23

SS Model Description .....	23
Assessment Program with Last Revision Date .....	24
Likelihood Components, Constraints on Parameters, Selectivity Assumptions .....	24
Stock-recruitment .....	25
Convergence criteria .....	25
Model Selection and Evaluation .....	25
Base Model Results .....	26
Growth .....	26
Selectivity estimates and fits to composition data .....	26
Fits to DEPM and TEP Survey Indices .....	26
Fits to PFFS and WCVI Survey Indices .....	27
Fit to Aerial Survey 2009 .....	27
Harvest and exploitation rates .....	27
Spawning stock biomass .....	28
Recruitment .....	28
Stock biomass (ages 1+) for PFMC management .....	28
Stock-recruitment .....	28
Uncertainty, Sensitivity, and Unresolved Problems .....	28
Sensitivity to natural mortality assumptions .....	28
Prospective analysis .....	29
Retrospective analysis .....	29
Comparison to previous assessments .....	29
HARVEST GUIDELINE FOR 2010 .....	30
RESEARCH AND DATA NEEDS .....	30
LITERATURE CITED .....	32
TABLES .....	39
FIGURES .....	53
APPENDICES .....	157
Appendix I – Revised estimation of spawning biomass of Pacific sardine using the Daily Egg Production Method .....	158
Appendix II – PFMC scientific peer reviews and advisory body reports .....	182

## ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

ABC	allowable biological catch (equivalent to HG in the CPS-FMP)
ADMB	automatic differentiation model builder (programming language)
Aerial	West Coast Aerial Sardine Survey of 2009
ASAP	age structured assessment program
BAMM	best ad-hoc mortality method (Lorenzen's hockey-stick <i>M</i> )
BC	British Columbia
CA	State of California
CANSAR-TAM	catch-at-age analysis for sardine – two area model
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CalVET	California Vertical Egg Tow (ichthyoplankton net)
CCA	Central California fishery
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
ENS	Ensenada (México) fishery
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
MLE	maximum likelihood estimate
Model Year	Annual model increment from July 1 to June 30 of the following year
MSY	maximum sustainable yield
mt	metric tons
mmt	million metric tons
MX	México
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NWFSC	Northwest Fisheries Science Center
OR	State of Oregon
ODFW	Oregon Department of Fish and Wildlife
PFFS	Predator-forage fish survey (NWFSC Newport Lab)
PFMC	Pacific Fishery Management Council
PNW	Pacific Northwest fishery (Oregon, Wash., and British Columbia)
SAFE	stock assessment and fishery evaluation
S1	Season 1 (Jul-Dec)
S2	Season 2 (Jan-Jun)
SCA	Southern California fishery
SIO	Scripps Institution of Oceanography
SS2	Stock Synthesis version 2
SS3	Stock Synthesis version 3

SSB	spawning stock biomass
SSC	Scientific and Statistical Committee
SST	sea surface temperature
STAR	Stock Assessment Review
STAT	Stock Assessment Team
SWFSC	Southwest Fisheries Science Center
TEP	Total egg production
VPA	virtual population analysis
WA	State of Washington
WCVI	West Coast Vancouver Island sardine survey (CDFO)
WDFW	Washington Department of Fish and Wildlife



## ACKNOWLEDGMENTS

This annual stock assessment depends in large part on the diligent efforts of many colleagues and the timely receipt of their data products. Landings data from the Ensenada fishery were provided by INP-CRIP and CONAPESCA of México. Port samples for the Ensenada, México, fishery were collected by INP-CRIP (Ensenada) and aged by Roberto Felix-Uraga and Casimiro Quiñonez (CICIMAR, La Paz). Port samples and age data for the California fishery were provided by CDFG Marine Region personnel in Los Alamitos, Santa Barbara, San Diego, and Monterey, with special thanks to Dianna Porzio, Bob Read, Leeanne Laughlin, Mandy Lewis, Bill Miller, Paul Ton, Santi Luangpraseut, Dale Sweetnam, Briana Brady, Ed Dunn, Sonia Torres, and Lou Zeidberg for long dockside and laboratory hours. Thanks also go to the dedicated staff that collected and processed biological samples from the fisheries off Oregon and Washington, including Jill Smith, Keith Matteson, Sheryl Manley, Kelly Corbet, and David Wolfe Wagman of ODFW, and Carol Henry of WDFW. Sandra Rosenfield and Jennifer Topping (WDFW) aged all Oregon and Washington otoliths. Monthly landings and size data for the British Columbia fishery along with data from the WCVI trawl survey, were kindly provided by Jake Schweigert, Vanessa Hodes, and Linnea Flostrand of DFO-Canada. We are grateful to Robert Emmett (NWFSC-Newport) for providing data and guidance regarding the PFFS survey. Numerous staff from SIO, NMFS, and CDFG assisted in the ongoing collection and identification of CalCOFI ichthyoplankton samples. Sea surface temperature data were provided by Scripps Institution of Oceanography's Shore Stations program, currently funded by the California Department of Boating and Motorways. We are indebted to Richard Methot (NWFSC) for developing and continuously improving the Stock Synthesis model. We thank Ian Stewart and Ian Taylor (NWFSC) for developing and maintaining the 'R' function to summarize SS3 outputs. Finally, we thank Kevin Piner and Hui-Hua Lee (PISFC), Mark Maunder (IATTC), and Jenny McDaniel (SWFSC), for providing valuable feedback and assistance throughout the assessment.

## **PREFACE**

The Pacific sardine resource is assessed each year in support of the Pacific Fishery Management Council (PFMC) process that, in part, establishes an annual harvest guideline ('HG', or 'ABC') for the U.S. fishery. The following assessment was conducted using the 'Stock Synthesis 3' (SS3) model, and includes fishery and survey data from updated and new sources. The draft assessment was reviewed by a STAR Panel 21-25 September, 2009, in La Jolla, California. During the course of the STAR meeting, modifications to input data and model structure were incorporated in the base model and are included in this report. The present draft was presented to the PFMC's advisory bodies (SSC, CPSMT, CPSAS) and the PFMC at their November 2009 meetings in Costa Mesa, CA. The outcome of these reviews formed the basis for U.S. Pacific sardine management in 2010. Reports of the STAR panel and PFMC advisory bodies are provided in Appendix II.

## EXECUTIVE SUMMARY

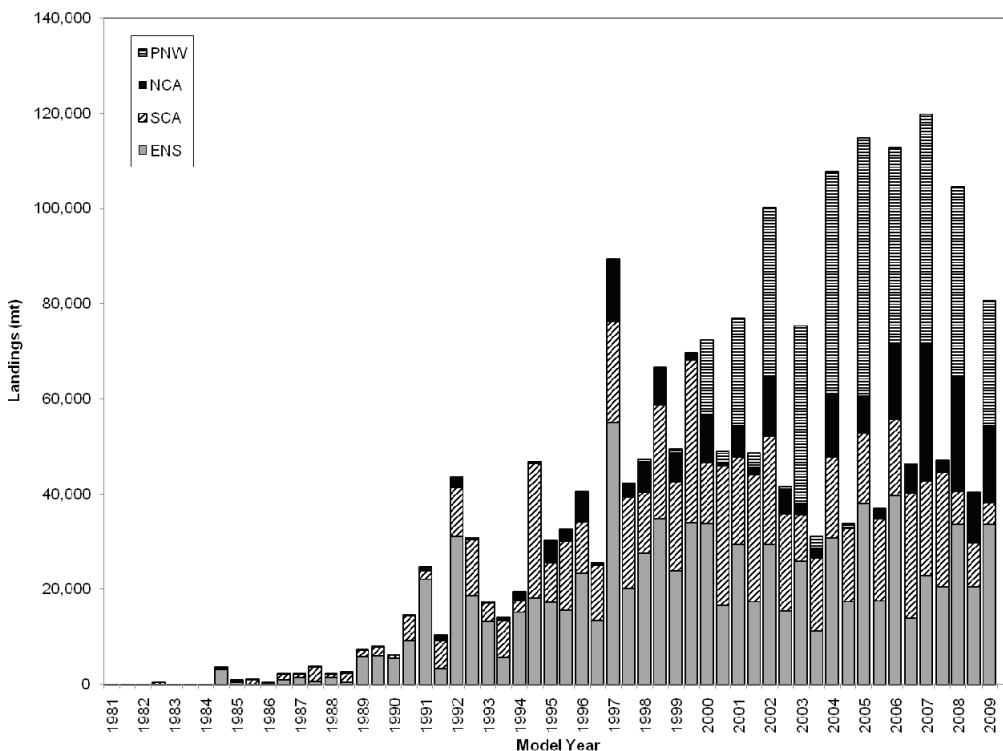
### Stock

The Pacific sardine (*Sardinops sagax caerulea*) ranges 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 seasonally 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 will explore a scenario separating the catches in Ensenada and San Pedro into the respective northern and southern stocks based on objective criteria.

### Catches

This assessment includes sardine landings from four commercial fisheries: Ensenada (México), Southern California (San Pedro to Santa Barbara), Central California (Monterey), and the Pacific Northwest (Oregon, Washington, and British Columbia), from 1981 to 2009.

Model Year	ENS	SCA	CCA	PNW
2000	50,457	42,059	10,857	17,923
2001	46,948	44,939	8,042	25,683
2002	44,938	43,125	17,589	36,123
2003	37,040	25,141	4,508	39,861
2004	48,007	32,581	13,278	47,747
2005	55,600	31,991	9,857	54,254
2006	53,617	42,472	21,724	41,221
2007	43,436	43,982	31,284	48,237
2008	54,213	16,108	34,834	39,800
2009	33,642	4,634	16,104	26,244



### Data and assessment

This assessment was conducted using ‘Stock Synthesis’ version 3.03a and utilizes fishery and survey data collected from mid-1981 through mid-2009. The model uses a July-June ‘model year’, with two semester-based seasons per year (1=Jul-Dec and 2=Jan-Jun). Fishery data include catch and biological samples for the fisheries off Ensenada, Southern California, Central California, and the Pacific Northwest. Two indices of relative abundance are included in the base model: Daily Egg Production Method and Total Egg Production estimates of spawning stock biomass (1986-2009), both based on annual surveys conducted off California. Finally, the tuned base model was run with the addition of the 2009 aerial survey estimate of absolute abundance ( $q=1$ ) to derive population quantities for 2010 management.

### Stock biomass and recruitment

Stock biomass, used for setting ABC, is defined as the sum of the biomass for sardines ages 1 and older. Biomass increased rapidly through the 1980s and 1990s, peaking at 1.69 million mt in 2000. Biomass has subsequently trended downward to the present (July 1, 2009) level of 702,024 mt.

Recruitment was modeled using the Ricker stock-recruitment relationship. The estimate of steepness was high ( $h=2.32$ ). Virgin recruitment ( $R_0$ ) was estimated at 4.94 billion age-0 fish for the base model. Recruitment increased rapidly through the mid-1990s, peaking at 16.79 billion fish in 1997, 22.01 billion in 1998, and 18.62 billion fish in 2003. Recruitments have been notably lower since 2006.

Model Year	Stock Biomass (age 1+, mt)	Recruits (age-0, Billions)
2000	1,686,190	2.875
2001	1,494,760	8.492
2002	1,312,620	0.739
2003	1,025,580	18.622
2004	1,112,660	10.226
2005	1,237,180	10.328
2006	1,317,350	2.943
2007	1,194,680	3.331
2008	955,948	1.737
2009	702,024	6.912

### Exploitation status

Exploitation rate is defined as calendar year catch divided by total mid-year biomass (July-1, ages 0+). Exploitation rate was relatively high during the early recovery period (mid-1980s) but declined and stabilized as the stock underwent the most rapid phase of recovery. Exploitation rate has subsequently increased in recent years as the stock has again declined. Ensenada catch during 2009 is unknown (unavailable), so is assumed the same as 2008. Total exploitation rate is currently less than 16%.

Calendar						
Year	ENS	SCA	CCA	PNW	Total	
2000	4.0%	2.7%	0.7%	0.9%	8.3%	
2001	2.9%	3.0%	0.5%	1.6%	8.0%	
2002	3.6%	3.7%	1.1%	2.9%	11.3%	
2003	3.5%	2.5%	0.6%	3.2%	9.8%	
2004	3.5%	2.7%	1.3%	4.1%	11.5%	
2005	4.2%	2.3%	0.6%	4.2%	11.2%	
2006	4.3%	2.5%	1.3%	3.1%	11.1%	
2007	3.0%	3.8%	2.8%	3.9%	13.6%	
2008	5.6%	3.2%	2.7%	4.1%	15.6%	
2009	7.1%	1.8%	3.5%	3.4%	15.8%	

### Management performance

Based on results from the base model, the harvest guideline for the U.S. fishery in calendar year 2010 would be 72,039 mt. The HG (=ABC) is based on the control rule defined in the CPS-FMP:

$$HG_{2010} = (BIOMASS_{2009} - CUTOFF) \cdot FRACTION \cdot DISTRIBUTION;$$

where  $HG_{2010}$  is the total USA (California, Oregon, and Washington) harvest guideline in 2010,  $BIOMASS_{2009}$  is the estimated July 1, 2009 stock biomass (ages 1+) from the assessment (702,024 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  $DISTRIBUTION$  (0.87) is the average portion of  $BIOMASS$  assumed in U.S. waters. The following formula is used to determine the appropriate  $FRACTION$  value:

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

where  $T$  is the running average sea-surface temperature at Scripps Pier, La Jolla, California during the three preceding seasons (July-June). Based on the current ( $T_{2009}$ ) SST estimate of 17.92 °C, the  $F_{msy}$  exploitation fraction should remain at 0.15.

Year	U.S. ABC	U.S. Landings	Total ABC	Total Landings
2000	186,791	67,985	214,702	120,876
2001	134,737	75,733	154,870	99,578
2002	118,442	96,876	136,140	141,357
2003	110,908	69,931	127,480	101,411
2004	122,747	92,723	141,089	141,364
2005	136,179	90,016	156,528	148,539
2006	118,937	91,039	136,709	149,834
2007	152,564	127,789	175,361	166,156
2008	89,093	87,184	102,406	151,832
2009	66,932	65,652	76,933	TBD

## INTRODUCTION

### Scientific Name, Distribution, Stock Structure, Management Units

Information regarding Pacific sardine (*Sardinops sagax caerulea*) biology 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 the 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).

The Pacific sardine has 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° N latitude) to southeastern Alaska (57° 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, sardines do not occur in commercial quantities north of Point Conception.

It is generally accepted that sardines 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 sardines 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 sardines 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. In recent decades, the combination of increased stock size and warmer sea surface temperatures resulted in the stock re-occupying areas off Central California, Oregon, Washington, and British Columbia, as well as distant-offshore areas off California. During a cooperative U.S.-U.S.S.R. research cruise for jack mackerel in 1991, several tons of sardines 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 sardines may reach 41 cm in length, but are seldom longer than 30 cm. They may live as long as 15 years, but individuals in 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 evidence for 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, sardines 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  $0.66\text{ d}^{-1}$ ). Adult natural mortality rates has been estimated to be  $M=0.4\text{ yr}^{-1}$  (Murphy 1966; MacCall 1979) and  $0.51\text{ yr}^{-1}$  (Clark and Marr 1955). A natural mortality rate of  $M=0.4\text{ yr}^{-1}$  means that 33% of the sardine stock would die each year of natural causes if there were no fishery.

Pacific sardines 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  $13^{\circ}\text{C}$  to  $15^{\circ}\text{C}$  and larvae are most abundant at  $13^{\circ}\text{C}$  to  $16^{\circ}\text{C}$ . Temperature requirements are apparently flexible, however, because eggs are most common at  $22^{\circ}\text{C}$  to  $25^{\circ}\text{C}$  in the Gulf of California and at  $17^{\circ}\text{C}$  to  $21^{\circ}\text{C}$  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 & 2005). 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.

Sardines 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 sardines spawn on average six times per year whereas the oldest sardines spawn up to 40 times

per year. Both eggs and larvae are found near the surface. Sardine eggs are spheroid, have a large perivitelline space, and require about three days to hatching at 15°C.

Sardines are planktivorous omnivores and consume both phytoplankton and zooplankton. When biomass is high, Pacific sardines may consume a considerable proportion of total organic production in the California Current system.

Pacific sardines are consumed by a variety of predators throughout all life stages. Sardine eggs and larvae are consumed by an assortment of invertebrate and vertebrate planktivores, including adult sardine. 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 sardines as forage, but juveniles and adults 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, dolphins, and whales). In all probability, sardines are consumed by the same predators (including endangered species) that utilize anchovies. It is also likely that sardine become more important as prey as their numbers increase. For example, while sardines 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 the (Cushing 1971). Estimates of the abundance of sardines from 300 through 1970 have been reconstructed 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 (Figure 54). Both sardine and anchovy populations tend to vary over periods of roughly 60 years, although sardines have varied more than anchovies. 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 19<sup>th</sup> and 20<sup>th</sup> centuries (Soutar and Isaacs 1969; Smith 1978) indicate that the biomass peaked in 1925 at about six million mt.

Sardines ages three and older were fully recruited to the fishery until 1953 (MacCall 1979). Recent fishery data indicate that sardines 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; Figure 53). 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).

Recruitment success for sardines is generally autocorrelated and affected by environmental processes occurring on long (decadal) time scales. Lluich-Belda et al. (1991) and Jacobson and MacCall (1995) demonstrated relationships between recruitment success in Pacific sardines 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 sardines is highly variable. Analyses of the sardine stock recruitment relationship have been controversial, with some studies showing a strong density-dependent relationship (production of young sardines 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 sardines 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 sardines during the peak of the historical fishery (>700,000 mt). Jacobson and MacCall (1995) found that MSY for sardines depends on environmental conditions and developed a Ricker stock-recruitment model that incorporates a three-season running average of sea-surface temperature measured off La Jolla, California. Their results indicate that MSY can range from 9,000 mt to 346,000 mt for mean SSTs between 16.5 °C and 17.3 °C, respectively (Jacobson and MacCall 1995). Their 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 sardines 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. Sardines were primarily used for reduction to fish meal, oil, and as canned food, with small quantities taken for live bait. A lucrative dead bait market developed in central California in the 1960s.

In the early 1980s, sardine fishers began to take sardines incidentally with Pacific (chub) mackerel and jack mackerel in the southern California mackerel fishery. Sardines were primarily canned for pet food, although some were canned for human consumption. As sardines continued to increase in abundance, a directed purse-seine fishery was reestablished. Sardines 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 for live bait.

Besides San Pedro and Monterey, California, substantial Pacific sardine landings are now made in the Pacific northwest and in Baja California, México. Sardines landed in México are used for reduction, canning, and frozen bait. Total annual harvest of Pacific sardines 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 México, the U.S., 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 sardines, 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 increased, 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 1,000 short tons (907 mt) once the spawning population had returned to this level. California’s annual directed quota was set at 907 mt from 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. The 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 sardines from being overfished and to maintain relatively high and consistent catch levels over a long-term horizon. The harvest formula for sardines is provided at the end of this report (‘Harvest Guideline for 2010’ section). A thorough description of PFMC management actions for sardines, including harvest guidelines, may be found in the most recent CPS SAFE document (PFMC 2009). 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 ABCs since 2000 are provided in Figure 2b. Pacific sardine landings for all major fishing regions off the West Coast of North America may be found in Table 2.

## **ASSESSMENT**

### **Biological Data**

#### Stock Structure

For purposes of this assessment, we model the northern subpopulation (‘cold stock’) that ranges from northern Baja California, México to British Columbia, Canada and extends out to 300 nm offshore (Macewicz and Abramenkoff 1993). More specifically, all U.S. and Canadian landings are assumed to be taken from the single stock being assessed. Similarly, all sardine landed in Ensenada, Baja California, México are also assumed to be taken from the single stock being assessed and sardines 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 consider a case that separates the catches in Ensenada and San Pedro into the respective northern (‘cold’) and southern (‘temperate’) stocks using temperature-at-catch and otolith morphometric criteria proposed by Felix-Uraga et al. (2004, 2005). Subpopulation differences in growth, maturation, and natural mortality will also be taken into account.

### Weight-at-length

The weight-length relationship for Pacific sardines (combined sexes) was modeled using fishery samples collected from 1981 to 2009 and the standard power function

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

where  $W$  is weight (kg) at length  $L$  (cm), and  $a$  and  $b$  are regression coefficients. The estimated coefficients were  $a = 9.47212e-06$  and  $b = 3.14752$  (corrected  $R^2 = 0.936$ ;  $n = 131,291$ ). Coefficients  $a$  and  $b$  were fixed parameters in all models (Figure 3a).

### 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 long and weighed 0.323 kg. The oldest recorded age is 15 years, but commercially-caught sardines 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 sardines 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. Lab-specific ageing errors were calculated and applied as described in ‘Conditional age-at-length compositions’.

Sardine growth was initially estimated outside the SS 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  $K$ . During the STAR panel of September 2009, examination of residuals for the age- and length-composition data revealed that growth was likely not constant over time. Specifically, there was strong evidence for a shift in growth rates in 1991. Growth parameters were therefore modeled for two time blocks (1981-1990 and 1991-2009) in the final base model (see Model Results section, Table 6 and Figure 3b).

### Maturity

Maturity-at-length was estimated using sardines 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 SS (Figure 4a), where the length-at-inflexion (i.e. 50% maturity) = 16.0 cm and slope = -0.7571, given:

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

Resultant maturity and fecundity-at-age during the spawning season derived from the final base model are presented in Figure 4b.

### Natural mortality

Adult natural mortality rates have been estimated to be  $M=0.4 \text{ yr}^{-1}$  (Murphy 1966; MacCall 1979) and  $0.51 \text{ yr}^{-1}$  (Clark and Marr 1955). A natural mortality rate of  $M=0.4 \text{ yr}^{-1}$  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  $0.4 \text{ yr}^{-1}$  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 from four regional fisheries: 1) Ensenada ('ENS', northern Baja California); Southern California ('SCA', San Pedro to Santa Barbara); 3) Central California ('CCA', Monterey Bay); and 4) the Pacific Northwest ('PNW': Oregon, Washington, and British Columbia). Biological data include individual weight (kg), standard length (cm), sex, maturity, and otoliths for age determination. Mexican port samples, collected by INP-Ensenada 1989-2002, were aged and made available for this assessment by Roberto Felix-Uraga (CICIMAR-IPN). CDFG currently collects 12 random port samples (25 fish per sample) per month from each region. California port samples span the entire range of model years. Oregon and Washington fishery samples are typically collected more intensively in time due to a compressed fishing season, but each sample contains 25 fish. ODFW and WDFW have collected port samples since 1999. CDFO collects 100 fish per sample from the Vancouver Island fishery.

All fishery data were compiled based on the sardine's biological year ('model year') to match the July-1 birth date assumption used in age assignments. Each model year is labeled with the first of the two calendar years spanned (e.g. model year '1981' includes data from July 1, 1981 through June 30, 1982). Further, each model year was assigned semester (6-month) seasons, where 'S1'=Jul-Dec and 'S2'=Jan-Jun. For the final model, the SCA and CCA fisheries were treated with semester-based selectivities and are labeled as such (e.g. SCA\_S1). See the 'SS Model Description' section for rationale.

Landings by model year and semester are provided in Table 3, and sample sizes (ESS) are provided in Table 4.

### Landings

Ensenada (ENS) landings from 1981 to 2002 were compiled using the 'Boletín Anual' series published by the Instituto Nacional de la Pesca's (INP) Ensenada office (e.g. see Garcia and Sánchez, 2003). Landings for 2003 to 2007 were taken from CONAPESCA's web archive of Mexican fishery yearbook statistics (CONAPESCA 2009). Total catch in 2008 was taken from Cota et al. (2009), as abstracted in the proceedings of Mexico's annual workshop on small pelagic species (Hernandez 2009). Ensenada's 2008 annual total was apportioned to months using monthly catch proportions from the previous three years, then aggregated to semester totals. Ensenada catch during 2009 is unknown, so it was assumed identical to 2008.

California (SCA & CCA) 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 through 1990), many processors reported sardines as mixed with jack or Pacific mackerel, but in some cases sardines were not accurately reported on landing receipts. For these years, sardine landings data were augmented with shore-side 'bucket' sampling of mixed-load fish bins to estimate species

portions by weight. CDFG reports these landings data in ‘Wetfish Tables’, which are still distributed monthly by the Department. These tables are considered more accurate than PacFIN or other landing receipt-based statistics for California CPS and were used for this assessment.

For the Pacific Northwest (PNW) fishery, we included sardines 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 SS model includes landings from 1981 through 2009. Landings by model year, semester, and fishery are presented in Table 3 and Figure 5.

### Length composition

Length compositions for each fishery and semester were the sums of weighted length observations, with monthly landings within semester being the sampling unit. Length compositions were comprised of 0.5-cm bins ranging from 9 cm to 26 cm standard length (35 bins total). The 9-cm bin reflects all fish  $\leq 9.49$  cm, the 26-cm bin reflects all fish  $\geq 26$  cm, and all other bins (9.5 to 25.5 cm) reflect the lower end of the respective 0.5-cm interval (e.g., the 9.5-cm bin includes fish ranging 9.5 to 9.99 cm).

Total numbers of lengths observed in each fishery-semester stratum were divided by the average number of fish collected per sampled load (25 fish per sample for most regions, 100 fish per sample in Canada) and were input as the effective sample sizes (ESS). Compositions having fewer than two samples ( $< 50$  fish) per semester were omitted from the analysis. Length-compositions were input as proportions. ESS by model year, semester, and fishery are provided in Table 4. Length-compositions by fishery are displayed in Figures 6a-f. Population length bins in SS were specified to range from 8 cm to 28 cm in 0.5-cm increments.

### Age composition

Implied (ghost) age compositions were compiled based on the same fishery samples and weighting methods described above in ‘Length composition’. Implied age-compositions were included as model inputs with effective sample sizes set to “-1”. Inclusion of these input data facilitated comparison of model predictions of age-composition to the inferred values through examination of model residual patterns. Implied age composition data are presented adjacent to corresponding length compositions in Figures 7a-f.

Conditional age-at-length compositions were constructed from the same fishery samples and weighting methods described above. Age bins included 0, 1, 2, 3, 4, 5, 6, 7, 8-10, 11-14, and 15 y (11 bins total). No fish older than 14 y were observed in the fishery samples, so the age-15 bin served as an accumulator allowing growth to approach  $L_{\infty}$ . 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 number of fish per sample to set the initial effective sample size. In most cases, age data were available for every length observation. Conditional age-at-length compositions for each fishery are presented in Figures 8a-f.

Ageing error vectors (std. dev. by age) were calculated and linked to fishery-specific age compositions (Figure 9). Error estimates were based on paired readings by two or more individuals within each ageing laboratory (CICIMAR-IPN for ENS samples; CDFG for SCA and CCA samples; WDFW for PNW 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.

## **Fishery-Independent Data**

### Overview

Two fishery-independent series were used in previous SS assessments (Hill et al. 2007a, Hill et al. 2008), and both were based on the SWFSC's egg production survey that ranges from San Diego to San Francisco each spring. The daily egg production method (DEPM) index of SSB is used when adult daily-specific fecundity data are available from the survey. The total egg production (TEP) index of SSB is used when survey-specific fecundity data are unavailable. Both time series are treated as indices of relative abundance.

The SWFSC egg production survey and estimation methodology were reviewed by a STAR panel in May 2009. The panel made specific recommendations for modifying past estimates and improving standard estimation procedures across the complete time series. As a result, raw data and procedures from all past surveys were re-examined for this assessment. A complete description of these changes is provided in Appendix I. New DEPM and TEP estimates, summarized in Table 5, were used in all model runs this year. The September 2009 STAR panel reviewed these revisions and adopted the new DEPM and TEP values for use in the final base model.

In addition to the standard egg production time series from California, we examined the potential utility of three new data sources representing sardine abundance in the Pacific Northwest: 1) the NWFSO Predator Forage Fish Survey (PFFS) conducted off northern Oregon and southern Washington, 2) the CDFO's West Coast Vancouver Island (WCVI) swept area trawl survey, and 3) the West Coast Aerial Sardine Survey of 2009. During the course of the September STAR panel, results from the Aerial survey were adopted for use in the assessment model. The aerial survey estimate was included as an index of absolute abundance ( $q=1$ ) in the final base model.

### Daily Egg Production Method (DEPM)

Daily egg production method (DEPM) spawning biomass estimates were available for model years 1986, 1987, 1993, 2003, 2004, and 2006-2008 (Table 5, Figure 33a; see also Appendix I). In the past, DEPM estimates were input as total SSB (combined sexes). However, the May 2009 STAR panel recommended using only female SSB, so all DEPM values are input as such. The latest DEPM estimate, based on eggs and adults collected during cruise 0904 (April 15 to May 9, 2009; Figure 10a,b), was 99,162 mt of female SSB (CV=0.24) (Table 5). The 2009 DEPM estimate is slightly higher than the 2008 value but still considerably lower than estimates from other recent years. In SS, the DEPM series was taken to represent female SSB (length selectivity option '30') in the middle of Semester 2 (April).

### Total Egg Production (TEP)

Adult sardine samples are needed to calculate daily specific fecundity for true DEPM estimates. Adult sardine trawls were not always conducted during the egg production surveys (specifically, model years 1987, 1995-2002, and 2006; see Table 4a,b in Appendix I). 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 ( $\text{km}^2$ ). Recalculated TEP values are provided in Table 5 and displayed in Figure 34a. Details regarding the modified TEP estimates are provided in Appendix I. TEP was also taken to represent SSB in the model, but in this case the female fraction was unknown.

### NWFSC Predator-Forage Fish Survey (PFFS)

NOAA Fisheries (Northwest Fisheries Science Center, Hatfield Marine Science Center, Newport, OR) has conducted a Predator/Forage Fish Survey (PFFS) off the Columbia River mouth during the spring and summer months from 1998 to the present. The primary goal of the PFFS is to collect density/abundance and biological data applicable to both juvenile salmon (predator) and associated species (forage, including Pacific sardines) that typically inhabit these productive waters, based on season and oceanographic conditions. Data collection in the field entailed sampling at night using surface-trawl gear following a biweekly cruise schedule and two fixed transects, situated south and north of the river mouth (Emmett et al. 2005; Lo and Allen 2008). The resulting data were omitted from the overall data set, given concerns surrounding consistency in sampling methods across time (e.g., omission of 1998 data) and substantial (inherent) variability in catches early in the season due to the stock's movement, which is largely driven by oceanographic conditions in any given year (e.g., omission of April - June data). Throughout the development of the time series from this survey, we discussed the appropriateness of the data set summaries, statistical methods, and subsequent results with the principal investigator responsible for the PFFS (R. Emmett, NOAA Fisheries, NWFSC/HMSC, Newport, OR, August 2009). The PFFS sample-related statistics follow (1999-08): (1) the number of hauls (trawl samples) conducted in each year ranged from 33 (2000) to 86 (2005); and (2) the total number of fish sampled from all hauls in each year ranged from 677 (2000) to 1,703 (2005), i.e., roughly 20 fish per haul were collected.

It is important to note that the time series developed from the PFFS are intended as (potential) additional information to be used in the ongoing stock assessment of Pacific sardines, i.e., a PFFS index of relative abundance and associated length distributions (1999-08) has not been included in past assessment models. In this context, caution is recommended when considering such data in the formal assessment model now in place, given (1) the PFFS design represents a very small spatial area along the U.S. Pacific coast ( $\sim 7,660 \text{ km}^2$ , Figure 11a); (2) the movement dynamics of the stock necessarily hampered the timing of the PFFS; and finally, (3) this is the first year these data have been examined for purposes of inclusion in a relatively complex (multiple data source/multi-dimensional), fully-integrated stock assessment model.

Annual size (standard length in cm) distributions were developed from data collected in the PFFS (Figure 11b). For some cruises, all fish sampled were measured, and in cases when large numbers of fish were obtained, a random subset was collected. The size distributions were developed following methods previously described for the fishery length compositions.



A catch-per-unit-effort (CPUE or density) index was derived from the ratio of catch and effort data from the PFFS, based on a straightforward ‘volume swept’ method (see Emmett et al. 2005). Ultimately, individual CPUE (density) estimates represented the number of fish/10<sup>6</sup> m<sup>3</sup> associated with each haul (sample). As stated above, sardines captured during the PFFS were typically most abundant in July and August, and thus data from these months were used in the regression (standardization) analysis. The final time series was based on a classical generalized linear model (GLM), whereby (1) individual records of the summarized data set included year, month, haul, latitude/longitude, and density (number/10<sup>6</sup> m<sup>3</sup>); (2) a constant of 0.01 was added to each density estimate to allow logarithm (natural, *ln*) transformation of the ‘zero’ density estimates (effort exerted, but no catch realized); (3) density estimates represented the response variables and the years 1999-08 and months July-August the explanatory variables, i.e., no regional factors were included, given spatial limitations of the overall survey design; and finally, (4) results from the regression analysis based on *ln*(density) were back-transformed ( $e^{ln(\text{density})}$ ) to produce the final time series of standardized CPUE (in number of fish/10<sup>6</sup> m<sup>3</sup>) (Figure 35a).

#### West Coast Vancouver Island (WCVI) Trawl Survey

Surveys employing mid-water trawls near the surface have been conducted on the west coast of Vancouver Island from 1992 to present to examine the distribution and relative abundance of sardines (McFarlane and MacDougall 2001, McFarlane et al. 2005). Abundance estimates were calculated using sets from the surface to 30 m depth, and from cruises in late June, July and August. The July cruises have generally been most indicative of the relative sardine biomass in Canadian offshore waters. For estimating abundance, the west coast of Vancouver Island was partitioned into 6 major “regions” or strata, and the total surface volume to the maximum depth of the net (30m) was determined for each region to allow biomass estimates to be calculated regionally and coastwide (Figure 12a). Total volume for each region was determined by multiplying the area determined for each region by maximum net depth (30 m, or .030 km):

$$\text{Total volume (km}^3\text{)} = \text{Area of region (km}^2\text{)} * 0.030 \text{ km}$$

Each region contained 3-5 transects or sampling sites. At each site a total of 2-51 sets were completed. Total number of sardines caught per set was recorded either by frequency or by weight. Where sardine catch was recorded by weight only, the number of fish caught was converted to frequency by dividing weight in kg by average weight per fish, 0.165 kg.

In each region survey transects were run parallel to shore or perpendicular to the coast out to a bottom depth of 500 m. The water volume swept during each tow was determined by multiplying the area of the mid-water trawl net used during the fishing operations, by the distance travelled. Tows of 20-60 minutes duration are conducted sequentially along the length of each transect. Swept volume for each set was determined by multiplying the area of the net by the distance travelled during the completion of each set:

$$\text{Swept Volume (km}^3\text{)} = \text{Net height (km)} * \text{Net width (km)} * \text{Distance (km)}.$$

An average swept volume was determined from all sets in each region separately, to be used in the abundance calculations.

From 1997 to 2004 all tows were conducted during daytime hours. In July 2005, day/night catch comparisons were conducted off Nootka and Barkley Sounds. In each area tows were completed during 2 days and 2 nights of fishing. A calibration factor was developed for day/night catch ratios and applied to the 2006, 2008, and 2009 data to standardize the time series to day time catches. All tows were conducted at night during 2006, 2008 and 2009.

Biomass estimates were calculated from data collected during directed abundance cruises conducted in July of 1997 to 2009. Biomass estimates were calculated according to the method described in Beamish et al. (2000) assuming a stratified random sampling design:

$$C_h = \frac{V_h}{v_h} \cdot \bar{c}_h$$

where

$C_h$  = estimated number of sardine in stratum  $h$

$c_h$  = the average number of sardine sampled in stratum  $h$

$V_h$  = volume of stratum  $h$

$v_h$  = average of the volumes sampled in stratum  $h$

$N_h = V_h/v_h$  or the total number of possible samples of size  $v_h$  in stratum  $h$

Abundance in numbers of sardines was converted to weight (kg) by multiplying abundance in numbers by average weight (kg) of an individual sardine (calculated to be 0.165 kg) from 1997, 1999, and 2001, as the average size of fish during these years was similar. Areas where sardines were captured in three or fewer sets were not included in abundance estimates. Total abundance for each region was determined from numbers of sardines in the swept volume, extrapolated to the total volume. The log-scale time series is presented in Figure 37a. Length compositions were compiled for each annual survey as described above for the fishery data (Figure 12b).

During the course of the Sept '09 STAR Panel, it was decided that only estimates derived from nighttime surveys (i.e. 2006, 2008, and 2009; Table 5, Figure 37) should be considered in alternative case models. The decision was based on uncertainties regarding the day/night calibration approach, and the fact that that all night-trawl estimates, though calibrated, were considerably higher than day trawl estimates. Furthermore, variances for the survey estimates were not available at the time of this assessment, so nominal CVs of 0.5 were applied to all values. Future assessments may reconsider the full series once the raw survey data and estimation procedures are more rigorously documented and reviewed.

#### West Coast Aerial Sardine Survey of 2009

The Pacific sardine industry funded an aerial sardine survey ranging from Monterey to the northern border of Washington during summer of 2009 (Figure 13a). The 2009 survey was built upon methods developed during a pilot study conducted in 2008. The overall approach was reviewed and refined by a STAR panel held in May of 2009. The 2009 survey employed two sampling elements: 1) high-resolution photographs collected by spotter planes to estimate the number and surface area of sardine schools, and 2) using fishing vessels to conduct point sets on schools to determine the relationship between surface area and biomass and to determine size

composition of the schools. A complete description of the methods and results can be found in Jagiello et al. (2009).

The 2009 survey results were reviewed during the September 2009 STAR panel (STAR 2009). The Panel made numerous recommendations for analysis throughout the week, resulting in refinement of the survey estimate and associated CV. The Panel ultimately endorsed the 2009 aerial survey estimate of 1,353,170 mt (CV=0.55) for use in the stock assessment model. A weighted length composition for the survey (Figure 13b) was fit using the double-normal selectivity function. The estimate was fit with a catchability coefficient ( $q$ ) of 1. The final base model was tuned prior to adding the aerial survey value.

### **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 with separate selectivities per semester 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' (Methot 2005, 2007), and these results were adopted for management in 2008 (Hill et al. 2007a,b). The 2008 assessment update used for 2009 management was based on the same methodology and one additional year of fishery and survey data (Hill et al. 2008).

### **SS Model Description**

Stock Synthesis version 3.03a (Methot 2005, 2009) 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 SS model framework allows the integration of both size and age structure. The general estimation approach used in the SS model accounts for most relevant sources of variability and expresses goodness of fit in terms of the original data, potentially allowing final estimates of model precision to capture most relevant sources of uncertainty.

The SS 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; and 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 SS model uses forward-algorithms, which begin estimation prior to 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

SS Version 3.03a, compiled 11 May 2009, was used in this assessment. The reader is referred to Methot (2005, 2009) for a complete description of the SS model.

#### Likelihood Components, Constraints on Parameters, Selectivity Assumptions

The objective function for the final base model included likelihood contributions from the DEPM, TEP, and Aerial surveys, contributions from the length-compositions and conditional age-at-length data from the four fisheries, a contribution from the deviations about the spawner-recruit relationship and minor contributions from parameter soft-bound penalties (Table 7).

Length data from four fisheries (ENS, SCA, CCA, PNW) were fit using a length-based selectivity functions (double-normal, 6 parameters). Pronounced shifts in length-composition were observed to occur over time in both the Ensenada and California fisheries. The change was attributed to increasing sardine density and shifts in sardine distribution (i.e. local availability) throughout phases of the population's recovery, with expansion to offshore and northern feeding and spawning habitats. During 1981-91, sardine abundance was low and large fish were primarily caught in areas off Ensenada and Southern California. Sardine abundance substantially increased by the 1992-98 period: pure schools were common off northern Baja California and California, large spawning events were observed off central California, and sardines were encountered 300 nm off the California coast (Macewicz and Abramenkoff 1993) and as far north as British Columbia. By the third period (1999-09), substantial fisheries for larger sardines had developed in the Pacific Northwest, and the Ensenada and California fisheries typically caught smaller, younger fish. To capture this dynamic, Ensenada and California fishery selectivities were broken into three periods: 1981-91, 1992-99, and 1999-09 for ENS and SCA fisheries; and 1981-92, 1993-99, and 1999-09 for CCA.

Related to the above discussion, observations of length composition data for the California fisheries suggest that large fish are present in the southern part of the range in spring (S2) but not in summer (S1), when they move northward. To better model this dynamic, the SCA and CCA fisheries were modeled with seasonal selectivities. Early test models displayed better than expected improvements to the likelihood for these two fisheries when seasonal selectivities were applied, so this change was retained in the final base model. In some seasons and time periods, selectivities for SCA and CCA had very narrow tops, so in this event the 'top' parameter (#2) was not estimable and so was fixed to a minimal value. The initial selectivity parameter (#5) was fixed at a minimal value (-10) for all fleets.

For the PNW fishery, the double normal function was forced to assume an asymptotic shape by fixing four parameters and freely estimating the peak and ascending slope parameters. This approach permitted a more flexible form than the simple logistic function and provided better

overall fits to the data. Consistent with recommendations from the 2007 STAR panel, the PNW selectivity was modeled in two periods: 1981-03, and 2004-09.

The pre-STAR base model displayed chronic residual patterns in the fits to implied age composition data (consistent under-estimation of the first several ages) for the ENS and SCA fisheries during the 1980s. This was presumed due to a change in growth rate between the early and later periods, perhaps a density-dependent effect. Examination of growth residuals during the STAR revealed poor fit to size-at-age prior to 1991. Growth was therefore modeled for two periods in the final base model (1981-90 and 1991-09) with marked improvement to the MLE and better overall fit to all data for the early model period.

To start the population in a depleted state, the recruitment  $R_0$  offset parameter ' $R_I$ ' 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 sardines are believed to have a broad spawning season, beginning 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 semester-based model, we calculated SSB at the mid-point of S2 (i.e. April). Recruitment was specified to occur in Semester-1 of the following model year (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 sardines 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 sardines), limitations to spawning or feeding habitat, or shifts in habitat size related to environmental change.

#### Convergence criteria

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

### **Model Selection and Evaluation**

Parameter estimates for the base model are provided in Table 6. The final base model had the following specifications:

- Model Year based on the July 1 birth date assumption (July 1-June 30 time span);
- Assessment years 1981-2009; Two semesters per year (S1=Jul-Dec; S2=Jan-Jun);
- Four fisheries (ENS, SCA, CCA, PNW), with annual selectivity patterns for ENS and PNW and seasonal selectivity patterns for SCA and CCA (S1 & S2).
- Use of length-frequency and conditional age-at-length data for all fisheries;
- Length-based, double-normal selectivity with time-blocking:
  - ENS, SCA\_S1, & SCA\_S2: 1981-91, 1992-98, 1999-09;

- CCA\_S1 & CCA\_S2: 1981-92, 1993-98, 1999-09;
- PNW: 1981-03, 2004-09;
- $M = 0.4\text{yr}^{-1}$  for all ages and years;
- Two growth periods: 1981-90 and 1991-09;
- Ricker stock-recruitment relationship;  $\sigma_R = 0.89$ ; Steepness estimated;
- Initial recruitment ( $R_1$ ) estimated; recruitment devs estimated from 1975 to 2007;
- Hybrid-F fishing mortality option;
- DEPM and TEP measures of spawning biomass (1986, 1987, 1993, 2003, 2004, and 2006-08 for DEPM, and 1987, 1995-2002 and 2005 for TEP) and the 2009 aerial survey estimate of abundance.
- Length-frequency data for the 2009 aerial survey, taken from point-set samples

## Base Model Results

### Growth

Growth parameters (size at age 0.5, size at age 15, von Bertalanffy growth rate ‘ $K$ ’) were estimated for two periods within the model: 1981-90, and 1991-09. For the 1981-90 period, sardines were estimated to grow to 9.78 cm SL by age 0.5, to 22.9 cm SL by age 15, with a growth rate ( $K$ ) of  $0.91\text{ yr}^{-1}$ . For the 1991-09 period, sardines grew to 9.77 cm SL by age 0.5, to 24.4 cm SL by age 15, with a growth rate ( $K$ ) of  $0.46\text{ yr}^{-1}$ . Modeled length-at-age is displayed in Figure 3b and growth parameters and standard deviations are shown in Table 6.

### Selectivity estimates and fits to composition data

Selectivity estimates for each fishery and time period are displayed in Figures 14a-d. The ENS, SCA and CCA fisheries caught progressively smaller fish over time, but the shift was most pronounced for the SCA fishery, particularly SCA\_S2 (Figure 14b). Selectivity for the PNW fishery shifted toward smaller fish after 2003 (Figure 14d).

Model fits to length frequencies and implied age-frequencies, along with associated Pearson residuals, are shown in Figures 15-26. Results are grouped by fleet so, for example, the reader can examine fits to length compositions, bubble plots of the input data, and bubble plots of Pearson residuals across facing pages. Corresponding fits to implied age compositions for the same fishery are subsequently found on the following two pages. Results indicate random residual patterns for most fleets. Some fisheries (e.g. SCA and PNW) displayed notable residuals patterns when the strongest year classes (e.g. 1997, 1998, and 2003) moved through each fishery. Residual patterns for the PNW fishery compositions improved in comparison to past assessments. This may be due to re-weighting of composition data and/or inclusion of new data (larger fish) from the BC fishery.

Observed and effective sample sizes for length frequency and conditional age-at-length data are displayed in Figures 27-32. Input effective sample sizes for each fishery composition were iteratively reweighted (multiplicative constant) to match model estimates of variance.

### Fits to DEPM and TEP Survey Indices

Fits to the DEPM and TEP series are displayed in Figures 33 and 34. Input CVs for each index were iteratively adjusted (additive constant) to match model estimates of variance. Catchability

coefficient ( $q$ ) for the DEPM series of female SSB was estimated to be 0.1645. The TEP series was best fitted with  $q=0.4195$ .

#### Fits to PFFS and WCVI Survey Indices

Alternative models were run in which fits to the PFFS and/or WCVI indices were included in the model likelihood. The PFFS time series was relatively flat (except for the 2000 observation) and not influential to the overall model fit or population estimates due to the large standard errors (Figures 35 and 36). The STAR concluded, and the STAR concurred, that the PFFS series was uninformative to the assessment and should be excluded from the base model.

The WCVI survey (night trawls only, 2006-2009) was fit in an alternative case of the base model. The trend observed for these three survey years was consistent with the overall model, and had a  $q$  of 0.2815 (Figure 37). Fits to the length composition data are displayed in Figure 38. Stock biomass from the WCVI alternative model is compared to that from the base model in Figure 44. The STAR panel concluded that the WCVI survey should not be included in the base model or this assessment, but that this index should be considered in future assessments once the data and methods are more thoroughly reviewed. A detailed analysis of the day/night trawl calibration is warranted. Survey estimates should have associated standard errors available before this survey is further explored.

#### Fit to Aerial Survey 2009

The aerial survey estimate (1.35 mmt, CV=0.55) was fit with  $q$  fixed at 1. The aerial survey observation was considerably higher than biomass from the DEPM and TEP surveys, and this scaled model estimates of biomass upward and caused the model to shift, in some cases, to a different parameter space. Because of this contrast among data sources, the base model was first tuned (i.e. variance adjustments, Sigma-R) without the aerial spotter estimate. Once tuned, the aerial estimate was included, without subsequent retuning, to derive final base model results. The base model estimate corresponding to the 2009 aerial survey estimate of selected abundance was outside of the lower 99% confidence interval for the estimate. This discrepancy would be lessened if the survey composition were to be fit with an asymptotic rather than dome-shaped selectivity. Fit to the aerial survey length composition is displayed in Figure 39.

#### Harvest and exploitation rates

Harvest rates (catch per selected biomass) by fishery for the base model (w/ aerial survey) are displayed in Figure 40a. For comparison, harvest rates for the model fit without the aerial survey are shown in Figure 40b. Harvest rates for the model excluding the 2009 aerial survey are extremely high ( $F=3.8$  for ENS and  $F=2.3$  for CCA\_S1). Addition of the aerial survey scaled biomass upward and brought harvest rates into a more plausible range (Figure 40a).

Exploitation rates (calendar year catch/total mid-year biomass, ages 0+) by fishery and country for the base model are displayed in Figure 41. Total exploitation rate has trended upward since the mid-1990s but was still relatively low in recent years (<16%).

### Spawning stock biomass

Base model estimates of total SSB are presented in Tables 8-9 and Figure 42a. Unexploited SSB ( $S_0$ ) from the update model was estimated to be 1.03 mmt. Addition of the aerial survey datum scaled SSB considerably upward and increased uncertainty around the estimate.

### Recruitment

Time series of recruit (age-0) abundance are provided in Tables 8-9 and Figures 42b and 43b. Virgin recruitment ( $R_0$ ) was estimated at 4.94 billion age-0 fish. Recruitment increased rapidly through the mid-1990s, peaking at 16.79 billion fish in 1997, 22.01 billion in 1998, and 18.62 billion fish in 2003. Recruitments have been notably lower since 2005. Recruitments for 2008 and 2009 were derived from the spawner-recruit curve.

### Stock biomass (ages 1+) for PFMC management

Stock biomass, used for management purposes, is defined as the sum of the biomass for sardines aged 1 and older. Base model estimates of stock biomass are shown in Table 9 and Figure 43a. Stock biomass increased rapidly through the 1980s and 1990s, starting at 8,210 mt in 1981 and peaking at 1.69 mmt in 2000. Stock biomass has subsequently declined to the present (July 1, 2009) level of 702,024 mt.

### Stock-recruitment

The Ricker stock-recruitment relationship for the base model is displayed in Figure 45a. The estimate of steepness ( $h$ ) was 2.32462 for the base model (Table 6). Ricker model fit to the recruitment time series is shown in Figure 45b.

Recruitment deviations (main period) were estimated from 1981 through 2007. Initial models estimating recruitment deviations through 2008 had high standard error (0.839) for that year. Recruitments for 2008 and 2009 were thus taken directly from the stock-recruitment curve. Recruitment deviations and their asymptotic standard errors are shown in Figure 46.

Steepness ( $h$ ) was profiled using values ranging from 1.0 to 3.5. The profile was bowl-shaped, with the lowest likelihood centered on the estimate for the converged model (Figure 47a).

Recruitment variance ( $\sigma$ -R) for the base model (0.84708) was adjusted to approximately match the root mean square error estimate from the model. Model estimates of  $\sigma$ -R were examined over a broad range of input values (0.5-1.2); they ranged from 0.79 to 0.88 (Figure 47b).

## **Uncertainty, Sensitivity, and Unresolved Problems**

### Sensitivity to natural mortality assumptions

Natural mortality ( $M$ ) was profiled for the base model, with and without the aerial survey, using values ranging 0.1 to 0.8  $\text{yr}^{-1}$ . For the model excluding aerial survey (Figure 48b), the best length and survey likelihoods occurred at  $M = 0.40 \text{ yr}^{-1}$ . Age compositions were better fit at higher values of  $M$ . Inclusion of the aerial survey resulted in no appreciable change to  $M$  profiles for the length or age compositions but did affect the survey likelihoods toward better fit at higher  $M$



values (Figure 48a). The current, long-standing assumption that  $M=0.4 \text{ yr}^{-1}$  appears to be reasonable given the model fits to the data.

Uncertainty around base model biomass estimates was bracketed using a range of plausible  $M$  values (0.3 to  $0.5 \text{ yr}^{-1}$ ). Results for base models including aerial survey are shown in Figure 49a, and results for the model excluding aerial survey are presented in Figure 49b.

#### Prospective analysis

A series of prospective runs were conducted in which the model start year was incrementally advanced from 1981 to 1989. The first year for calculation of recruitment deviations was likewise adjusted forward. The prospective analysis was repeated for the base model including and excluding the aerial survey (Figures 50-51). The base model excluding the aerial survey appeared to be fairly robust with respect to initial years of data. Advancing the model start year resulted in a very minor upward scaling of the biomass and recruitment series (Figures 50-51). When the aerial survey was included, the models were stable through start year 1984. Models beginning in 1985 or later were unstable and produced estimates that scaled considerably higher (Figure 50a).

#### Retrospective analysis

Like prospective analysis, retrospective analysis can provide an additional means of examining properties of the model and further characterizing uncertainty. A retrospective analysis of the base model was performed, where data were incrementally removed from the end year back to 2003. Stock biomasses and recruitment series from these analyses are displayed in Figure 52. The models exhibited no obvious retrospective pattern.

#### Comparison to previous assessments

Stock biomass and recruits from the base model were compared to final values from SS assessments used for management in 2008 and 2009 (Figures 43a,b). Stock biomass and recruitment from the 2009 base model (w/Aerial) was very similar to results from the final 2007 assessment. Both the 2009-Base and final 2007 models scaled higher than the 2008 update and the 2009 base model that excluded the aerial survey (Figure 43).

Historically, Pacific sardines have undergone wide fluctuations in abundance (boom-bust cycles) typical of coastal pelagic species worldwide. Base model biomass of sardines aged 2 and older are compared to Murphy's estimates for the historic period (1932-1960) in Figure 53. The recent era of high abundance is still low relative to estimates from the 1930s, when biomass peaked at 4 million mt. Baumgartner et al's. (1992) analysis of sardine scales deposited in the sedimentary record shows strong inter-decadal fluctuations in sardine abundance occurring back to the year 300, centuries before commercial-scale fisheries ever developed (Figure 54). Sardine recruitment success and total abundance are strongly dependent upon environmental forcing factors.

## HARVEST GUIDELINE FOR 2010

Based on results from the base model, the harvest guideline (HG, or ABC) for the U.S. fishery in calendar year 2010 would be 72,039 mt. Parameters used to determine this harvest guideline are discussed below and presented in Table 10. To calculate the proposed harvest guideline for 2010, 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 sardines is:

$$HG_{2010} = (\text{BIOMASS}_{2009} - \text{CUTOFF}) \cdot \text{FRACTION} \cdot \text{DISTRIBUTION};$$

where  $HG_{2010}$  is the total USA (California, Oregon, and Washington) harvest guideline in 2010,  $\text{BIOMASS}_{2009}$  is the estimated July 1, 2009 stock biomass (ages 1+) from the assessment (702,024 mt),  $\text{CUTOFF}$  is the lowest level of estimated biomass at which harvest is allowed (150,000 mt),  $\text{FRACTION}$  is an environmentally-based percentage of biomass above the  $\text{CUTOFF}$  that can be harvested by the fisheries, and  $\text{DISTRIBUTION}$  (87%) is the average portion of  $\text{BIOMASS}$  assumed in U.S. waters.

The value for  $\text{FRACTION}$  in the MSY control rule for Pacific sardines is a proxy for  $F_{msy}$  (i.e., the fishing mortality rate that achieves equilibrium MSY). Given that  $F_{msy}$  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)  $\text{FRACTION}$  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 (Figure 55), the appropriate  $F_{msy}$  exploitation fraction has consistently been 15%; and this remains the case under current conditions ( $T_{2009} = 17.92$  °C).

## RESEARCH AND DATA NEEDS

The following recommendations are excerpted from the STAR panel report (STAR 2009):

- 1) Future assessments should consider the fishery-independent mid-water trawl surveys off the west coast of Vancouver Island. This data set needs to be analyzed further before it can be included in a future assessment. If necessary, the lead investigator from CDFO should be invited to attend the next STAR Panel to present results for this time series.
- 2) Further review the sampling protocols and analysis methods for other potential indices of abundance (such as the SWFSC juvenile rockfish survey and the acoustic surveys, which have been conducted in conjunction with egg surveys since 2003) should be conducted and inclusion of such data in future assessments should be considered.

- 3) Density-dependent changes in growth or reproduction have not been fully evaluated. Maturity at length is variable from year to year, although adult sampling has not been consistent, and young fish may be under-represented. Available maturation ogives could be compared to biomass estimates to identify possible density-dependent effects.
- 4) Fecundity at age is based on weight and does not account for the total number of batches of eggs produced during a season (annual fecundity). While the spawning frequency during the peak season does not appear to be age-dependent, the length of the spawning season may be longer in older fish. This may affect the stock-recruitment relationship. Whether visual estimates of activity (presence of developed gonads) from port-collected samples can be used to estimate length-specific timing and duration of spawning across the stock's range should be explored.
- 5) There continues to be uncertainty in the DEPM survey as a key indicator of spawning stock biomass trends coastwide. Attempts should be made to expand coastwide sampling of adult fish to further refine the estimate of the proportion spawning.
- 6) Temperature at catch could provide insight in stock structure and the appropriate catch stream to use for assessments, because the southern subpopulation is thought to prefer warmer water. Sensitivity tests to alternative assumptions regarding the fraction of the ENS and SCA catch that comes from the northern subpopulation should be conducted.
- 7) The assessment would benefit not only from data from Mexico and Canada, but also from a joint assessment, which includes assessment team members from these countries.
- 8) The magnitude of discards in each fishery should be re-evaluated, and discards accounted for in future assessments.
- 9) Otolith and microchemistry studies are useful tools for evaluating stock structure. Results should be evaluated to determine if the spatial distribution is purely age-dependent or due to an alternate life history strategy. These evaluations could be combined with a traditional tagging study (which has not been done since the 1940s) to provide useful information about fish migration and distribution.
- 10) The relationship between environmental correlates and abundance should be examined. In particular, the relationship between environmental covariates and recruitment deviations should be explored further.
- 11) The appropriate form of stock-recruitment relationship for Pacific sardines should be evaluated, including appropriate environmental covariates.
- 12) Spatial models for Pacific sardines should be considered. These can be used to explore the implications of regional recruitment patterns and region-specific biological parameters. These models could be used to identify critical biological data gaps.
- 13) Age-reading error matrices should be re-estimated and included in updated assessments.
- 14) The method of variance estimation to account for all sources of uncertainty in the aerial survey should be refined. Specifically, methods (e.g., bootstrapping) should be identified that can take into account: (a) inter-transect variation in density, (b) uncertainty about the school weight – school area relationship, (c) variation for individual schools about the school weight – school area relationship, and (d) uncertainty arising from attempting to estimate the size of schools.
- 15) Protocols used to distinguish sardine and non-sardine schools in aerial survey photographs should be defined.
- 16) Methods (e.g. acoustics) that can be used to determine the proportion of sardine schools that are visible from aircraft should be considered, including whether it is possible to use

acoustics to calculate the density associated with schools that are too large to be sampled using point sets.

### 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.
- CONAPESCA. 2009. Anuario Estadístico de Acuicultura y Pesca. [http://www.conapesca.sagarpa.gob.mx/wb/cona/cona\\_anuario\\_estadistico\\_de\\_pesca](http://www.conapesca.sagarpa.gob.mx/wb/cona/cona_anuario_estadistico_de_pesca)
- 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 M. Romero-M. 2009. La pesquería de pelágicos menores in Ensenada, Baja California. Temporada de pesca 2008. (Abstract) *In*: Hernandez, M. (Ed.). 2009. XVII Taller del Comité Técnico de Pelágicos Menores - Memorias. Guaymas, Sonora, México, 10 al 12 de Junio del 2009. 39 p.
- 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](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, P. J. Bentley, G. K. Krutzikowsky, and J. McCrae. 2005. Pacific sardine (*Sardinops sagax*) abundance, distribution and ecological relationships in the Pacific Northwest. *Calif. Coop. Ocean. Fish. Invest. 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.
- Hernandez, M. (Ed.). 2009. XVII Taller del Comité Técnico de Pelagicos Menores - Memorias. Guaymas, Sonora, México, 10 al 12 de Junio del 2009. 39 p.
- 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.

- Hill, K. T., E. Dorval, N. C. H. Lo, B. J. Macewicz, C. Show, and R. Felix-Uraga. 2008. Assessment of the Pacific sardine resource in 2008 for U.S. management in 2009. PFMC, Nov 2008, Agenda Item G.2.b, 236 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.
- Jagiello, T., D. Hanan, and R. Howe. 2009. West coast aerial sardine survey: sampling results in 2009. PFMC, November 2009 Briefing Book, Agenda Item I.1.b., Attachment 1. 319 p. [http://www.pcouncil.org/bb/2009/1109/I1b\\_ATT1\\_1109.pdf](http://www.pcouncil.org/bb/2009/1109/I1b_ATT1_1109.pdf)
- 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, Mercedes 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 Trilateral Sardine Forum. Southwest Fisheries Science Center, National Marine Fisheries Service, Admin. Rep. LJ-06-05. 118 pp.
- 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 pp.
- 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 pp.

- 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 pp.
- Lo, N. C. H., and A. C. Allen. 2008 (editors). Proceedings of the 2007 Trilateral Sardine Forum. Pages 15-24 in NOAA/NMFS/SWFSC Administrative Report LJ-08-02., October 2008.
- Lo, N. C. H. and B. J. Macewicz, D. A. Griffith and R. L. Charter. 2008. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2008. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-430. 33 pp.
- Lo, N. C. H., B. J. Macewicz, and D. A. Griffith. 2009. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2009. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-449. 31 pp.
- 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 pp.
- Macewicz B. J., J. J. Castro-Gonzalez, C. E. Coter 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](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](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](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](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](http://www.dfw.state.or.us/MRP/publications/sardine_5.pdf)



- McFarlane, G. A. and L. A. MacDougall. 2001. Biological information for Pacific sardine (*Sardinops sagax*) captured during research cruises, 1992–2000. Can. Tech. Rep. Fish. Aquat. Sci. 2372. 149pp.
- 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. 2009. User manual for Stock Synthesis. Model version 3.03a. May 11, 2009. NOAA Fisheries, Seattle, WA. 143 p.
- 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.pfcouncil.org/research/resdocs/Res\\_Data\\_Needs\\_0608\\_final\\_DEC06.pdf](http://www.pfcouncil.org/research/resdocs/Res_Data_Needs_0608_final_DEC06.pdf)
- PFMC. 2009. Status of the Pacific Coast Coastal Pelagic Species Fishery and Recommended Acceptable Biological Catches: Stock Assessment and Fishery Evaluation-2009. Pacific Fishery Management Council, Portland, Oregon. June 2009.  
[http://www.pfcouncil.org/bb/2009/0609/H1a\\_SUP\\_ELEC\\_ATT1\\_0609.pdf](http://www.pfcouncil.org/bb/2009/0609/H1a_SUP_ELEC_ATT1_0609.pdf)
- 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](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 19<sup>th</sup> and 20<sup>th</sup> centuries as recorded in anaerobic sediment off the Californias. Fish. Bull. 72: 257-273.
- Stock Assessment Review (STAR) Panel. 2009. Pacific sardine STAR panel meeting report. André Punt (chair) and members Selina Heppell, Dvora Hart, and John Wheeler. NOAA Fisheries, Southwest Fisheries Science Center, La Jolla CA, September 21-25, 2009. 27 p.
- 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](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](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](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 the onset of federal management (ABC=HG). Total ABCs are limits inferred by the U.S. harvest control rule, but they are not implemented or enforced through any international treaty. U.S. landings for 2009 are preliminary, and total catch during 2009 is unknown.

Calendar Year	U.S. ABC	U.S. Landings	Total ABC	Total Landings
2000	186,791	67,985	214,702	120,876
2001	134,737	75,733	154,870	99,578
2002	118,442	96,876	136,140	141,357
2003	110,908	69,931	127,480	101,411
2004	122,747	92,723	141,089	141,364
2005	136,179	90,016	156,528	148,539
2006	118,937	91,039	136,709	149,834
2007	152,564	127,789	175,361	166,156
2008	89,093	87,184	102,406	151,832
2009	66,932	65,652	76,933	<i>TBD</i>

Table 2. Pacific sardine landings for major fishing regions off the West Coast of North America, calendar years 1981-2008. The stock assessment includes northern subpopulation catches from Ensenada, México to British Columbia, Canada.<sup>1</sup>

Calendar Year	MÉXICO					UNITED STATES					CANADA		GRAND TOTAL
	Gulf of California*	Magdalena Bay	Cedros Island	Ensenada	México Total	So. Calif.	Gen. Calif.	Oregon	Wash.	U.S. Total	British Columbia		
1981	93,989	10,557	1,705	0	106,251	6	0	0	0	6	0	0	106,256
1982	71,425	9,392	2,362	0	83,179	131	0	0	0	131	0	0	83,310
1983	111,526	2,386	1,580	274	115,766	352	0	0	0	352	0	0	116,119
1984	146,467	2,454	1,044	0	149,965	171	64	0	0	235	0	0	150,199
1985	160,391	10,979	1,429	3,722	176,521	559	34	0	0	593	0	0	177,114
1986	240,226	14,203	2,808	243	257,480	1,051	113	0	0	1,164	0	0	258,644
1987	272,574	8,599	2,856	2,432	286,461	2,056	39	0	0	2,095	0	0	288,556
1988	261,363	12,081	846	2,035	276,325	3,775	10	0	0	3,785	0	0	280,109
1989	294,095	7,746	2,344	6,224	310,410	3,443	238	0	0	3,681	0	0	314,091
1990	109,942	16,975	2,086	11,375	140,378	2,508	307	0	0	2,815	0	0	143,193
1991	113,631	15,893	551	31,392	161,468	6,774	976	0	0	7,750	0	0	169,217
1992	6,858	5,026	348	34,568	46,801	16,061	3,128	4	0	19,193	0	0	65,993
1993	7,594	7,671	1,505	32,045	48,814	15,488	705	0	0	16,192	0	0	65,007
1994	127,486	33,787	1,685	20,877	183,835	10,346	2,359	0	0	12,705	0	0	196,540
1995	174,951	34,541	0	35,396	244,888	36,561	4,928	0	0	41,489	23	0	286,400
1996	200,870	25,795	0	39,065	265,730	25,171	8,885	0	0	34,056	0	0	299,786
1997	203,529	14,656	0	68,439	286,624	32,837	13,361	0	0	46,198	71	0	332,893
1998	59,400	2,493	0	47,812	109,705	31,975	9,081	1	0	41,056	488	0	151,249
1999	51,266	11,795	0	58,569	121,630	42,863	13,884	775	0	57,522	24	0	179,177
2000	65,593	42,276	0	67,845	175,715	46,835	11,367	9,529	4,765	72,496	1,722	0	249,933
2001	190,862	40,572	0	46,071	277,505	47,662	7,241	12,780	10,837	78,520	1,266	0	357,292
2002	220,360	50,969	0	46,845	318,174	49,366	14,078	22,711	15,212	101,367	739	0	420,280
2003	198,757	53,862	0	41,342	293,961	30,289	7,448	25,258	11,604	74,599	977	0	369,537
2004	102,034	47,173	0	41,897	191,104	32,393	15,308	36,112	8,799	92,613	4,438	0	288,155
2005	94,341	40,000	0	55,323	189,664	30,253	7,940	45,008	6,929	90,130	3,232	0	283,025
2006	133,650	52,429	0	57,237	243,316	33,286	17,743	35,648	4,099	90,776	1,575	0	335,667
2007	178,205	55,550	0	36,847	270,602	46,199	34,782	42,052	4,663	127,695	1,522	0	399,820
2008	488,573	36,289	0	54,213	579,075	31,089	26,711	22,940	6,435	87,175	10,425	0	676,675

<sup>1</sup> U.S. and Canadian landings are based on the 2009 CPS SAFE document. Mexican landings for 2008 were presented by INP scientists during the annual Pelagicos Menores workshop held in Guaymas, Mexico (June 10-12, 2009).

<sup>2</sup> Gulf of California catch statistics are compiled by an Oct-Sep fishing season, e.g. the 2008 value represents landings made between Oct. 2007 and Sep. 2008.

Table 3. Pacific sardine landings (mt) by model year, semester, and fishery for the base model.

Model Year	Sem	ENS	SCA	CCA	PNW	Model Year	Sem	ENS	SCA	CCA	PNW
1981	1	0	6	0	0	1996	1	23,399	10,762	6,399	0
1981	2	0	57	0	0	1996	2	13,498	11,524	343	44
1982	1	0	74	0	0	1997	1	54,941	21,313	13,018	27
1982	2	150	263	0	0	1997	2	20,239	19,094	2,747	1
1983	1	124	89	0	0	1998	1	27,573	12,881	6,334	488
1983	2	0	159	0	0	1998	2	34,760	24,050	7,741	75
1984	1	0	12	64	0	1999	1	23,810	18,813	6,143	725
1984	2	3,174	312	10	0	1999	2	33,933	34,119	1,285	430
1985	1	548	247	24	0	2000	1	33,912	12,716	10,082	15,586
1985	2	99	854	65	0	2000	2	16,545	29,343	774	2,337
1986	1	143	197	48	0	2001	1	29,526	18,318	6,467	22,547
1986	2	975	1,282	22	0	2001	2	17,422	26,621	1,575	3,136
1987	1	1,457	773	17	0	2002	1	29,424	22,745	12,503	35,526
1987	2	620	3,012	8	0	2002	2	15,514	20,380	5,086	597
1988	1	1,415	763	3	0	2003	1	25,827	9,909	2,363	37,242
1988	2	461	1,919	235	0	2003	2	11,213	15,232	2,146	2,618
1989	1	5,763	1,524	3	0	2004	1	30,684	17,161	13,163	46,731
1989	2	5,900	1,887	245	0	2004	2	17,323	15,419	115	1,016
1990	1	5,475	621	62	0	2005	1	38,000	14,834	7,825	54,153
1990	2	9,271	5,082	90	0	2005	2	17,601	17,158	2,033	102
1991	1	22,121	1,692	885	0	2006	1	39,636	16,128	15,711	41,221
1991	2	3,327	5,884	1,113	0	2006	2	13,981	26,344	6,013	0
1992	1	31,242	10,177	2,014	4	2007	1	22,865	19,855	28,769	48,237
1992	2	18,648	11,759	369	0	2007	2	20,571	24,127	2,515	0
1993	1	13,397	3,729	335	0	2008	1	33,642	6,962	24,196	39,800
1993	2	5,712	7,738	629	0	2008	2	20,571	9,146	10,638	0
1994	1	15,165	2,607	1,730	0	2009	1	33,642	4,634	16,104	26,244
1994	2	18,227	28,122	443	0						
1995	1	17,169	8,439	4,485	23						
1995	2	15,666	14,409	2,486	0						

Table 4. Number of samples (input effective sample sizes) for composition data by model year, semester, and fishery.

Model Year	Sem	ENS	SCA	CCA	PNW
1981	1	0.00	7.00	0.00	0.00
1981	2	0.00	9.52	0.00	0.00
1982	1	0.00	14.44	0.00	0.00
1982	2	0.00	23.32	0.00	0.00
1983	1	0.00	12.16	0.00	0.00
1983	2	0.00	7.52	0.00	0.00
1984	1	0.00	0.00	0.00	0.00
1984	2	0.00	8.64	0.00	0.00
1985	1	0.00	15.00	0.00	0.00
1985	2	0.00	33.40	0.00	0.00
1986	1	0.00	20.20	0.00	0.00
1986	2	0.00	44.20	0.00	0.00
1987	1	0.00	29.40	0.00	0.00
1987	2	0.00	87.68	0.00	0.00
1988	1	0.00	22.76	0.00	0.00
1988	2	0.00	46.80	0.00	0.00
1989	1	3.88	45.76	0.00	0.00
1989	2	2.92	50.28	0.00	0.00
1990	1	9.96	14.56	4.00	0.00
1990	2	26.36	86.60	5.00	0.00
1991	1	49.64	18.88	20.00	0.00
1991	2	38.00	77.08	9.00	0.00
1992	1	19.24	95.48	0.00	0.00
1992	2	9.56	64.84	0.00	0.00
1993	1	4.96	22.12	0.00	0.00
1993	2	8.88	104.84	0.00	0.00
1994	1	10.56	25.92	0.00	0.00
1994	2	9.20	277.56	0.00	0.00
1995	1	12.68	58.52	0.00	0.00
1995	2	7.32	60.88	11.00	0.00

Model Year	Sem	ENS	SCA	CCA	PNW
1996	1	12.80	33.96	87.64	0.00
1996	2	6.32	59.00	2.00	0.00
1997	1	14.16	53.88	54.96	0.00
1997	2	5.24	59.80	5.00	0.00
1998	1	7.56	53.88	52.00	0.00
1998	2	13.92	60.56	14.00	0.00
1999	1	10.60	48.60	0.00	2.96
1999	2	11.52	58.28	0.00	4.16
2000	1	11.92	56.20	0.00	97.49
2000	2	8.56	67.96	4.00	10.56
2001	1	5.80	66.80	27.92	97.38
2001	2	8.68	64.84	12.96	17.92
2002	1	0.00	69.92	35.00	199.67
2002	2	0.00	70.00	19.00	4.96
2003	1	0.00	61.00	8.00	180.87
2003	2	0.00	67.28	8.00	10.92
2004	1	0.00	69.00	23.96	136.37
2004	2	0.00	70.96	0.00	5.00
2005	1	0.00	73.00	24.00	105.47
2005	2	0.00	67.00	32.00	3.00
2006	1	0.00	60.96	58.00	26.96
2006	2	0.00	73.84	46.96	0.00
2007	1	0.00	72.08	68.04	112.76
2007	2	0.00	52.64	14.80	0.00
2008	1	0.00	25.48	29.84	320.54
2008	2	0.00	19.88	19.88	0.00

Table 5. Fishery-independent indices of Pacific sardine relative abundance. Complete details regarding revised estimation of DEPM and TEP values can be found in Table 4 of Appendix I. In the SS3 model, indices had a lognormal error structure with units of standard error of  $\log_e(\text{index})$ . Variance of the observations was only available as a CV, so the S.E. was approximated as  $\sqrt{\log_e(1+CV^2)}$ .

Model Year	DEPM	SE of $\ln(\text{index})$	TEP	SE of $\ln(\text{index})$	TEP_all	SE of $\ln(\text{index})$	PFFS	SE of $\ln(\text{index})$	WCVI	SE of $\ln(\text{index})$	Aerial	SE of $\ln(\text{index})$
1981	---	---	---	---	---	---	---	---	---	---	---	---
1982	---	---	---	---	---	---	---	---	---	---	---	---
1983	---	---	---	---	---	---	---	---	---	---	---	---
1984	---	---	---	---	---	---	---	---	---	---	---	---
1985	---	---	---	---	---	---	---	---	---	---	---	---
1986	4,061	0.60	---	---	11,220	0.73	---	---	---	---	---	---
1987-1	8,661	0.56	---	---	25,637	0.48	---	---	---	---	---	---
1987-2	---	---	17,266	0.35	17,266	0.35	---	---	---	---	---	---
1988	---	---	---	---	---	---	---	---	---	---	---	---
1989	---	---	---	---	---	---	---	---	---	---	---	---
1990	---	---	---	---	---	---	---	---	---	---	---	---
1991	---	---	---	---	---	---	---	---	---	---	---	---
1992	---	---	---	---	---	---	---	---	---	---	---	---
1993	69,065	0.29	---	---	73,374	0.21	---	---	---	---	---	---
1994	---	---	---	---	---	---	---	---	---	---	---	---
1995	---	---	97,923	0.40	97,923	0.40	---	---	---	---	---	---
1996	---	---	482,246	0.21	482,246	0.21	---	---	---	---	---	---
1997	---	---	369,038	0.33	369,038	0.33	---	---	---	---	---	---
1998	---	---	332,177	0.34	332,177	0.34	---	---	---	---	---	---
1999	---	---	1,252,539	0.39	1,252,539	0.39	1.485	0.90	---	---	---	---
2000	---	---	928,806	0.38	928,806	0.38	13.328	1.07	---	---	---	---
2001	---	---	236,660	0.17	236,660	0.17	1.075	0.86	---	---	---	---
2002	---	---	556,177	0.18	556,177	0.18	1.033	0.84	---	---	---	---
2003	145,274	0.23	---	---	307,795	0.24	2.022	0.91	---	---	---	---
2004	459,943	0.55	---	---	486,950	0.40	2.858	0.82	---	---	---	---
2005	---	---	651,994	0.25	651,994	0.25	1.654	0.83	---	---	---	---
2006	198,404	0.30	---	---	306,297	0.26	1.590	0.71	258,702	0.50	---	---
2007	66,395	0.27	---	---	128,118	0.21	3.276	0.84	---	---	---	---
2008	99,162	0.24	---	---	162,188	0.22	2.622	0.88	229,721	0.50	---	---
2009	---	---	---	---	---	---	---	---	198,365	0.50	1,353,170	0.55

Table 6. Base model parameters.

Parameter	Min	Max	Init	Value	Std Dev	Phase	Estimated or Fixed
NatM_p_1_Fem_GP_1	0.3	0.7	0.4	0.4	—	-3	Fixed
L_at_Amin_Fem_GP_1	3	15	9.8	9.8	—	-3	Fixed
L_at_Amax_Fem_GP_1	20	30	24	24	—	-3	Fixed
VonBert_K_Fem_GP_1	0.05	0.99	0.5	0.5	—	-3	Fixed
CV_young_Fem_GP_1	0.05	0.3	0.171502	0.17212	0.00563342	3	Estimated
CV_old_Fem_GP_1	0.01	0.1	0.032336	0.033293	0.00181412	3	Estimated
Wtlen_1_Fem	-3	3	9.47E-06	9.47E-06	—	-3	Fixed
Wtlen_2_Fem	-3	5	3.14752	3.14752	—	-3	Fixed
Mat50%_Fem	9	19	16	16	—	-3	Fixed
Mat_slope_Fem	-20	3	-0.7571	-0.7571	—	-3	Fixed
Eg/gm_inter_Fem	0	10	1	1	—	-3	Fixed
Eg/gm_slope_wt_Fem	-1	5	0	0	—	-3	Fixed
L_at_Amin_Fem_GP_1_BLK_mult1981	-2	2	0.00215292	-0.00253016	0.0340922	3	Estimated
L_at_Amin_Fem_GP_1_BLK_mult1991	-2	2	-0.00305681	-0.00325134	0.0155378	3	Estimated
L_at_Amax_Fem_GP_1_BLK_mult1981	-2	2	-0.0463661	-0.048862	0.00560037	3	Estimated
L_at_Amax_Fem_GP_1_BLK_mult1991	-2	2	0.0201076	0.0172309	0.00517785	3	Estimated
VonBert_K_Fem_GP_1_BLK_mult1981	-2	2	0.572263	0.60153	0.0468559	3	Estimated
VonBert_K_Fem_GP_1_BLK_mult1991	-2	2	-0.106793	-0.0840529	0.0326669	3	Estimated
SR_R0	3	25	16	15.412	0.242698	1	Estimated
SR_steep	0.2	3	2.36989	2.32462	0.195501	6	Estimated
SR_sigmaR	0	2	0.88789	0.88789	—	-3	Fixed
SR_R1_offset	-15	15	-4.15911	-4.19955	0.306528	2	Estimated
InitAgeComp_6	—	—	—	-1.2107	0.612633	—	Estimated
InitAgeComp_5	—	—	—	-1.2436	0.603737	—	Estimated
InitAgeComp_4	—	—	—	-0.983579	0.578194	—	Estimated
InitAgeComp_3	—	—	—	-0.871336	0.529359	—	Estimated
InitAgeComp_2	—	—	—	-0.752996	0.43393	—	Estimated
InitAgeComp_1	—	—	—	0.45449	0.238896	—	Estimated
RecrDev_1981	—	—	—	-0.789973	0.322206	—	Estimated
RecrDev_1982	—	—	—	-0.114602	0.278082	—	Estimated
RecrDev_1983	—	—	—	-0.549448	0.266723	—	Estimated
RecrDev_1984	—	—	—	-0.938099	0.2452	—	Estimated
RecrDev_1985	—	—	—	-0.223452	0.220821	—	Estimated
RecrDev_1986	—	—	—	-0.123764	0.230035	—	Estimated
RecrDev_1987	—	—	—	-0.104458	0.213207	—	Estimated
RecrDev_1988	—	—	—	-0.641137	0.207543	—	Estimated
RecrDev_1989	—	—	—	-0.201099	0.194794	—	Estimated
RecrDev_1990	—	—	—	0.50309	0.18142	—	Estimated
RecrDev_1991	—	—	—	0.122672	0.196762	—	Estimated
RecrDev_1992	—	—	—	0.927209	0.161276	—	Estimated
RecrDev_1993	—	—	—	0.834127	0.14236	—	Estimated
RecrDev_1994	—	—	—	-0.245854	0.143908	—	Estimated
RecrDev_1995	—	—	—	0.222993	0.147164	—	Estimated
RecrDev_1996	—	—	—	1.40216	0.151503	—	Estimated
RecrDev_1997	—	—	—	1.6349	0.127121	—	Estimated
RecrDev_1998	—	—	—	-0.0325931	0.191922	—	Estimated
RecrDev_1999	—	—	—	0.189453	0.276459	—	Estimated
RecrDev_2000	—	—	—	1.49181	0.302691	—	Estimated
RecrDev_2001	—	—	—	-1.22396	0.330093	—	Estimated
RecrDev_2002	—	—	—	1.71315	0.178505	—	Estimated
RecrDev_2003	—	—	—	0.874841	0.144749	—	Estimated



Table 6 (cont'd). Base model parameters.

Parameter	Min	Max	Init	Value	Std Dev	Phase	Estimated or Fixed
RecrDev_2004	-	-	-	0.876842	0.142363	-	Estimated
RecrDev_2005	-	-	-	-0.220949	0.216494	-	Estimated
RecrDev_2006	-	-	-	-0.00418719	0.282129	-	Estimated
RecrDev_2007	-	-	-	-0.771949	0.397111	-	Estimated
Q_base_7_DEPM	-3	3	-1.10601	-1.80507	0.345537	5	Estimated
Q_base_8_TEP	-3	3	-0.374949	-0.868593	0.328443	5	Estimated
Q_base_12_Aerial	-3	3	0	0	-	-5	Fixed
SizeSel_1P_1_ENS_BLK_repl1981	10	26	23.8106	23.7986	0.112334	4	Estimated
SizeSel_1P_1_ENS_BLK_repl1992	10	26	16.5277	16.3718	0.286257	4	Estimated
SizeSel_1P_1_ENS_BLK_repl1999	10	26	16.9992	16.9177	0.454103	4	Estimated
SizeSel_1P_2_ENS_BLK_repl1981	-5	3	-4.9	-4.9	-	-4	Fixed
SizeSel_1P_2_ENS_BLK_repl1992	-5	3	-0.51709	-0.512477	0.126427	4	Estimated
SizeSel_1P_2_ENS_BLK_repl1999	-5	3	-1.68387	-1.75189	0.487246	4	Estimated
SizeSel_1P_3_ENS_BLK_repl1981	-1	9	3.01542	3.07381	0.09168	4	Estimated
SizeSel_1P_3_ENS_BLK_repl1992	-1	9	0.940063	0.846381	0.27349	4	Estimated
SizeSel_1P_3_ENS_BLK_repl1999	-1	9	1.44534	1.42845	0.358774	4	Estimated
SizeSel_1P_4_ENS_BLK_repl1981	-4	9	-3.99421	-3.9951	0.158455	4	Estimated
SizeSel_1P_4_ENS_BLK_repl1992	-1	9	0.145243	0.159489	0.57941	4	Estimated
SizeSel_1P_4_ENS_BLK_repl1999	-1	9	0.928352	1.01292	0.454546	4	Estimated
SizeSel_1P_5_ENS_BLK_repl1981	-10	10	-10	-10	-	-4	Fixed
SizeSel_1P_5_ENS_BLK_repl1992	-10	10	-10	-10	-	-4	Fixed
SizeSel_1P_5_ENS_BLK_repl1999	-10	10	-10	-10	-	-4	Fixed
SizeSel_1P_6_ENS_BLK_repl1981	-10	10	-0.630716	-0.745852	0.771985	4	Estimated
SizeSel_1P_6_ENS_BLK_repl1992	-10	10	-3.06322	-3.26799	1.0753	4	Estimated
SizeSel_1P_6_ENS_BLK_repl1999	-10	10	-5.80902	-6.68789	6.62913	4	Estimated
SizeSel_2P_1_SCA_S1_BLK_repl1981	10	26	21.3865	21.1367	0.743523	4	Estimated
SizeSel_2P_1_SCA_S1_BLK_repl1992	10	26	18.2913	18.2024	0.264981	4	Estimated
SizeSel_2P_1_SCA_S1_BLK_repl1999	10	26	16.269	16.1772	0.178893	4	Estimated
SizeSel_2P_2_SCA_S1_BLK_repl1981	-5	3	0.913317	0.970416	8.14492	4	Estimated
SizeSel_2P_2_SCA_S1_BLK_repl1992	-5	3	-5	-5	-	-4	Fixed
SizeSel_2P_2_SCA_S1_BLK_repl1999	-5	3	-5	-5	-	-4	Fixed
SizeSel_2P_3_SCA_S1_BLK_repl1981	-1	9	2.55337	2.49915	0.367617	4	Estimated
SizeSel_2P_3_SCA_S1_BLK_repl1992	-1	9	2.20117	2.19923	0.138507	4	Estimated
SizeSel_2P_3_SCA_S1_BLK_repl1999	-1	9	2.09147	2.07525	0.120424	4	Estimated
SizeSel_2P_4_SCA_S1_BLK_repl1981	-1	9	3.99209	3.98956	112.435	4	Estimated
SizeSel_2P_4_SCA_S1_BLK_repl1992	-1	9	0.812195	0.862713	0.362726	4	Estimated
SizeSel_2P_4_SCA_S1_BLK_repl1999	-1	9	1.02159	1.05588	0.184464	4	Estimated
SizeSel_2P_5_SCA_S1_BLK_repl1981	-10	10	-10	-10	-	-4	Fixed
SizeSel_2P_5_SCA_S1_BLK_repl1992	-10	10	-10	-10	-	-4	Fixed
SizeSel_2P_5_SCA_S1_BLK_repl1999	-10	10	-10	-10	-	-4	Fixed
SizeSel_2P_6_SCA_S1_BLK_repl1981	-10	10	-1.10102	-1.26334	168.823	4	Estimated
SizeSel_2P_6_SCA_S1_BLK_repl1992	-10	10	-2.91214	-3.11073	0.55762	4	Estimated
SizeSel_2P_6_SCA_S1_BLK_repl1999	-10	10	-6.07771	-6.2836	1.21283	4	Estimated
SizeSel_3P_1_SCA_S2_BLK_repl1981	10	26	25.9884	25.3615	1.35723	4	Estimated
SizeSel_3P_1_SCA_S2_BLK_repl1992	10	26	16.4992	16.4099	0.180466	4	Estimated
SizeSel_3P_1_SCA_S2_BLK_repl1999	10	26	14.5503	14.4982	0.148161	4	Estimated
SizeSel_3P_2_SCA_S2_BLK_repl1981	-5	3	-1.33524	-1.33913	73.0515	4	Estimated
SizeSel_3P_2_SCA_S2_BLK_repl1992	-5	3	-5	-5	-	-4	Fixed
SizeSel_3P_2_SCA_S2_BLK_repl1999	-5	3	-5	-5	-	-4	Fixed
SizeSel_3P_3_SCA_S2_BLK_repl1981	-1	9	3.46286	3.42353	0.211388	4	Estimated
SizeSel_3P_3_SCA_S2_BLK_repl1992	-1	9	1.80316	1.77844	0.107204	4	Estimated

Table 6 (cont'd). Base model parameters.

Parameter	Min	Max	Init	Value	Std Dev	Phase	Estimated or Fixed
SizeSel_3P_3_SCA_S2_BLK_repl1999	-1	9	1.38232	1.36337	0.129763	4	Estimated
SizeSel_3P_4_SCA_S2_BLK_repl1981	-1	9	3.98324	3.97282	113.363	4	Estimated
SizeSel_3P_4_SCA_S2_BLK_repl1992	-1	9	1.55826	1.60135	0.234798	4	Estimated
SizeSel_3P_4_SCA_S2_BLK_repl1999	-1	9	1.77072	1.75114	0.116634	4	Estimated
SizeSel_3P_5_SCA_S2_BLK_repl1981	-10	10	-10	-10	—	-4	Fixed
SizeSel_3P_5_SCA_S2_BLK_repl1992	-10	10	-10	-10	—	-4	Fixed
SizeSel_3P_5_SCA_S2_BLK_repl1999	-10	10	-10	-10	—	-4	Fixed
SizeSel_3P_6_SCA_S2_BLK_repl1981	-10	10	-1.32541	-1.47319	149.118	4	Estimated
SizeSel_3P_6_SCA_S2_BLK_repl1992	-10	10	-2.29699	-2.54593	0.356843	4	Estimated
SizeSel_3P_6_SCA_S2_BLK_repl1999	-10	10	-5.58708	-5.73821	0.695096	4	Estimated
SizeSel_4P_1_CCA_S1_BLK_repl1981	10	26	20.5704	20.5678	0.0715173	4	Estimated
SizeSel_4P_1_CCA_S1_BLK_repl1993	10	26	18.7071	18.6391	0.218724	4	Estimated
SizeSel_4P_1_CCA_S1_BLK_repl1999	10	26	16.7855	16.7379	0.175116	4	Estimated
SizeSel_4P_2_CCA_S1_BLK_repl1981	-5	3	-5	-5	—	-4	Fixed
SizeSel_4P_2_CCA_S1_BLK_repl1993	-5	3	-5	-5	—	-4	Fixed
SizeSel_4P_2_CCA_S1_BLK_repl1999	-5	3	-5	-5	—	-4	Fixed
SizeSel_4P_3_CCA_S1_BLK_repl1981	-1	9	1.00548	1.02414	0.317835	4	Estimated
SizeSel_4P_3_CCA_S1_BLK_repl1993	-1	9	2.3574	2.36622	0.129496	4	Estimated
SizeSel_4P_3_CCA_S1_BLK_repl1999	-1	9	1.39614	1.42018	0.204039	4	Estimated
SizeSel_4P_4_CCA_S1_BLK_repl1981	-4	9	-3.98895	-3.98856	0.363696	4	Estimated
SizeSel_4P_4_CCA_S1_BLK_repl1993	-1	9	0.256433	0.310354	0.376603	4	Estimated
SizeSel_4P_4_CCA_S1_BLK_repl1999	-1	9	0.160941	0.19473	0.298321	4	Estimated
SizeSel_4P_5_CCA_S1_BLK_repl1981	-10	10	-10	-10	—	-4	Fixed
SizeSel_4P_5_CCA_S1_BLK_repl1993	-10	10	-10	-10	—	-4	Fixed
SizeSel_4P_5_CCA_S1_BLK_repl1999	-10	10	-10	-10	—	-4	Fixed
SizeSel_4P_6_CCA_S1_BLK_repl1981	-10	10	-0.965405	-1.06739	0.590748	4	Estimated
SizeSel_4P_6_CCA_S1_BLK_repl1993	-10	10	-3.52512	-3.70197	0.672509	4	Estimated
SizeSel_4P_6_CCA_S1_BLK_repl1999	-10	10	-3.01732	-3.13967	0.222514	4	Estimated
SizeSel_5P_1_CCA_S2_BLK_repl1981	10	26	17.0497	16.9949	1.04284	4	Estimated
SizeSel_5P_1_CCA_S2_BLK_repl1993	10	26	17.7861	17.4878	1.32467	4	Estimated
SizeSel_5P_1_CCA_S2_BLK_repl1999	10	26	17.7112	17.4916	0.432469	4	Estimated
SizeSel_5P_2_CCA_S2_BLK_repl1981	-5	3	-5	-5	—	-4	Fixed
SizeSel_5P_2_CCA_S2_BLK_repl1993	-5	3	-5	-5	—	-4	Fixed
SizeSel_5P_2_CCA_S2_BLK_repl1999	-5	3	-5	-5	—	-4	Fixed
SizeSel_5P_3_CCA_S2_BLK_repl1981	-1	9	0.0205592	-0.0348736	1.63061	4	Estimated
SizeSel_5P_3_CCA_S2_BLK_repl1993	-1	9	2.41869	2.33174	0.604088	4	Estimated
SizeSel_5P_3_CCA_S2_BLK_repl1999	-1	9	3.94488	4.11383	0.587075	4	Estimated
SizeSel_5P_4_CCA_S2_BLK_repl1981	-4	9	6.24069	6.30341	49.2259	4	Estimated
SizeSel_5P_4_CCA_S2_BLK_repl1993	-1	9	2.93323	2.92072	1.30693	4	Estimated
SizeSel_5P_4_CCA_S2_BLK_repl1999	-1	9	1.3935	1.48486	0.367564	4	Estimated
SizeSel_5P_5_CCA_S2_BLK_repl1981	-10	10	-10	-10	—	-4	Fixed
SizeSel_5P_5_CCA_S2_BLK_repl1993	-10	10	-10	-10	—	-4	Fixed
SizeSel_5P_5_CCA_S2_BLK_repl1999	-10	10	-10	-10	—	-4	Fixed
SizeSel_5P_6_CCA_S2_BLK_repl1981	-10	10	0.814964	-1.16342	15.8463	4	Estimated
SizeSel_5P_6_CCA_S2_BLK_repl1993	-10	10	-2.98473	-3.16175	8.56425	4	Estimated
SizeSel_5P_6_CCA_S2_BLK_repl1999	-10	10	-2.73732	-2.82446	0.418307	4	Estimated
SizeSel_6P_1_PNW_BLK_repl1981	10	26	22.2464	22.1264	0.450873	4	Estimated
SizeSel_6P_1_PNW_BLK_repl2004	10	26	20.0824	20.053	0.366911	4	Estimated
SizeSel_6P_2_PNW_BLK_repl1981	-5	3	1	1	—	-4	Fixed
SizeSel_6P_2_PNW_BLK_repl2004	-5	3	1	1	—	-4	Fixed
SizeSel_6P_3_PNW_BLK_repl1981	-1	9	2.16289	2.17506	0.248839	4	Estimated

Table 6 (cont'd). Base model parameters.

Parameter	Min	Max	Init	Value	Std Dev	Phase	Estimated or Fixed
SizeSel_6P_3_PNW_BLK_repl2004	-1	9	1.77802	1.81436	0.216623	4	Estimated
SizeSel_6P_4_PNW_BLK_repl1981	-1	9	1.6	1.6	—	-4	Fixed
SizeSel_6P_4_PNW_BLK_repl2004	-1	9	1.6	1.6	—	-4	Fixed
SizeSel_6P_5_PNW_BLK_repl1981	-10	10	-10	-10	—	-4	Fixed
SizeSel_6P_5_PNW_BLK_repl2004	-10	10	-10	-10	—	-4	Fixed
SizeSel_6P_6_PNW_BLK_repl1981	-10	10	10	10	—	-4	Fixed
SizeSel_6P_6_PNW_BLK_repl2004	-10	10	10	10	—	-4	Fixed
SizeSel_12P_1_Aerial	10	26	18.0002	18.9837	0.602042	4	Estimated
SizeSel_12P_2_Aerial	-5	3	-0.999933	-1.9814	0.889281	4	Estimated
SizeSel_12P_3_Aerial	-1	9	4.00004	-0.724977	1.4	4	Estimated
SizeSel_12P_4_Aerial	-1	9	3.99994	-0.41581	1.05746	4	Estimated
SizeSel_12P_5_Aerial	-10	10	-10	-10	—	-4	Fixed
SizeSel_12P_6_Aerial	-10	10	-0.000129392	-5.44967	2.8267	4	Estimated

Table 7. Likelihood components and derived quantities for the base and alternative models.

<b>Component \ Model</b>	<b>BASE- w/Aerial</b>	<b>BASE- no Aerial</b>	<b>w/WCVI survey</b>	<b>Beverton-Holt S-R</b>
<b>Surveys</b>				
DEPM	-1.138200	-2.276760	-0.787860	-2.366930
TEP	-0.764622	-0.402065	-0.615410	-0.505086
WCVI	---	---	-4.776420	---
Aerial	9.513680	---	7.979060	23.750400
<b>Survey Subtotal</b>	<b>7.610860</b>	<b>-2.678830</b>	<b>1.799370</b>	<b>20.878400</b>
<b>Length Comp</b>				
ENS	361.712	361.837	363.551	359.674
SCA_S1	352.866	352.452	354.284	356.114
SCA_S2	426.604	428.692	430.651	429.575
CCA_S1	161.505	163.891	161.485	163.442
CCA_S2	191.526	192.779	192.231	193.012
PNW	190.870	183.168	189.030	183.711
WCVI	---	---	16.431	---
Aerial	1.282	---	1.087	3.126
<b>Length Comp Subtotal</b>	<b>1686.370</b>	<b>1682.820</b>	<b>1708.750</b>	<b>1688.650</b>
<b>Age Comp</b>				
ENS	265.060	263.495	266.794	263.994
SCA_S1	223.171	223.411	222.537	223.039
SCA_S2	492.886	487.581	494.465	483.260
CCA_S1	108.877	109.410	108.925	109.978
CCA_S2	158.659	160.642	157.783	160.957
PNW	135.033	133.145	135.161	131.902
<b>Age Comp Subtotal</b>	<b>1383.690</b>	<b>1377.680</b>	<b>1385.670</b>	<b>1373.130</b>
<b>Recruitment</b>	55.600	56.899	51.389	58.574
<b>Catch Penalty</b>	0.000	0.005	0.000	0.005
<b>Parm Soft Bounds</b>	0.032	0.031	0.026	0.040
<b>TOTAL LIKELIHOOD</b>	<b>3133.290</b>	<b>3114.760</b>	<b>3147.630</b>	<b>3141.280</b>
<b>Derived Quantities of Interest</b>				
SSB-virgin (mt)	1,034,580	653,583	1,089,240	865,844
R-virgin (1,000s)	4,935,470	3,132,820	5,127,770	4,160,960
B-1+ peak (mt)	1,686,190	1,092,410	1,710,750	1,293,090
B-1+ 2009 (mt)	702,024	220,025	834,402	268,237
HG-2010	72,039	9,138	89,314	15,430

Table 8. Derived SSB (mt) and Recruits (1,000s of age-0 fish) and standard deviations from the base model. SSB estimates are calculated near the end of each model year, e.g. the 2009 value is SSB in spring of calendar year 2010. Recruits are age-0 fish calculated at the beginning of each subsequent model year so, for example, the 2003 year class (18.622e+06) is displayed in row 2002 since they were produced by the SSB of that year.

YEAR	SSB (mt)	SSB Std Dev	Recruits in year+1 (1,000s)	Recruits Std Dev
VIRG	1,034,600	254,160	4,935,500	1,197,800
INIT	15,521	6,159	74,044	29,080
1981	7,686	2,812	112,750	41,086
1982	9,935	3,535	284,900	93,224
1983	12,676	4,362	233,860	78,474
1984	21,621	6,943	265,050	82,456
1985	27,080	9,504	670,110	196,570
1986	34,074	11,403	917,010	258,170
1987	51,103	16,870	1,349,500	403,790
1988	79,974	25,150	1,157,200	361,900
1989	119,240	37,947	2,452,900	732,530
1990	148,680	49,322	5,788,900	1,490,700
1991	169,720	63,111	4,308,700	1,177,700
1992	217,120	81,733	11,078,000	2,643,800
1993	304,250	110,580	11,629,000	2,563,800
1994	482,160	155,030	4,196,200	960,430
1995	717,270	214,770	5,882,200	1,301,600
1996	851,700	246,250	16,791,000	3,573,800
1997	815,380	244,070	22,012,000	4,262,100
1998	937,480	266,480	3,630,200	729,910
1999	1,278,100	334,470	2,874,800	549,580
2000	1,423,600	367,340	8,492,100	1,374,200
2001	1,240,500	331,160	738,750	231,670
2002	1,027,600	284,090	18,622,000	3,735,100
2003	821,820	239,900	10,226,000	2,203,000
2004	814,100	237,780	10,328,000	2,065,400
2005	955,530	276,820	2,943,100	622,860
2006	1,030,500	302,630	3,330,900	822,910
2007	935,690	295,190	1,736,800	687,480
2008	728,740	259,020	6,911,700	1,273,500
2009	529,540	217,620	7,857,700	1,489,500

Table 9. Pacific sardine biomass and population number-at-age (1,000s) by model year and semester from the base model.

Model Year	Sem	BIOMASS (mt)										POPULATION NUMBERS-AT-AGE (1,000s of fish)									
		Total (0+)	Age 1+	SSB	0 (R)	1	2	3	4	5	6	7	8	9	10+						
VIRG	1	1,193,010	1,149,100	-	4,935,470	3,308,340	2,217,650	1,486,530	996,453	667,943	447,735	300,126	201,180	134,855	274,194						
VIRG	2	1,153,330	1,095,890	1,034,580	4,040,820	2,708,640	1,815,660	1,217,070	815,827	546,865	366,575	245,722	164,713	110,410	224,491						
INIT	1	17,898	17,239	-	74,044	49,633	33,270	22,302	14,949	10,021	6,717	4,503	3,018	2,023	4,114						
INIT	2	17,303	16,441	15,521	60,622	40,636	27,239	18,259	12,239	8,204	5,500	3,686	2,471	1,656	3,368						
1981	1	8,909	8,210	-	78,647	52,719	10,564	6,291	3,769	1,948	1,350	4,503	3,018	2,023	4,114						
1981	2	9,429	8,514	7,686	64,391	43,153	8,642	5,146	3,083	1,594	1,104	3,683	2,469	1,655	3,365						
1982	1	11,557	10,554	-	112,752	52,712	35,216	7,026	4,176	2,500	1,292	895	2,986	2,001	4,069						
1982	2	12,147	10,835	9,935	92,313	43,070	28,613	5,702	3,389	2,029	1,048	726	2,423	1,624	3,302						
1983	1	15,980	13,445	-	284,896	75,527	34,594	22,488	4,439	2,629	1,572	812	562	1,876	3,813						
1983	2	17,178	13,862	12,676	233,252	61,603	27,869	18,025	3,553	2,104	1,258	650	450	1,501	3,051						
1984	1	24,047	21,966	-	233,861	190,926	50,154	22,543	14,536	2,862	1,694	1,012	523	362	3,663						
1984	2	27,355	24,634	21,621	191,469	156,191	40,821	18,367	11,856	2,335	1,382	826	427	295	2,989						
1985	1	31,097	28,739	27,080	265,051	156,350	117,278	27,842	12,071	7,704	1,512	894	534	276	2,122						
1985	2	32,872	29,787	27,080	265,051	156,350	117,278	27,842	12,071	7,704	1,512	894	534	276	2,122						
1986	1	42,081	36,120	-	670,107	177,538	102,170	73,468	17,125	9,473	6,041	1,185	419	216	1,664						
1986	2	44,773	36,975	34,074	548,635	144,982	82,684	59,329	13,827	5,960	3,796	744	440	263	1,482						
1987	1	62,026	53,869	-	917,012	448,678	115,013	63,332	44,762	10,376	4,464	2,841	557	329	1,079						
1987	2	68,620	57,949	51,103	750,773	363,372	89,772	48,663	34,249	7,929	3,410	2,170	425	251	824						
1988	1	94,889	82,885	-	1,349,470	613,842	287,239	68,181	36,290	25,366	5,857	2,516	1,601	314	793						
1988	2	105,470	89,766	79,974	1,104,840	499,188	228,326	53,662	28,485	19,894	4,593	1,973	1,255	246	622						
1989	1	138,600	128,306	-	1,157,210	903,987	401,808	180,801	42,183	22,330	15,580	3,595	1,544	982	679						
1989	2	147,351	133,884	119,243	947,424	729,975	309,018	135,809	31,467	16,624	11,591	2,674	1,148	730	505						
1990	1	182,662	160,842	-	2,452,920	774,826	577,379	235,649	102,068	23,538	12,416	8,652	1,996	857	922						
1990	2	190,291	161,747	148,677	2,008,250	629,286	455,172	182,988	78,900	18,171	9,580	6,675	1,540	661	711						
1991	1	270,166	218,670	-	5,788,900	1,641,620	491,401	337,228	132,675	56,794	13,047	6,873	4,787	1,104	984						
1991	2	267,086	199,859	169,724	4,739,290	1,315,440	352,645	229,281	89,102	38,061	8,741	4,605	3,207	740	658						
1992	1	344,887	306,559	-	4,308,670	3,878,300	1,052,840	271,422	173,488	67,069	28,604	6,566	3,458	2,408	1,050						
1992	2	350,240	300,212	217,118	3,526,800	2,929,080	676,463	193,364	132,544	52,400	22,508	5,180	2,731	1,902	830						
1993	1	470,856	372,311	-	11,077,800	2,857,370	2,129,630	498,560	150,806	105,725	42,077	18,112	4,171	2,200	2,201						
1993	2	512,641	383,996	304,249	9,069,140	2,286,370	1,633,010	388,991	121,147	85,745	34,214	14,740	3,396	1,791	1,792						
1994	1	708,982	605,536	-	11,628,900	7,390,860	1,792,990	1,286,460	312,792	98,370	69,798	27,869	12,009	2,767	2,919						
1994	2	794,963	659,916	482,157	9,520,460	5,952,150	1,399,550	1,011,110	251,173	79,956	56,897	22,736	9,799	2,258	2,383						
1995	1	920,582	883,254	717,270	4,196,240	7,724,440	4,480,360	1,065,180	794,594	201,741	64,752	46,163	18,456	7,956	3,768						
1995	2	982,276	933,546	717,270	3,435,340	6,218,560	3,495,090	838,846	636,970	163,801	52,796	37,673	15,066	6,495	3,076						
1996	1	1,060,110	1,007,780	-	5,882,250	2,800,420	4,878,530	2,749,560	670,321	514,241	133,115	43,002	30,702	12,280	7,802						
1996	2	1,040,140	971,834	851,698	4,815,550	2,800,420	3,768,280	2,148,500	535,226	415,835	108,351	35,072	25,052	10,021	6,368						
1997	1	1,179,700	1,030,330	-	16,790,900	3,925,470	1,764,100	2,971,700	1,721,170	432,817	337,889	88,260	28,592	20,427	13,365						
1997	2	1,114,290	919,335	815,380	13,743,700	3,032,510	1,222,470	2,129,020	1,311,580	341,998	271,244	71,383	23,180	16,572	10,845						
1998	1	1,374,150	1,178,340	-	22,012,300	11,159,800	2,293,420	931,009	1,670,110	1,047,770	275,800	219,656	57,928	18,826	22,272						
1998	2	1,451,150	1,195,540	937,483	18,020,000	8,884,090	1,732,320	714,395	1,319,860	842,589	223,489	178,534	47,154	15,332	18,143						
1999	1	1,623,340	1,591,050	-	3,630,240	14,652,800	6,763,050	1,317,640	557,569	1,050,700	678,372	180,865	144,807	38,293	27,202						
1999	2	1,706,630	1,664,490	1,278,080	2,970,850	11,633,300	5,264,700	1,053,740	452,790	857,303	554,192	147,807	118,352	31,299	22,234						

Table 9 (cont'd). Pacific sardine biomass and population number-at-age (1,000s) by model year and semester from the base model.

Model Year	Sem	BIOMASS (mt)										POPULATION NUMBERS-AT-AGE (1,000s of fish)									
		Total (0+)	Age 1+	SSB	0 (R)	1	2	3	4	5	6	7	8	9	10+						
2000	1	1,711,760	1,686,190	-	2,874,750	2,379,710	8,815,240	4,130,540	849,269	368,797	700,398	453,127	120,881	96,800	43,787						
2000	2	1,614,520	1,581,150	1,423,630	2,352,520	1,874,920	6,733,680	3,247,190	678,628	296,159	563,186	364,492	97,248	77,879	35,229						
2001	1	1,570,300	1,494,760	-	8,492,140	1,832,980	1,334,550	5,230,100	2,617,700	552,227	241,549	459,602	297,503	79,380	92,329						
2001	2	1,408,910	1,310,460	1,240,460	6,940,440	1,353,630	937,048	3,982,950	2,067,610	440,371	193,079	367,616	238,012	63,512	73,876						
2002	1	1,319,190	1,312,620	-	738,754	5,331,960	911,882	702,780	3,165,930	1,674,110	358,339	157,316	299,639	194,027	112,006						
2002	2	1,154,850	1,146,280	1,027,600	603,625	3,803,600	595,748	511,976	2,435,360	1,307,670	281,006	123,501	235,317	152,398	87,983						
2003	1	1,191,240	1,025,580	-	18,621,900	470,342	2,651,160	448,119	406,578	1,973,440	1,065,700	229,352	100,844	192,179	196,331						
2003	2	1,068,940	852,953	821,818	15,226,200	350,380	1,823,250	328,122	310,567	1,528,850	828,781	178,560	78,540	149,696	152,943						
2004	1	1,203,630	1,112,660	-	10,226,100	12,094,100	256,134	1,392,180	260,995	251,304	1,243,350	674,920	145,469	63,994	246,609						
2004	2	1,179,810	1,061,150	814,095	8,365,070	9,102,970	174,841	997,452	194,928	190,514	946,447	514,334	110,898	48,793	188,044						
2005	1	1,329,050	1,237,180	-	10,328,000	6,761,790	7,058,830	138,028	804,250	158,685	155,538	773,284	420,327	90,636	193,575						
2005	2	1,282,270	1,162,400	955,534	8,451,020	5,257,970	5,110,390	101,555	605,581	120,602	118,519	589,669	320,596	69,137	147,669						
2006	1	1,343,540	1,317,350	-	2,943,080	6,798,340	4,045,810	4,040,990	82,088	493,786	98,586	96,948	482,442	262,317	177,402						
2006	2	1,256,530	1,222,370	1,030,540	2,407,780	5,204,320	2,891,290	3,015,180	63,163	383,893	76,859	75,640	376,498	204,732	138,468						
2007	1	1,224,310	1,194,680	-	3,330,930	1,900,950	3,827,390	2,256,060	2,430,980	51,457	313,615	62,834	61,850	307,886	280,668						
2007	2	1,056,400	1,017,780	935,692	2,722,900	1,378,530	2,553,230	1,653,200	1,853,770	39,613	241,980	48,511	47,761	237,768	216,758						
2008	1	971,399	955,948	-	1,736,820	2,075,030	905,263	1,891,810	1,310,970	1,502,920	32,309	197,672	39,647	39,040	371,567						
2008	2	803,671	783,527	728,737	1,420,080	1,437,630	536,531	1,297,790	975,869	1,146,220	24,797	151,974	30,498	30,038	285,927						
2009	1	763,509	702,024	-	6,911,700	1,091,040	926,854	372,917	994,335	781,249	929,602	20,181	123,812	24,856	257,580						

Table 10 Harvest guideline (=ABC) for Pacific sardine for the 2010 management year for the base model. See ‘Harvest Guideline’ section for methods used to derive the harvest guideline.

Model	Stock biomass (age 1+, mt)	Cutoff (mt)	Harvest Fraction	U.S. Distribution	U.S. ABC for 2010 (mt)
BASE	702,024	150,000	0.15	0.87	72,039



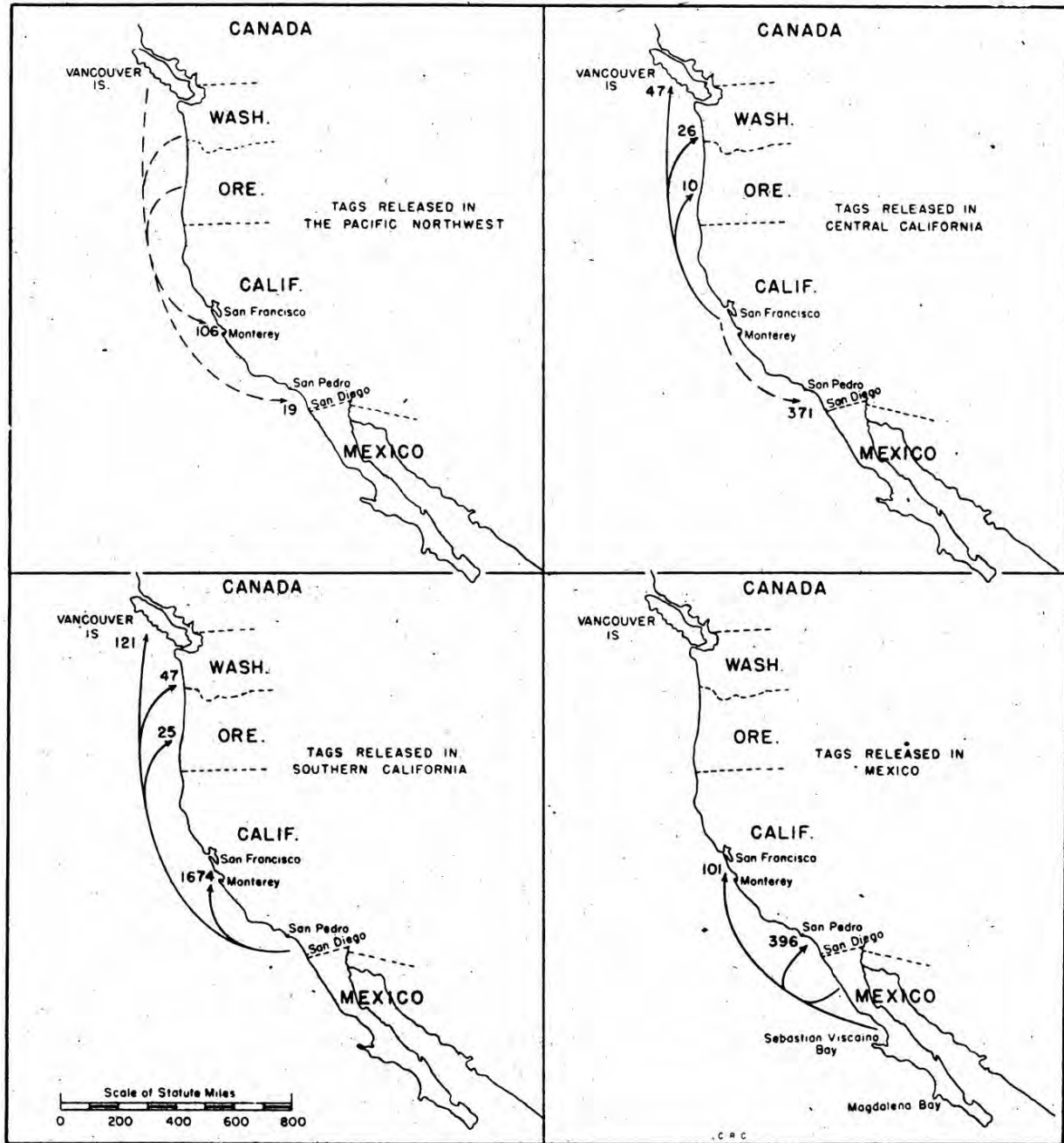


Figure 1. Sections of the Pacific Coast of North America showing the major movements of tagged sardines as indicated by recoveries from June 1935 to May, 1944 (reproduced from Clark and Janssen, 1945).

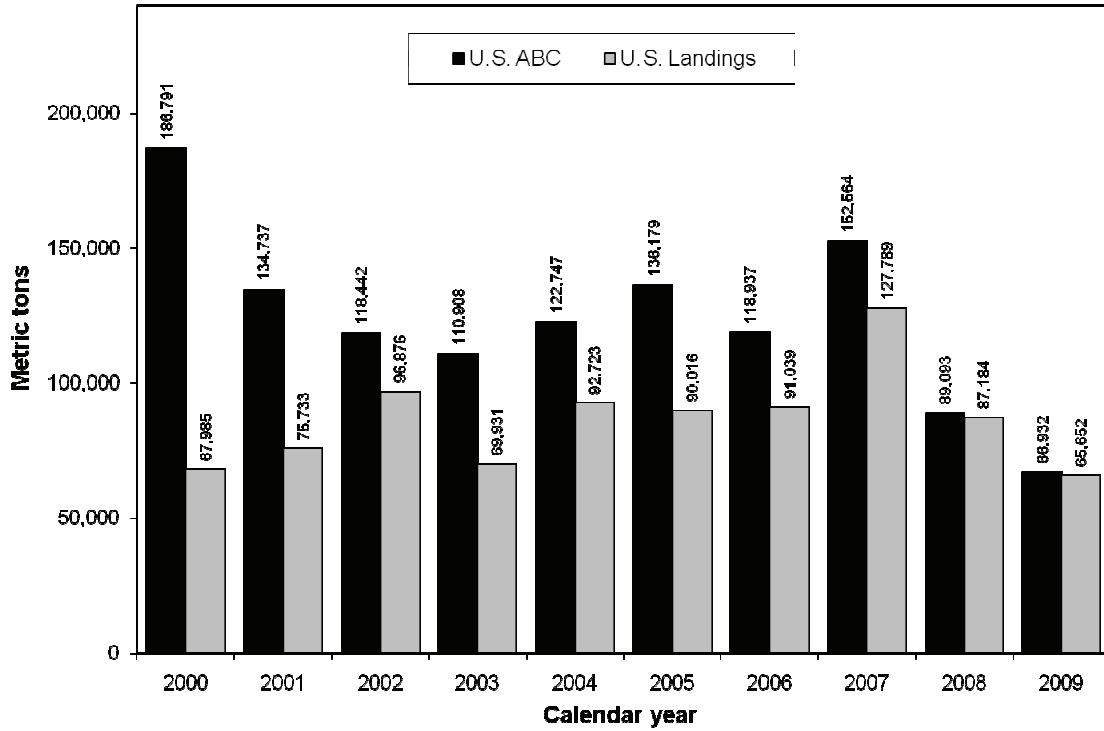


Figure 2a. Performance of the U.S. Pacific sardine fishery since calendar year 2000.

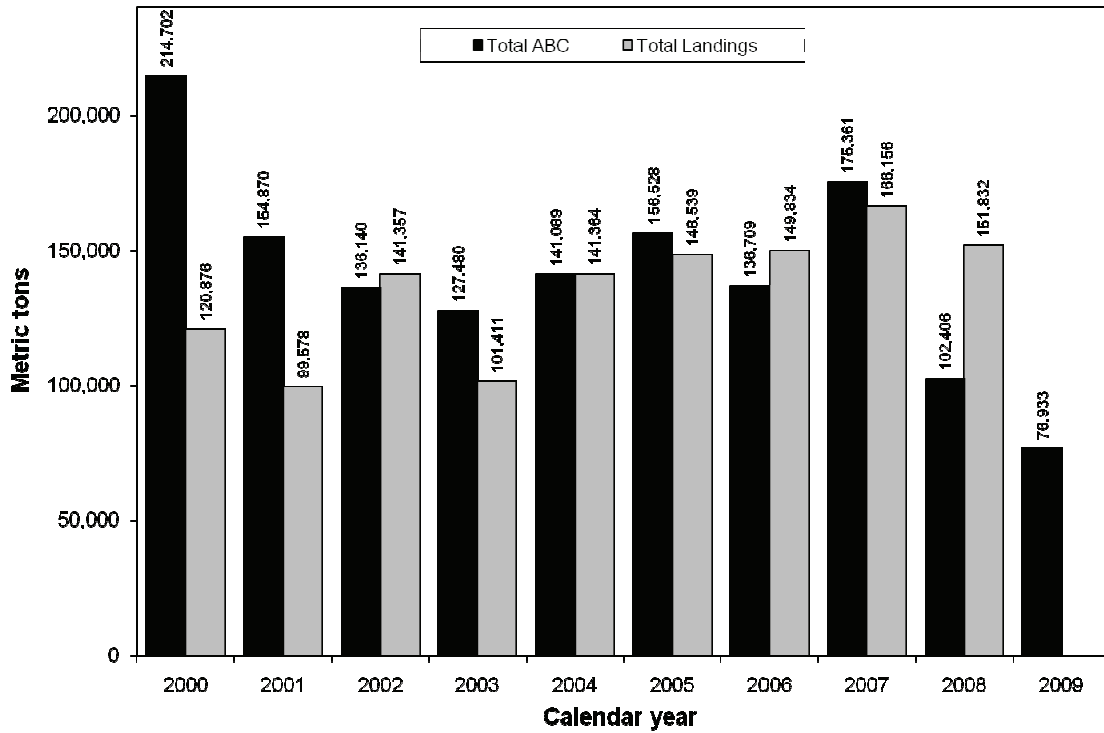


Figure 2b. Coast-wide harvest (Ensenada to British Columbia) and implied ABCs since 2000.

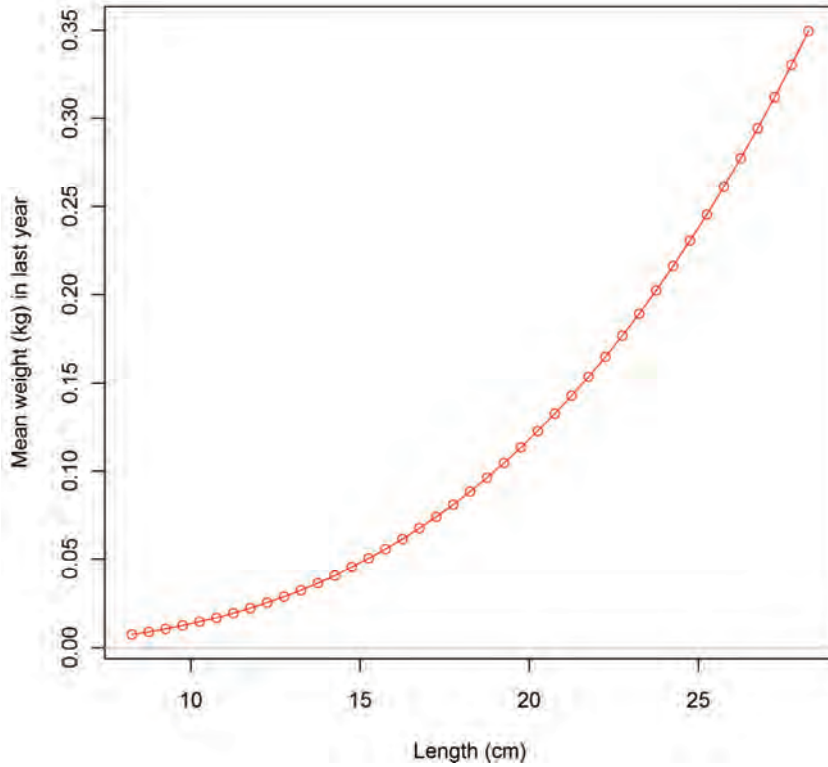


Figure 3a. Weight-at-length as applied in the base model ( $a = 9.47212e-06$ ,  $b = 3.14752$ ).

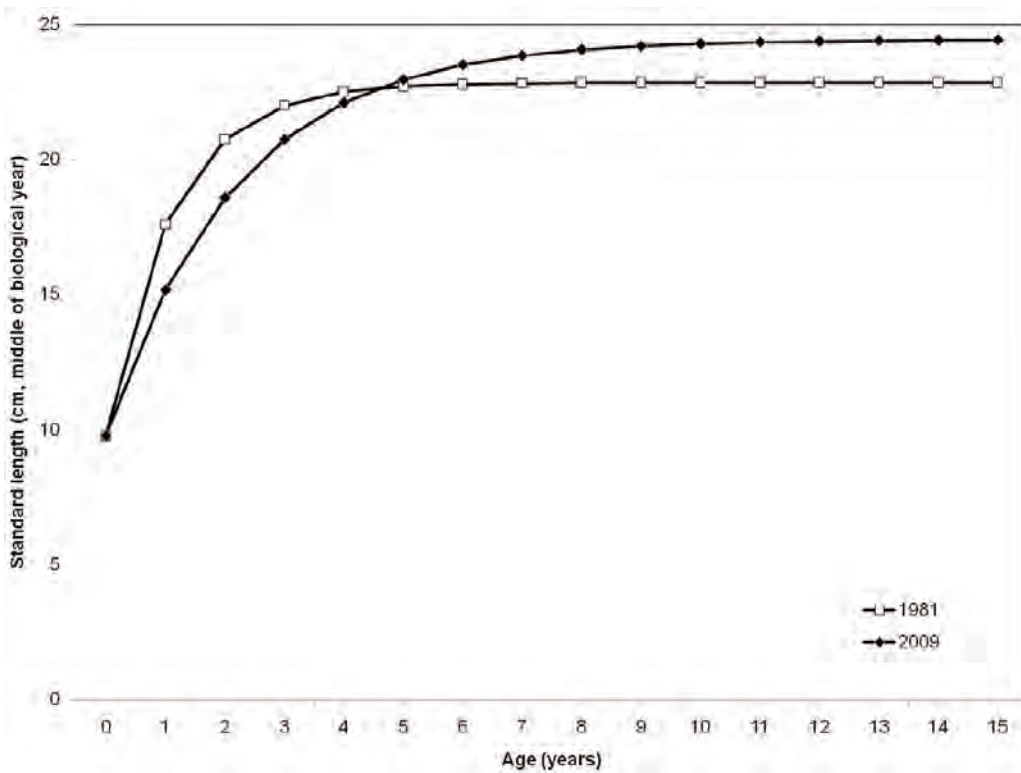


Figure 3b. Length-at-age as estimated in the base model (1981-90 period:  $L_{0.5yr} = 9.77524$ ,  $L_{15yr} = 22.8555$ ,  $K = 0.91246$ . 1991-09 period:  $L_{0.5yr} = 9.76819$ ,  $L_{15yr} = 24.4358$ ,  $K = 0.45969$ ).

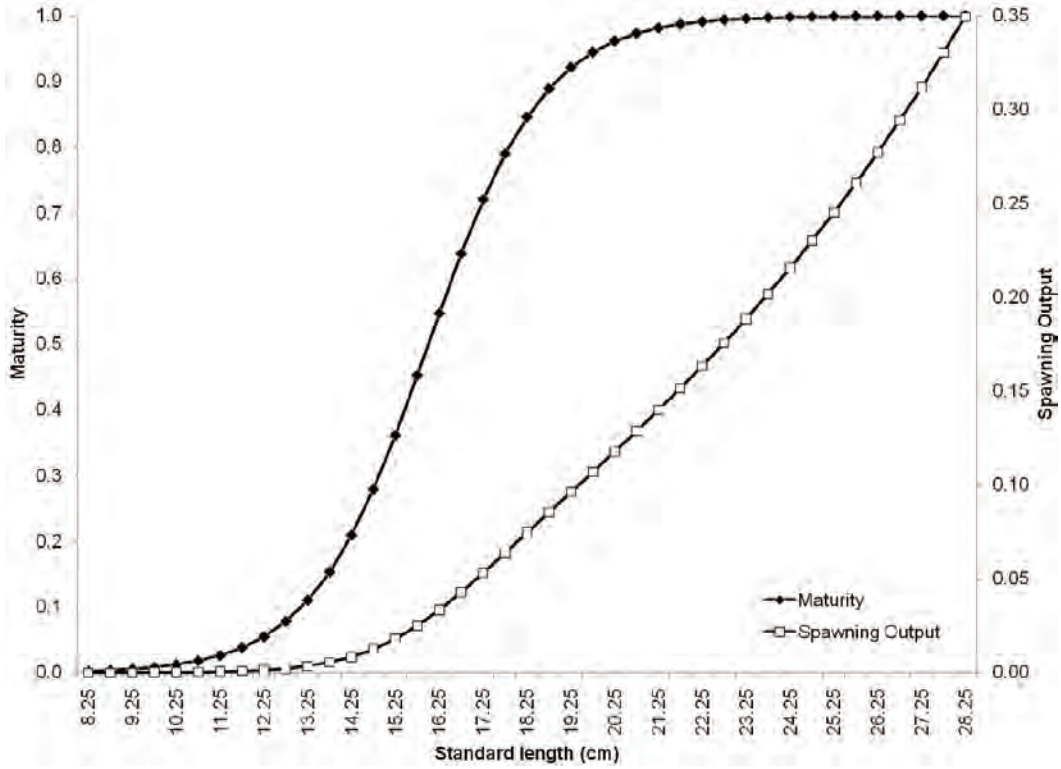


Figure 4a. Maturity ( $L_{50} = 16.0$  cm) and spawning output as a function of length in base model.

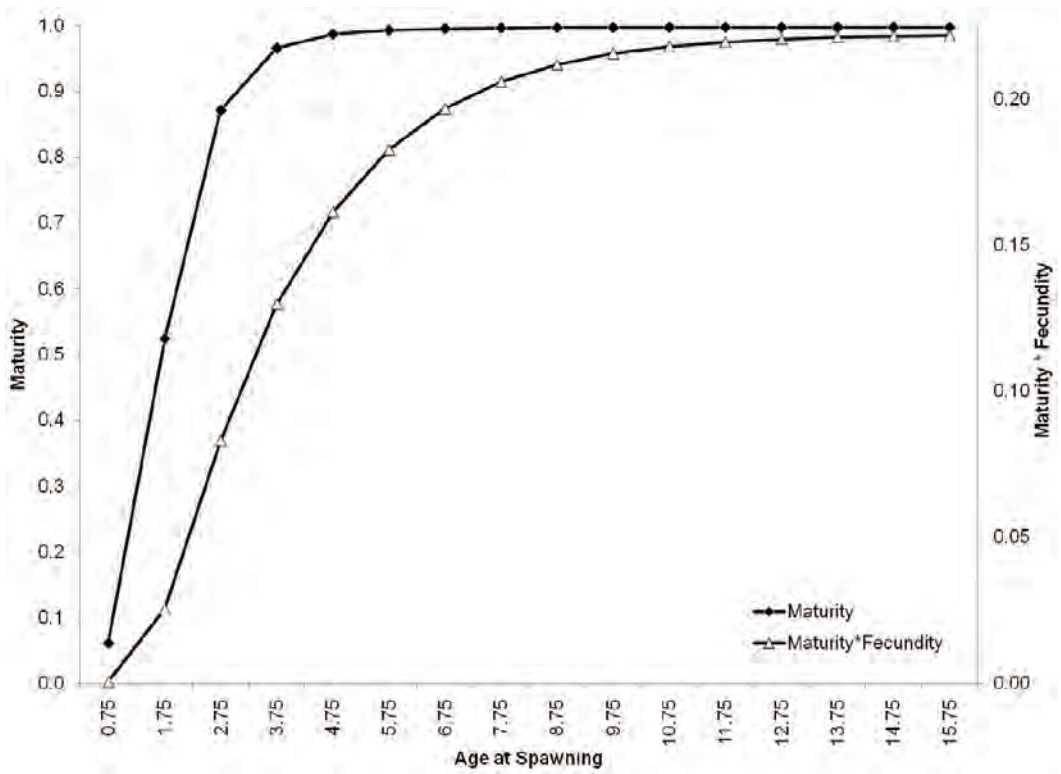


Figure 4b. Maturity and fecundity as a function of age, as derived from the base model.

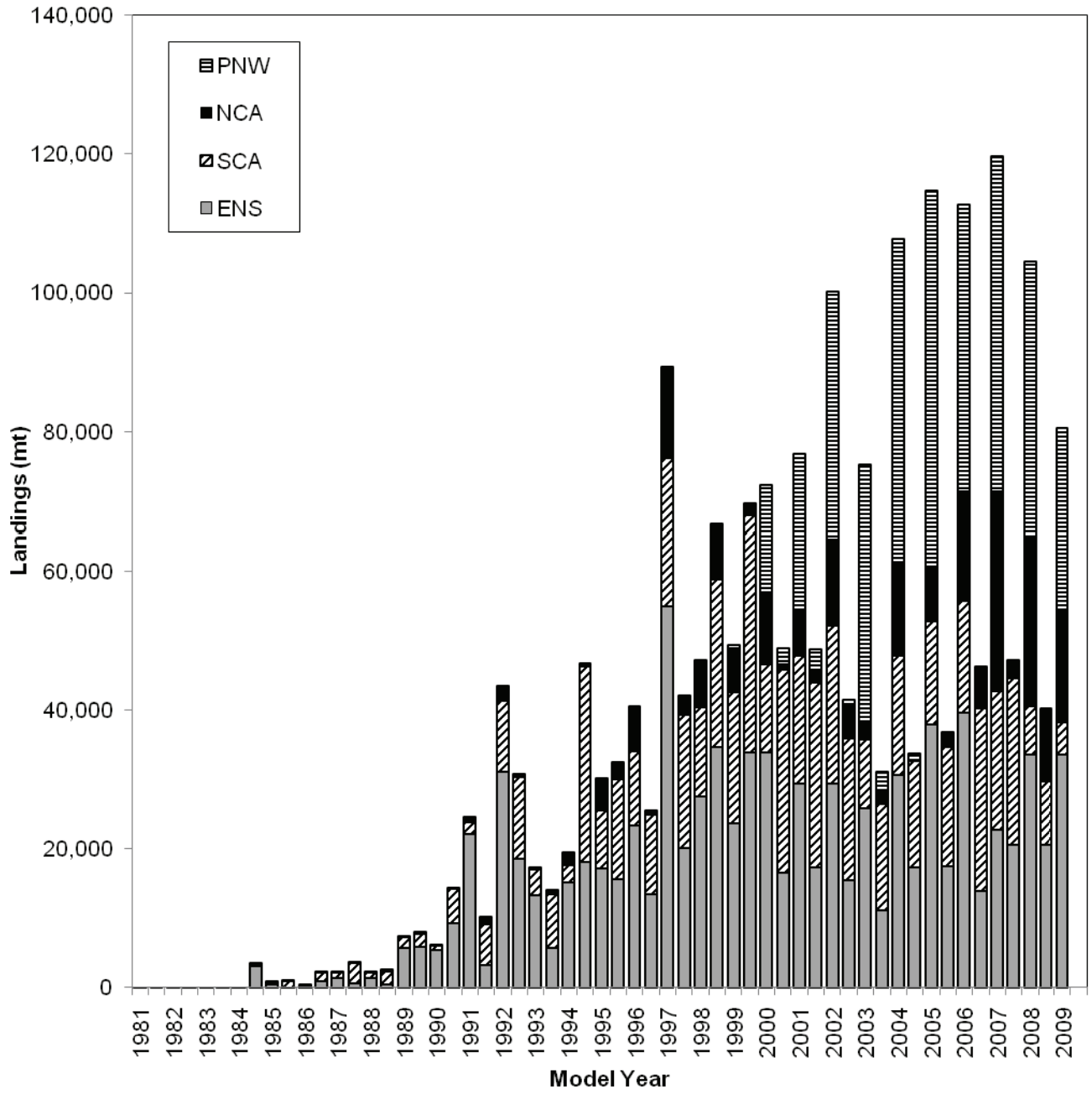


Figure 5. Pacific sardine landings (mt) by fishery, model year and semester as used in SS3.

length comp data, sexes combined, whole catch, ENS

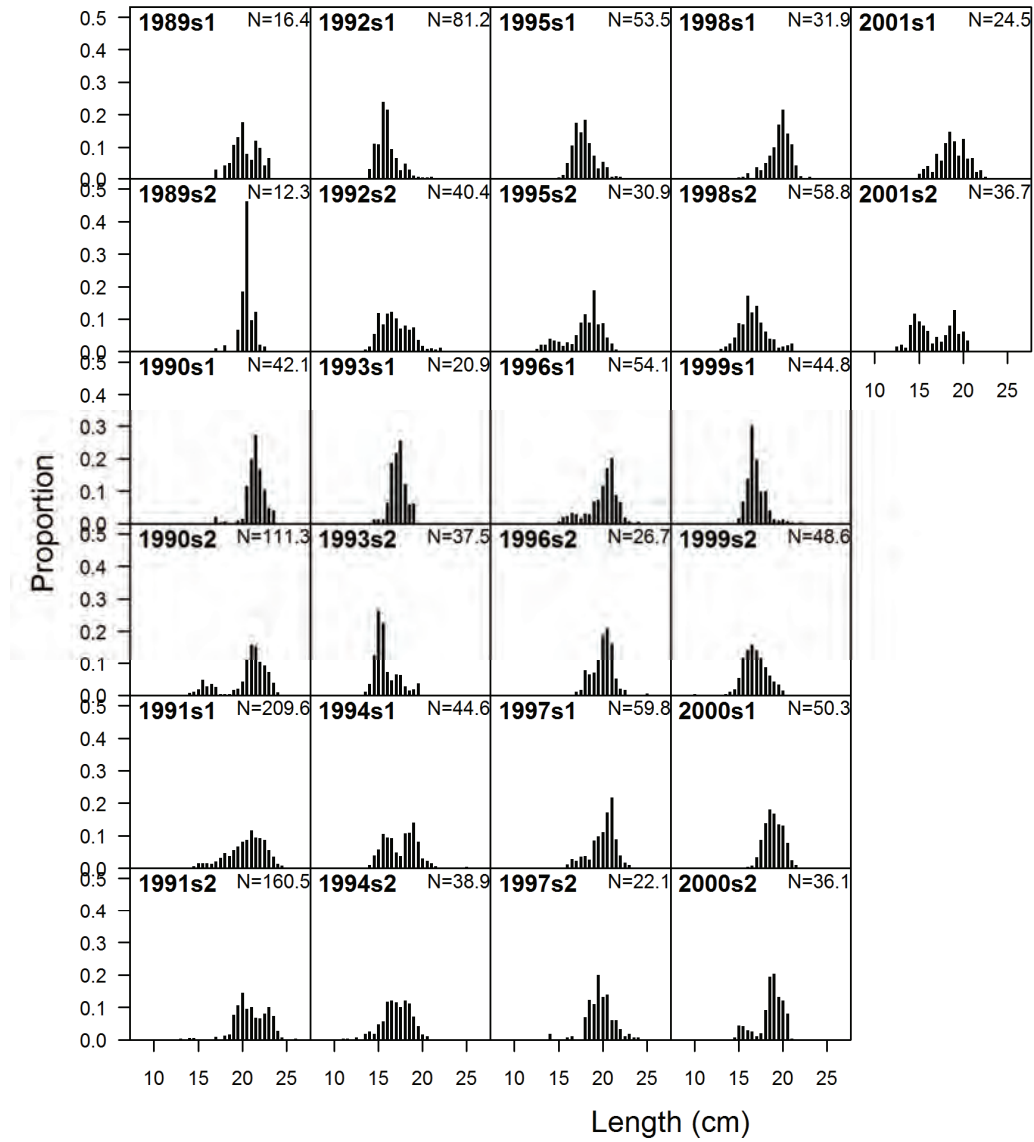


Figure 6a. Length-composition data for the ENS fishery.

gst age comp data, sexes combined, whole catch, ENS

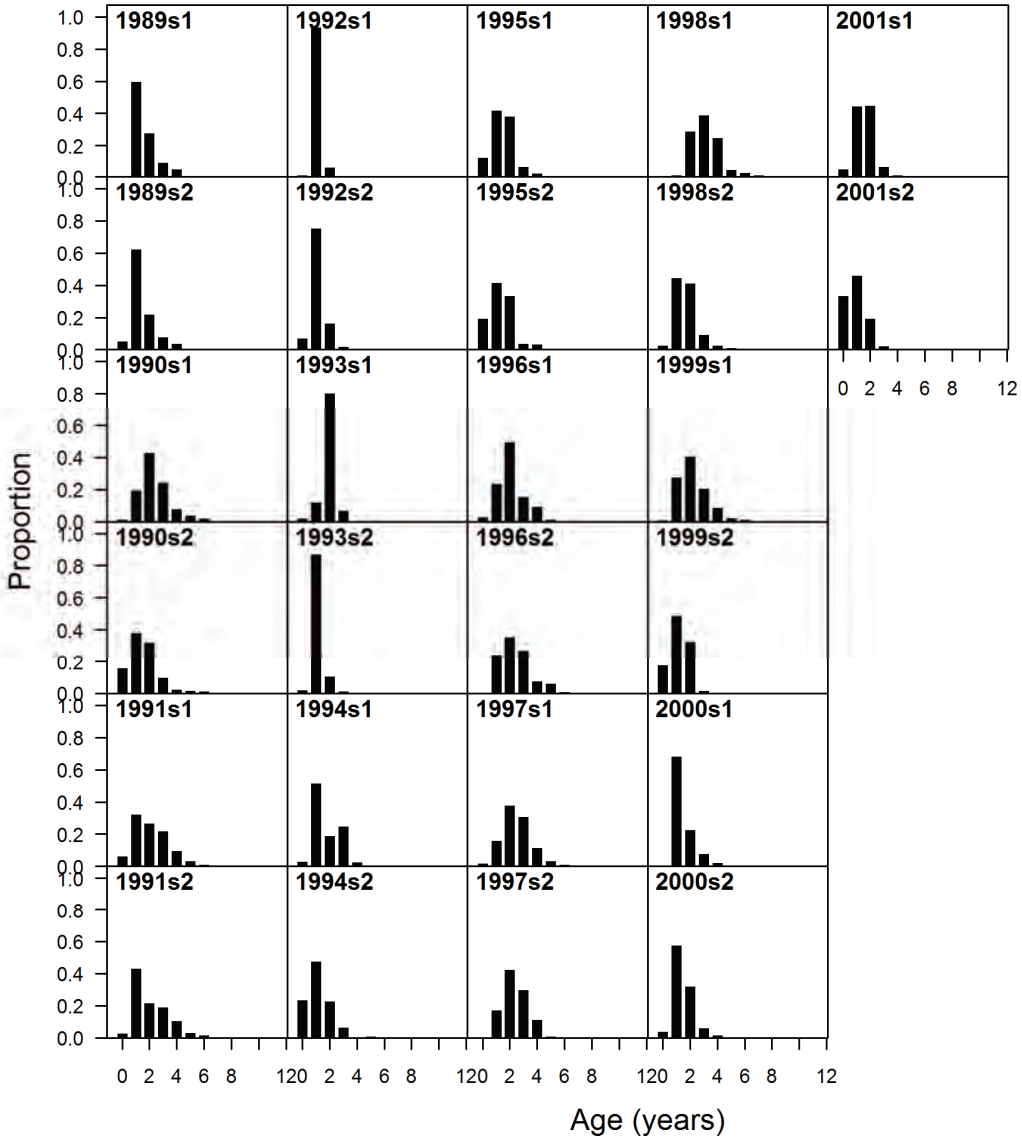


Figure 7a. Implied age-composition data for the ENS fishery.

length comp data, sexes combined, whole catch, SCA\_S1

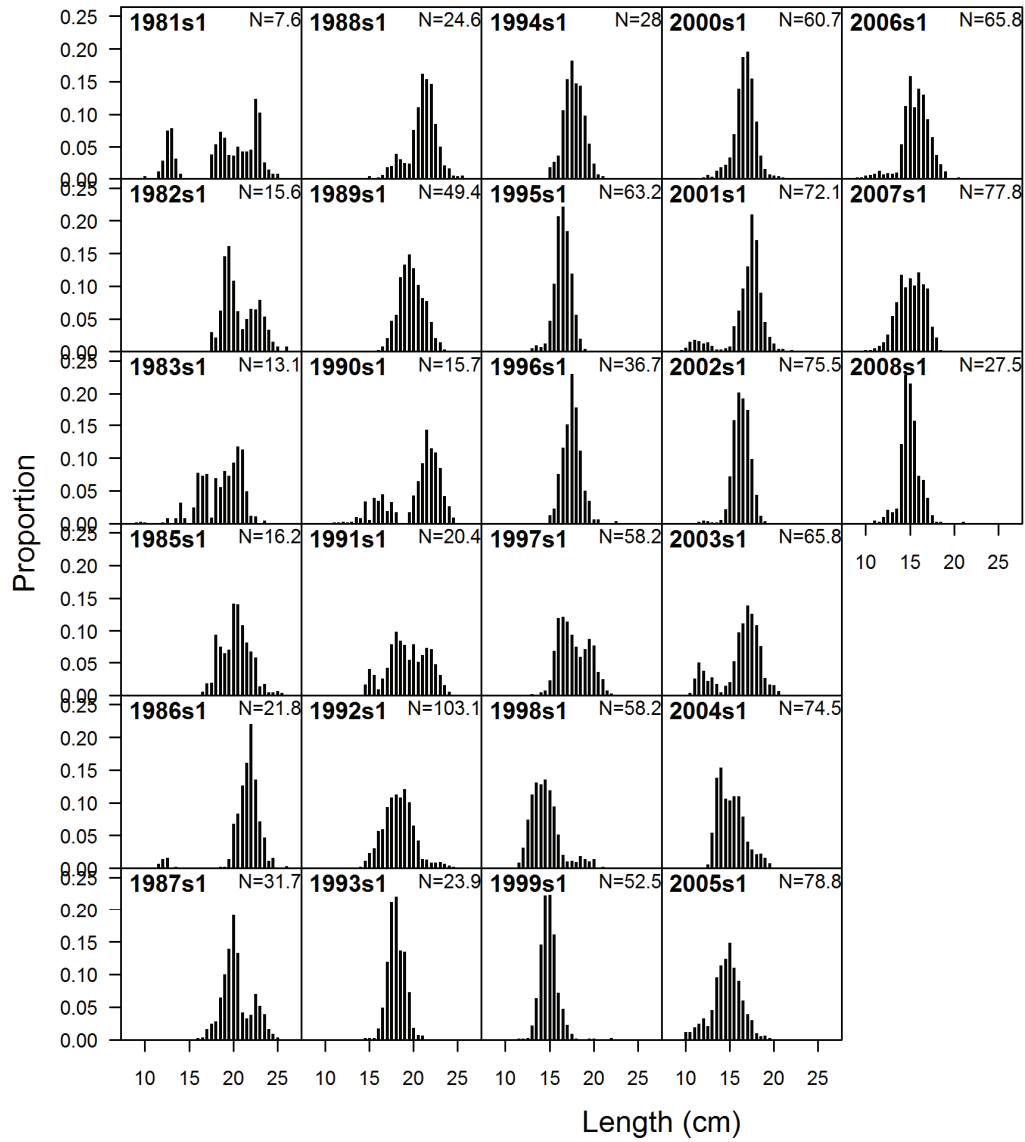


Figure 6b. Length-composition data for the SCA\_S1 fishery.



gst age comp data, sexes combined, whole catch, SCA\_S1

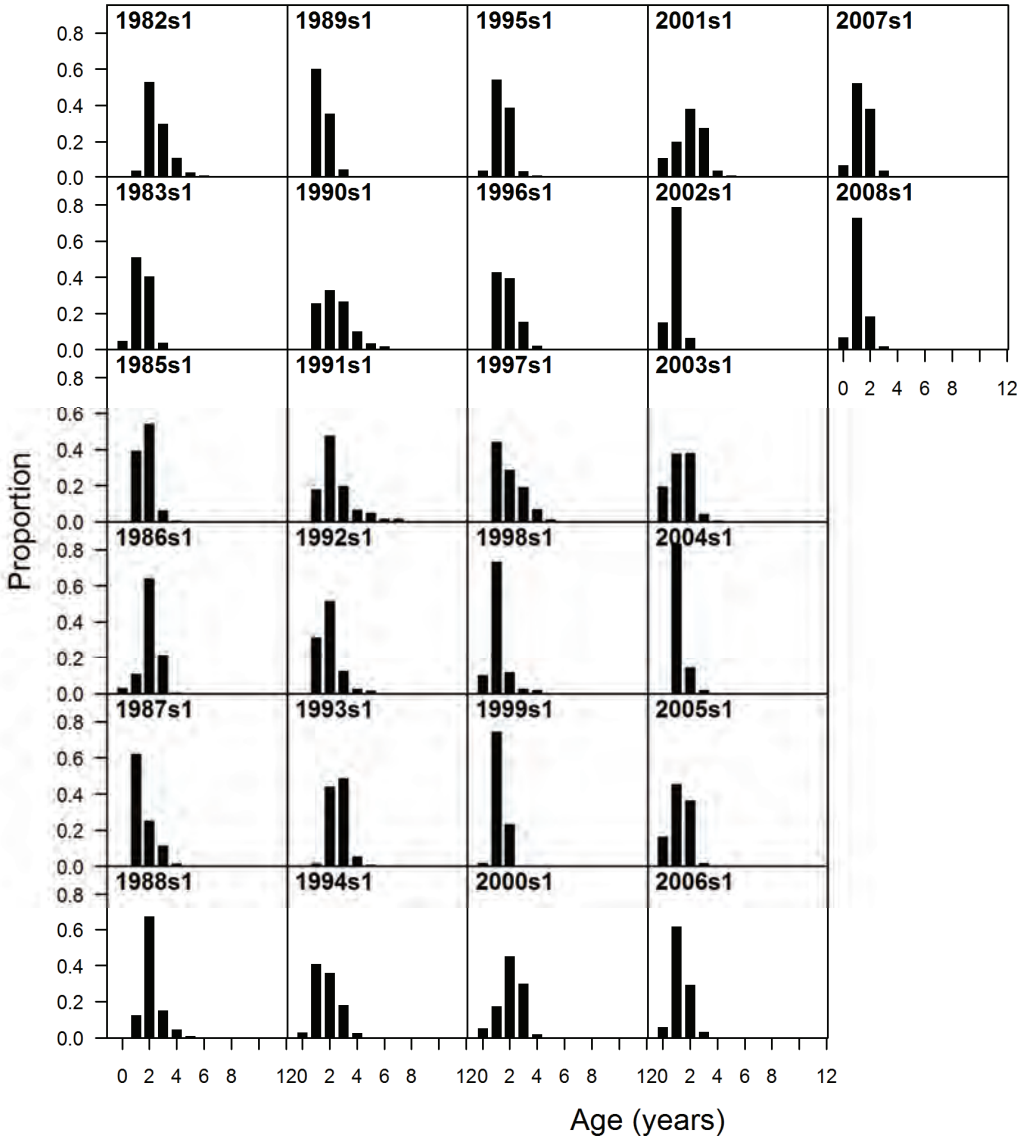


Figure 7b. Implied age-composition data for the SCA\_S1 fishery.

length comp data, sexes combined, whole catch, SCA\_S2

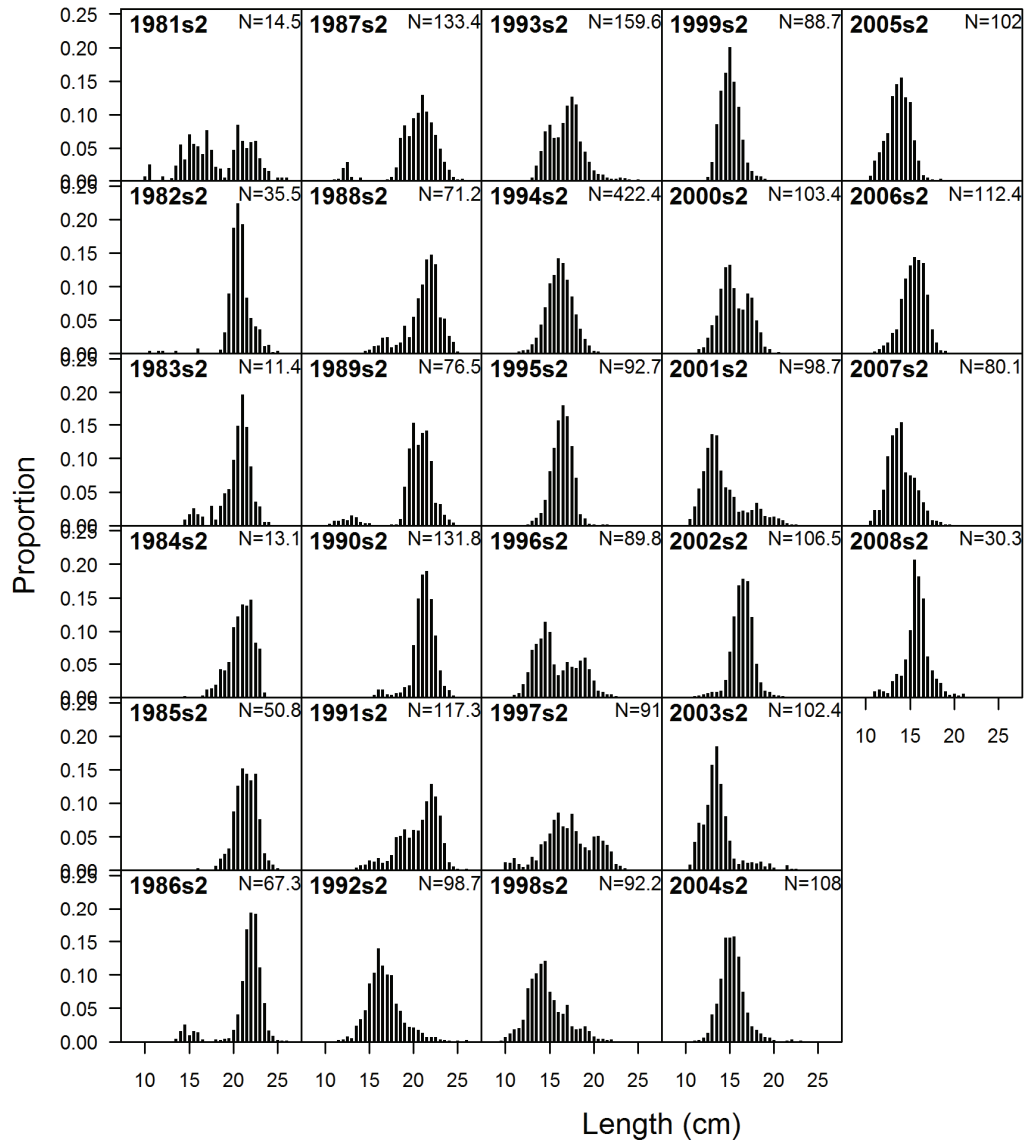


Figure 6c. Length-composition data for the SCA\_S2 fishery.

gst age comp data, sexes combined, whole catch, SCA\_S2

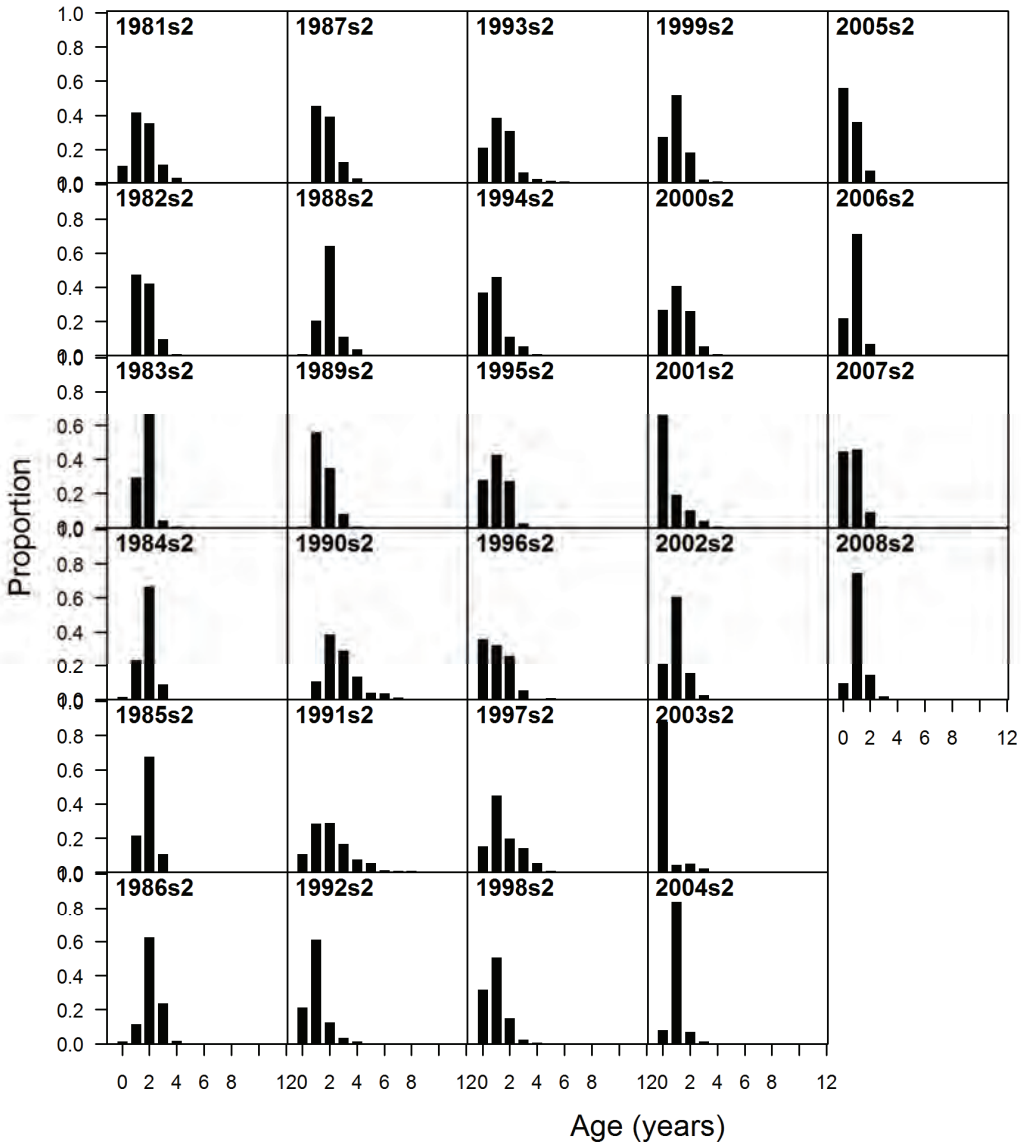


Figure 7c. Implied age-composition data for the SCA\_S2 fishery.

length comp data, sexes combined, whole catch, CCA\_S1

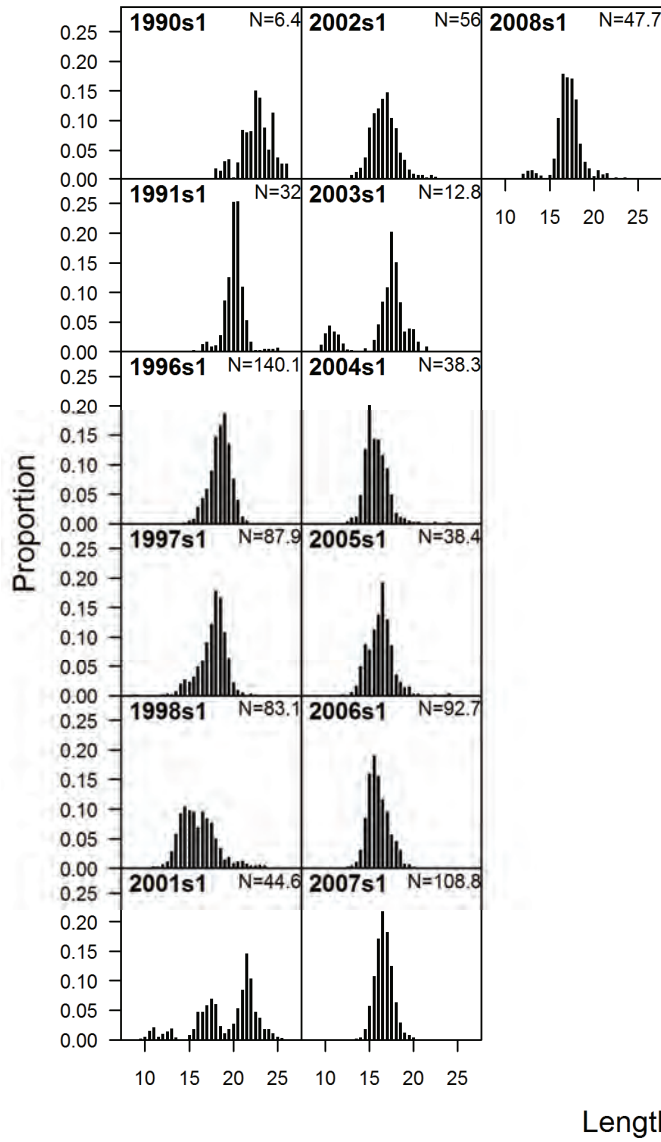


Figure 6d. Length-composition data for the CCA\_S1 fishery.

gst age comp data, sexes combined, whole catch, CCA\_S1

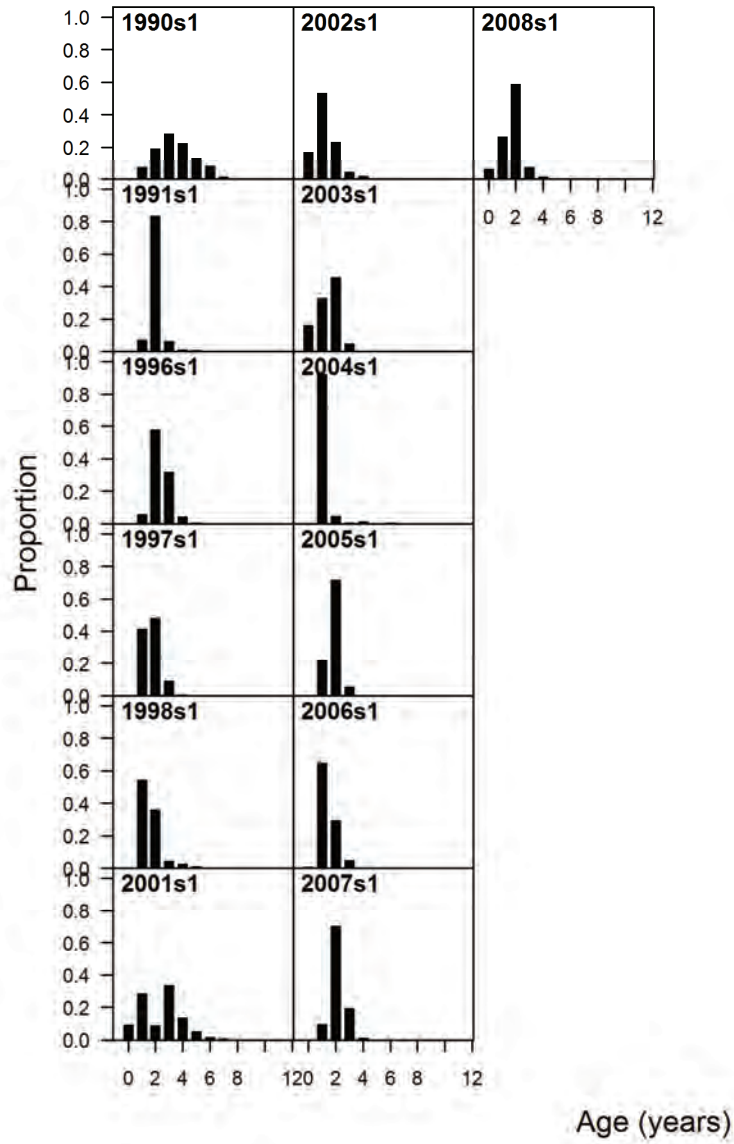


Figure 7d. Implied age-composition data for the CCA\_S1 fishery.

length comp data, sexes combined, whole catch, CCA\_S2

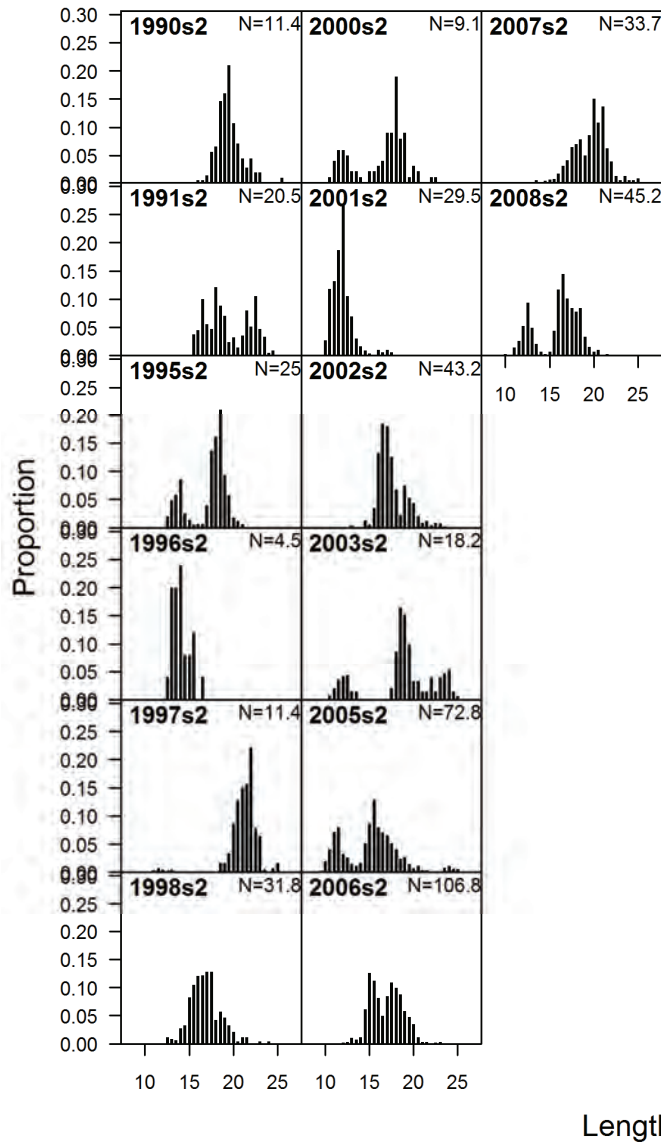


Figure 6e. Length-composition data for the CCA\_S2 fishery.

gst age comp data, sexes combined, whole catch, CCA\_S2

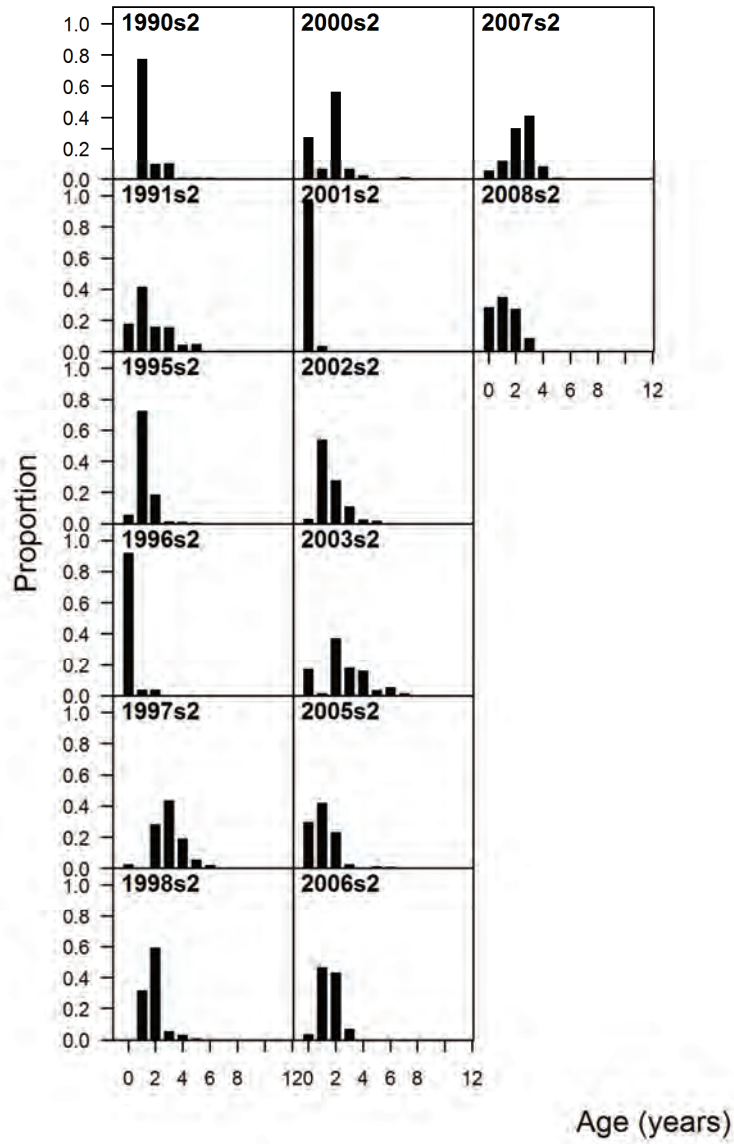


Figure 7e. Implied age-composition data for the CCA\_S2 fishery.

length comp data, sexes combined, whole catch, PNW

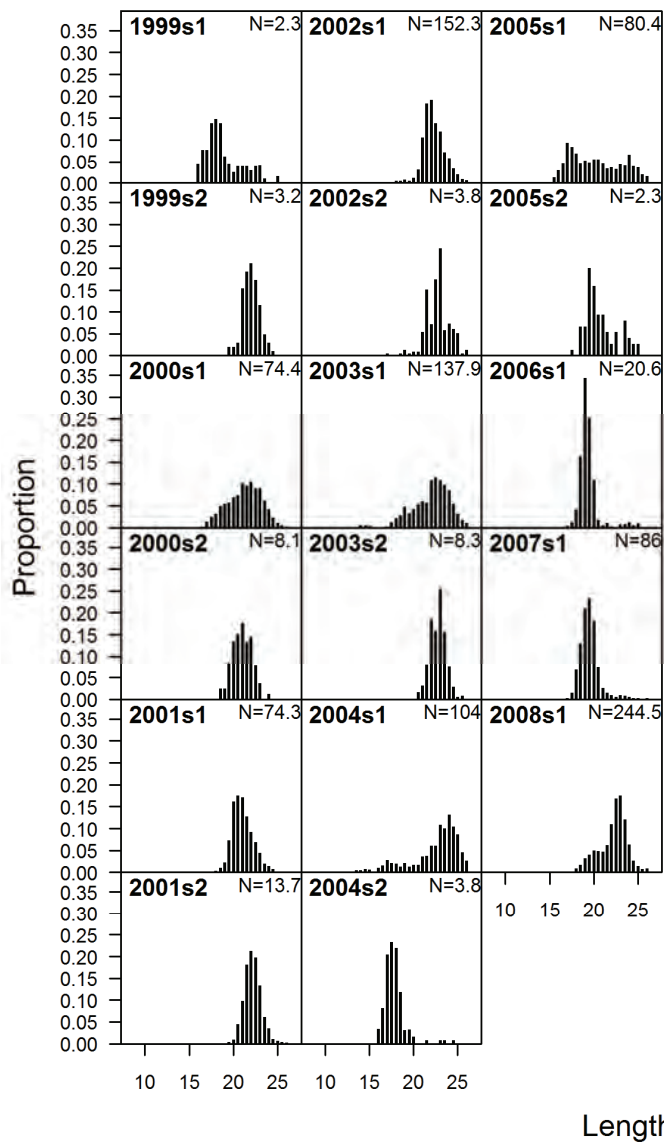


Figure 6f. Length-composition data for the PNW fishery.



gst age comp data, sexes combined, whole catch, PNW

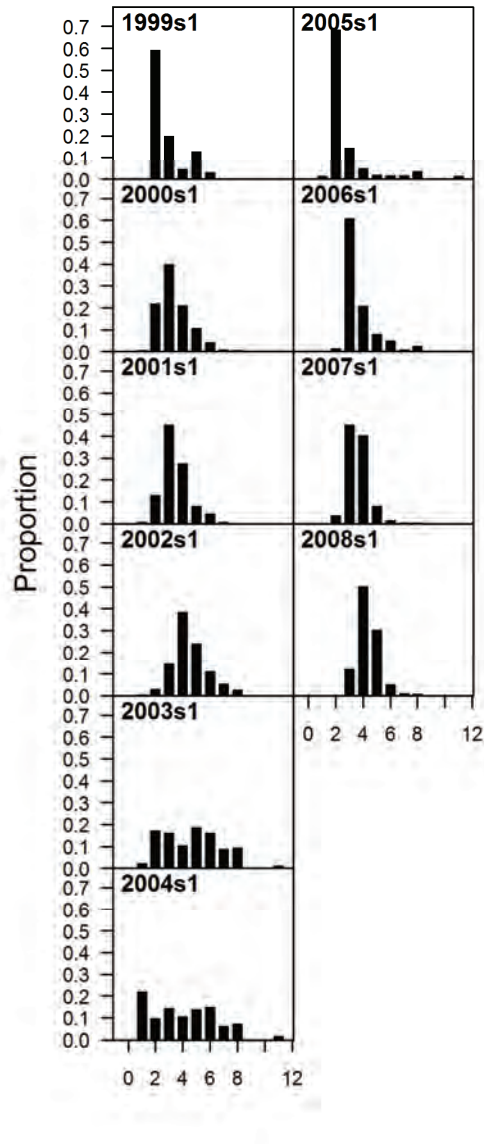


Figure 7f. Implied age-composition data for the PNW fishery.

conditional age at length data, sexes combined, whole catch, ENS (max=1)

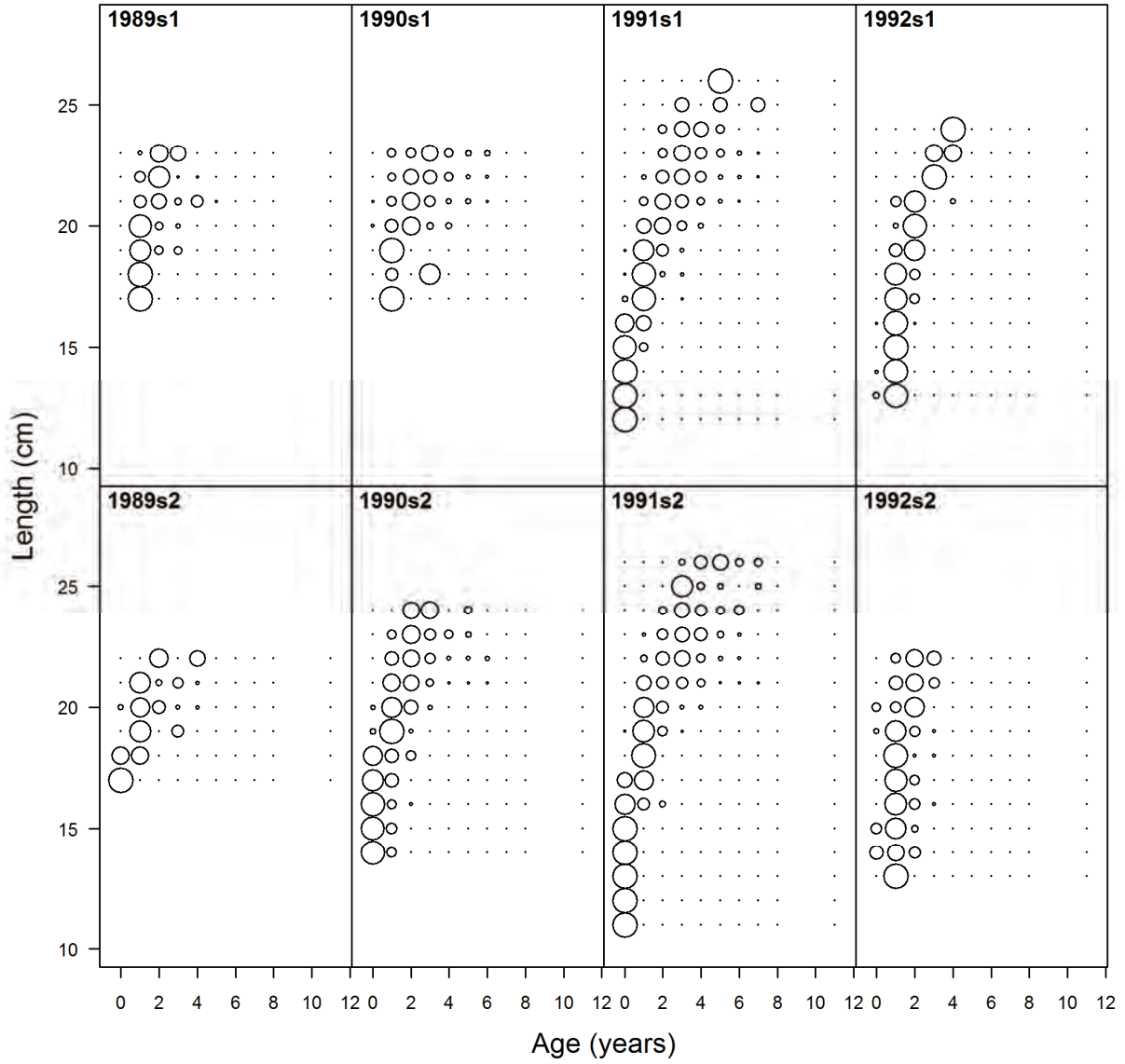


Figure 8a. Conditional age-at-length data for the ENS fishery, 1989-1992.

conditional age at length data, sexes combined, whole catch, ENS (max=1)

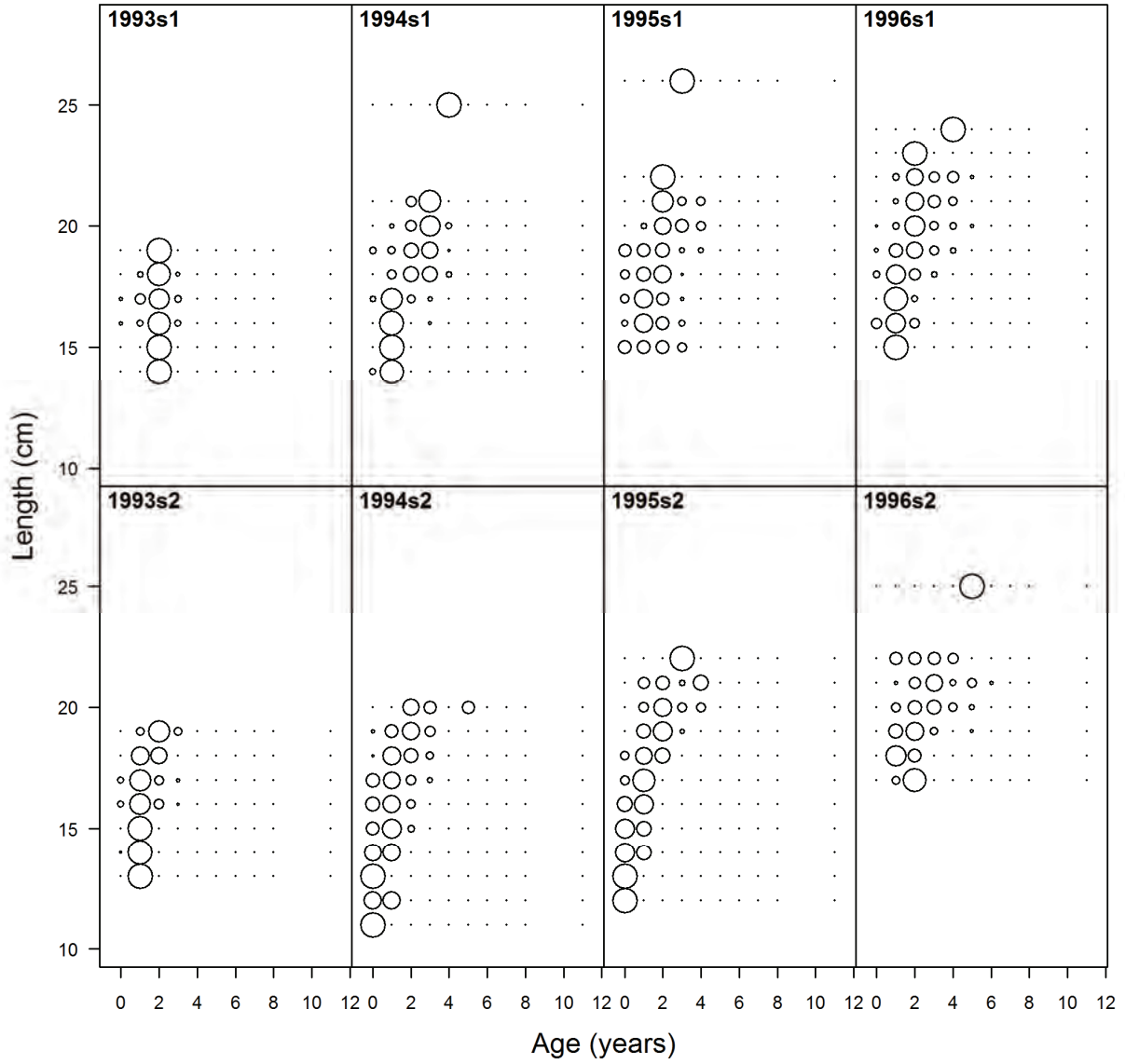


Figure 8a (cont'd). Conditional age-at-length data for the ENS fishery, 1993-1996.

conditional age at length data, sexes combined, whole catch, ENS (max=1)

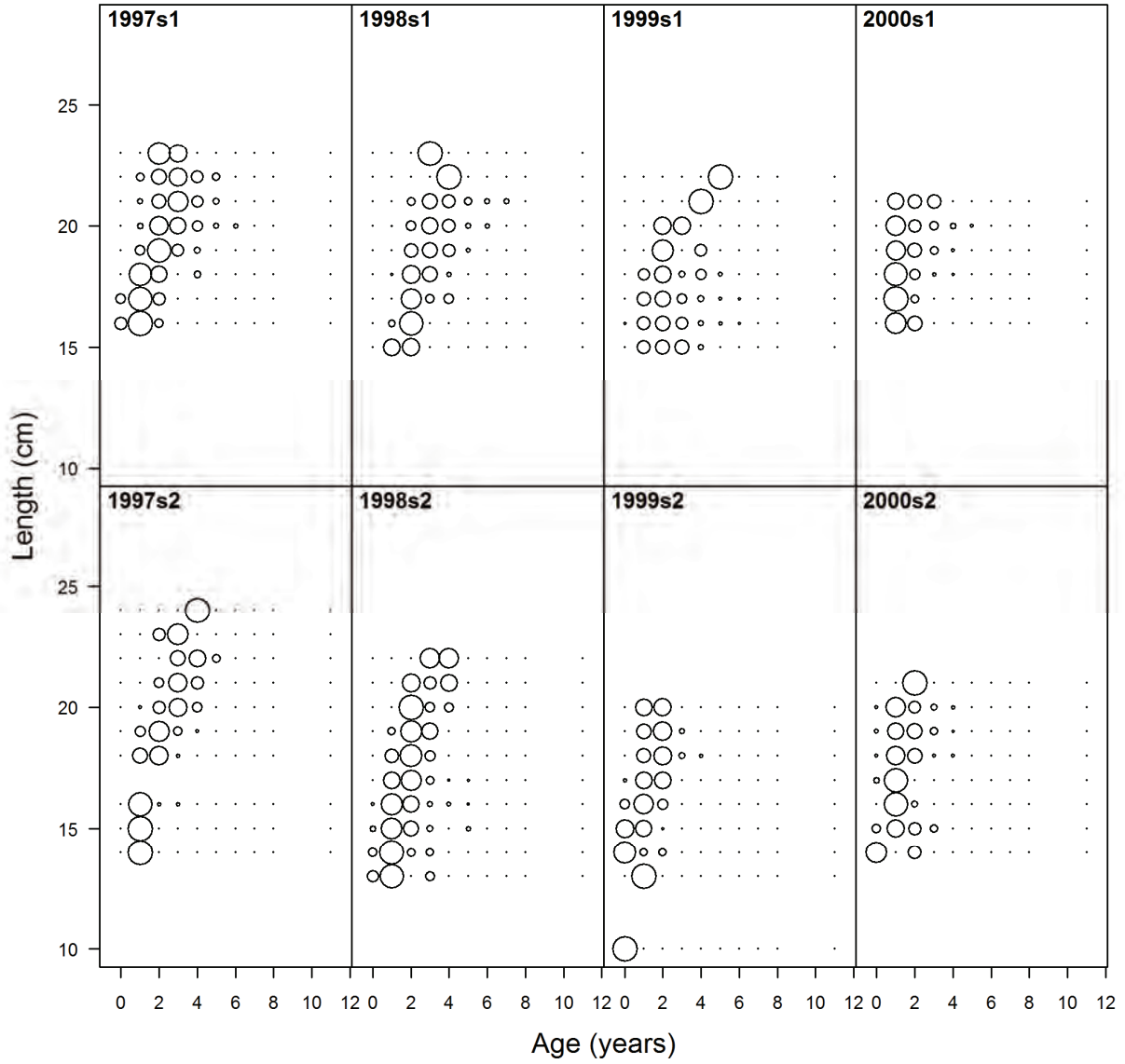


Figure 8a (cont'd). Conditional age-at-length data for the ENS fishery, 1997-2000.

conditional age at length data, sexes combined, whole catch, ENS (max=1)

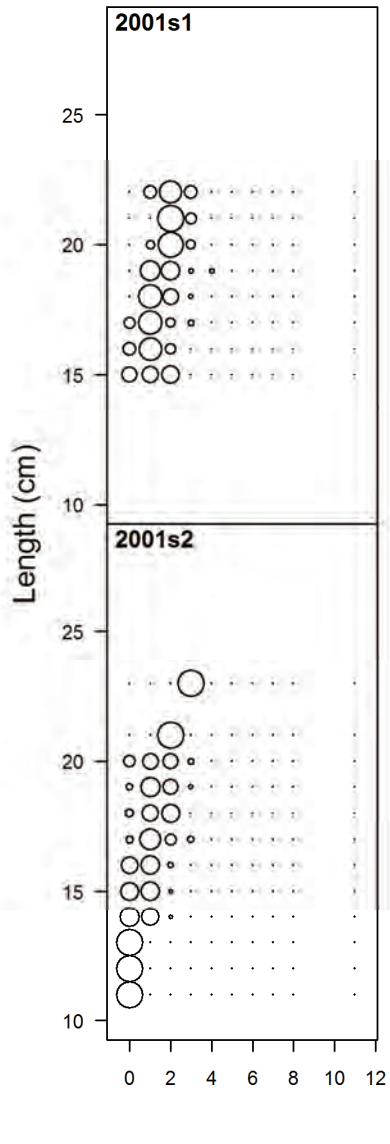


Figure 8a (cont'd). Conditional age-at-length data for the ENS fishery, 2001.

conditional age at length data, sexes combined, whole catch, SCA\_S1 (max=1)

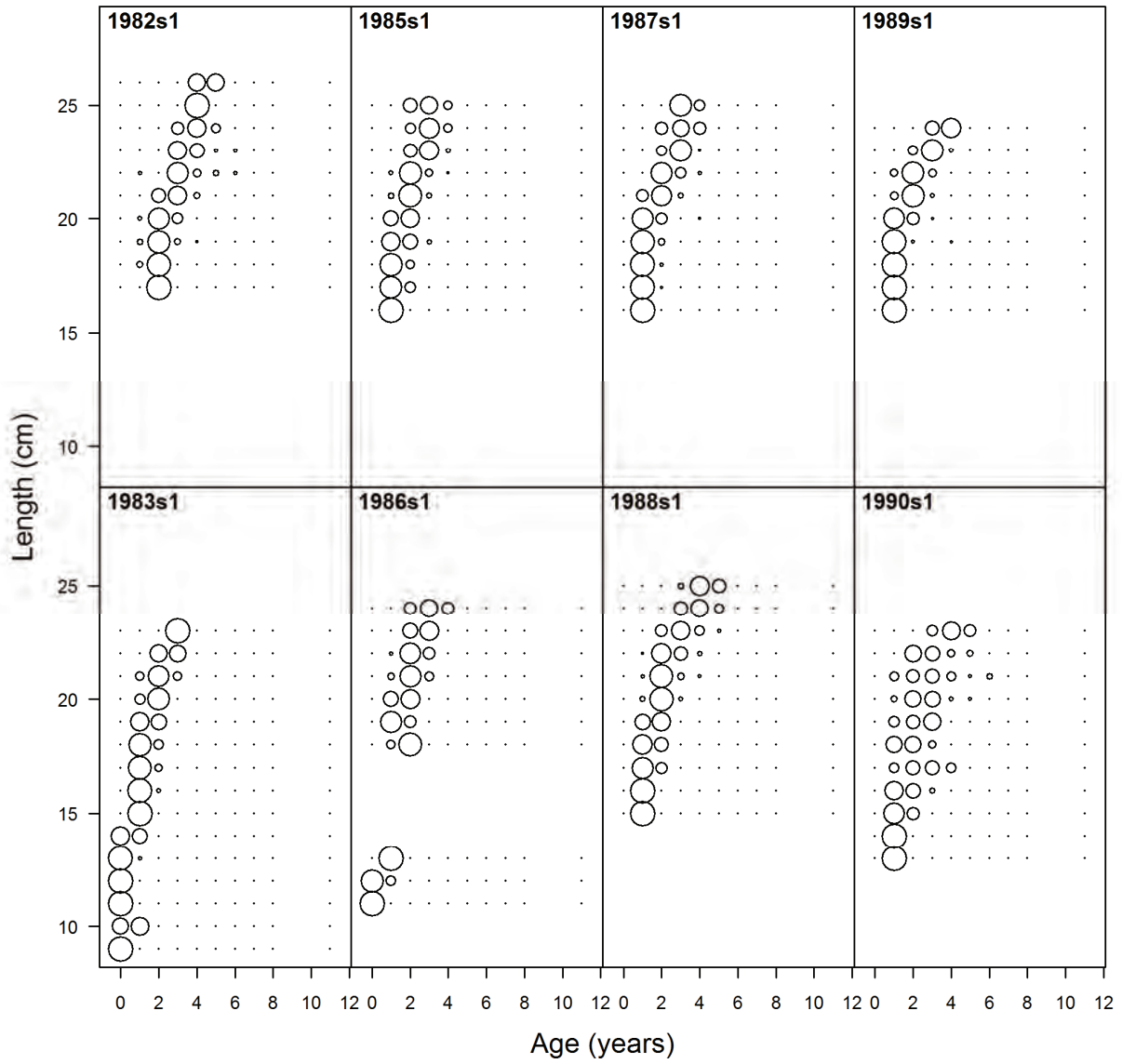


Figure 8b. Conditional age-at-length data for the SCA\_S1 fishery, 1982-1990.

conditional age at length data, sexes combined, whole catch, SCA\_S1 (max=1)

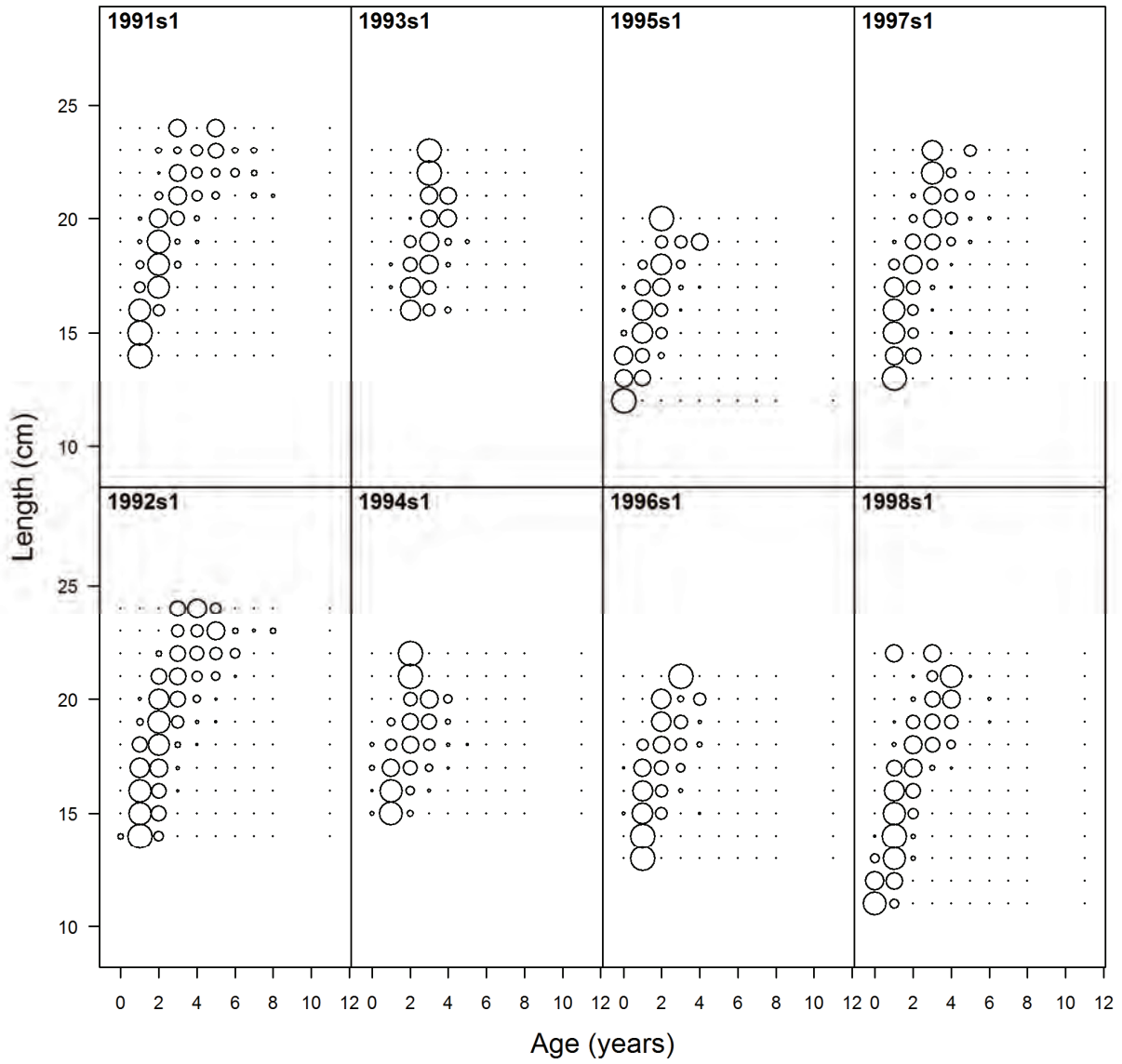


Figure 8b (cont'd). Conditional age-at-length data for the SCA\_S1 fishery, 1991-1998.

conditional age at length data, sexes combined, whole catch, SCA\_S1 (max=1)

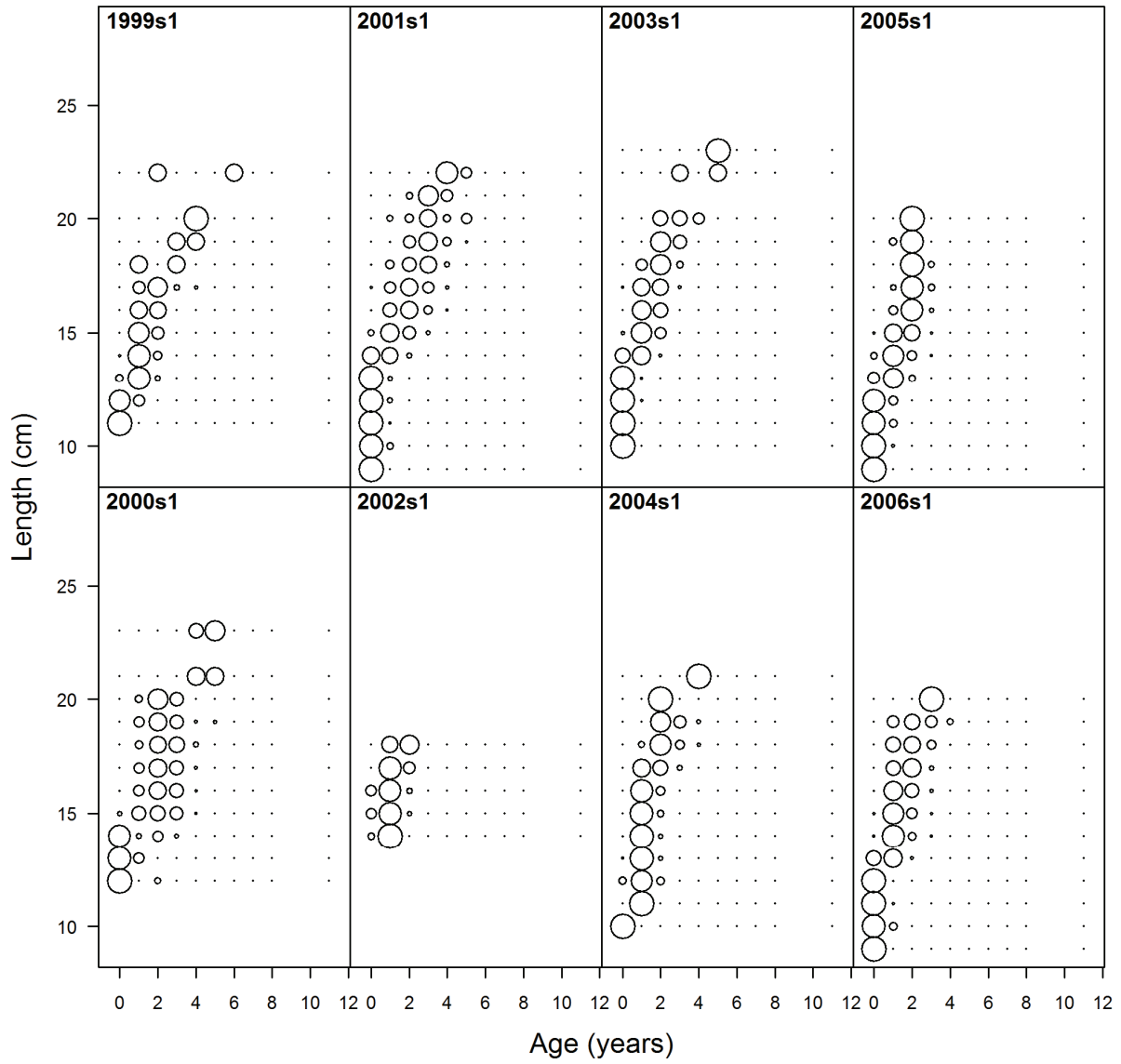


Figure 8b (cont'd). Conditional age-at-length data for the SCA\_S1 fishery, 1999-2006.



conditional age at length data, sexes combined, whole catch, SCA\_S1 (max=1)

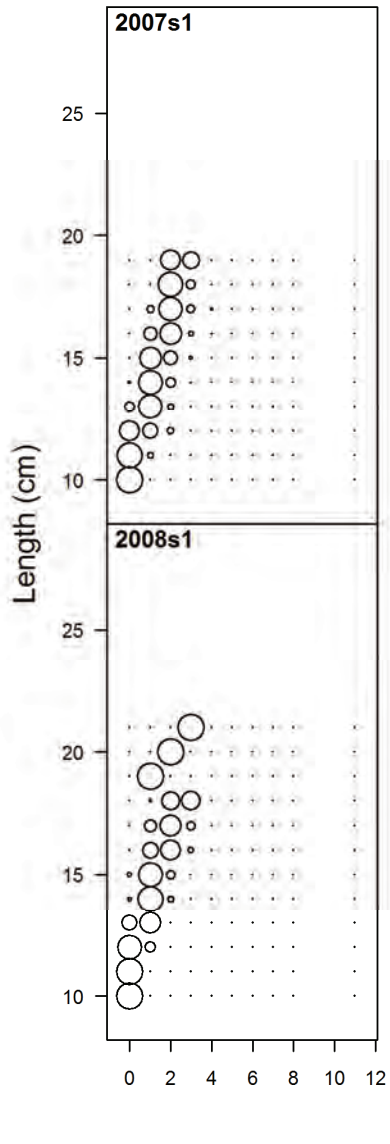


Figure 8b (cont'd). Conditional age-at-length data for the SCA\_S1 fishery, 2007-2008.

conditional age at length data, sexes combined, whole catch, SCA\_S2 (max=1)

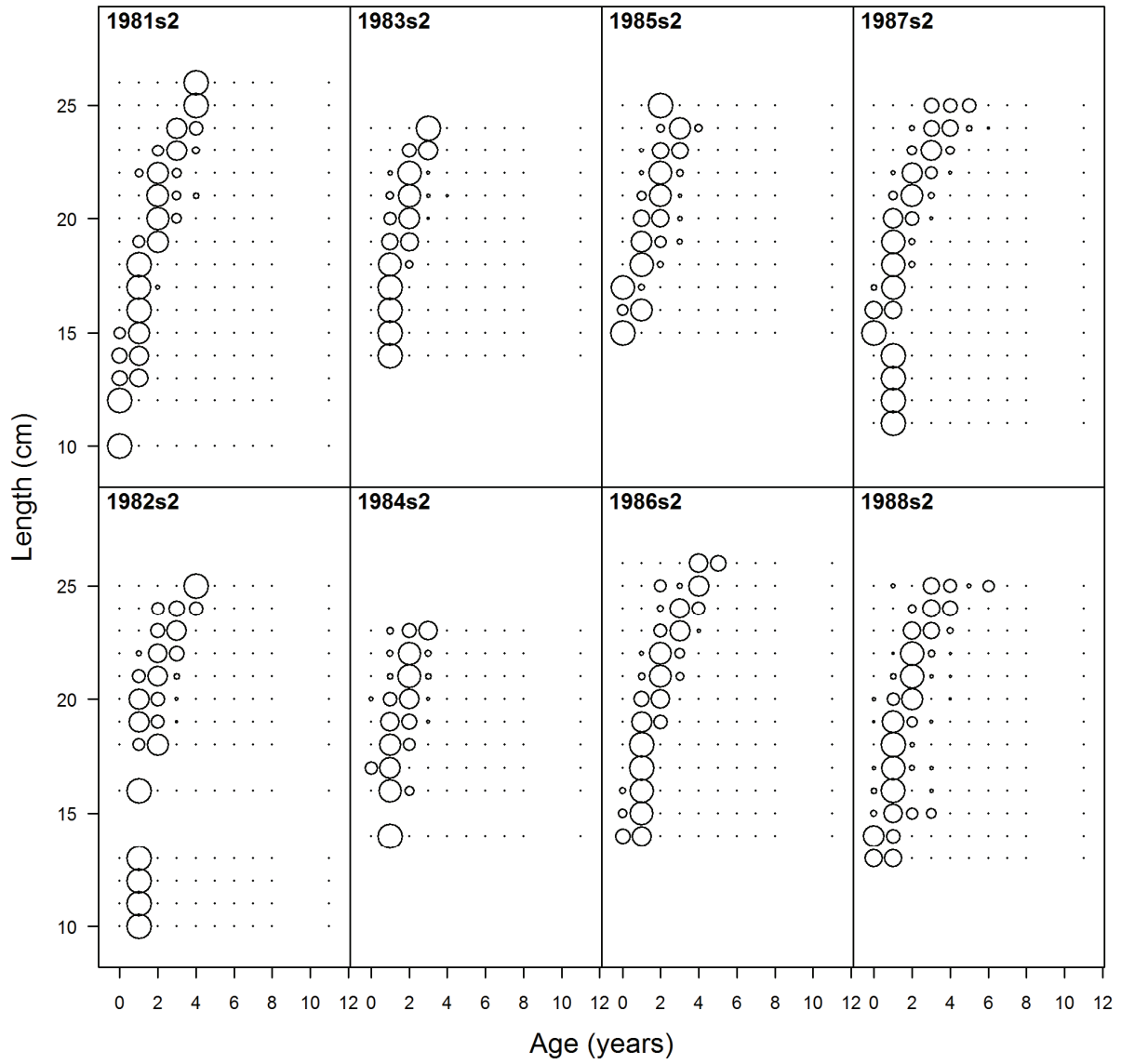


Figure 8c. Conditional age-at-length data for the SCA\_S2 fishery, 1981-1988.

conditional age at length data, sexes combined, whole catch, SCA\_S2 (max=1)

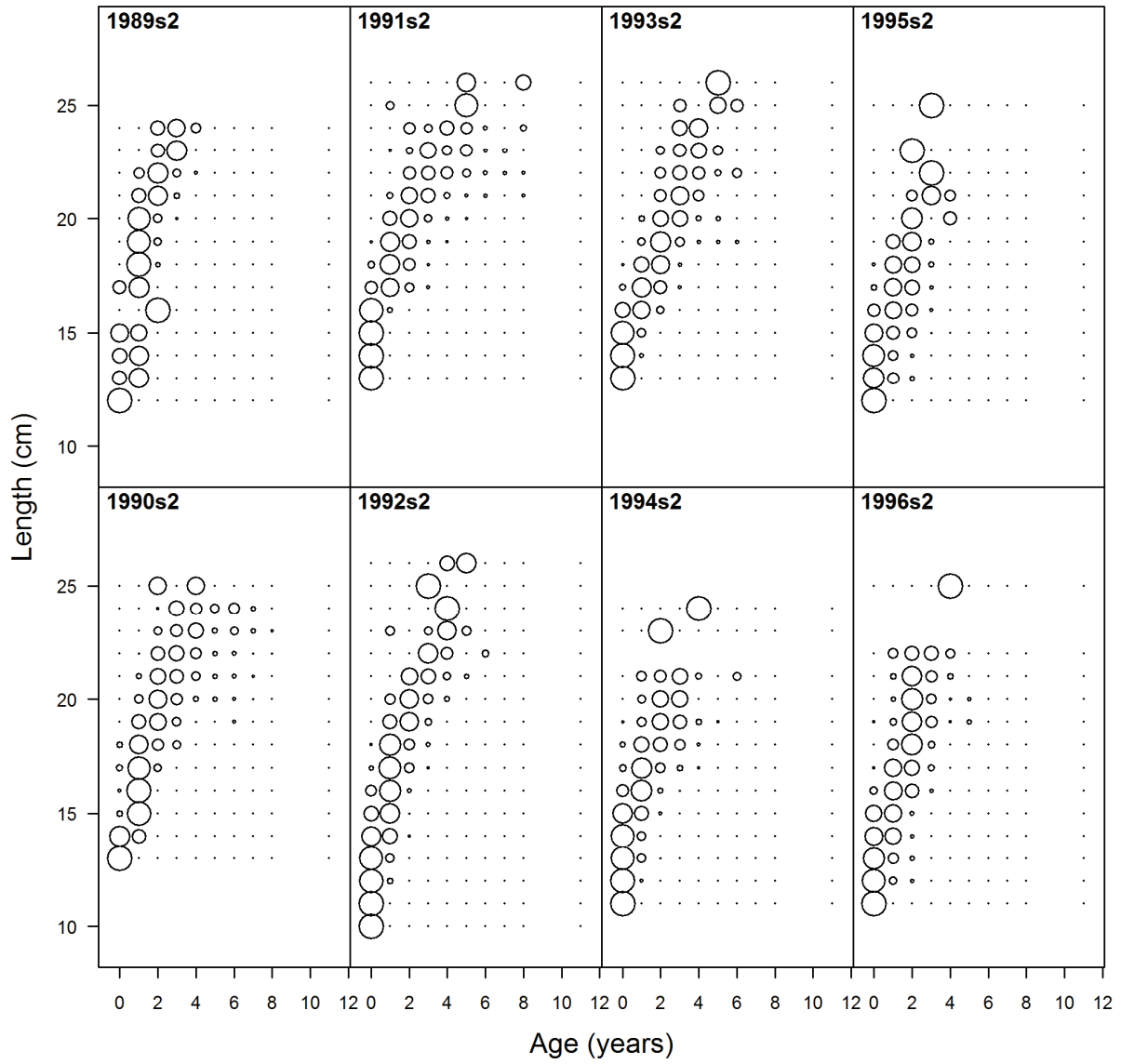


Figure 8c (cont'd). Conditional age-at-length data for the SCA\_S2 fishery, 1989-1996.

conditional age at length data, sexes combined, whole catch, SCA\_S2 (max=1)

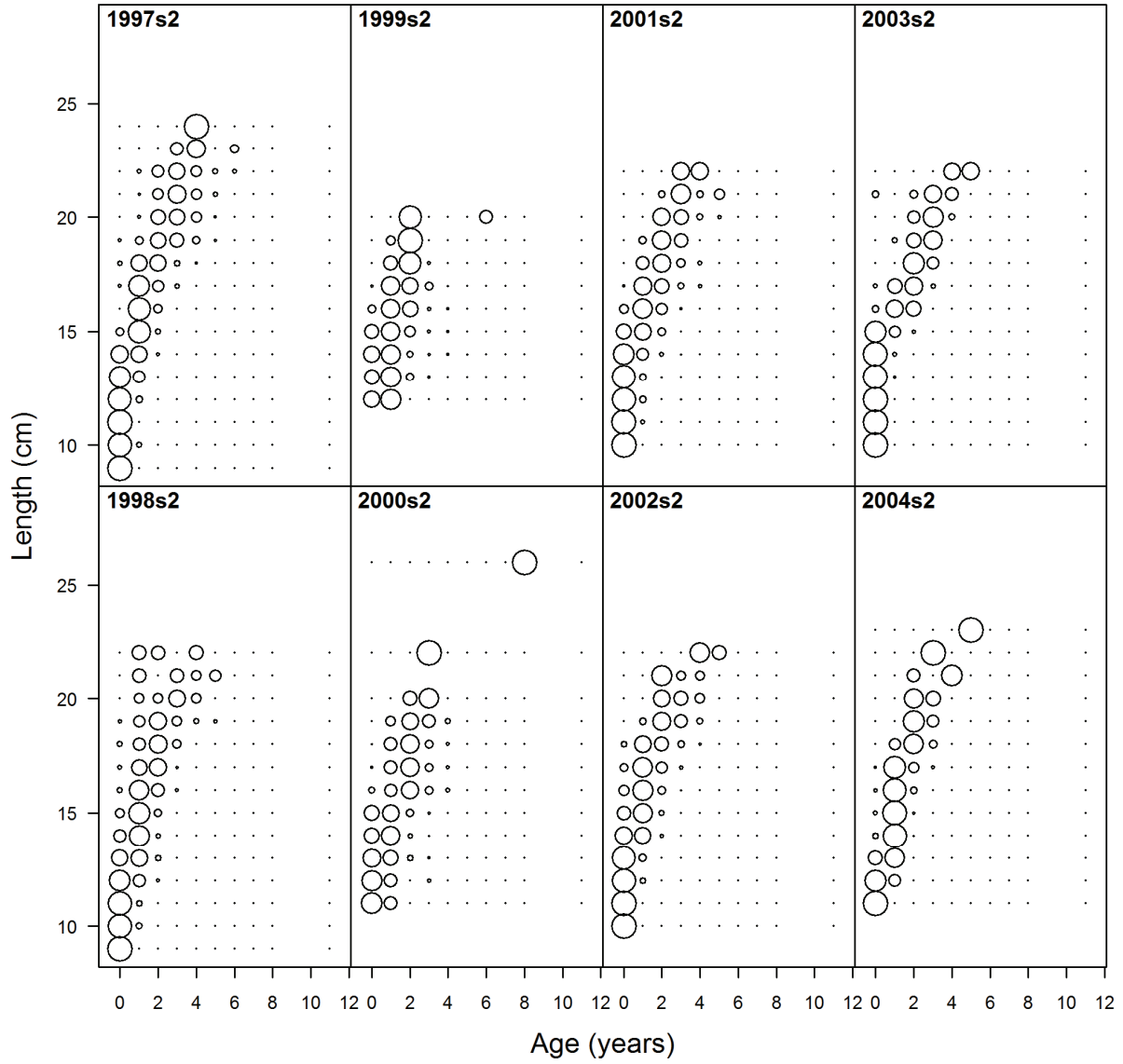


Figure 8c (cont'd). Conditional age-at-length data for the SCA\_S2 fishery, 1997-2004.

conditional age at length data, sexes combined, whole catch, SCA\_S2 (max=1)

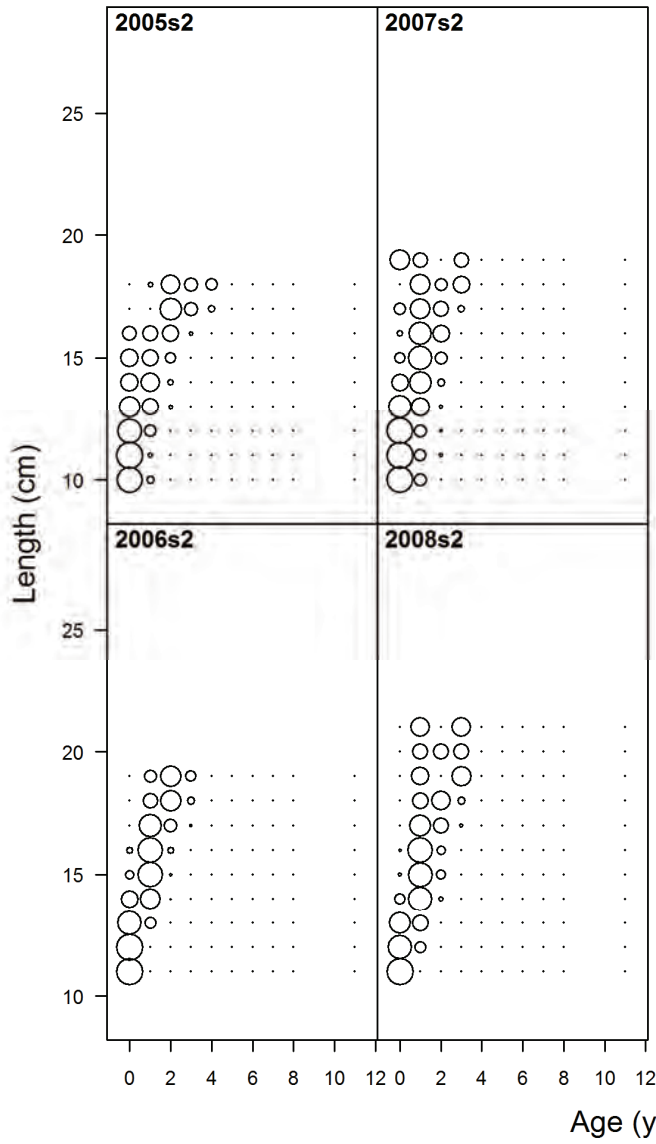


Figure 8c (cont'd). Conditional age-at-length data for the SCA\_S2 fishery, 2005-2008.

conditional age at length data, sexes combined, whole catch, CCA\_S1 (max=1)

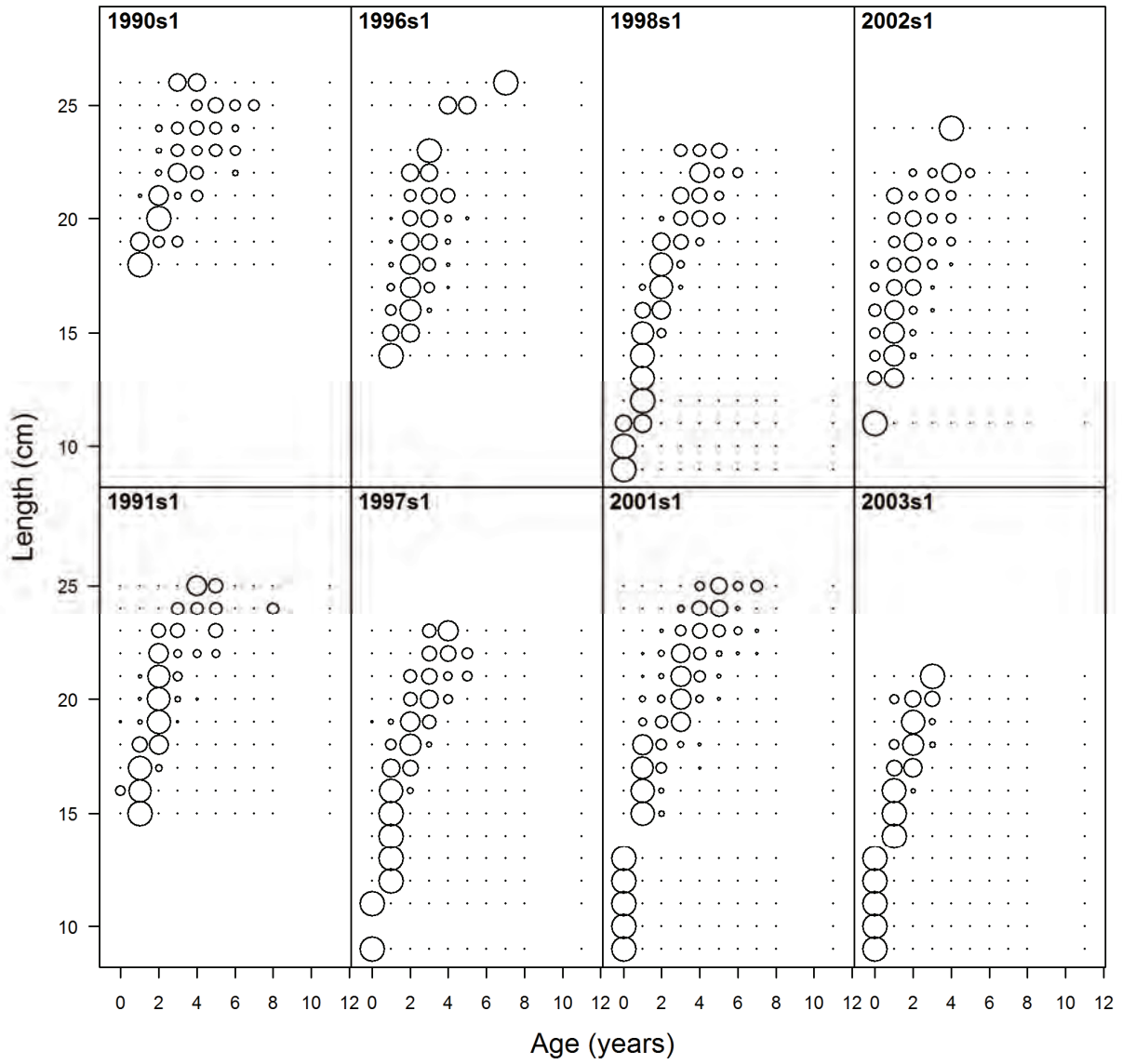


Figure 8d. Conditional age-at-length data for the CCA\_S1 fishery, 1990-2003.

conditional age at length data, sexes combined, whole catch, CCA\_S1 (max=1)

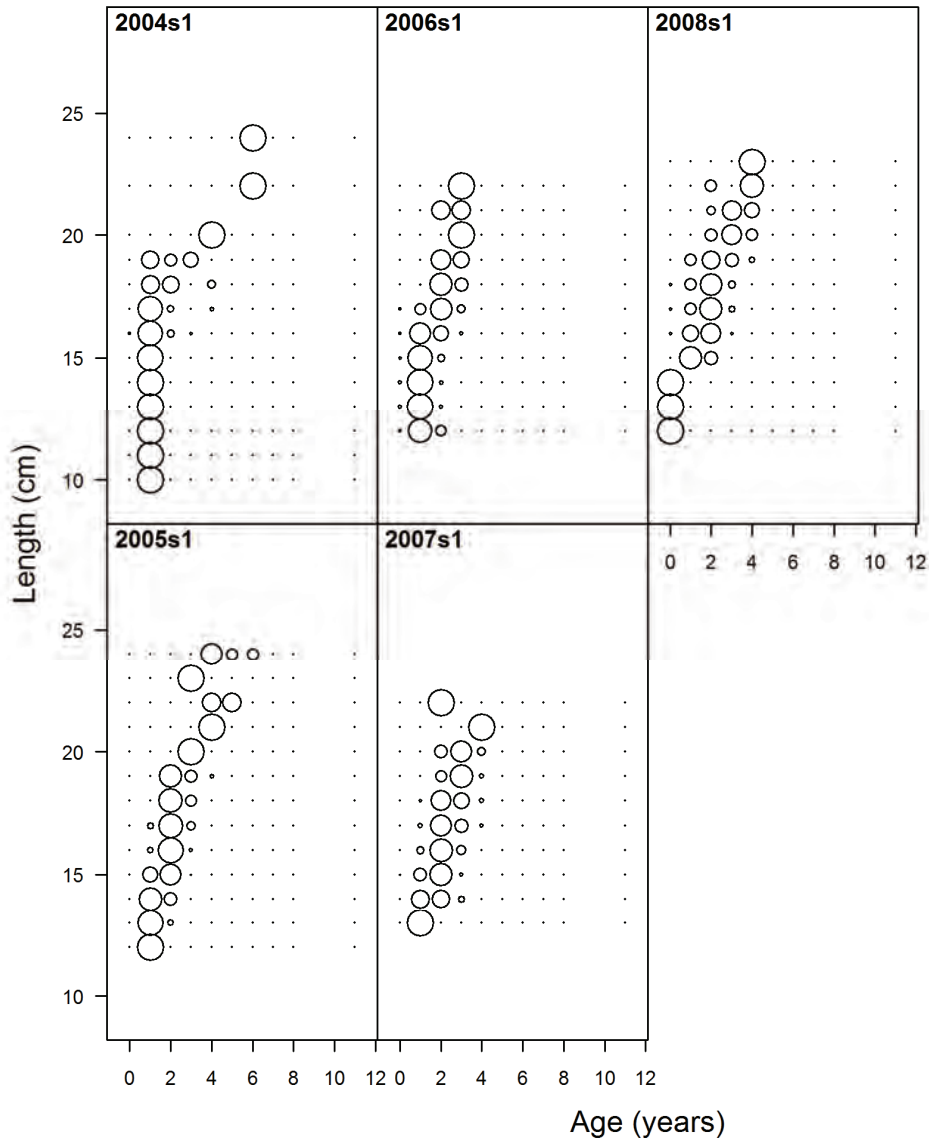


Figure 8d (cont'd). Conditional age-at-length data for the CCA\_S1 fishery, 2004-2007.

conditional age at length data, sexes combined, whole catch, CCA\_S2 (max=1)

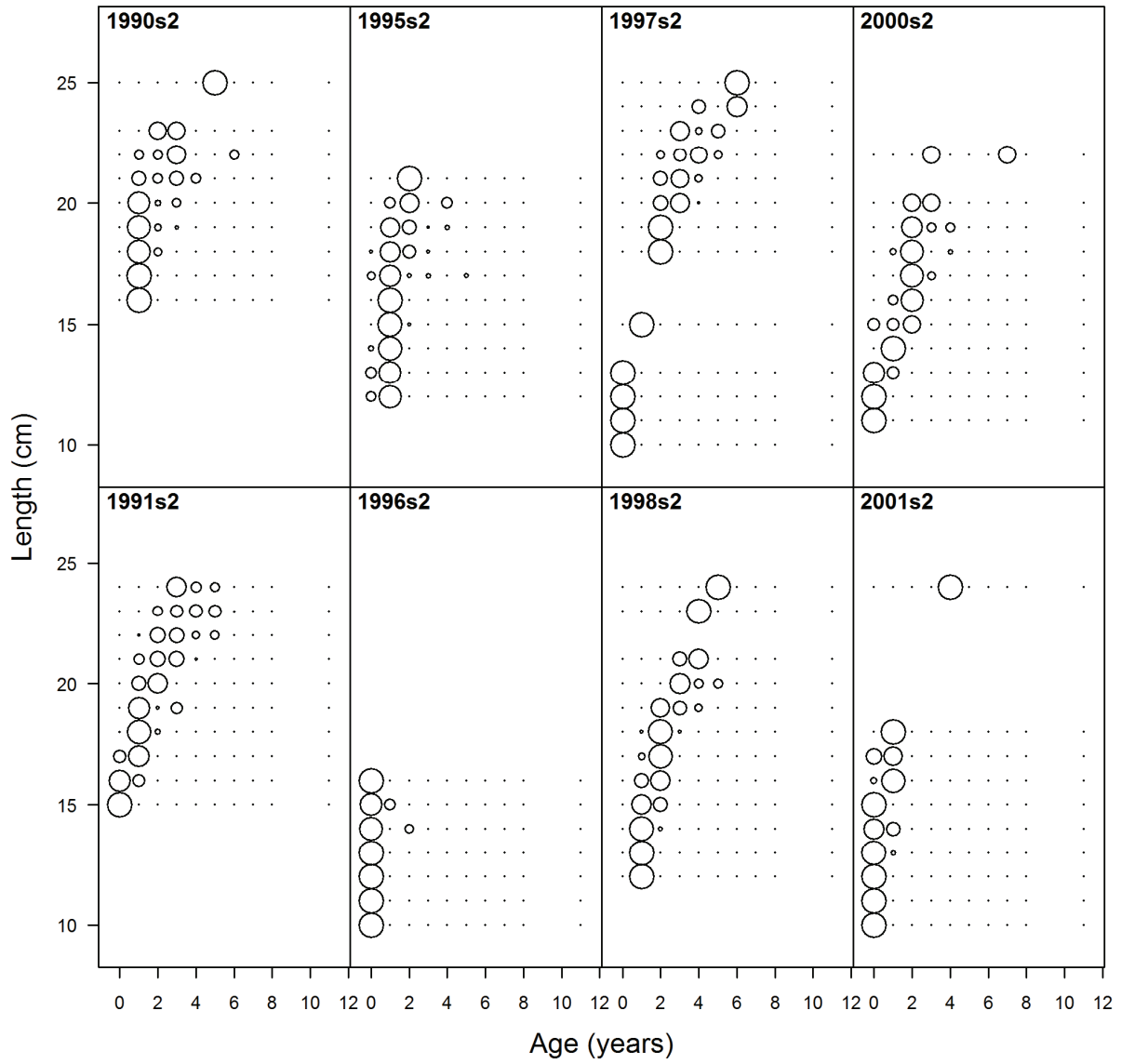


Figure 8e. Conditional age-at-length data for the CCA\_S2 fishery, 1990-2001.



conditional age at length data, sexes combined, whole catch, CCA\_S2 (max=1)

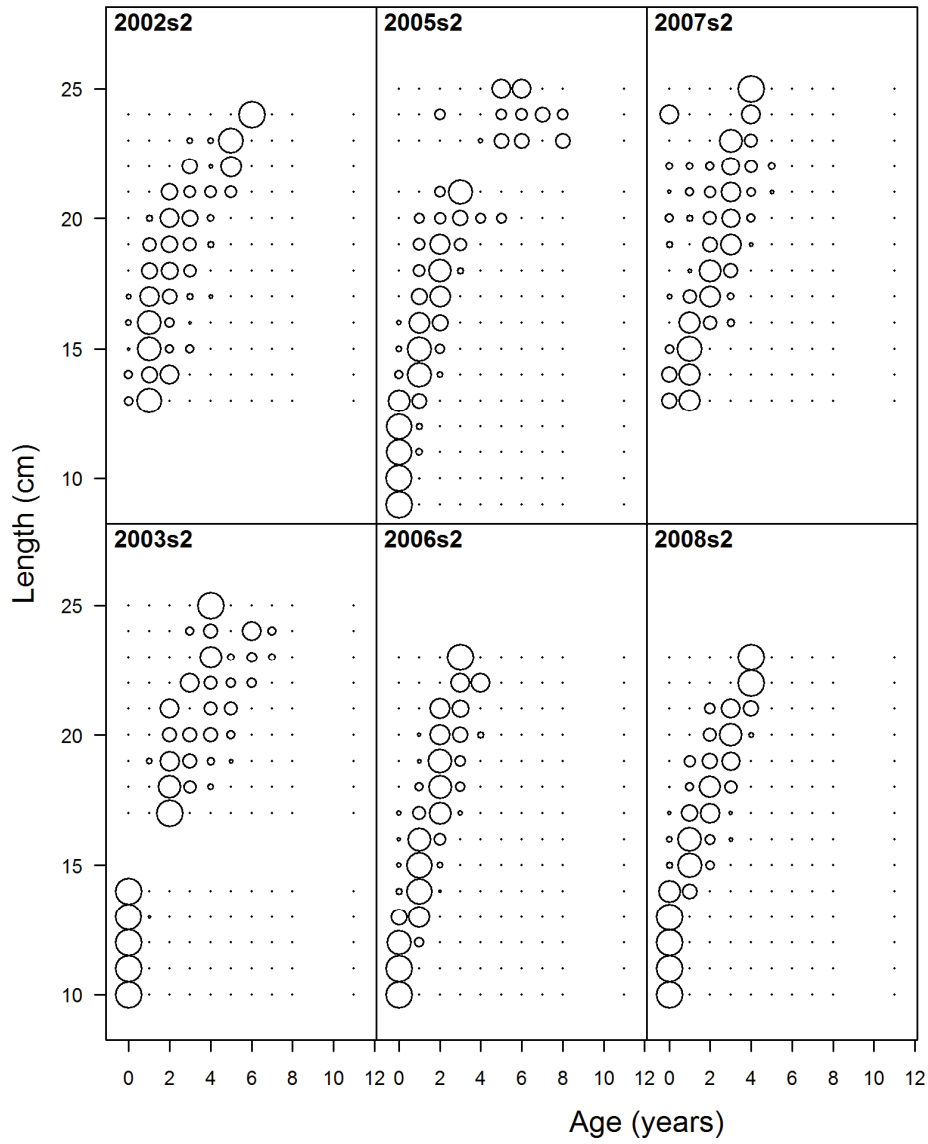


Figure 8e (cont'd). Conditional age-at-length data for the CCA\_S2 fishery, 2002-2008.

conditional age at length data, sexes combined, whole catch, PNW (max=1)

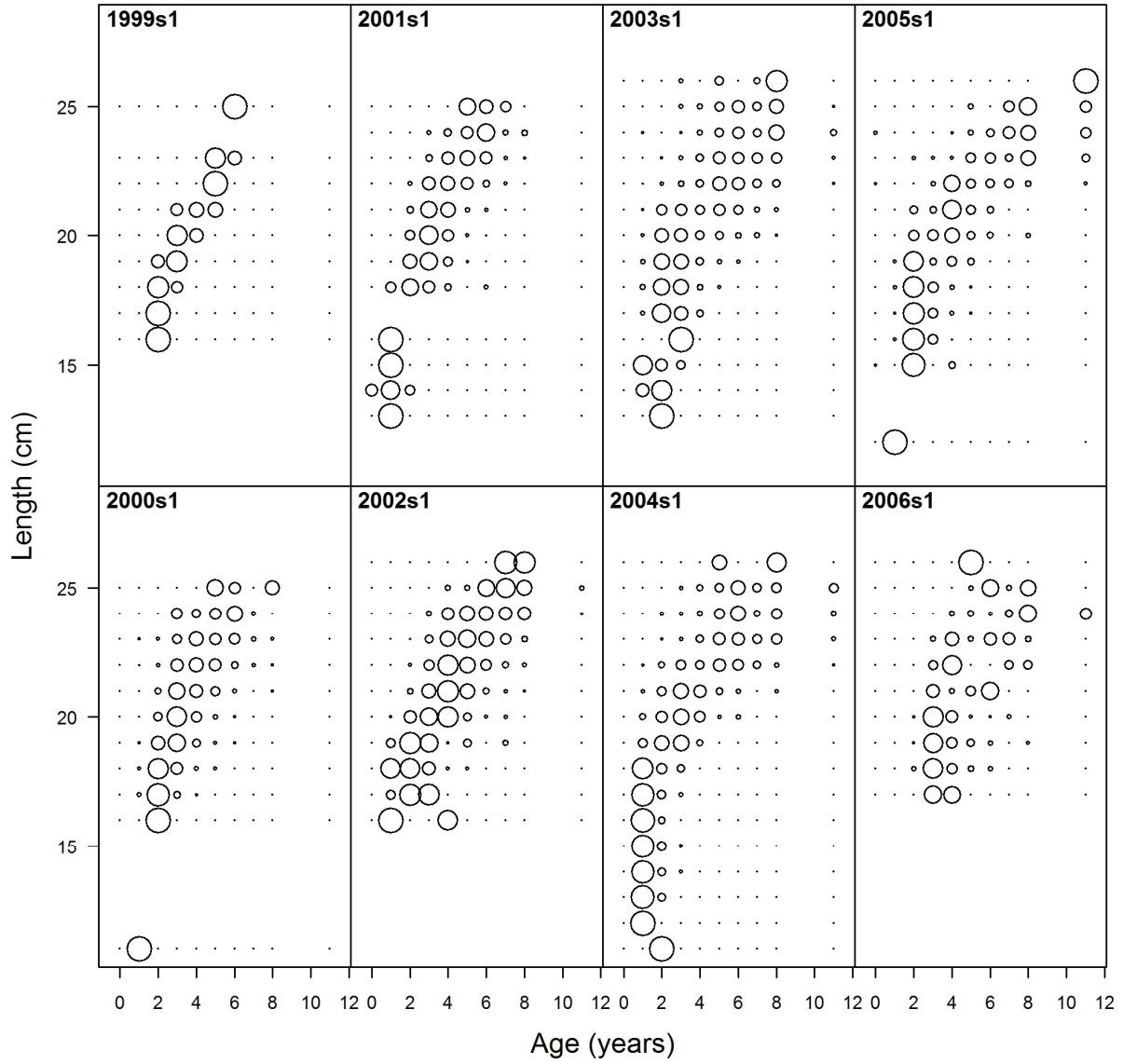


Figure 8f. Conditional age-at-length data for the PNW fishery, 1999-2006.

conditional age at length data, sexes combined, whole catch, PNW (max=1)

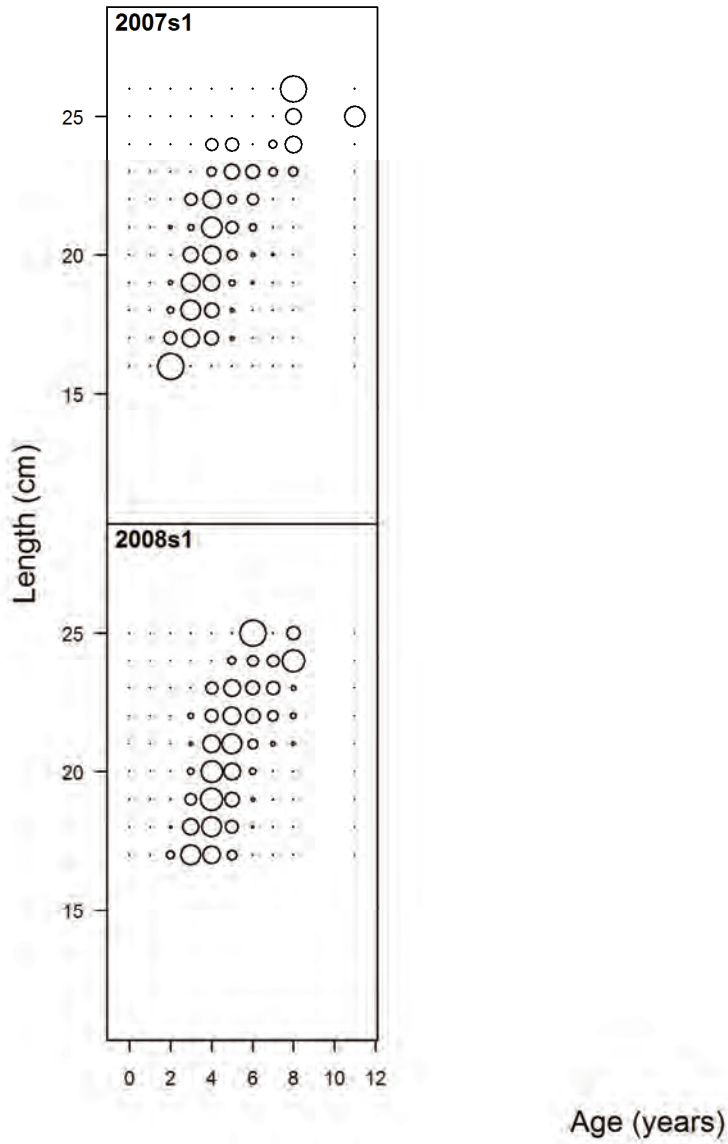


Figure 8f (cont'd). Conditional age-at-length data for the PNW fishery.

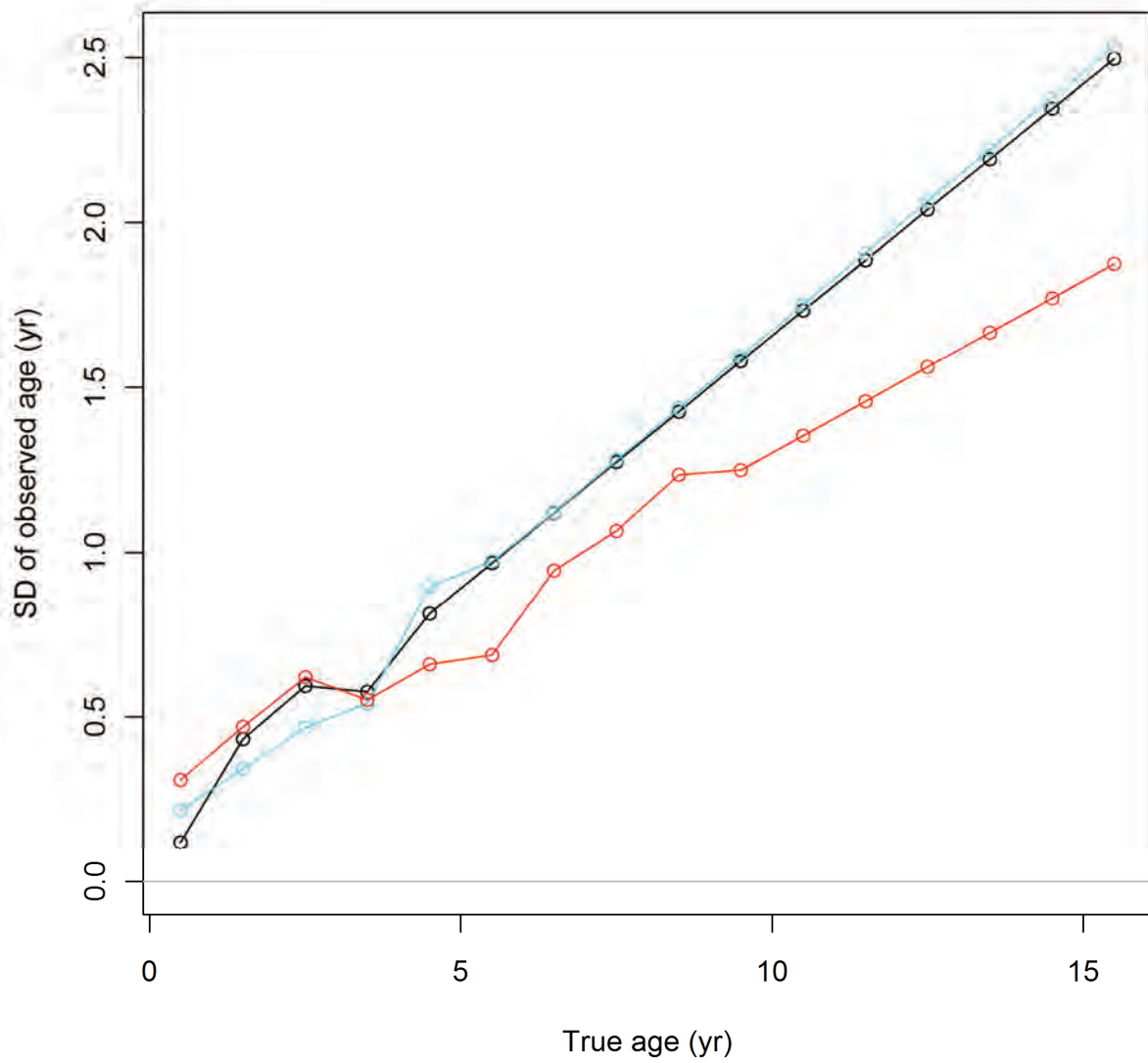


Figure 9. Fishery-specific ageing errors: black line is ENS, blue line is SCA and CCA, and red line is PNW.

*BLANK PAGE*

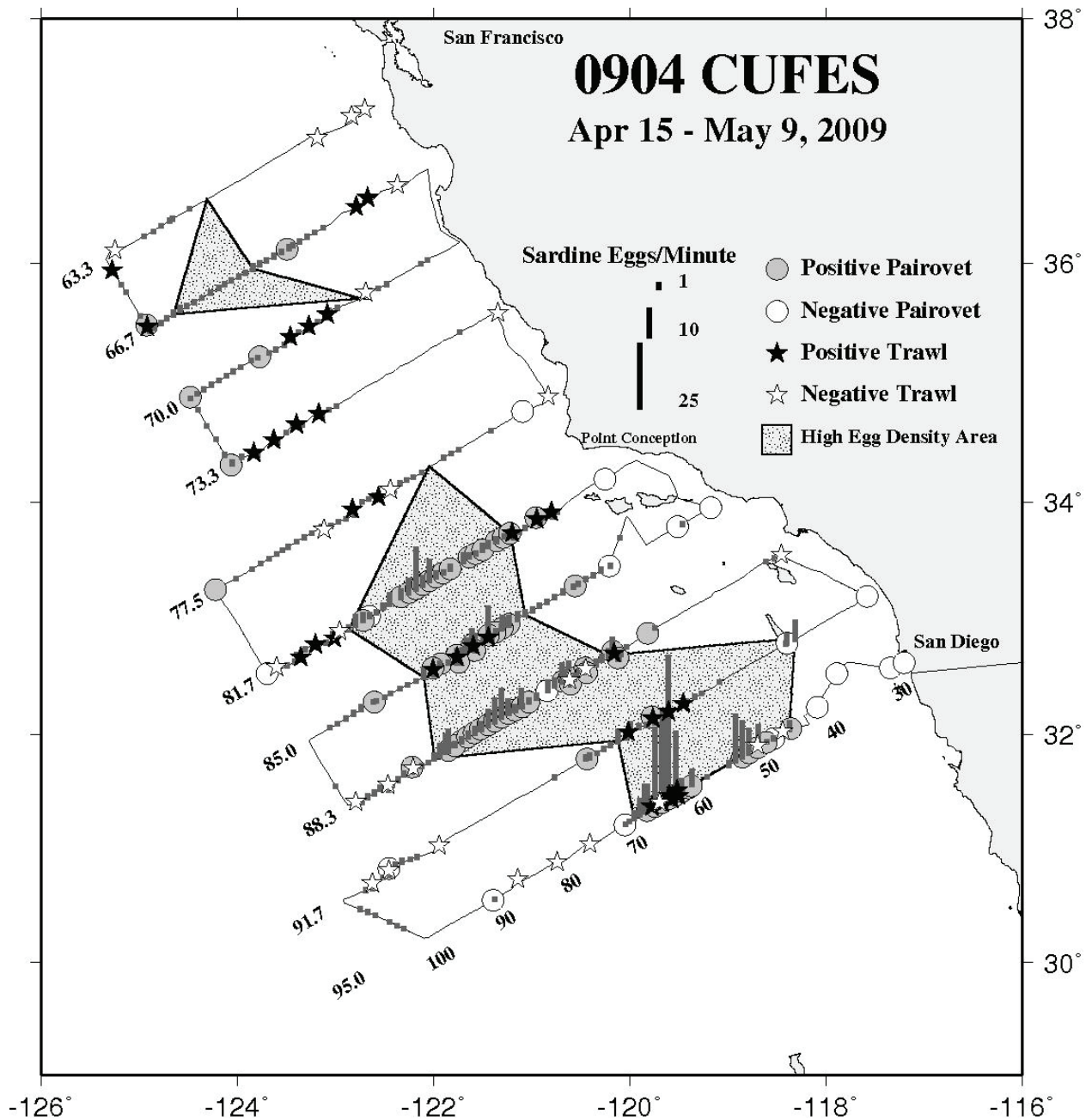


Figure 10a. Distribution of CUFES and Pairovet ichthyoplankton collections, and adult trawl samples from the SWFSC 0904 sardine survey, conducted onboard the F/V Frosti, April 15 to May 9, 2009.

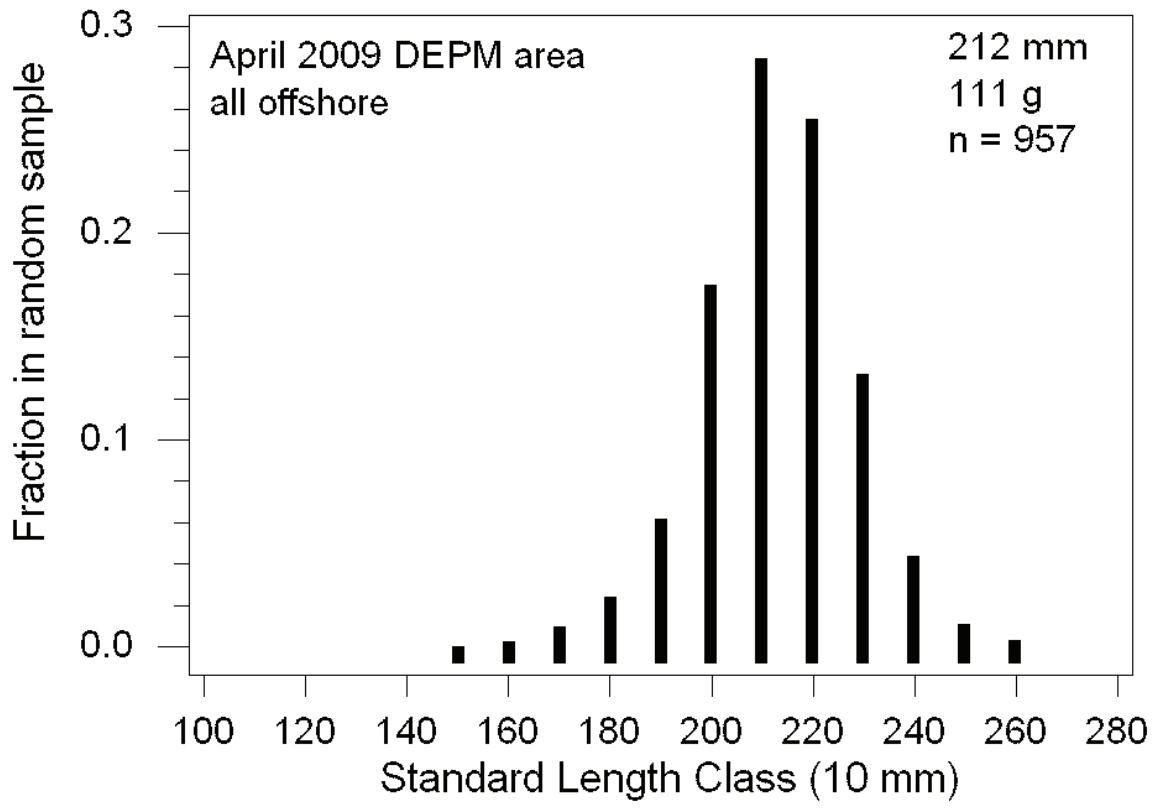


Figure 10b. Length-composition from the SWFSC 0904 survey.

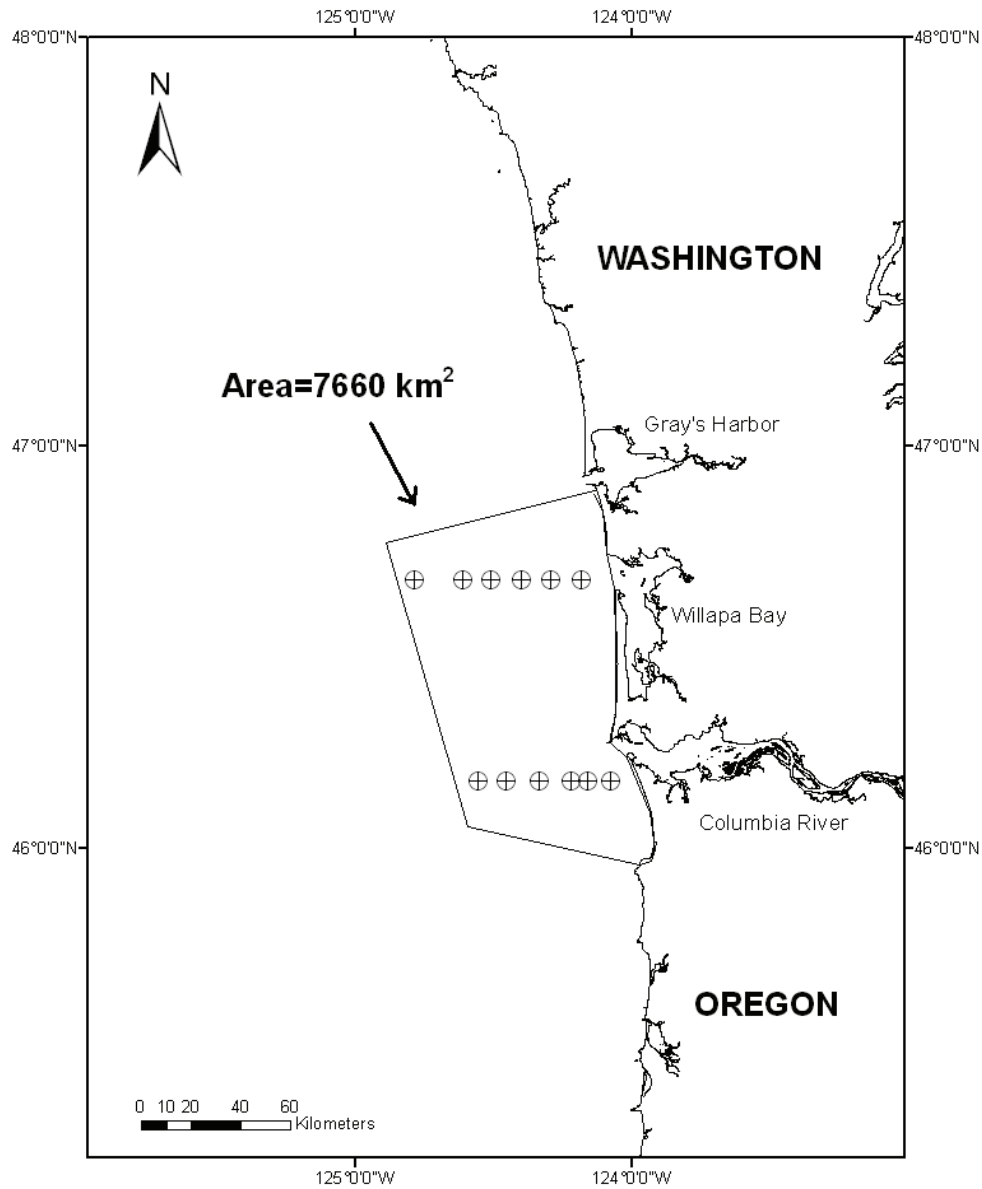


Figure 11a. NWFS Predator Forage-Fish Survey (PFFS) trawl locations sampled near the Columbia River from late April through early August, 1998-2008. Estimated representative survey area is 7,660 km<sup>2</sup>.



length comp data, sexes combined, whole catch, PFFS

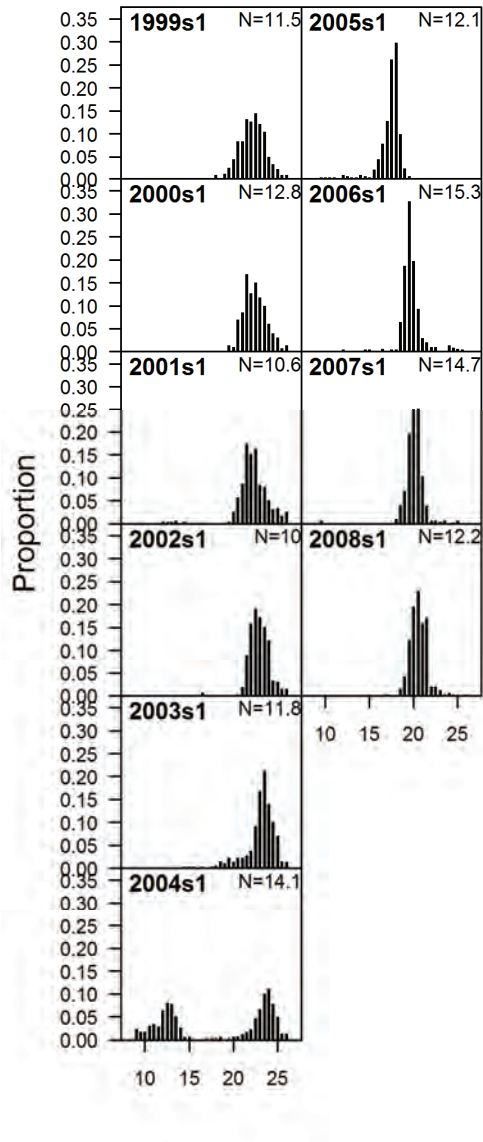


Figure 11b. Length-composition data for the NWFSC's PFFS survey (Predator Forage Fish Survey, 1999-2008).

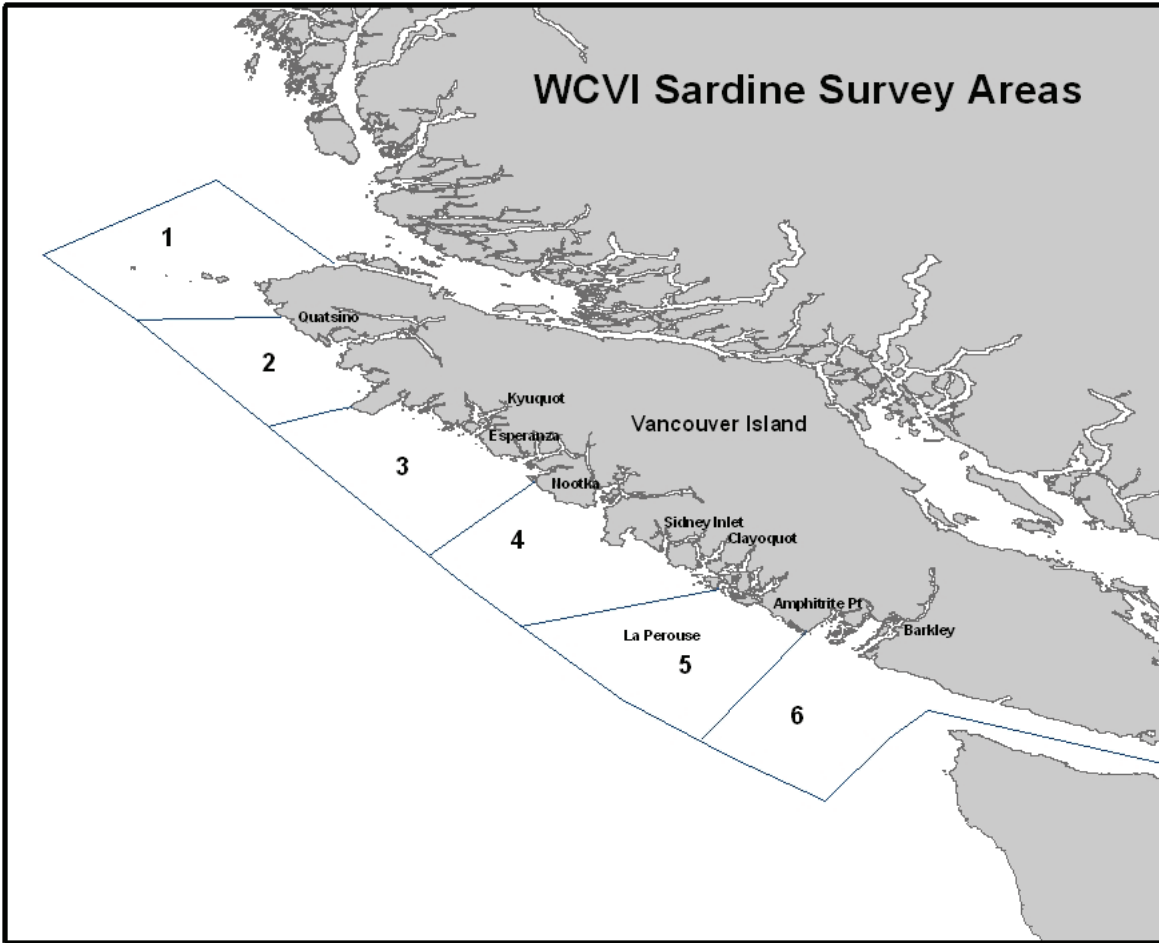
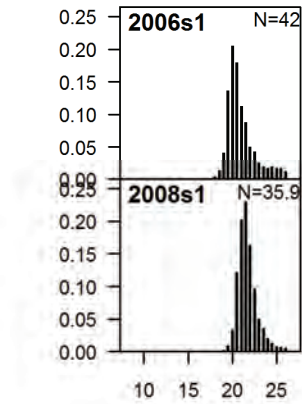


Figure 12a. CDFO West Coast Vancouver Island (WCVI) trawl survey areas sampled.

length comp data, sexes combined, whole catch, WCVI



Proportion

Length (cm)

Figure 12b. Length-composition data for CDFO's WCVI survey. Data collected from 1997 to 2005 were excluded from the analysis.

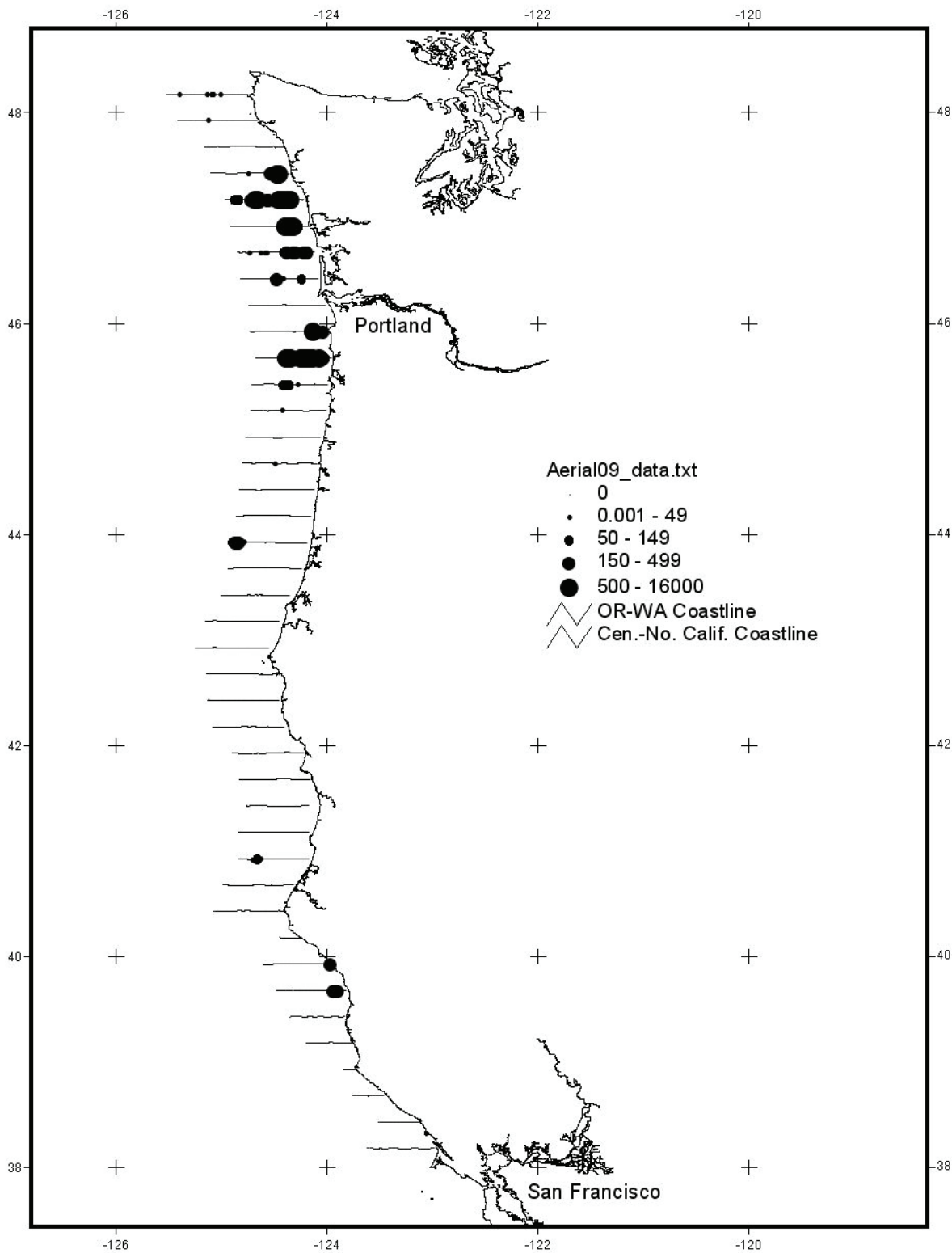


Figure 13a. Map showing the distribution of sardine schools observed in the 2009 Aerial Sardine Survey (data from Jagielo 2009).

length comp data, sexes combined, whole catch, Aerial

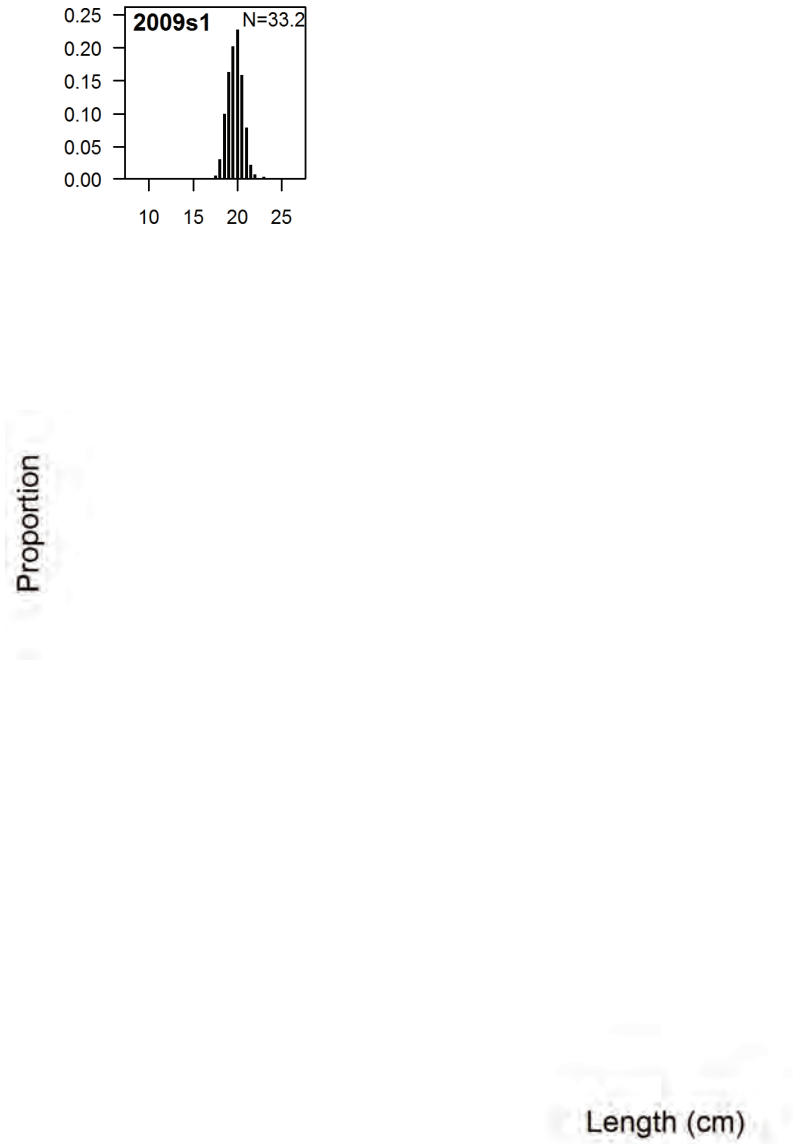


Figure 13b. Length-composition data for the 2009 Aerial Survey.

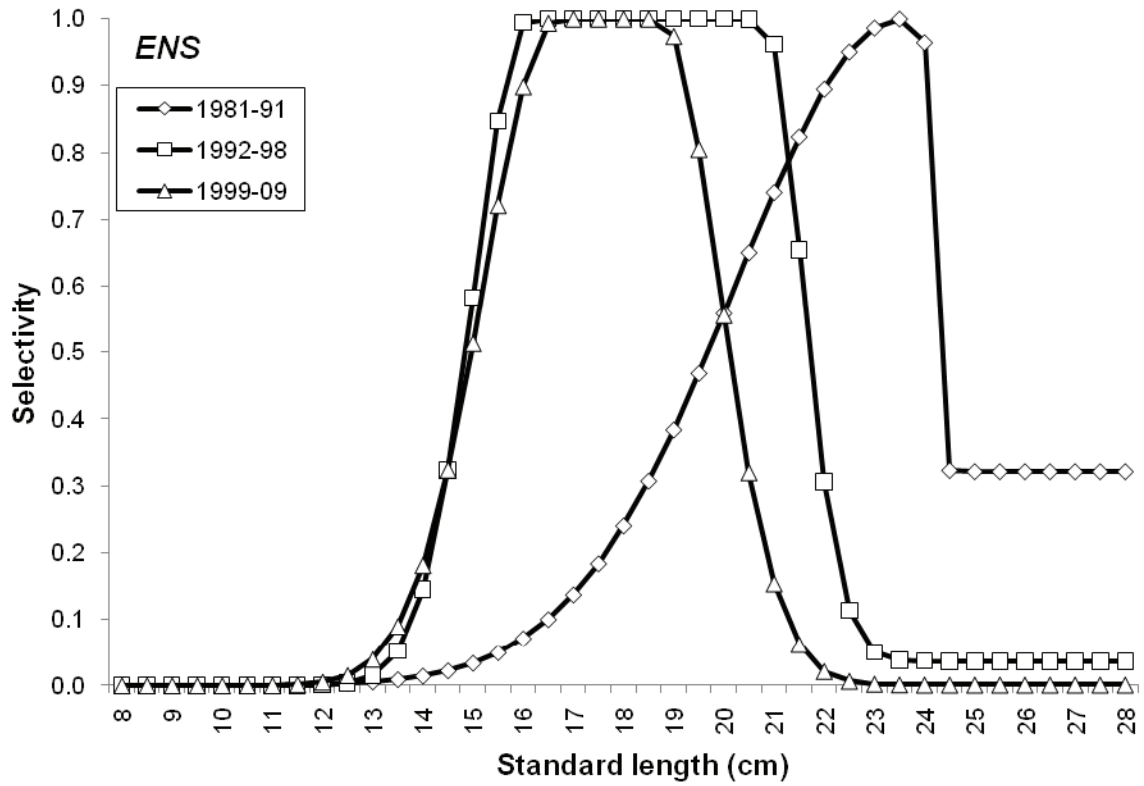


Figure 14a. Length-based selectivity for the ENS fleet by time block.

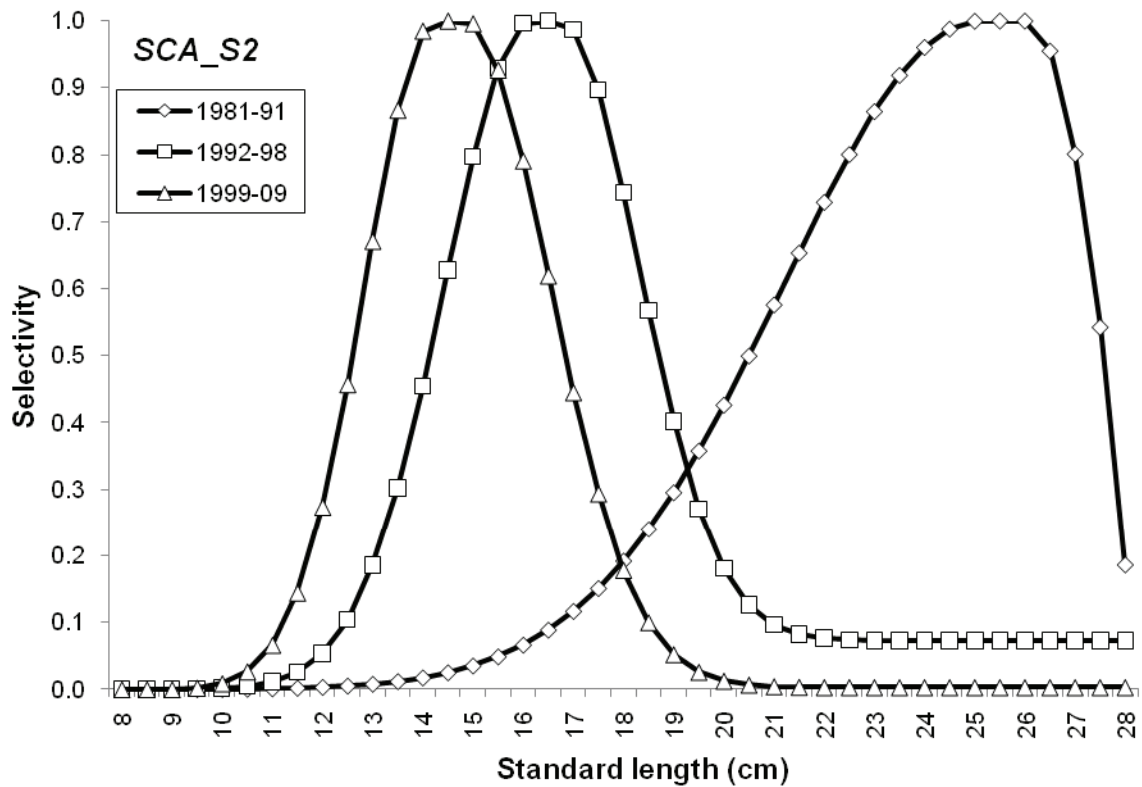
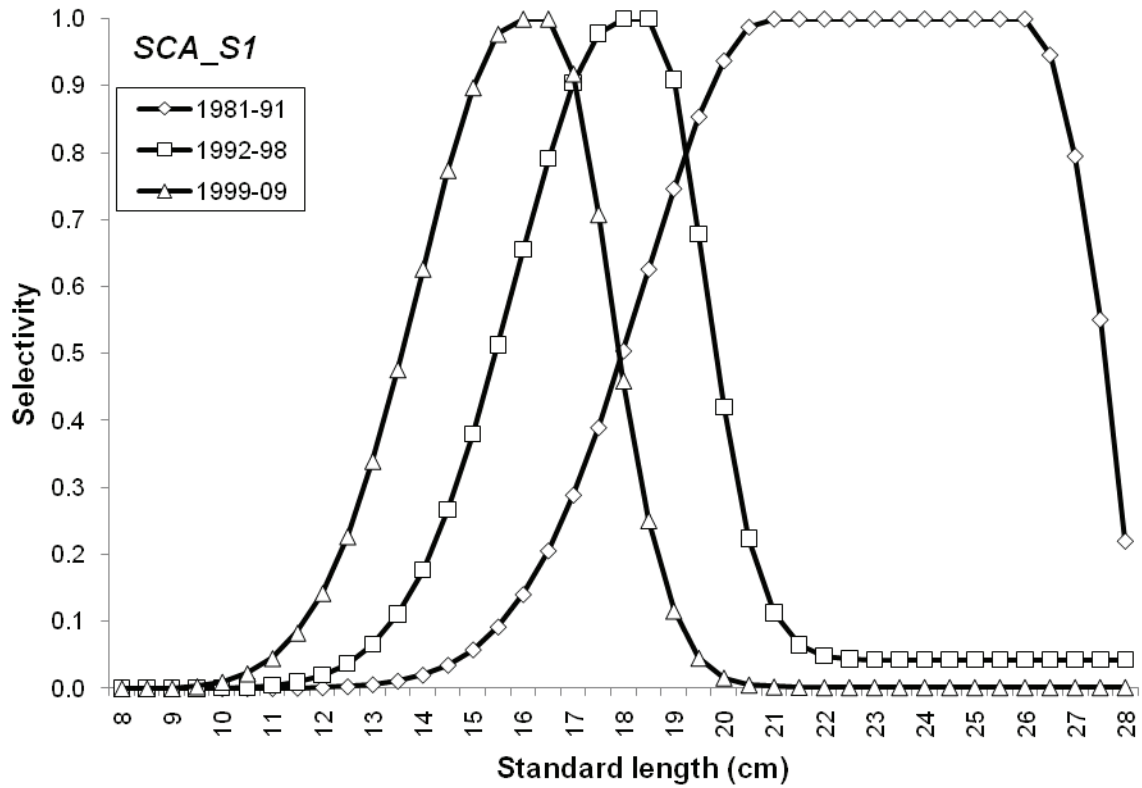


Figure 14b. Length-based selectivity for the SCA fleet by semester and time block.

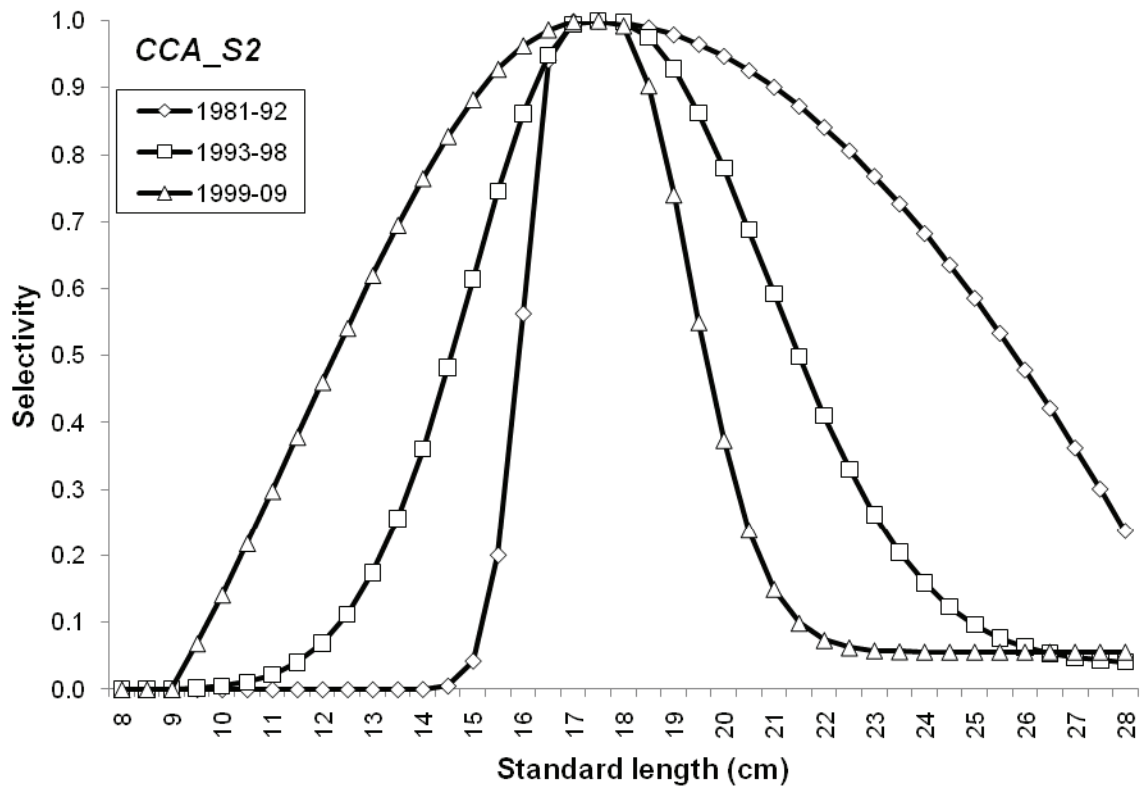
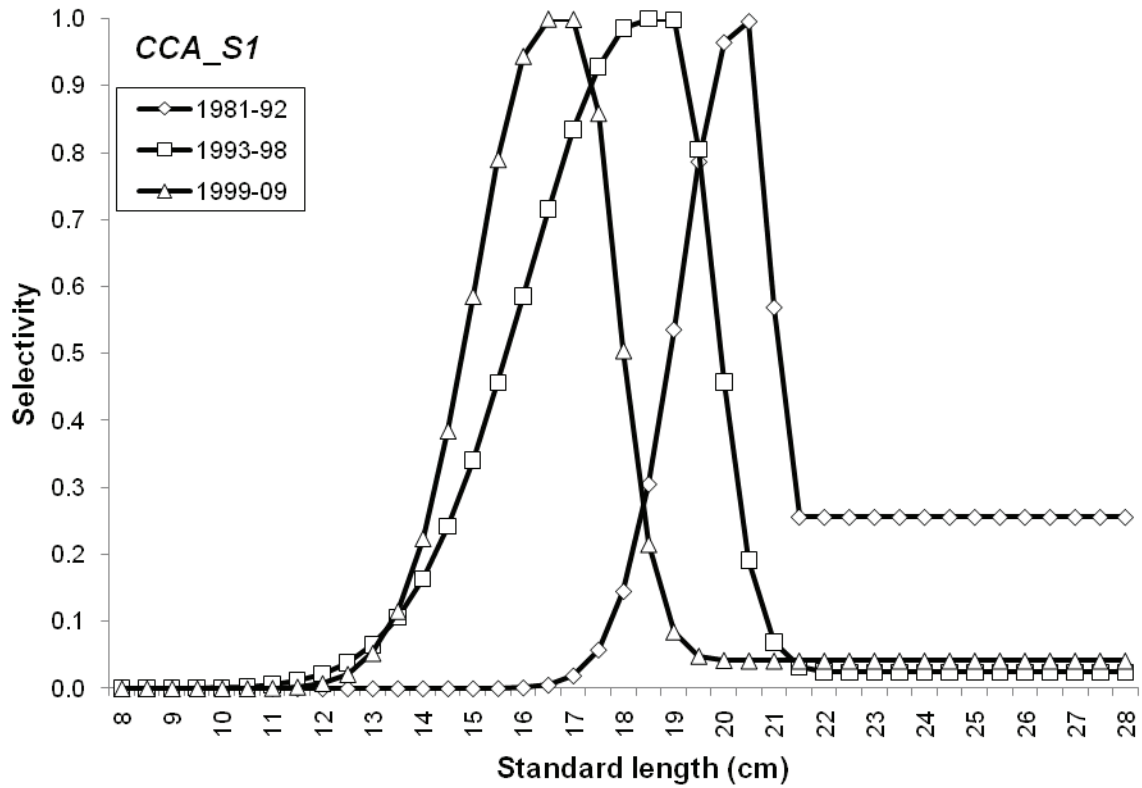


Figure 14c. Length-based selectivity for the CCA fleet by semester and time block.



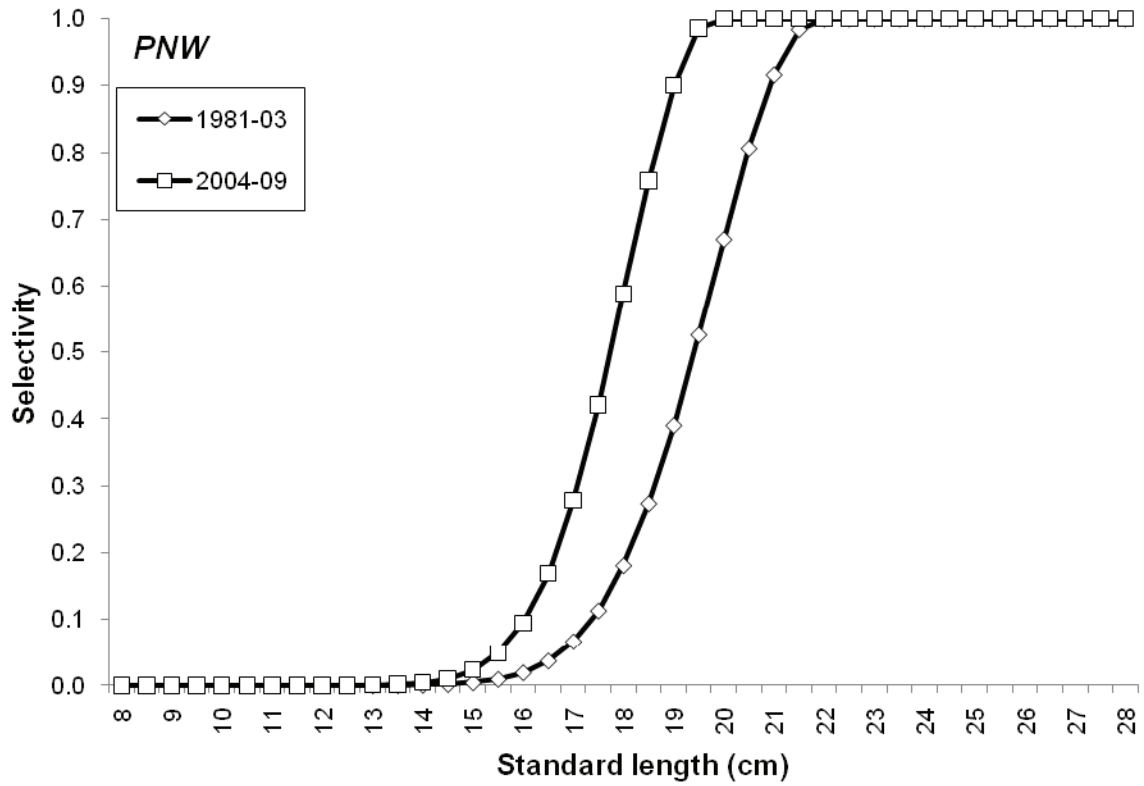


Figure 14d. Length-based selectivity by fleet and time block.

length comps, sexes combined, whole catch, ENS

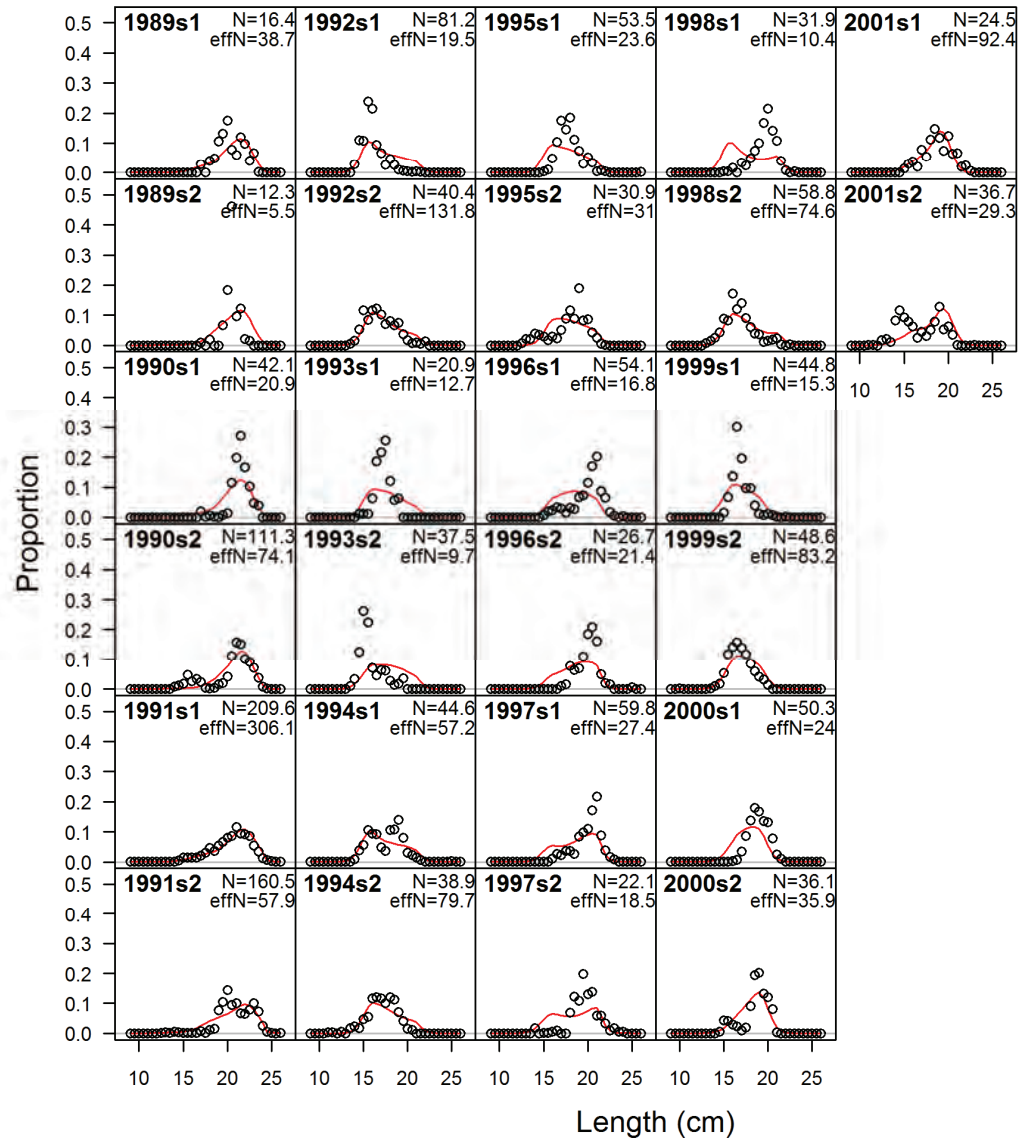


Figure 15a. Base model fits to length-frequency data for the ENS fishery.

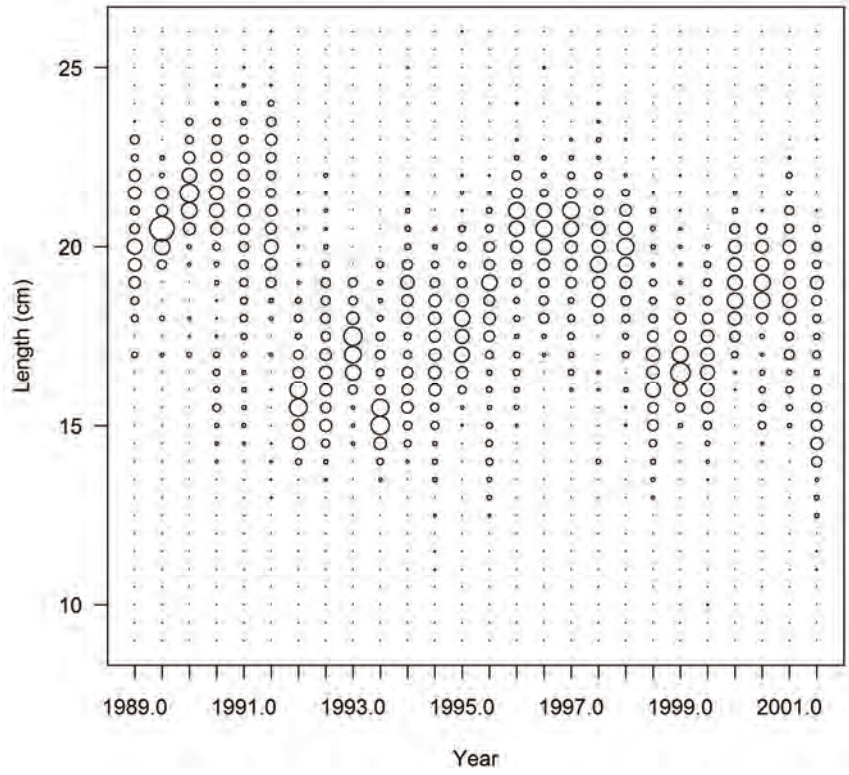


Figure 15b. Bubble plot of length-frequency data for the ENS fishery.

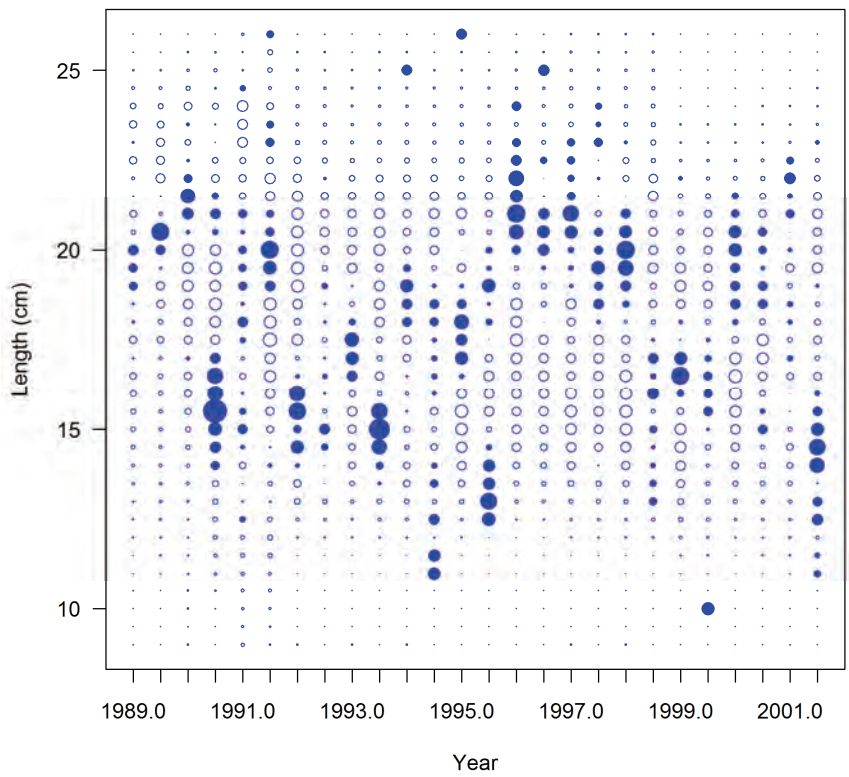


Figure 15c. Pearson residuals (max=7.43) for fit to length-frequency data for the ENS fishery.

**gst age comps, sexes combined, whole catch, ENS**

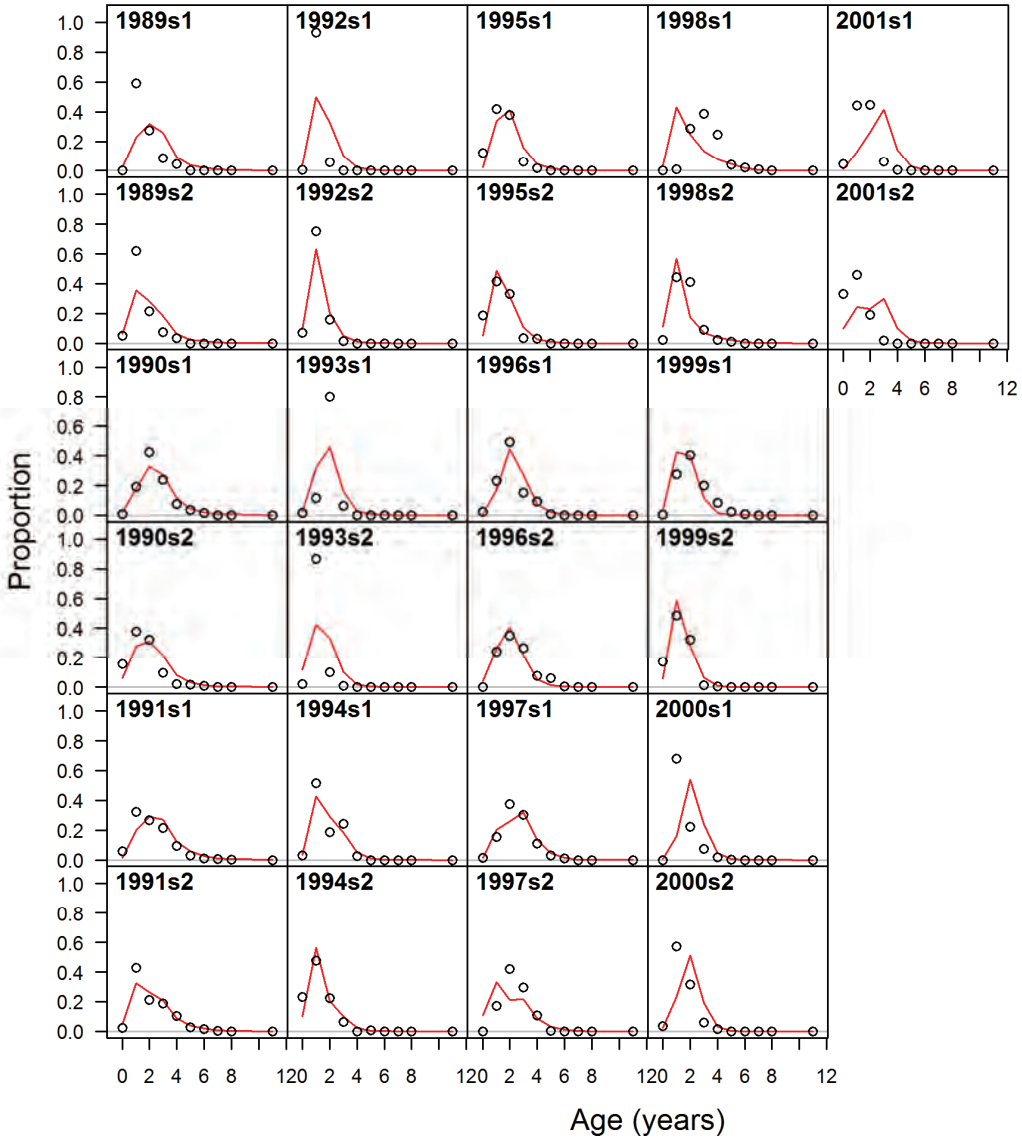


Figure 16a. Base model fits to implied age-frequency data for the ENS fishery.

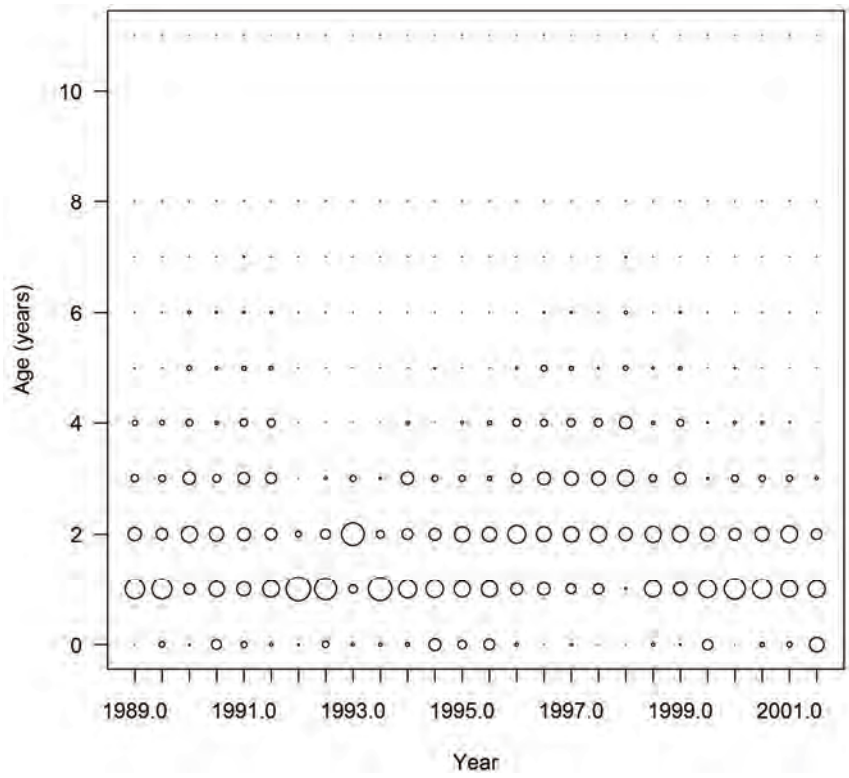


Figure 16b. Bubble plot of age-frequency data for the ENS fishery.

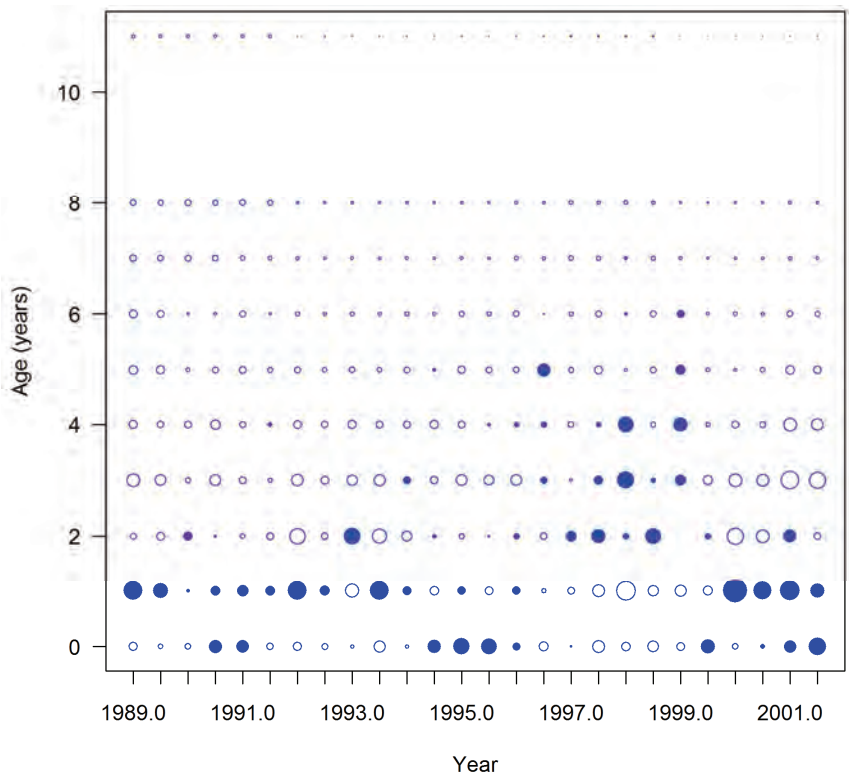


Figure 16c. Pearson residuals (max=1.41) for fit to implied age-frequency data for the ENS fishery.

length comps, sexes combined, whole catch, SCA\_S1

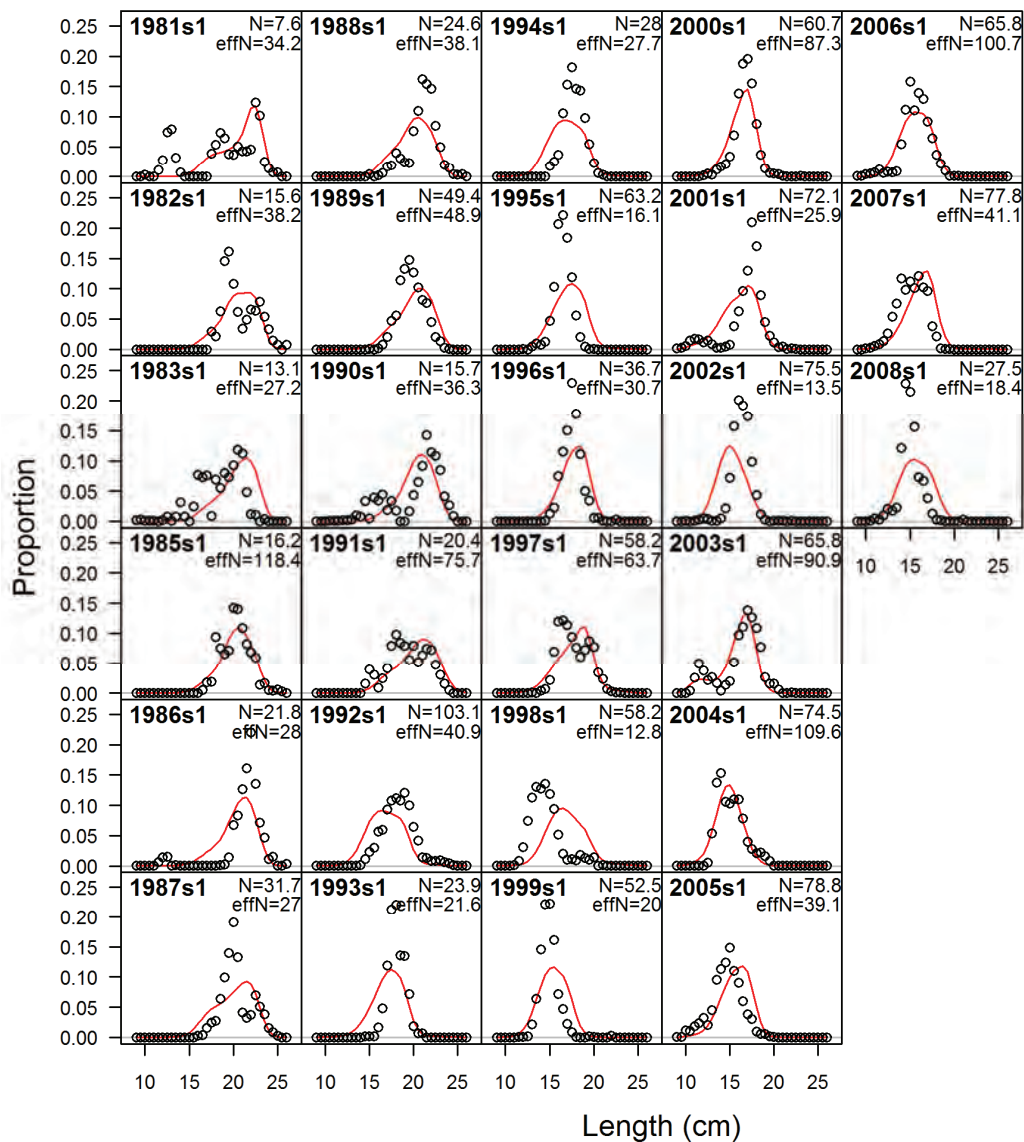


Figure 17a. Base model fits to length-frequency data for the SCA\_S1 fishery.

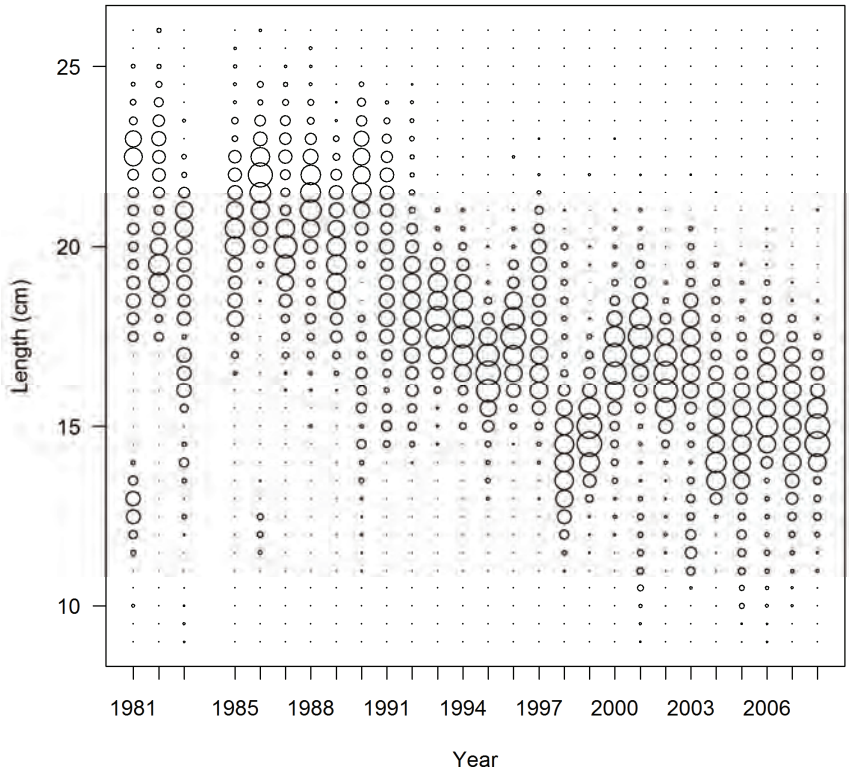


Figure 17b. Bubble plot of length-frequency data for the SCA\_S1 fishery.

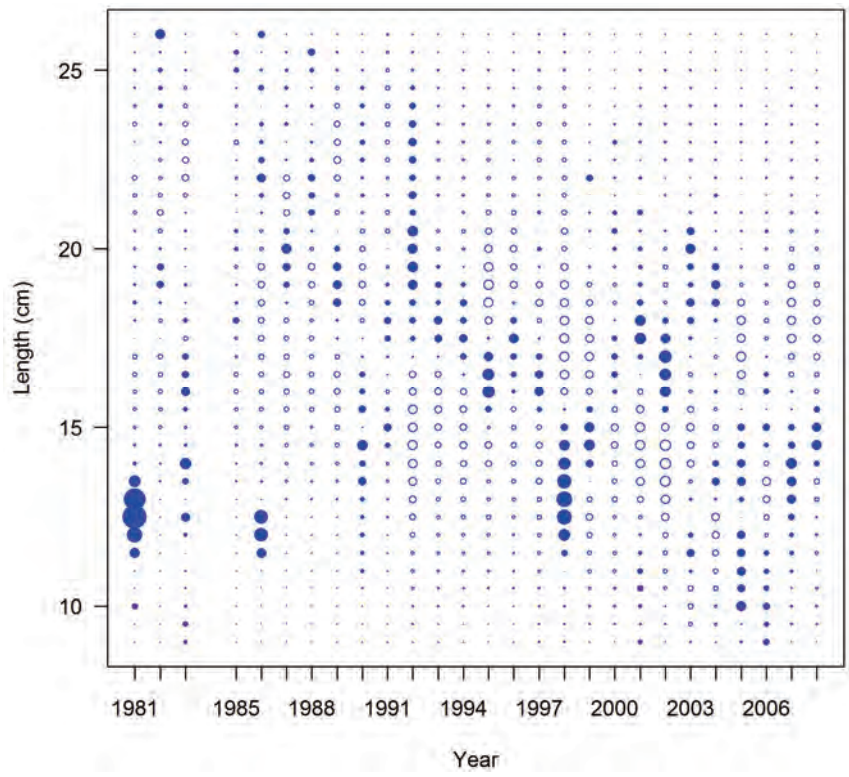


Figure 17c. Pearson residuals (max=14.67) for fit to length-frequency data for the SCA\_S1 fishery.

gst age comps, sexes combined, whole catch, SCA\_S1

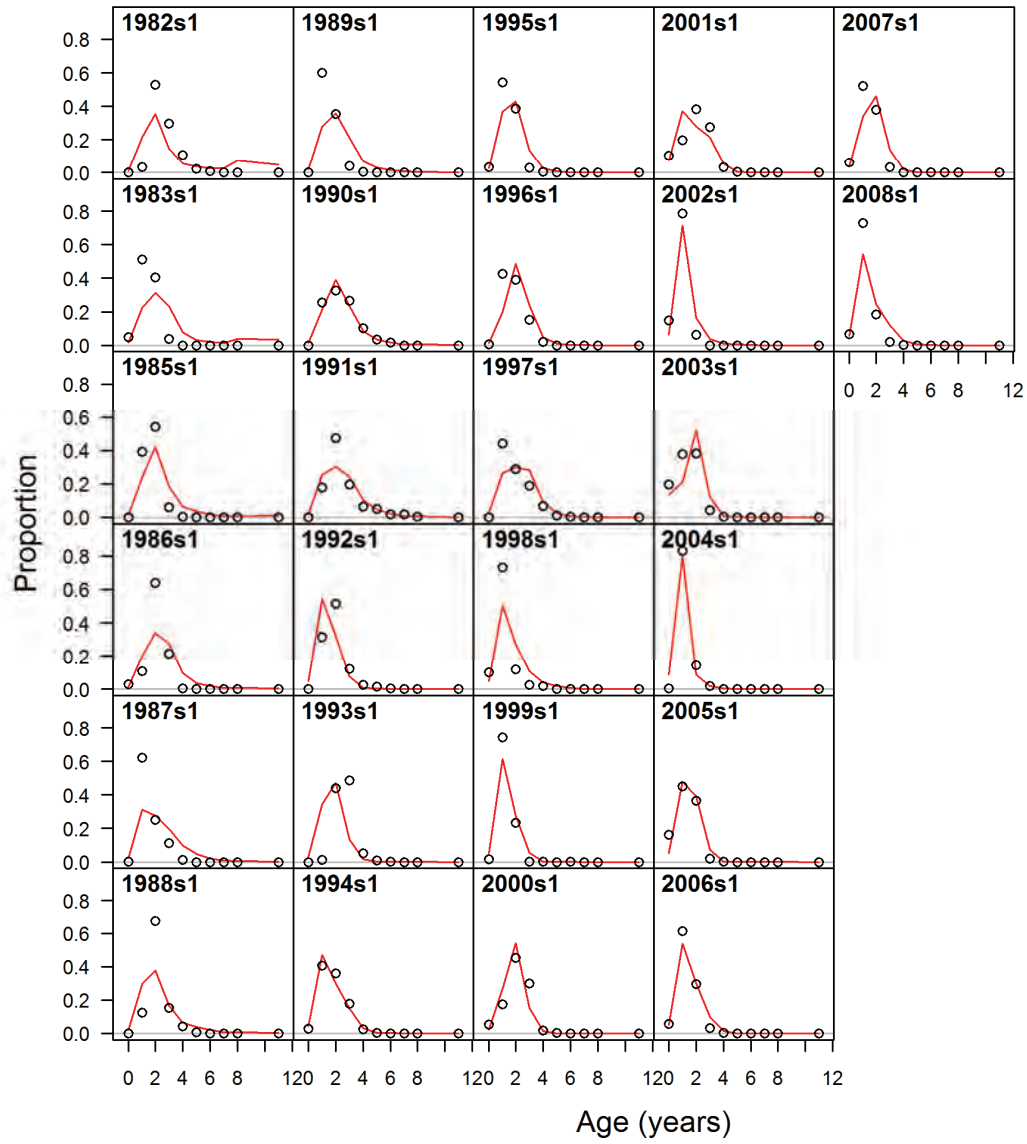


Figure 18a. Base model fits to implied age-frequency data for the SCA\_S1 fishery.



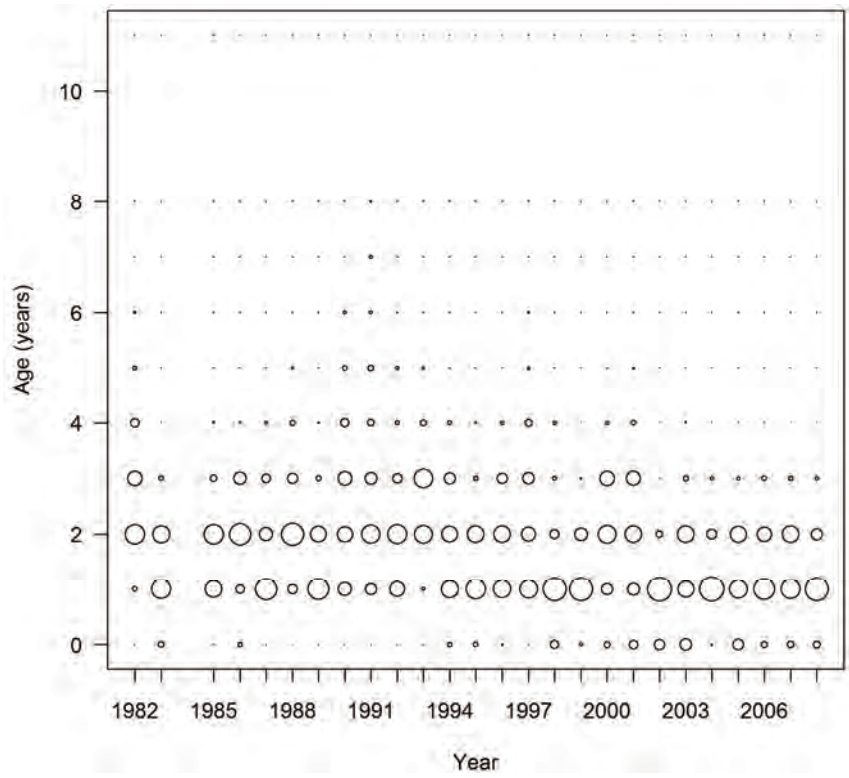


Figure 18b. Bubble plot of age-frequency data for the SCA\_S1 fishery.

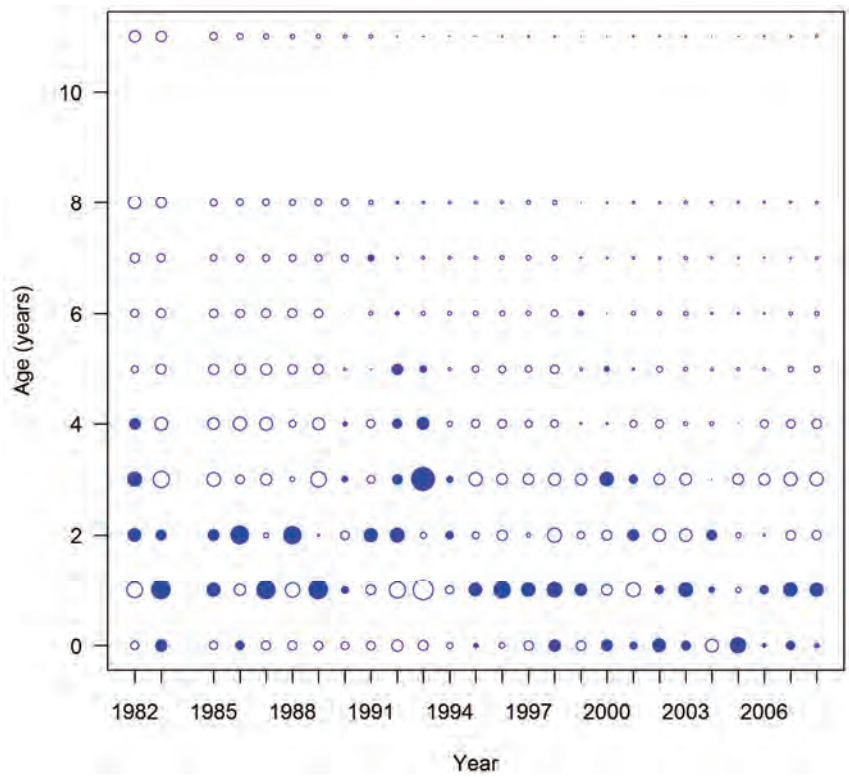


Figure 18c. Pearson residuals (max=1.04) for fit to implied age-frequency data for the SCA\_S1 fishery.

length comps, sexes combined, whole catch, SCA\_S2

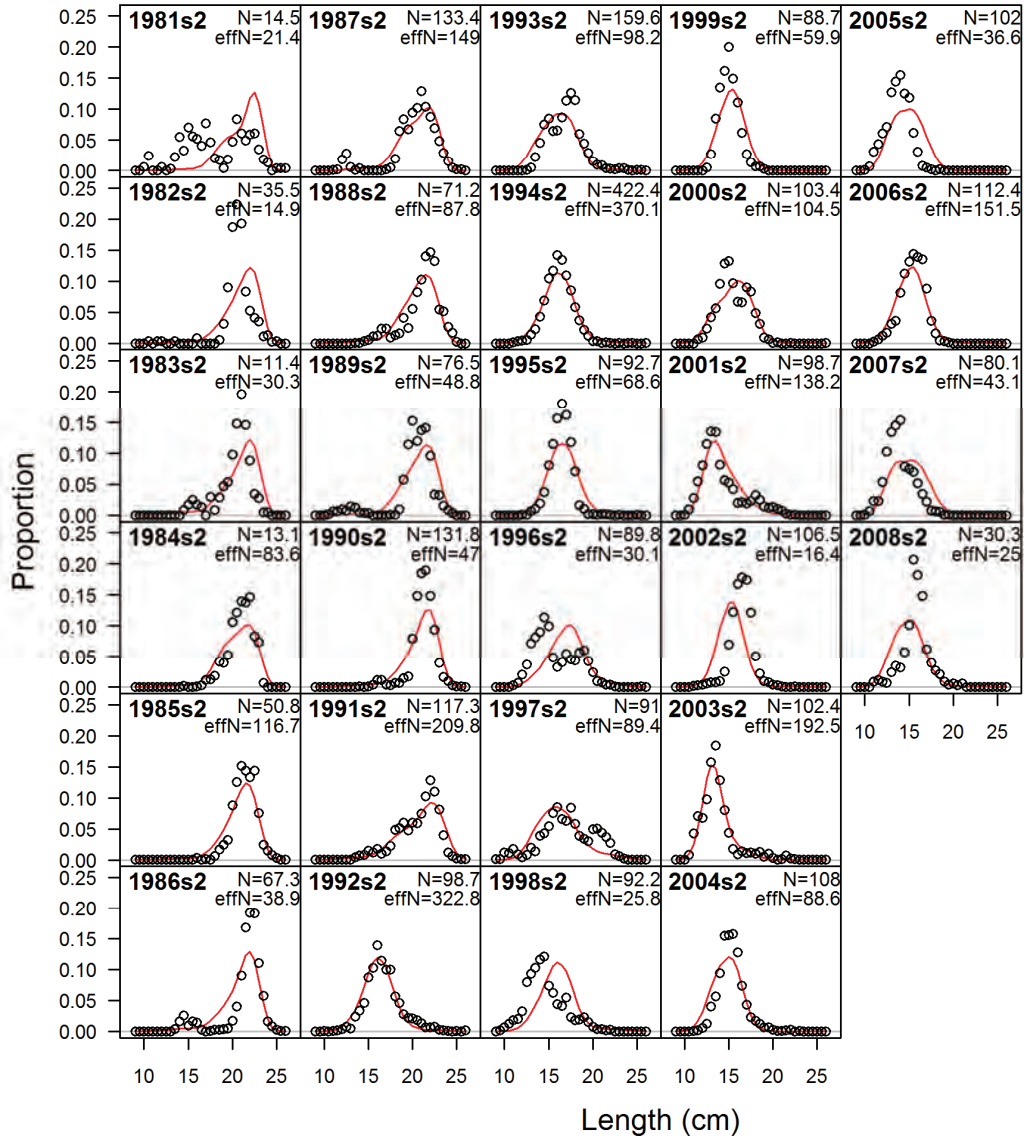


Figure 19a. Base model fits to length-frequency data for the SCA\_S2 fishery.

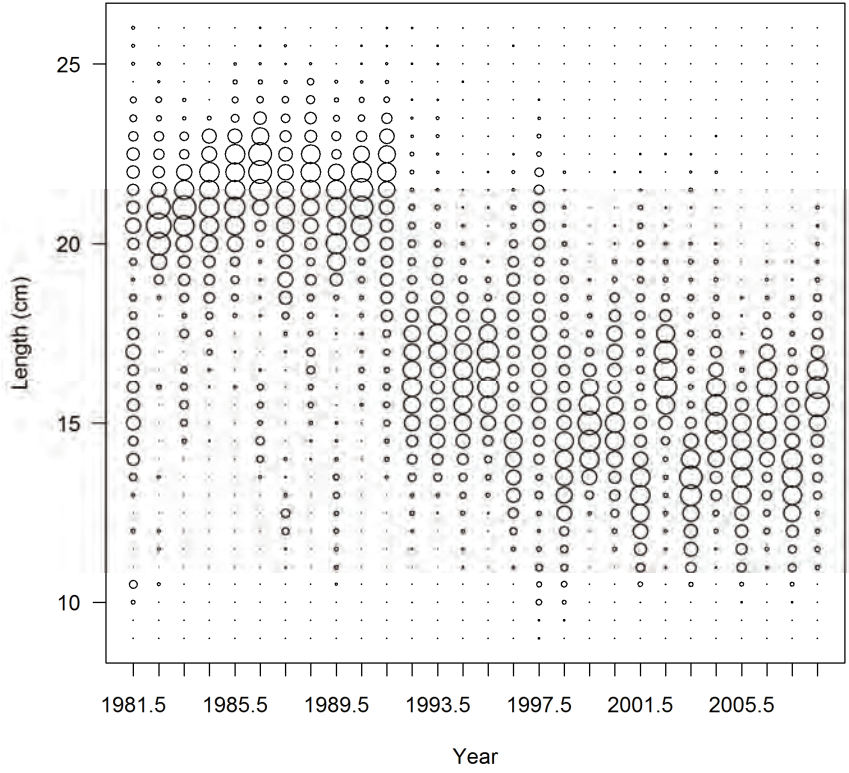


Figure 19b. Bubble plot of length-frequency data for the SCA\_S2 fishery.

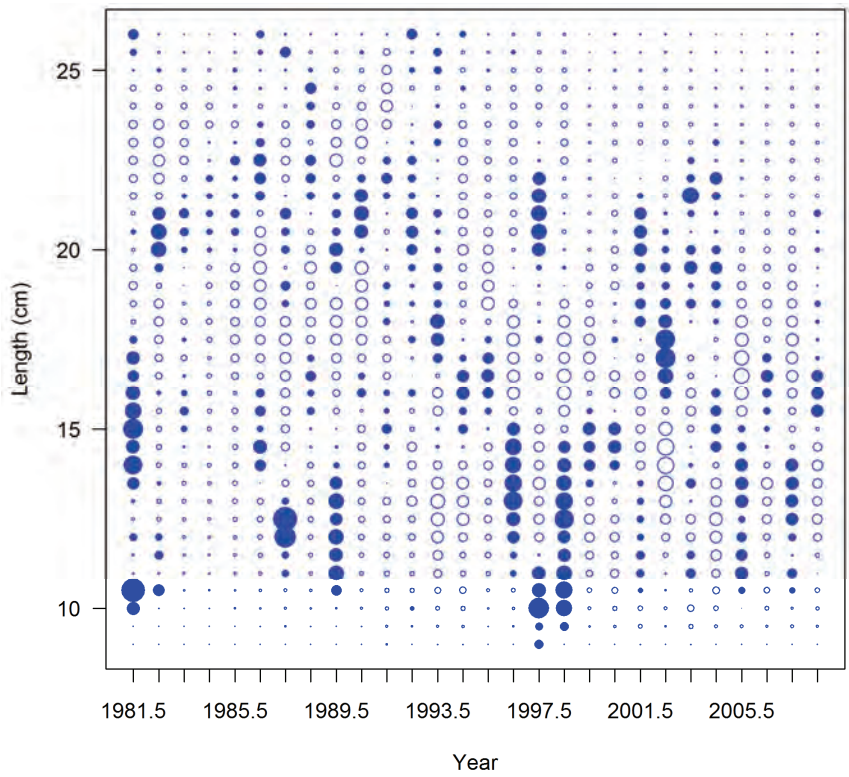


Figure 19c. Pearson residuals (max=6.75) for fit to length-frequency data for the SCA\_S2 fishery.

gst age comps, sexes combined, whole catch, SCA\_S2

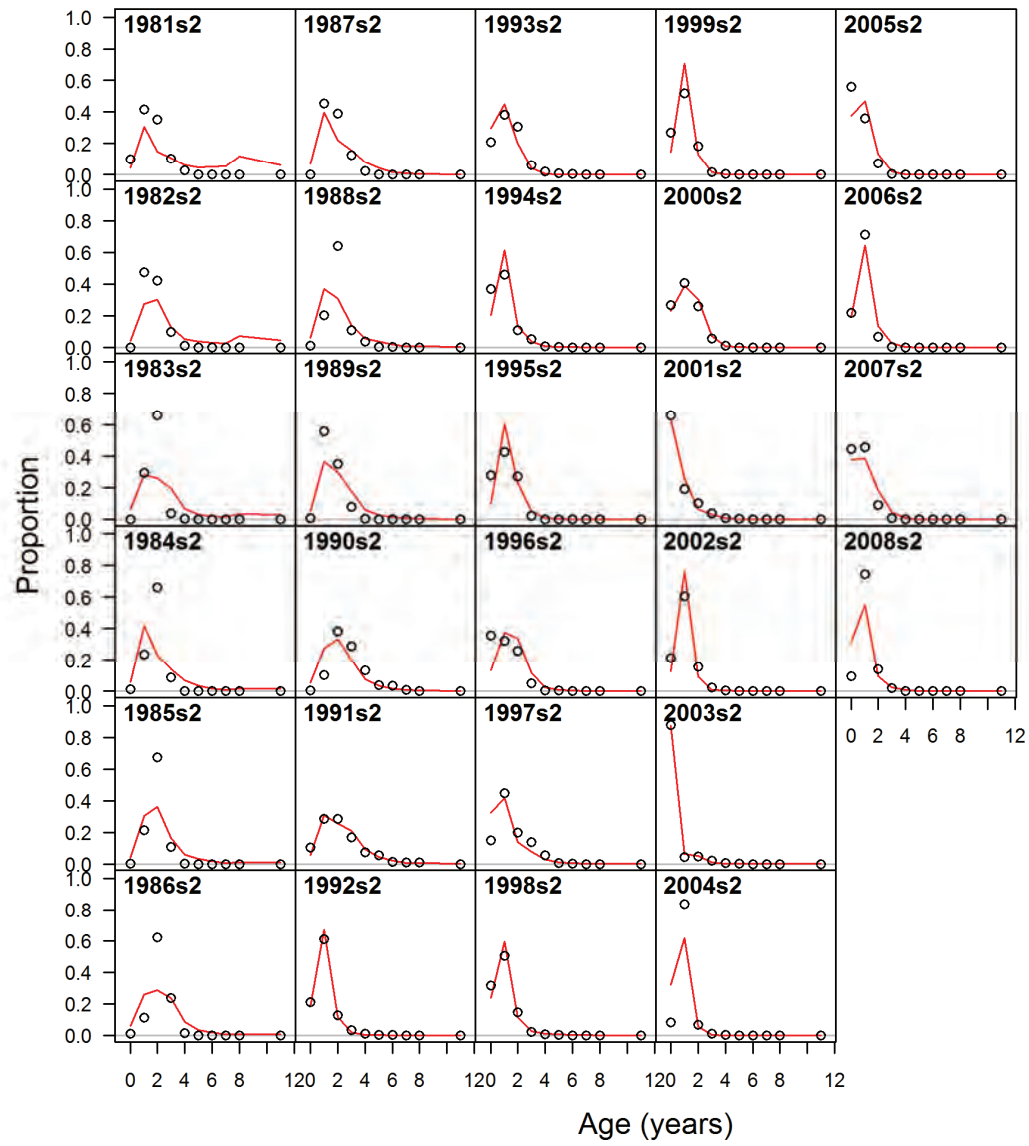


Figure 20a. Base model fits to implied age-frequency data for the SCA\_S2 fishery.

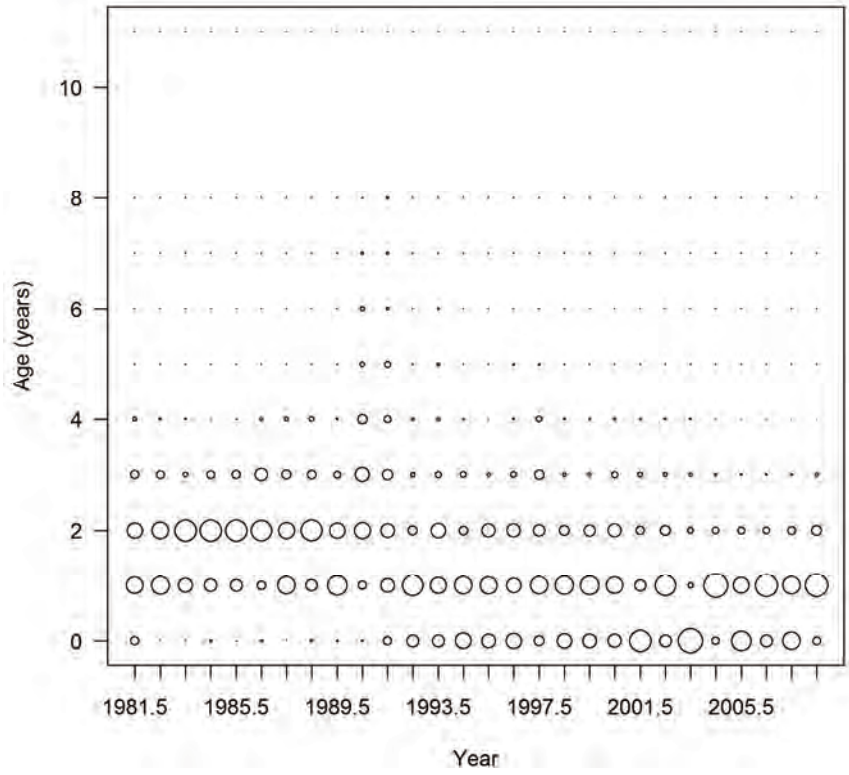


Figure 20b. Bubble plot of implied age-frequency data for the SCA\_S2 fishery.

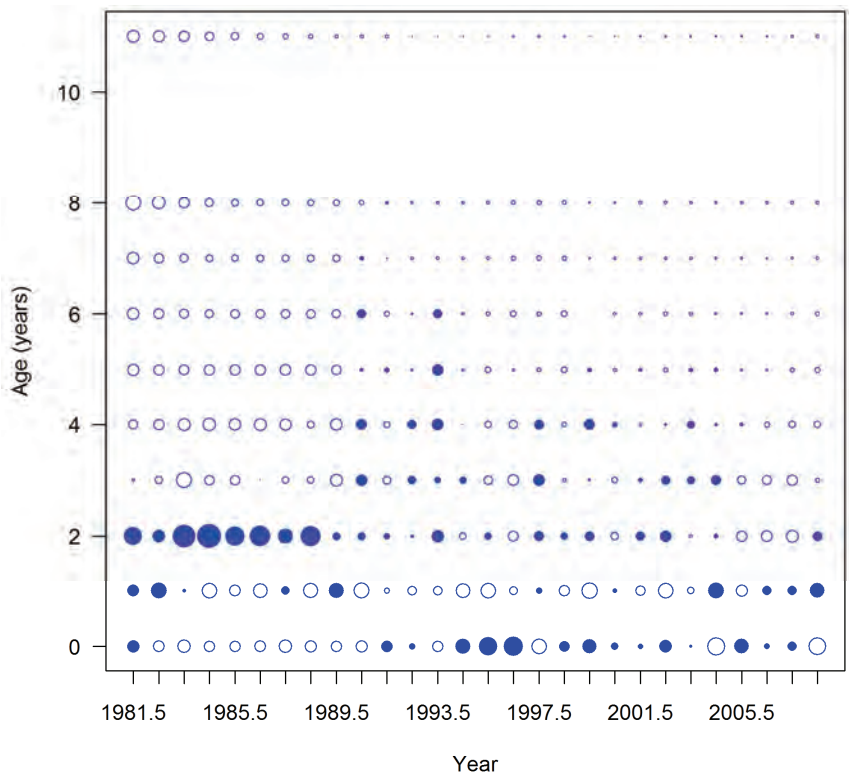


Figure 20c. Pearson residuals (max=1.03) for fit to implied age-frequency data for the SCA\_S2 fishery.

length comps, sexes combined, whole catch, CCA\_S1

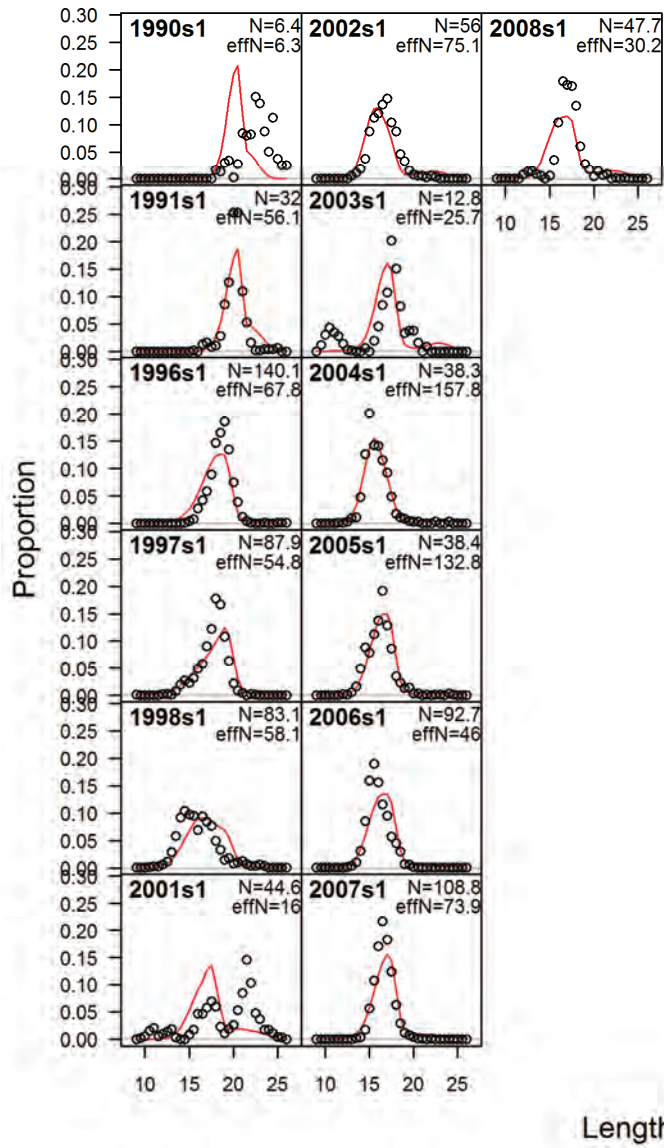


Figure 21a. Base model fits to length-frequency data for the CCA\_S1 fishery.

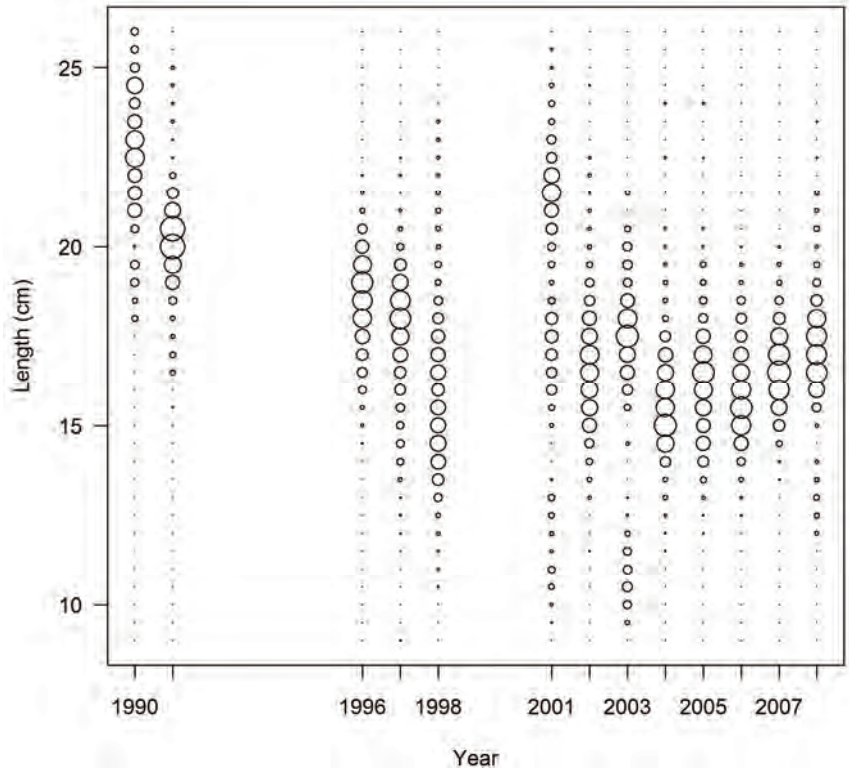


Figure 21b. Bubble plot of length-frequency data for the CCA\_S1 fishery.

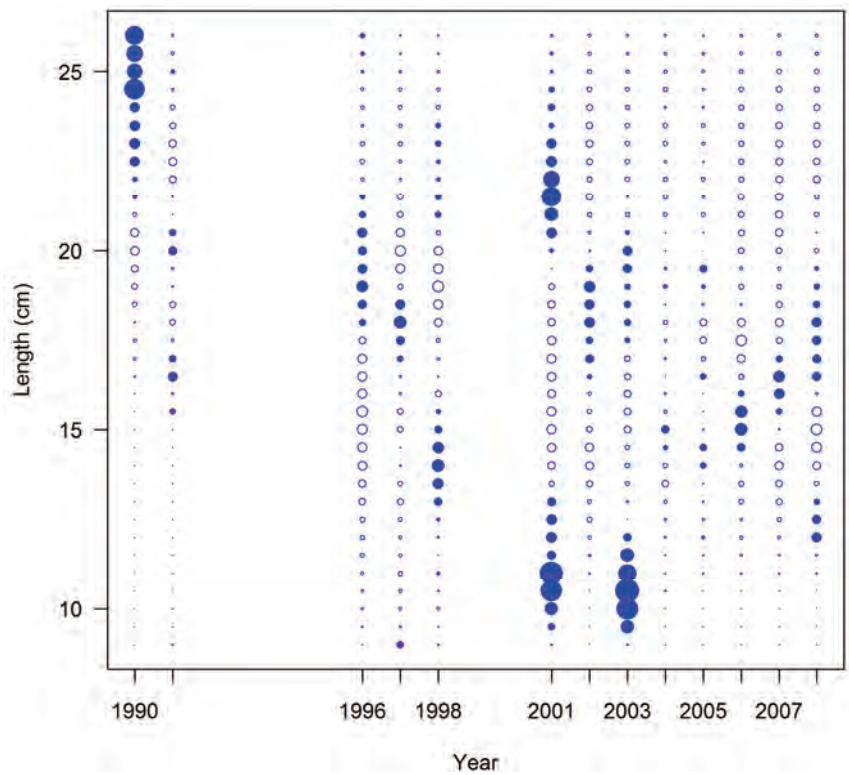


Figure 21c. Pearson residuals (max=9.73) for fit to length-frequency data for the CCA\_S1 fishery.

gst age comps, sexes combined, whole catch, CCA\_S1

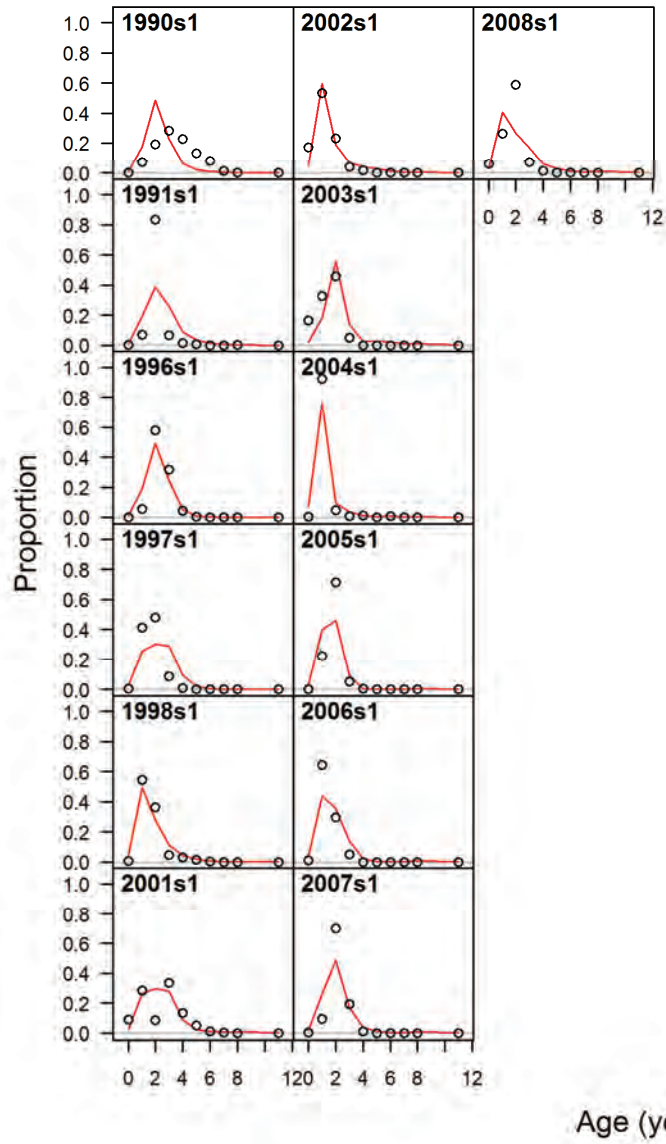


Figure 22a. Base model fits to implied age-frequency data for the CCA\_S1 fishery.



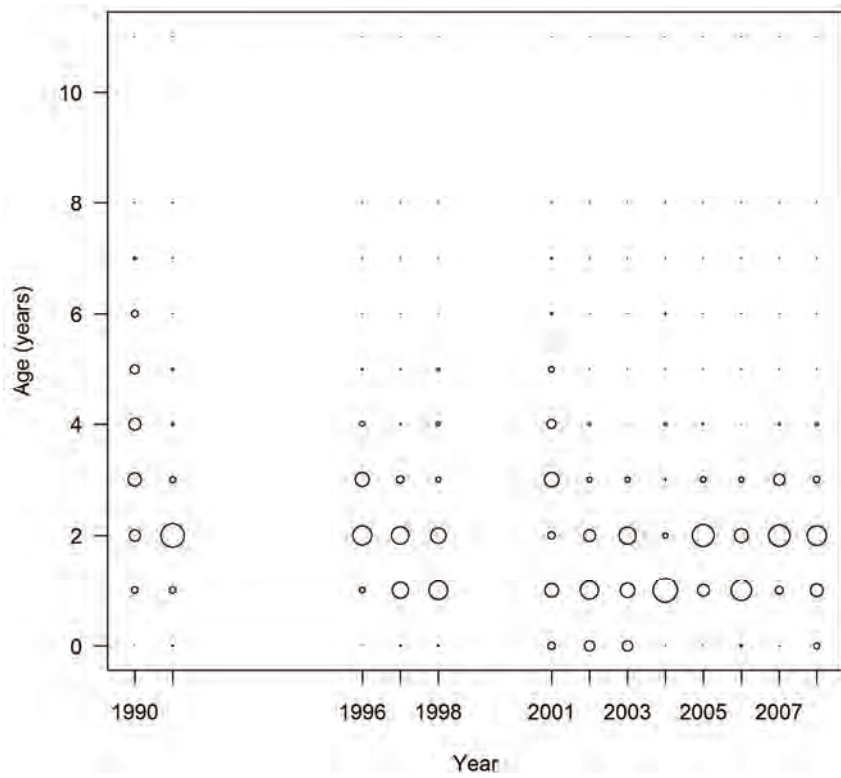


Figure 22b. Bubble plot of implied age-frequency data for the CCA\_S1 fishery.

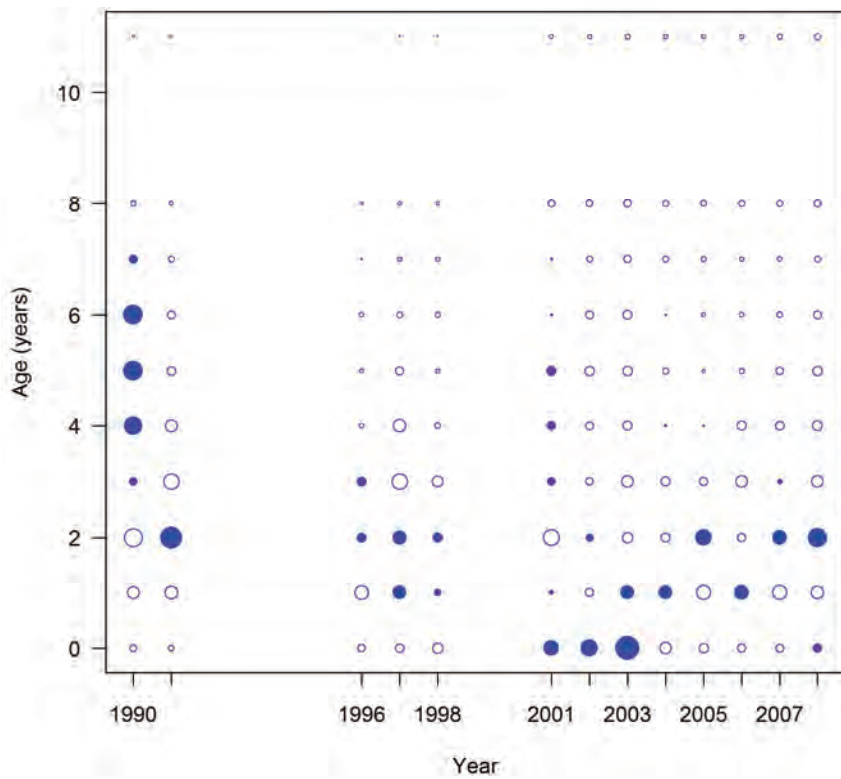


Figure 22c. Pearson residuals (max=1.1) for fit to implied age-frequency data for the CCA\_S1 fishery.

length comps, sexes combined, whole catch, CCA\_S2

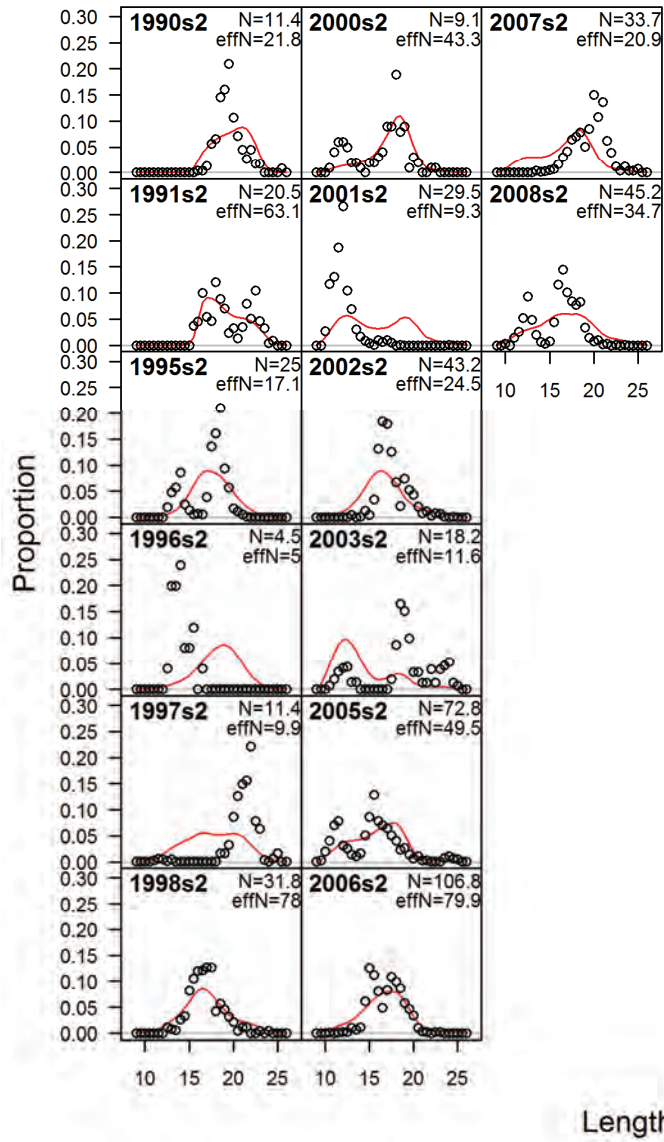


Figure 23a. Base model fits to length-frequency data for the CCA\_S2 fishery.

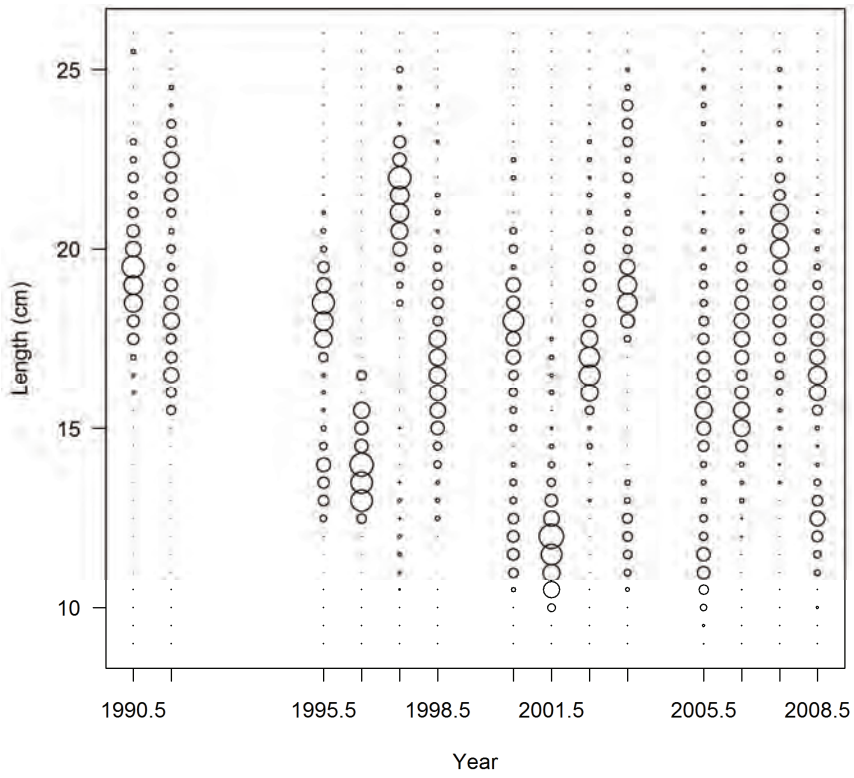


Figure 23b. Bubble plot of length-frequency data for the CCA\_S2 fishery.

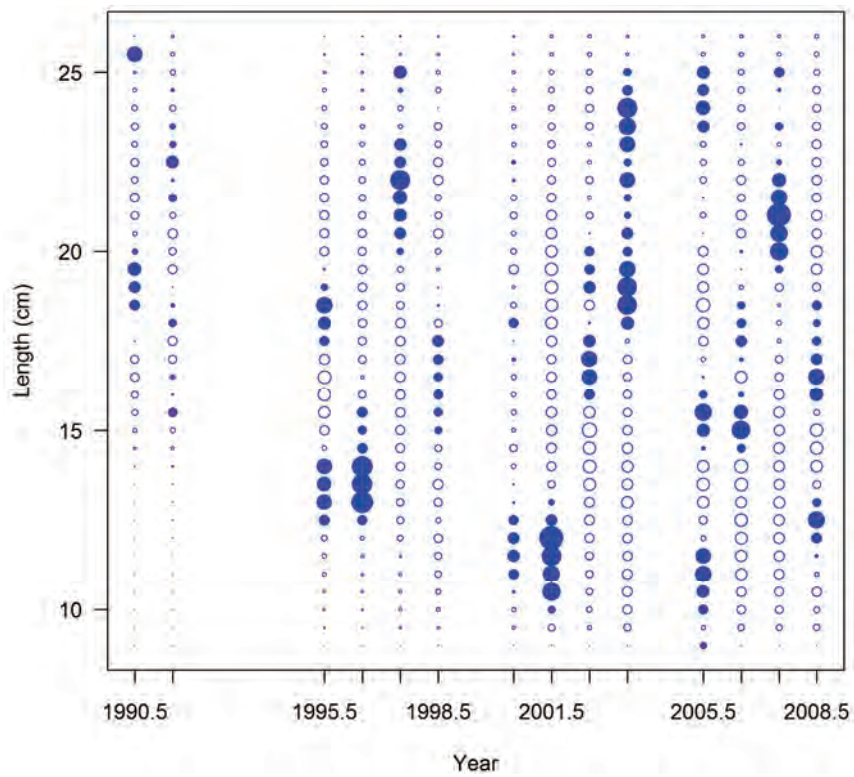


Figure 23c. Pearson residuals (max=4.97) for fit to length-frequency data for the CCA\_S2 fishery.

gst age comps, sexes combined, whole catch, CCA\_S2

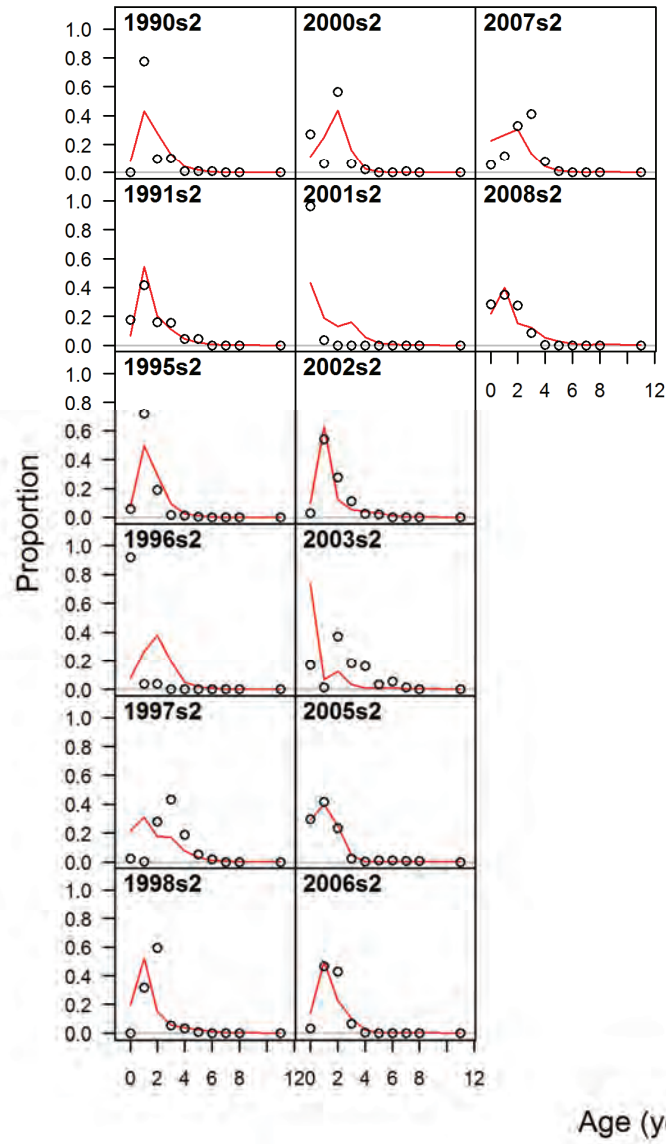


Figure 24a. Base model fits to implied age-frequency data for the CCA\_S2 fishery.

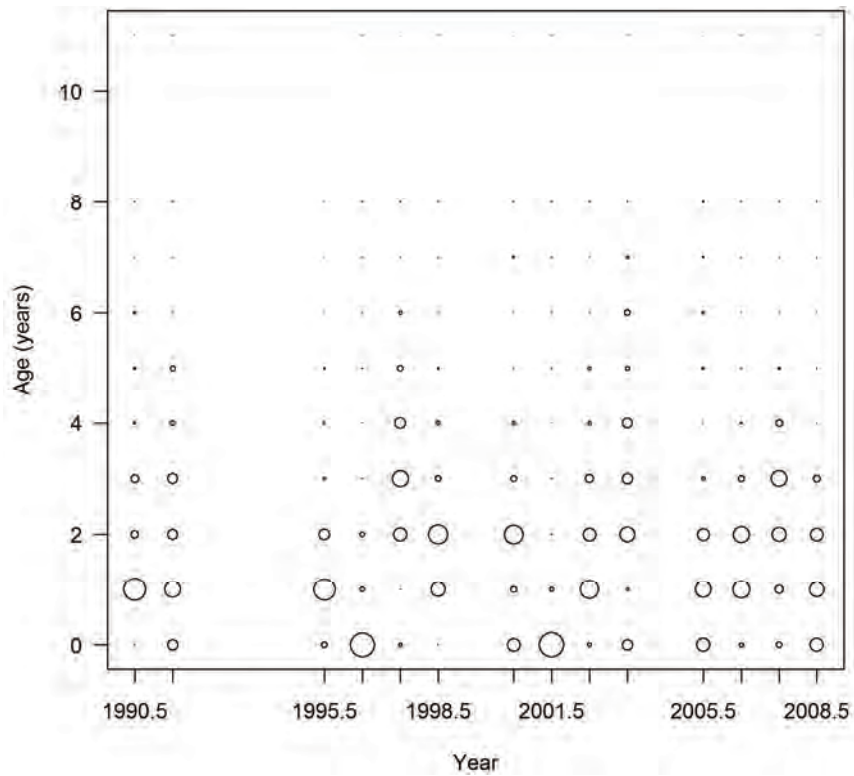


Figure 24b. Bubble plot of implied age-frequency data for the CCA\_S2 fishery.

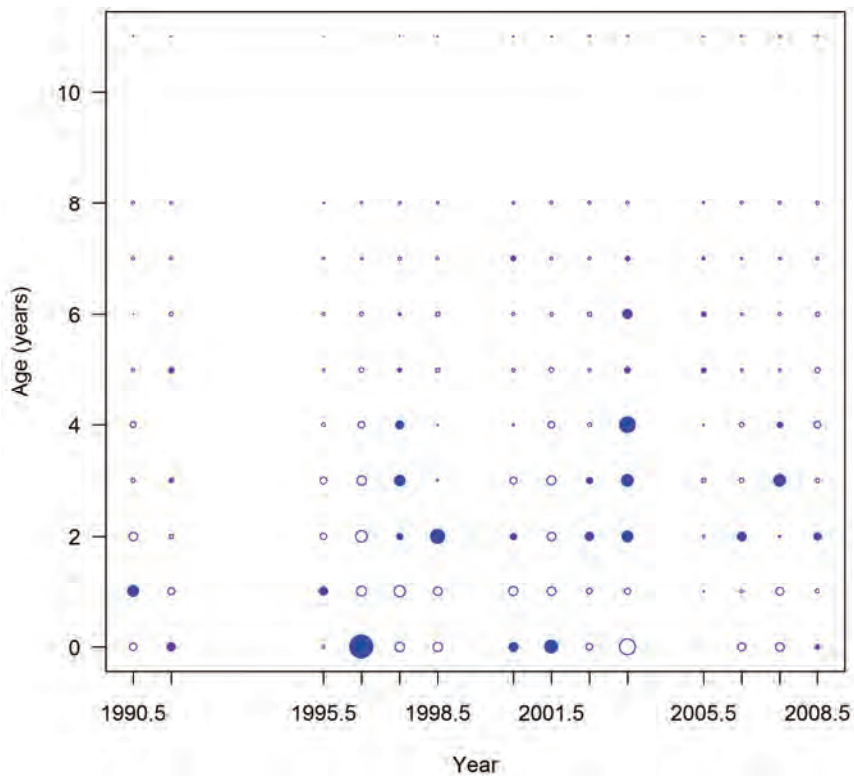


Figure 24c. Pearson residuals (max=3.11) for fit to implied age-frequency data for the CCA\_S2 fishery.

length comps, sexes combined, whole catch, PNW

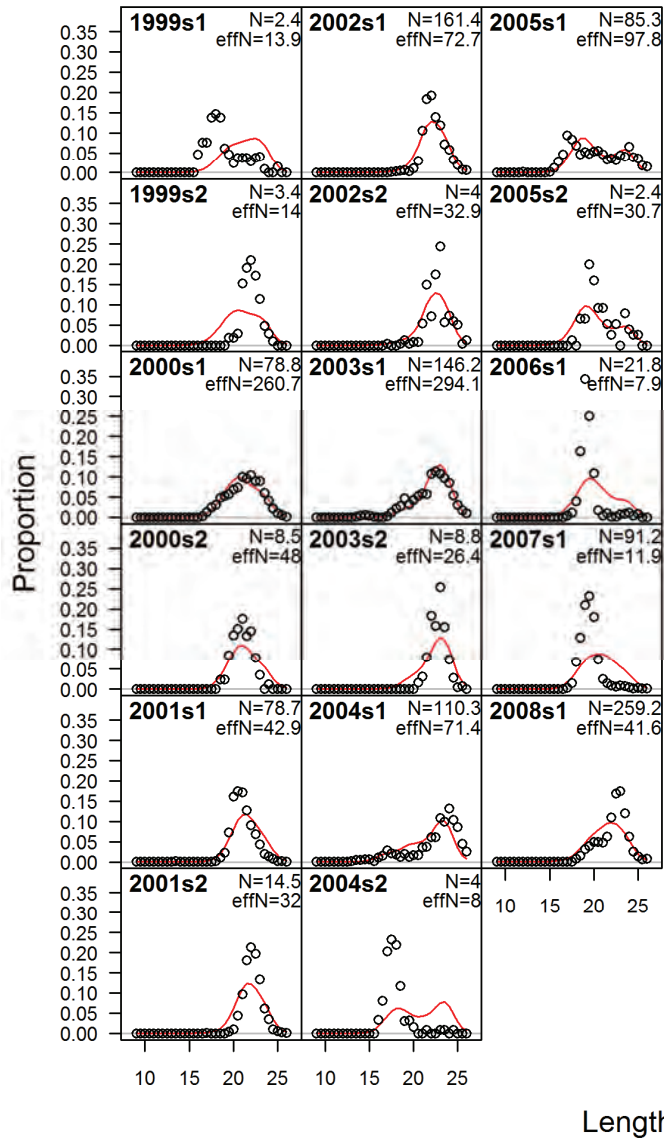


Figure 25a. Base model fits to length-frequency data for the PNW fishery.

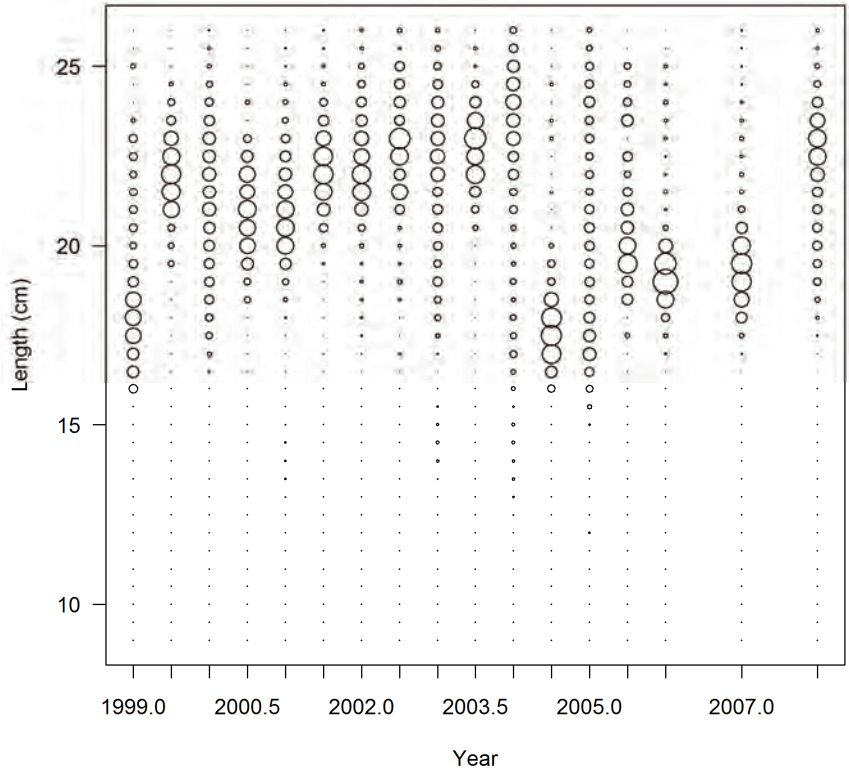


Figure 25b. Bubble plot of length-frequency data for the PNW fishery.

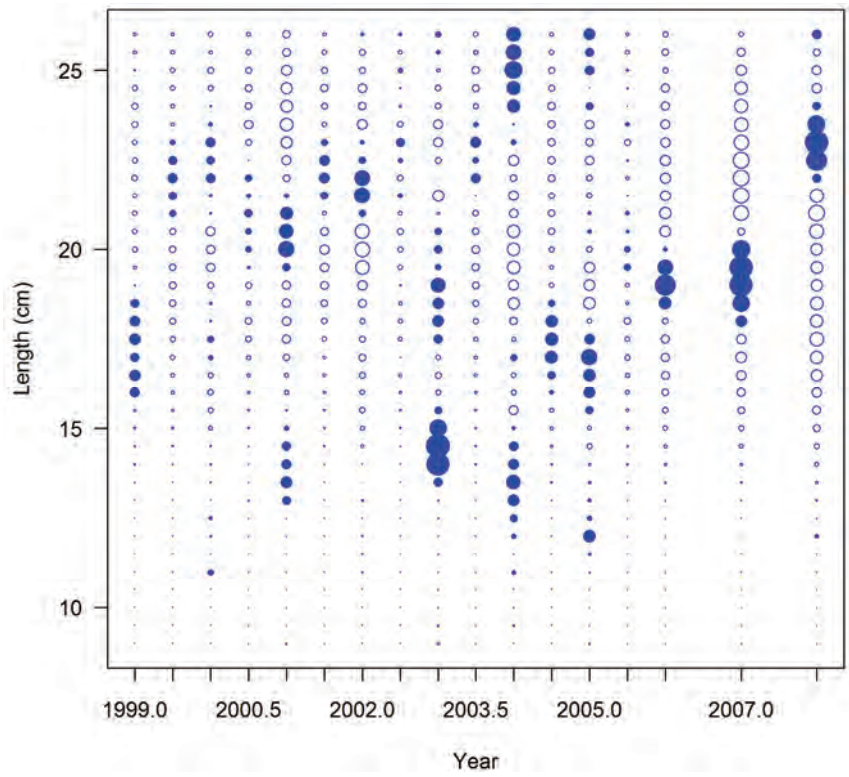


Figure 25c. Pearson residuals (max=5.51) for fit to length-frequency data for the PNW fishery.

gst age comps, sexes combined, whole catch, PNW

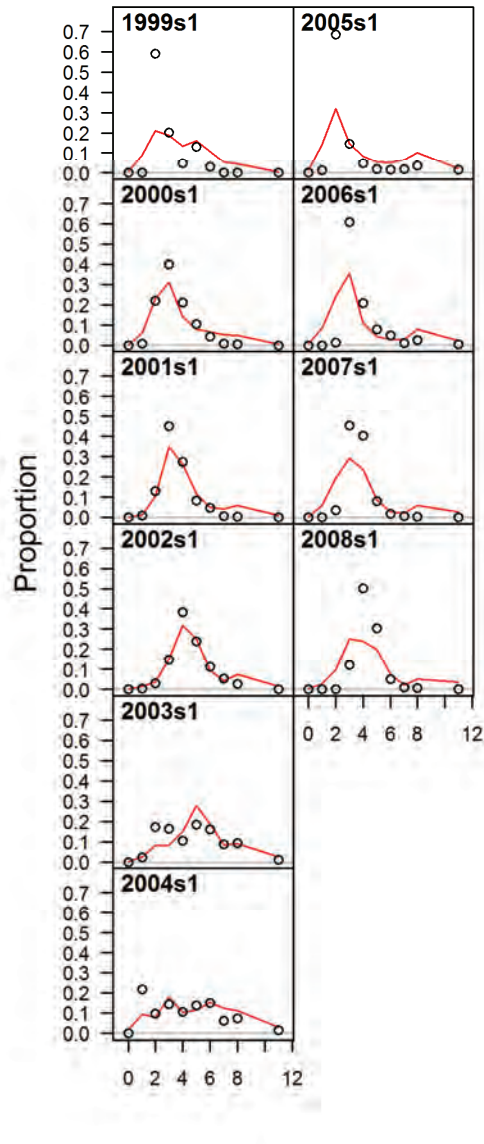


Figure 26a. Base model fits to implied age-frequency data for the PNW fishery.



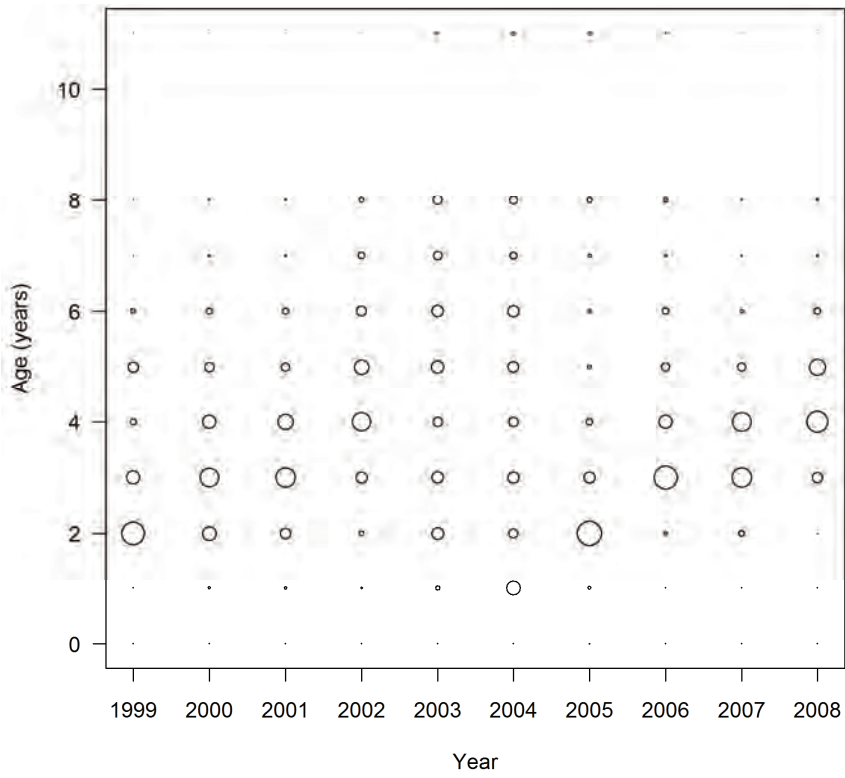


Figure 26b. Bubble plot of implied age-frequency data for the PNW fishery.

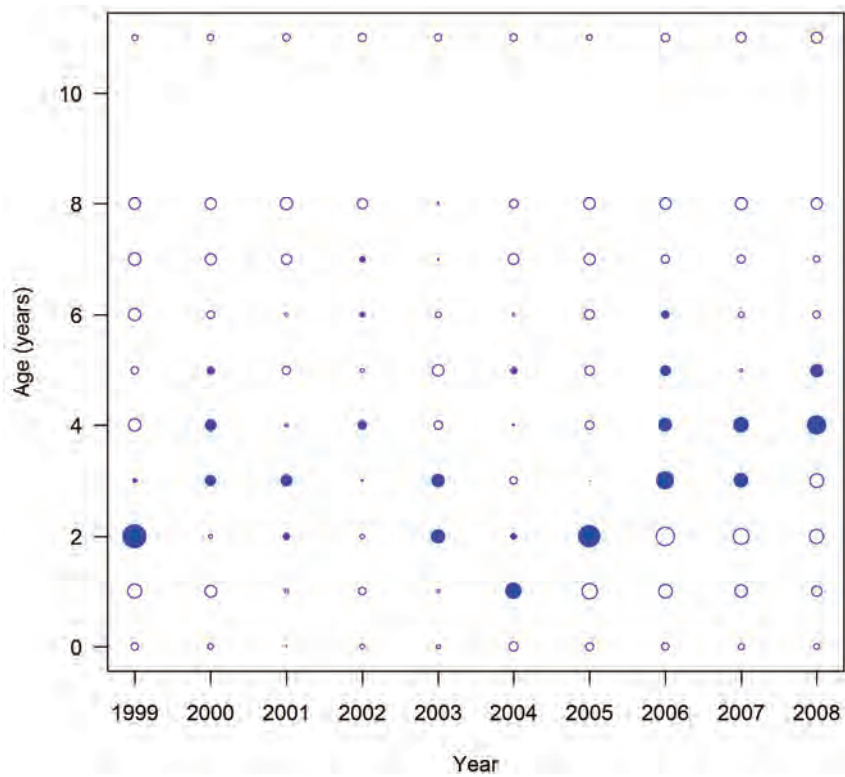


Figure 26c. Pearson residuals (max=0.94) for fit to implied age-frequency data for the PNW fishery.

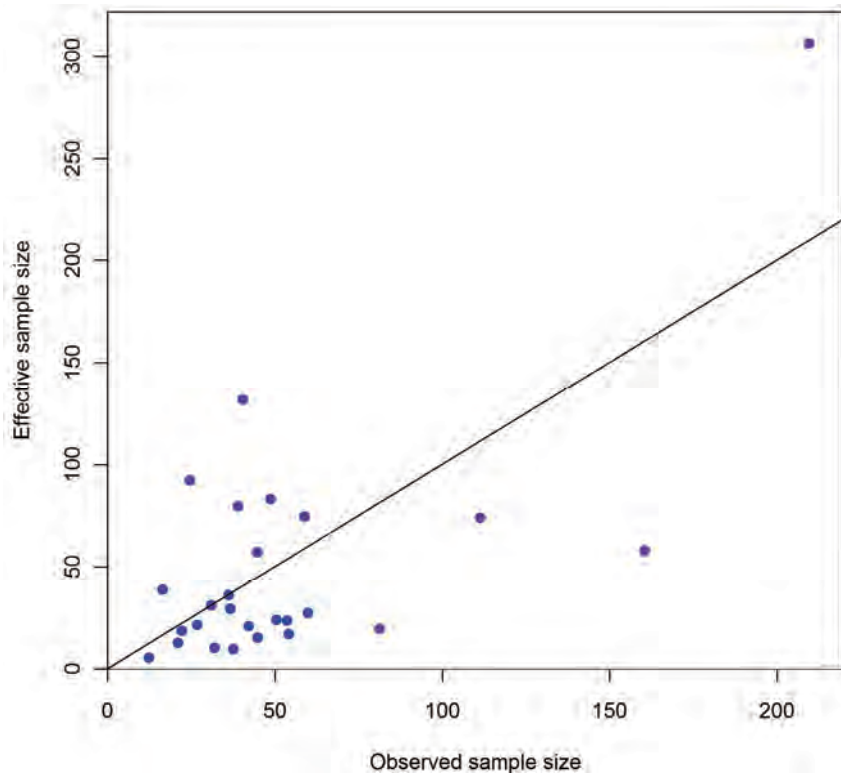


Figure 27a. Observed and effective sample sizes for the ENS fishery length-frequency data.

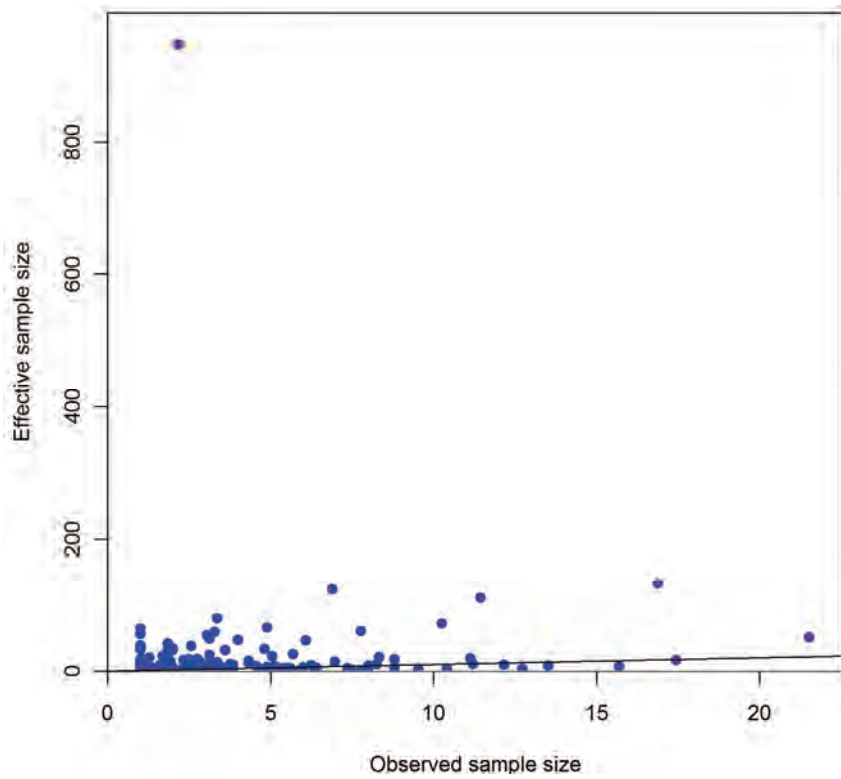


Figure 27b. Observed and effective sample sizes for the ENS fishery conditional age-at-length data.

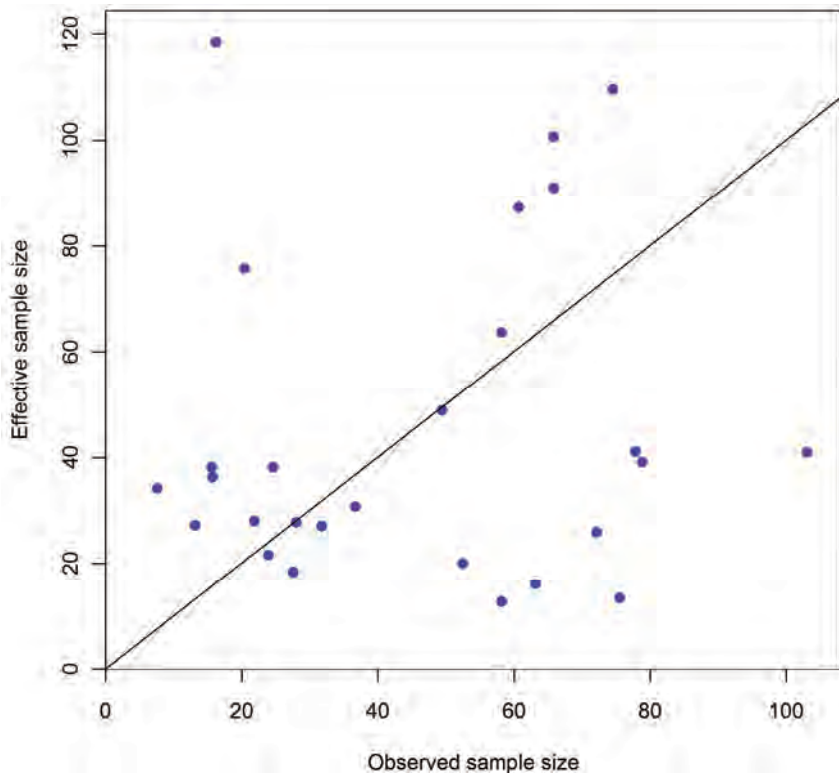


Figure 28a. Observed and effective sample sizes for the SCA\_S1 fishery length-frequency data.

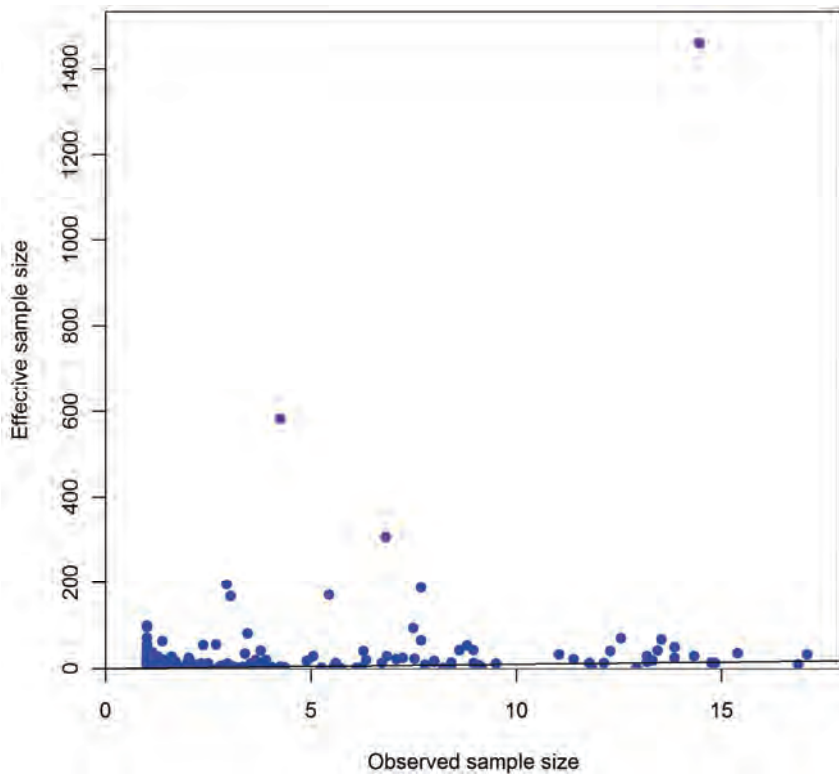


Figure 28b. Observed and effective sample sizes for the SCA\_S1 fishery conditional age-at-length data.

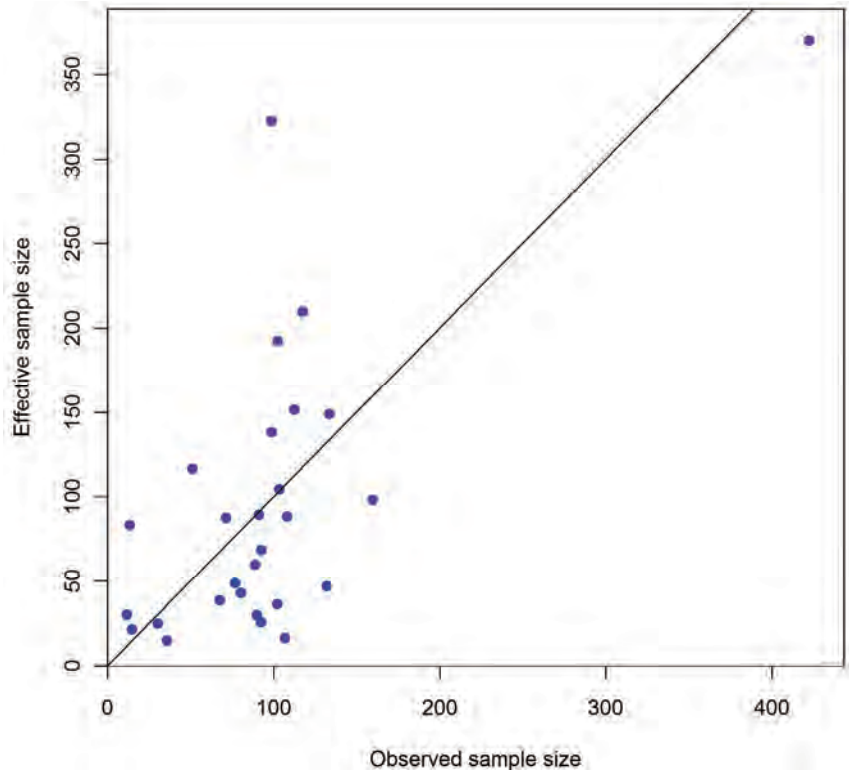


Figure 29a. Observed and effective sample sizes for the SCA\_S2 fishery length-frequency data.

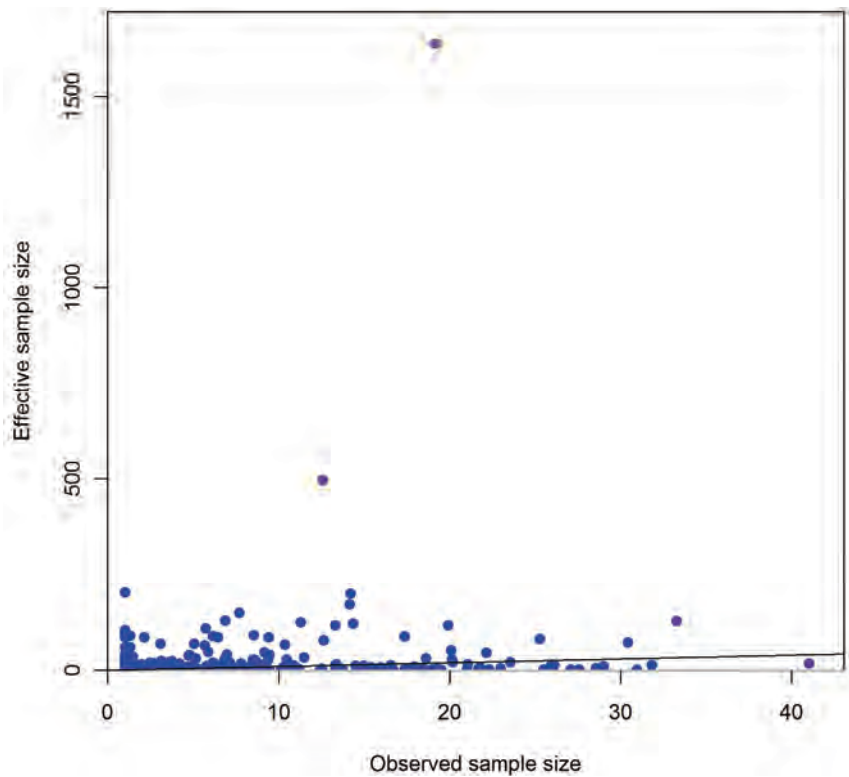


Figure 29b. Observed and effective sample sizes for the SCA\_S2 fishery conditional age-at-length data.

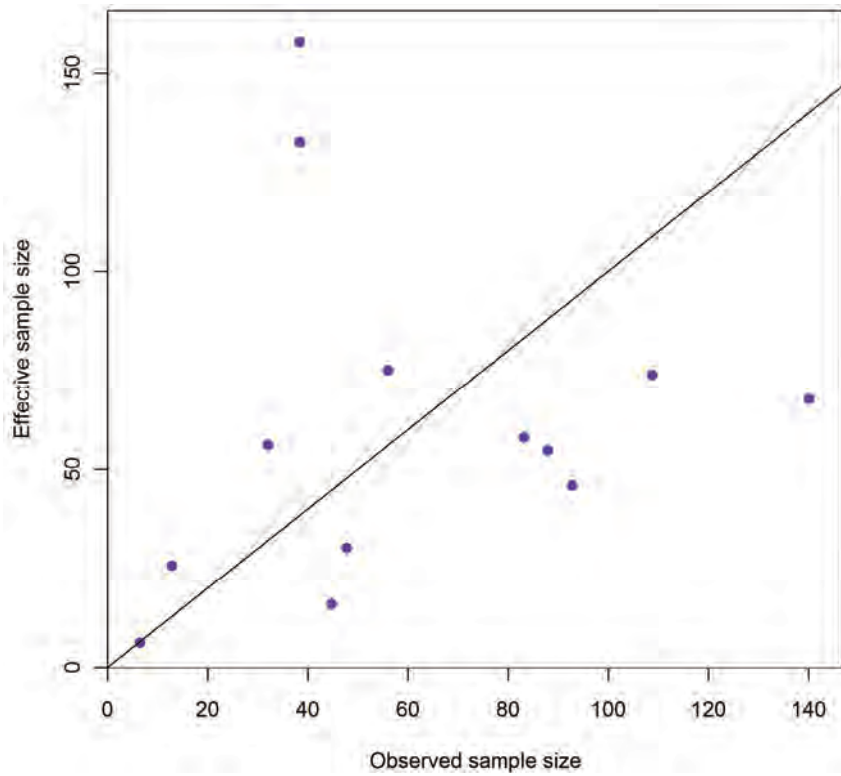


Figure 30a. Observed and effective sample sizes for the CCA\_S1 fishery length-frequency data.

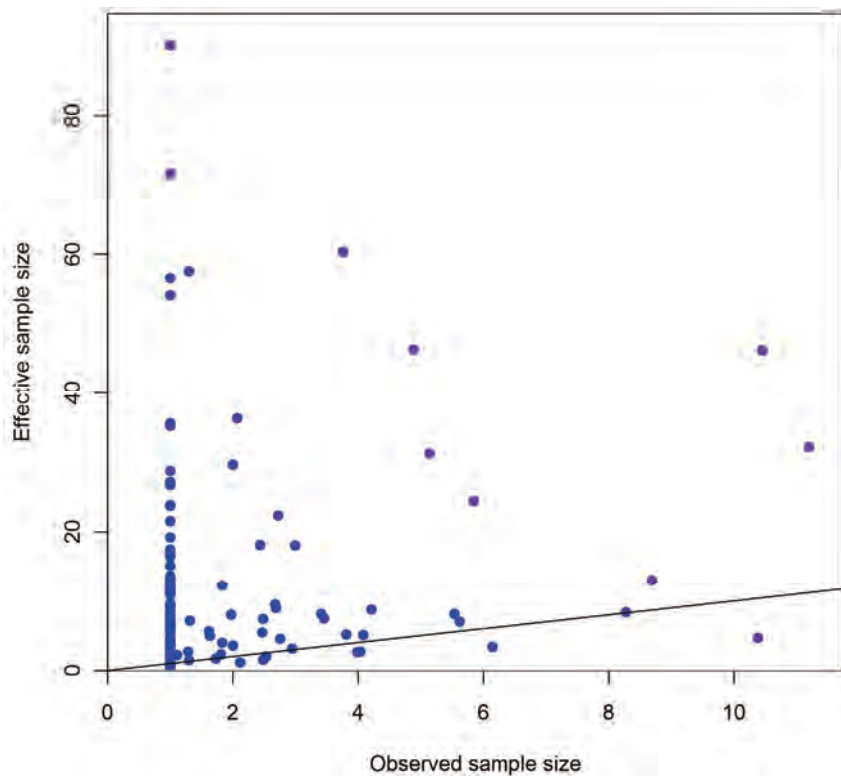


Figure 30b. Observed and effective sample sizes for the CCA\_S1 fishery conditional age-at-length data.

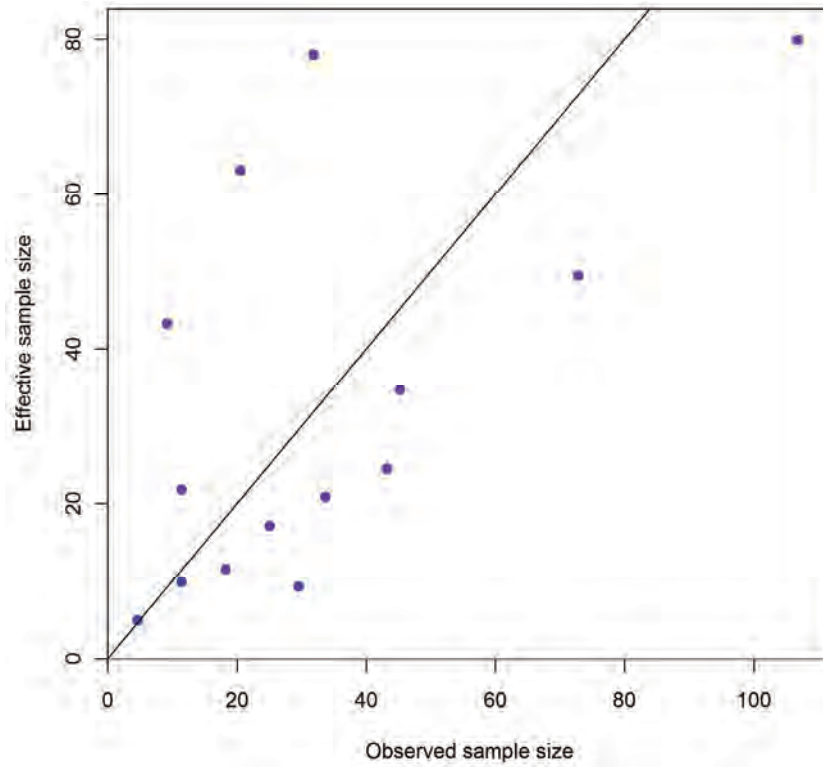


Figure 31a. Observed and effective sample sizes for the CCA\_S2 fishery length-frequency data.

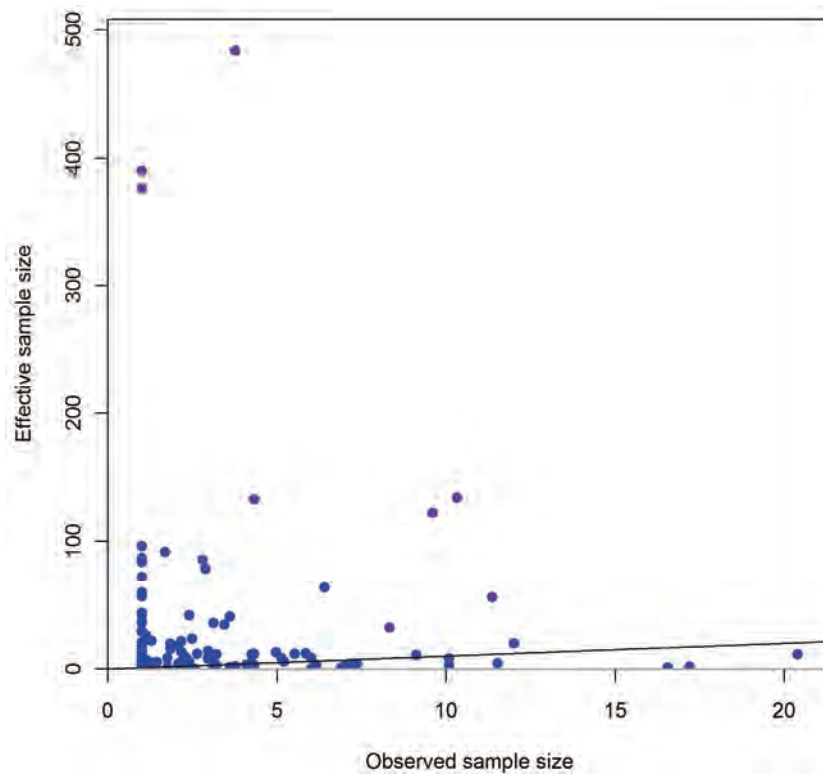


Figure 31b. Observed and effective sample sizes for the CCA\_S2 fishery conditional age-at-length data.

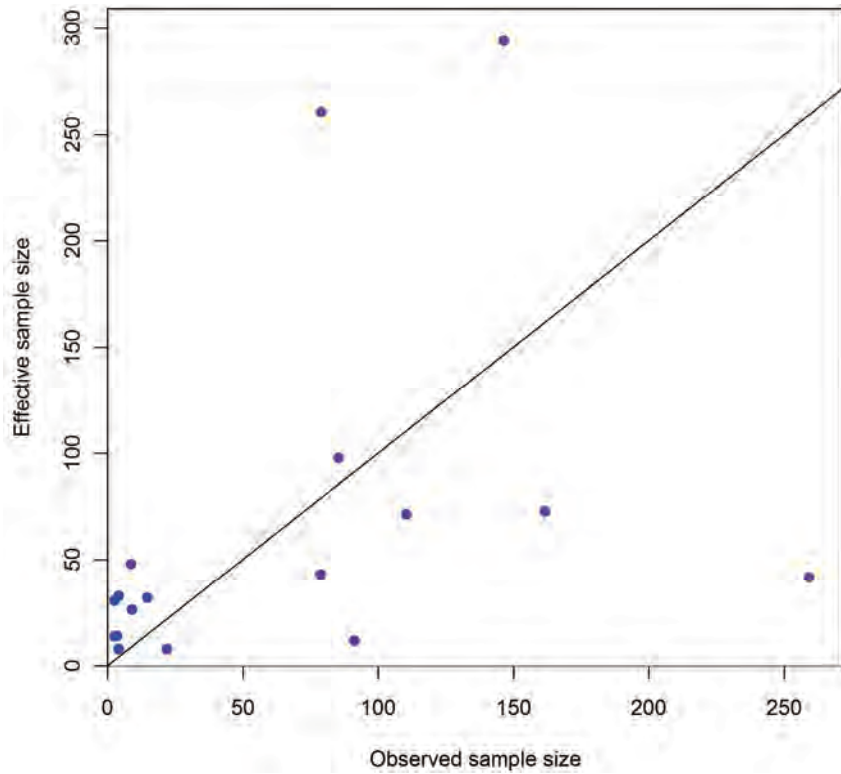


Figure 32a. Observed and effective sample sizes for the PNW fishery length-frequency data.

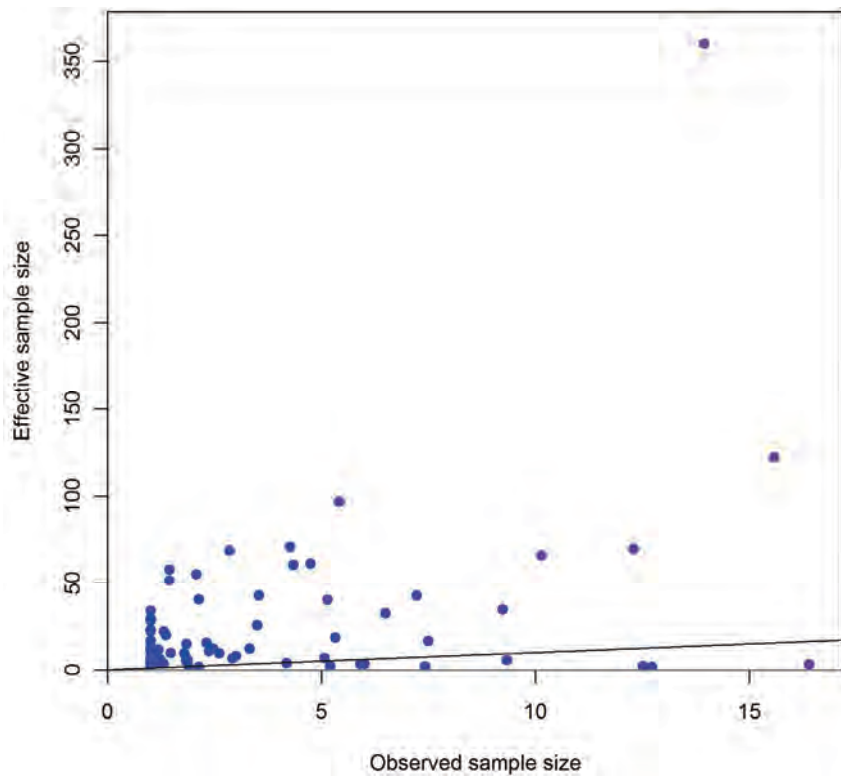


Figure 32b. Observed and effective sample sizes for the PNW fishery conditional age-at-length data.

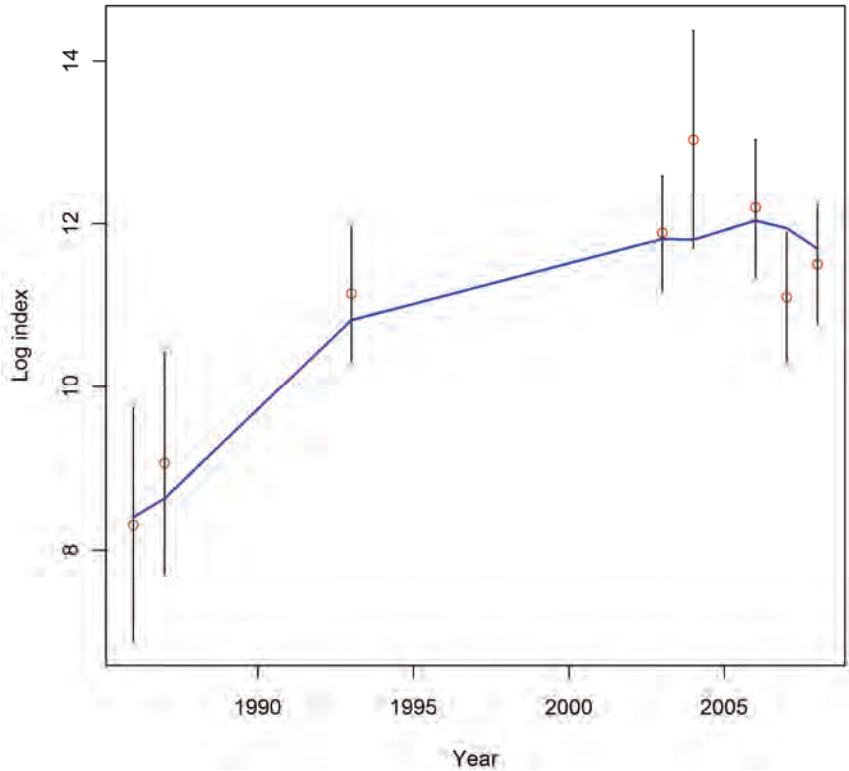


Figure 33a. Base model fit to the Daily Egg Production Method (DEPM) series of female spawning biomass ( $q=0.1645$ ).

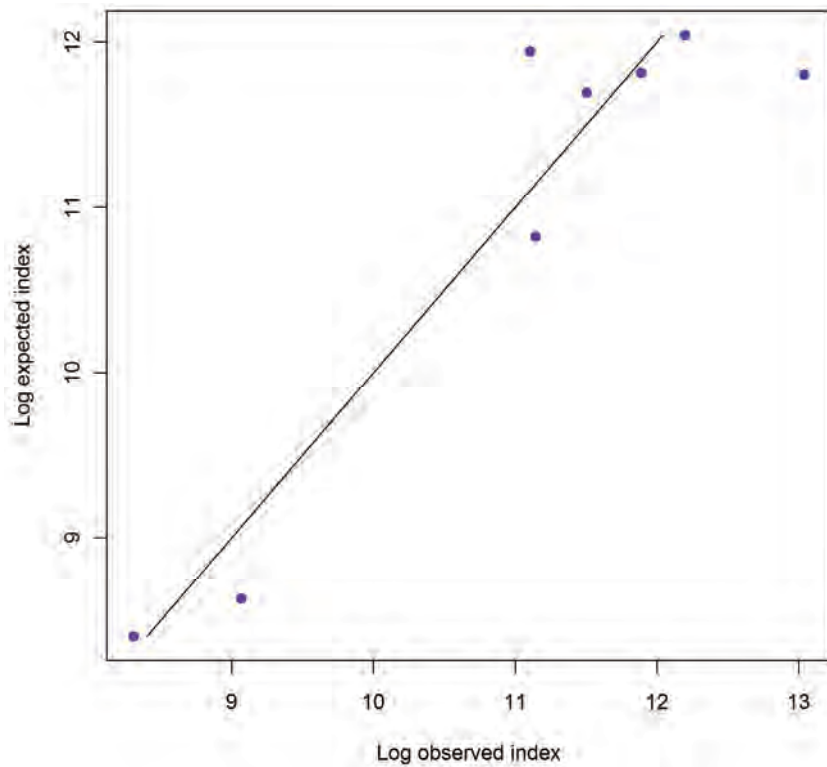


Figure 33b. Relationship between observed and expected values (log scale) for the DEPM survey (base model). Straight line is 1 to 1 relationship.



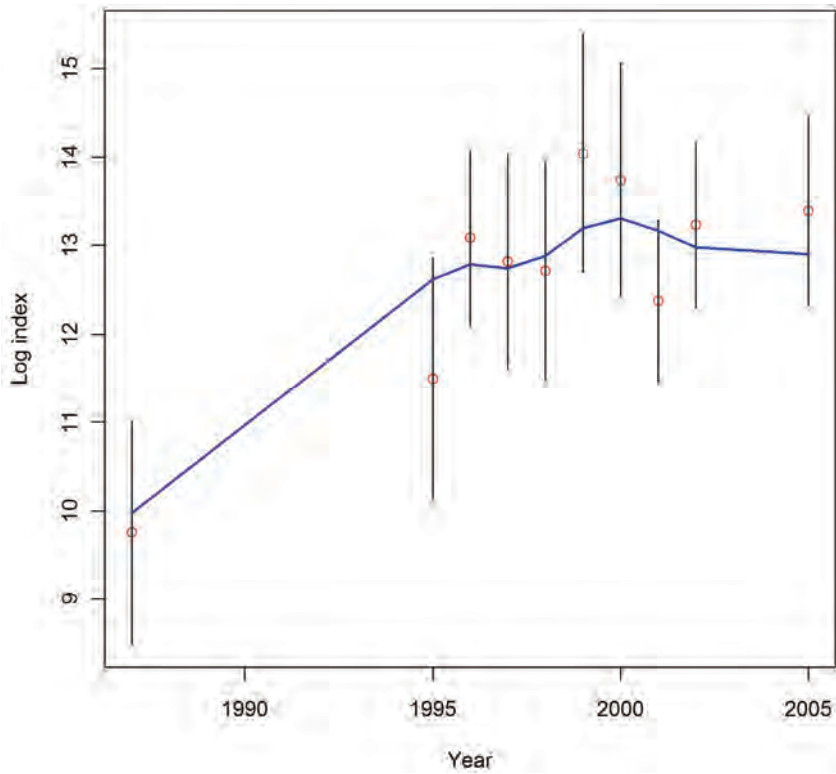


Figure 34a. Base model fit to the Total Egg Production (TEP) series of total spawning biomass ( $Q=0.4195$ ).

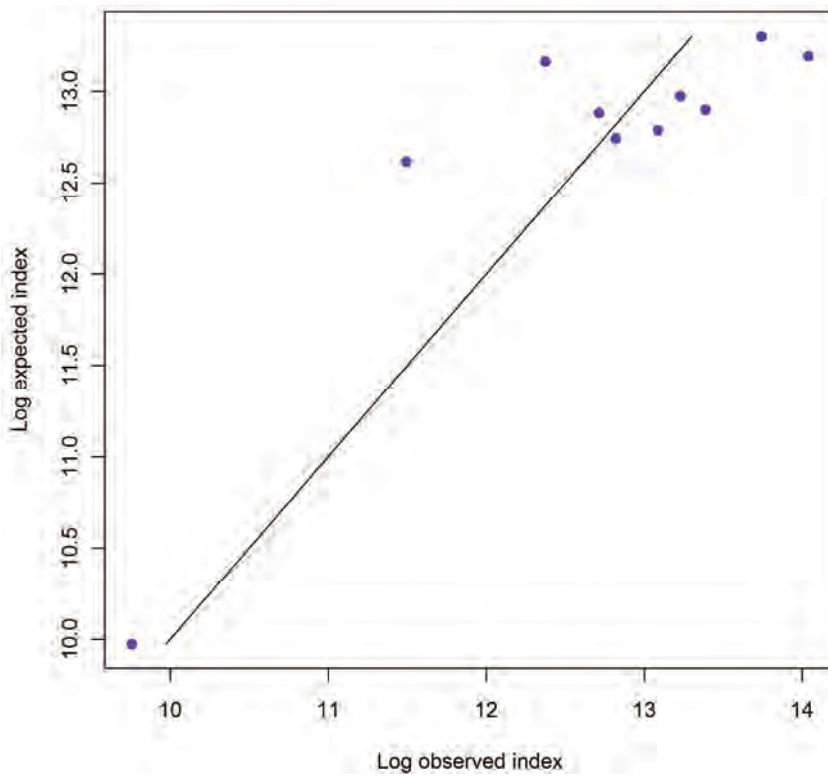


Figure 34b. Relationship between observed and expected values (log scale) for the TEP survey (base model). Straight line is 1 to 1 relationship.

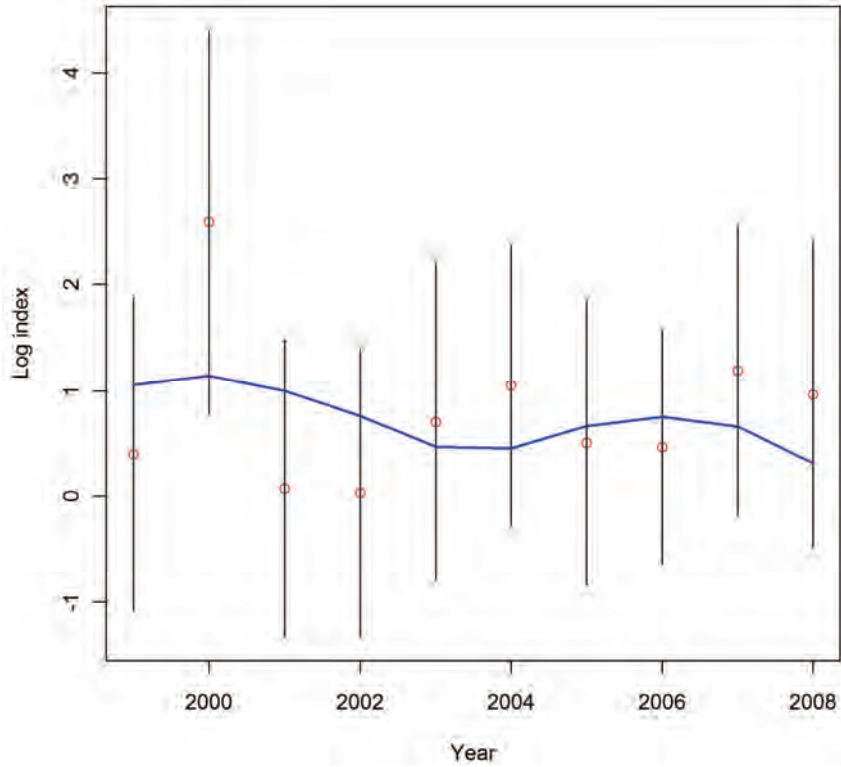


Figure 35a. Model fit (pre-STAR base model) to the Predator Forage Fish Survey (PFFS) series.

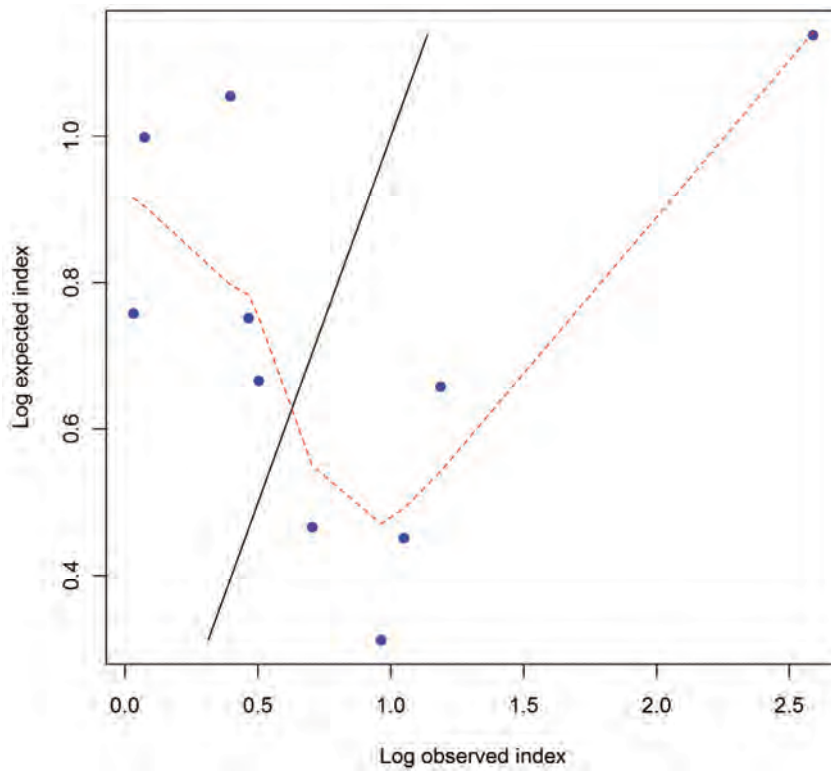


Figure 35b. Relationship between observed and expected values (log scale) for the PFFS survey (pre-STAR base model). Straight line is 1 to 1 relationship; dashed is LOESS fit.

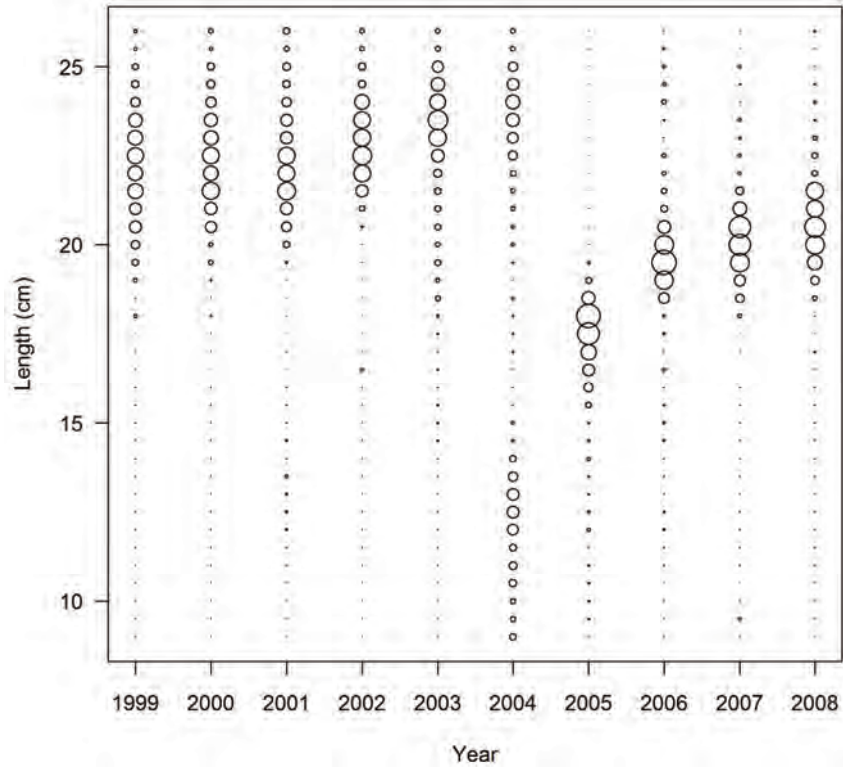


Figure 36a. Bubble plot of length-frequency data for the PFFS survey.

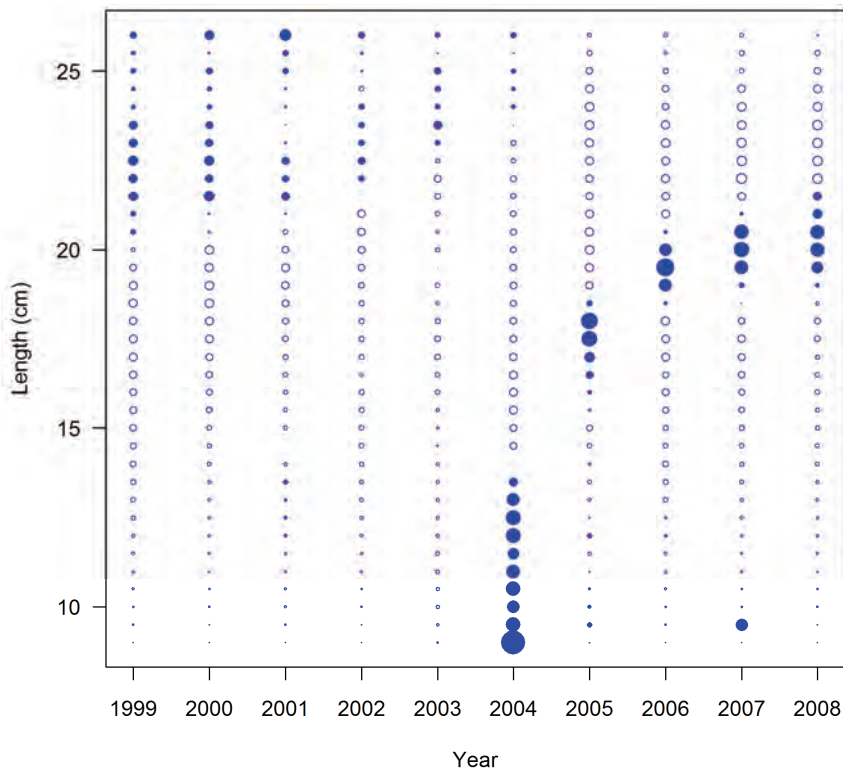


Figure 36b. Pearson residuals (max=9.52) for fit to length-frequency data for the PFFS survey (pre-STAR base model).

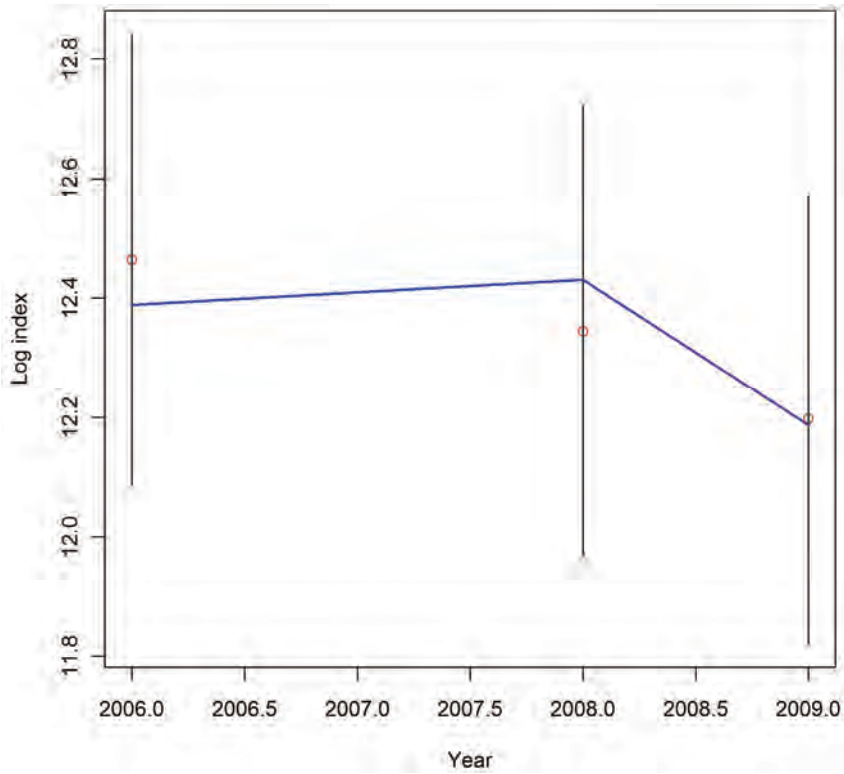


Figure 37a. Model fit to the West Coast Vancouver Island (WCVI) series ( $Q=0.2815$ ).

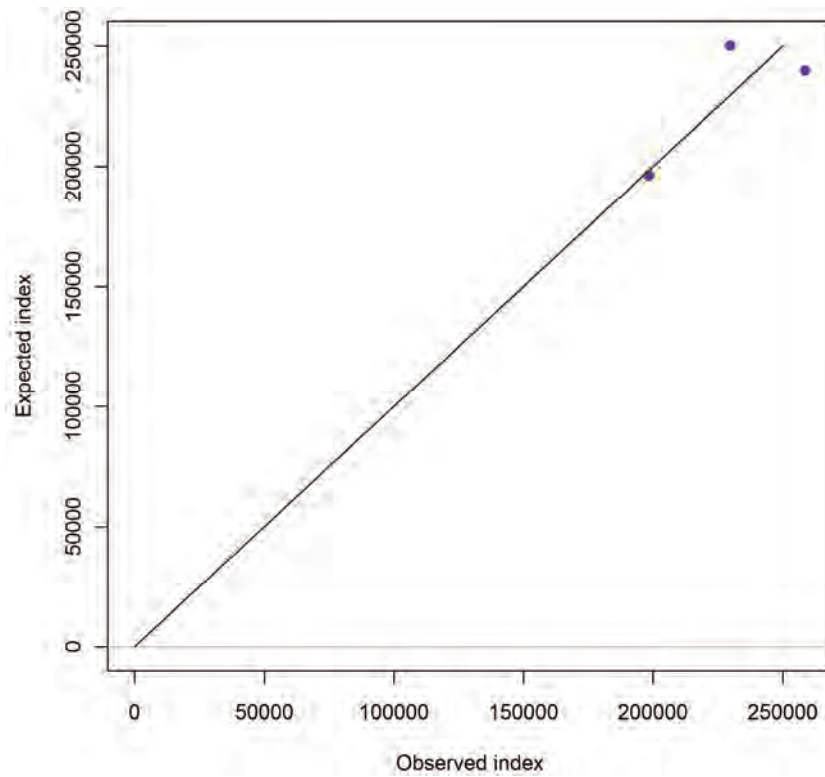


Figure 37b. Relationship between observed and expected values (log scale) for the WCVI survey. Straight line is 1 to 1 relationship.

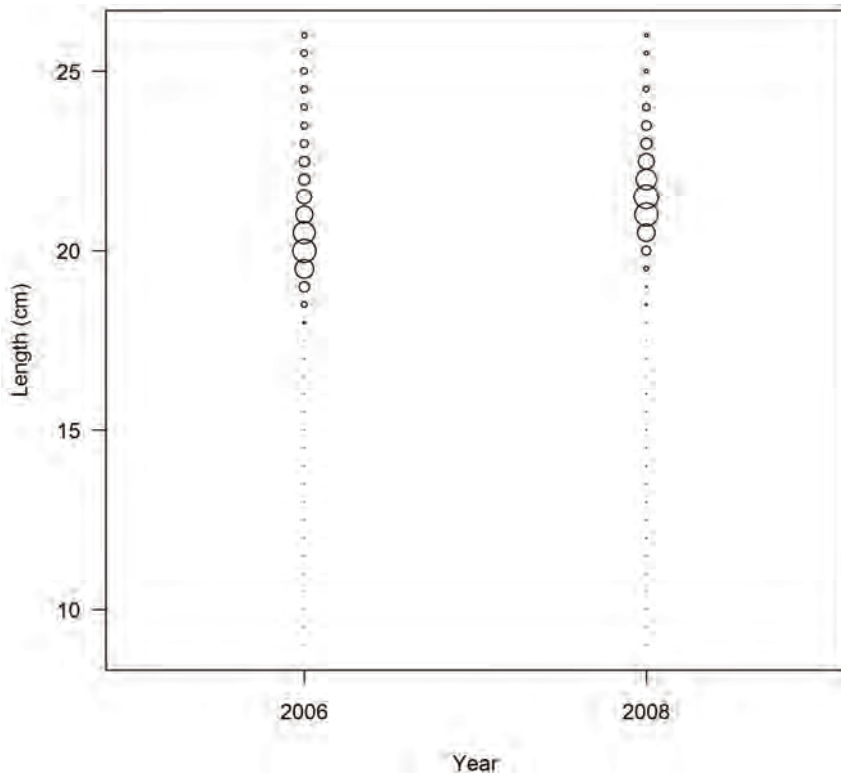


Figure 38a. Bubble plot of length-frequency data for the WCVI survey.

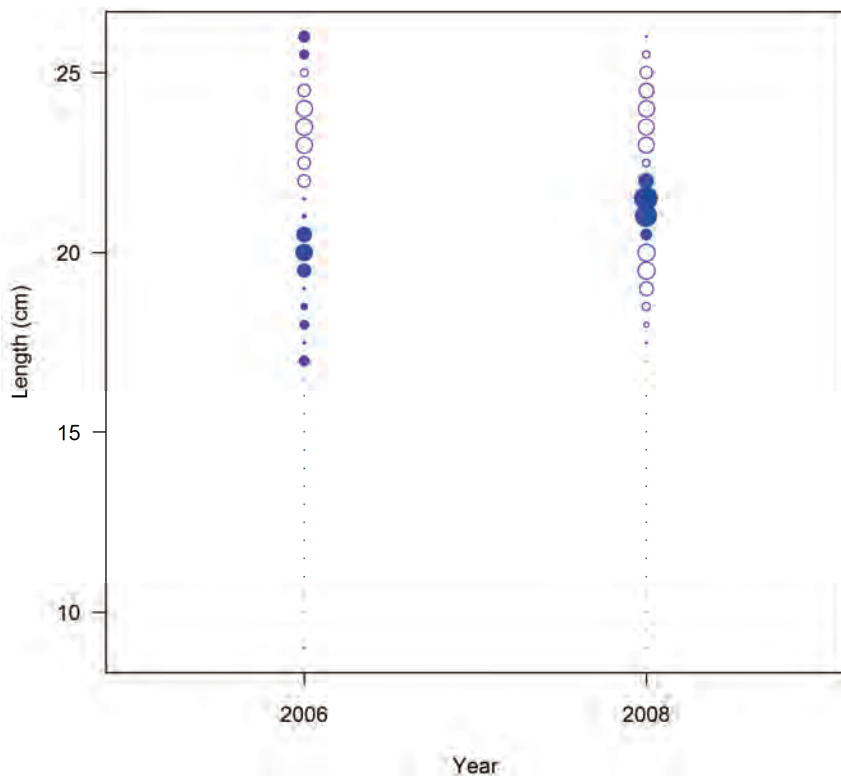


Figure 38b. Pearson residuals (max=2.65) for fit to length-frequency data for the WCVI survey.

length comps, sexes combined, whole catch, Aerial

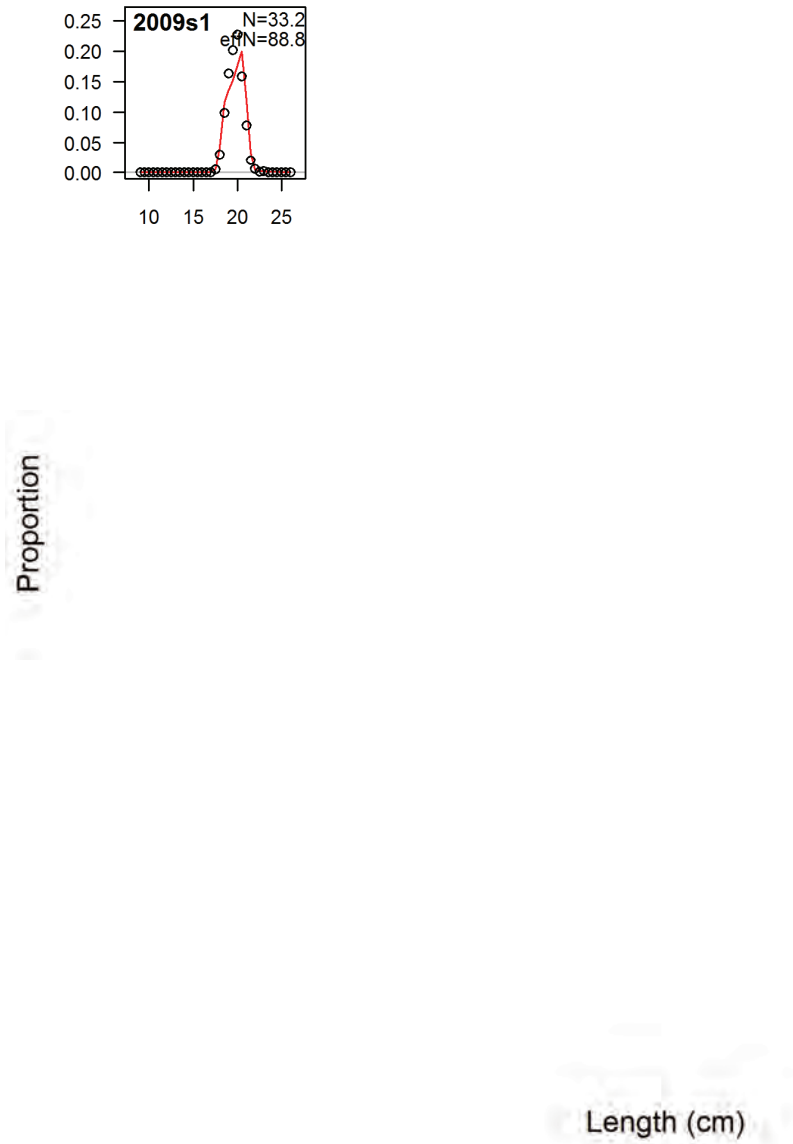


Figure 39. Base model fit to length-frequency data from the 2009 aerial survey.

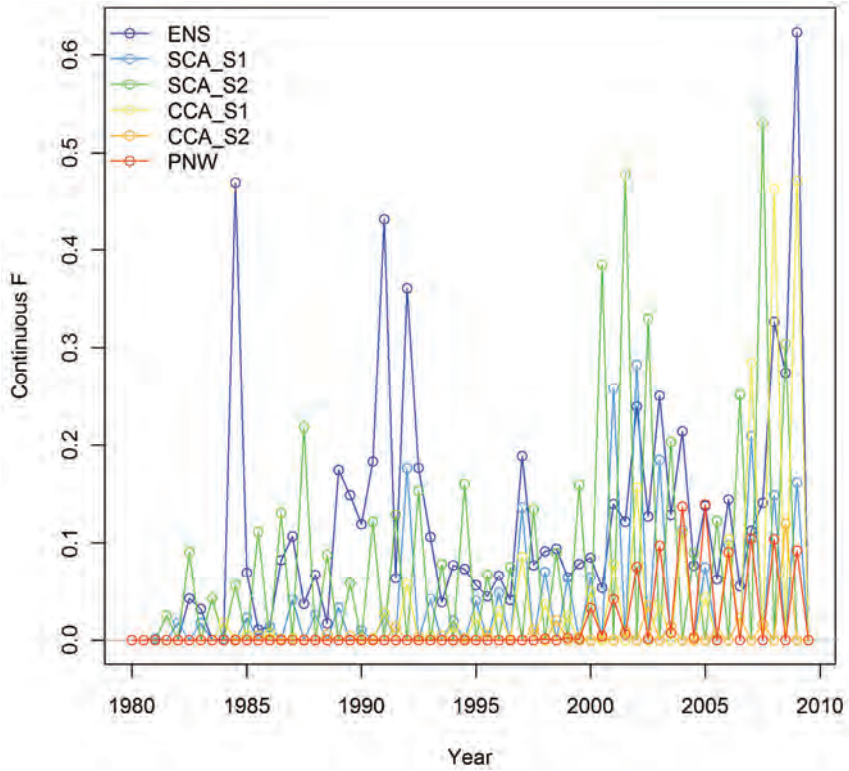


Figure 40a. Harvest rate (Hybrid F-method) from the base model including the Aerial '09 estimate.

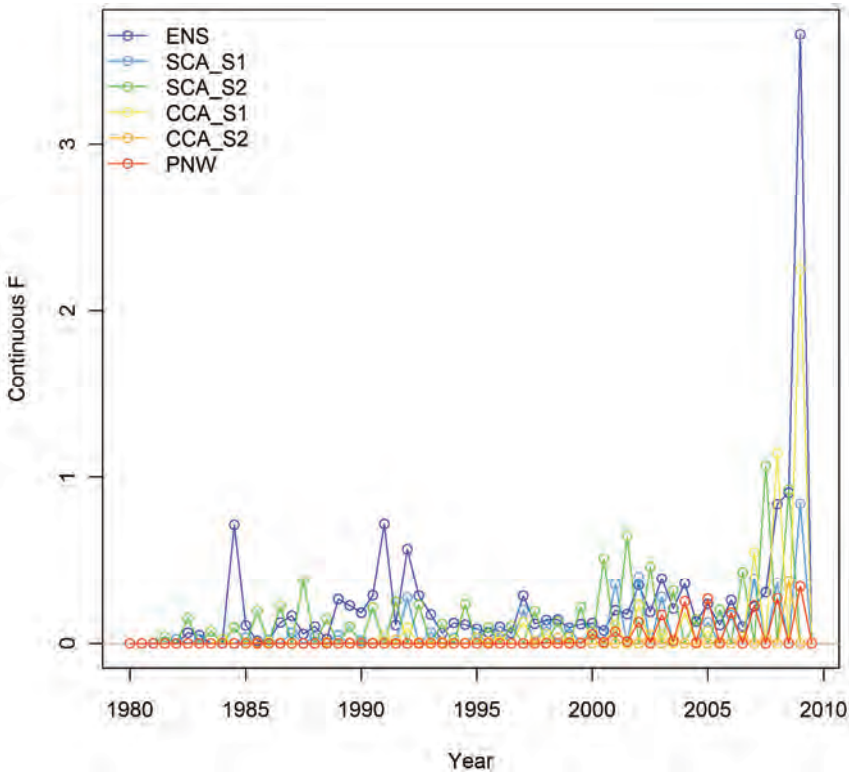


Figure 40b. Harvest rate (Hybrid F-method) from the base model excluding the Aerial '09 estimate.

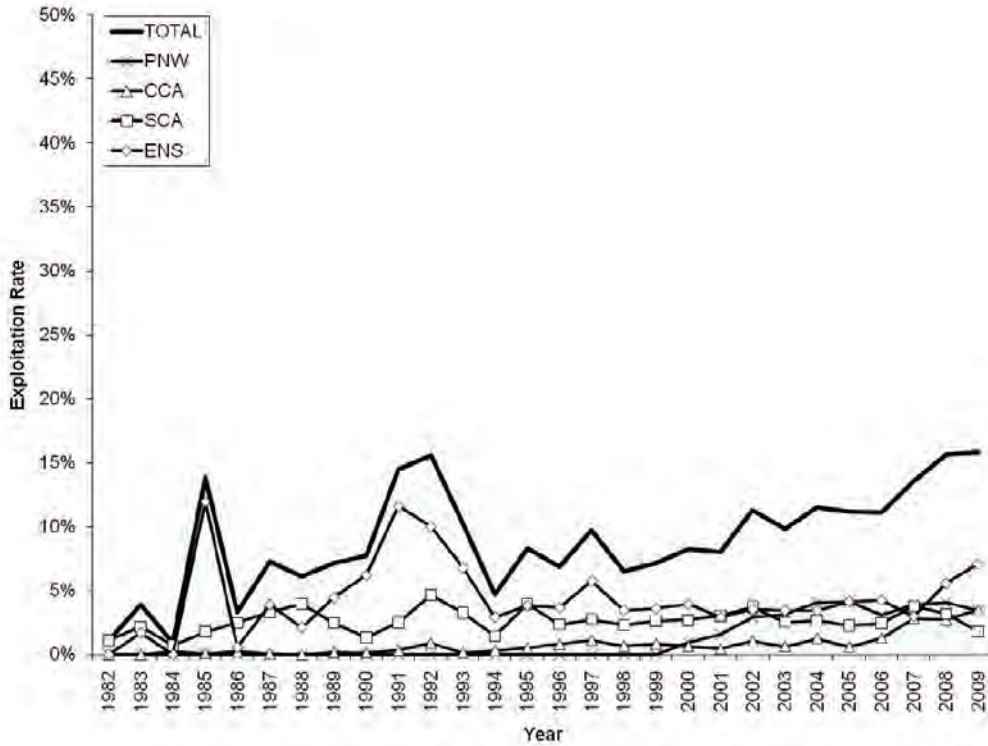


Figure 41a. Exploitation rate (CY landings / July total biomass) by fishery for the final base model.

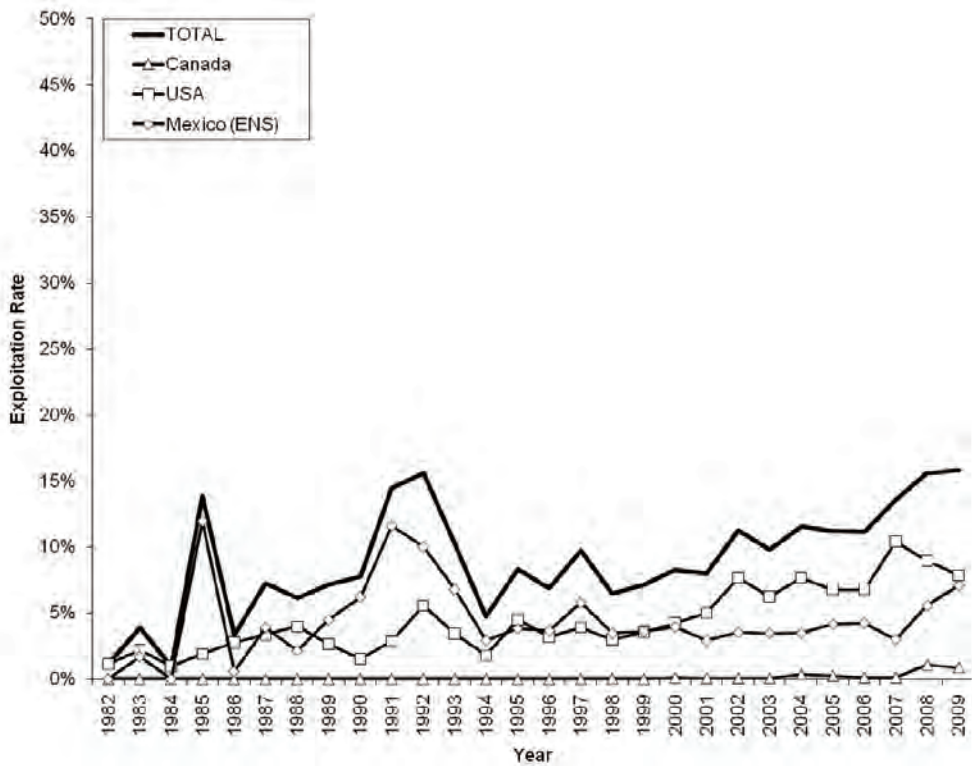


Figure 41a. Exploitation rate (CY landings / July total biomass) by country for the final base model.



*BLANK PAGE*

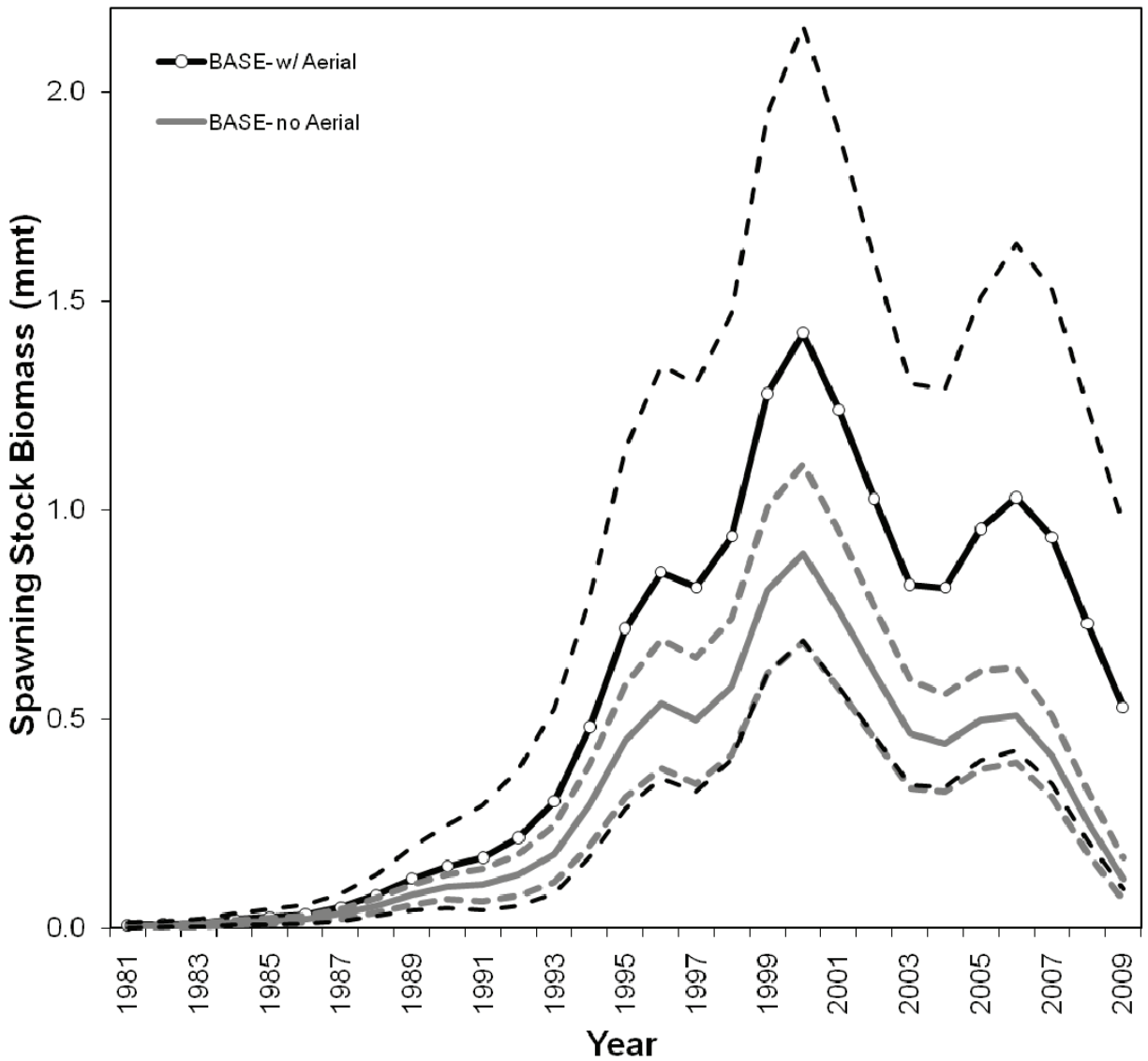


Figure 42a. Spawning stock biomass with ~95% asymptotic confidence intervals from the base model with the aerial survey (black line) and without the survey (gray line).

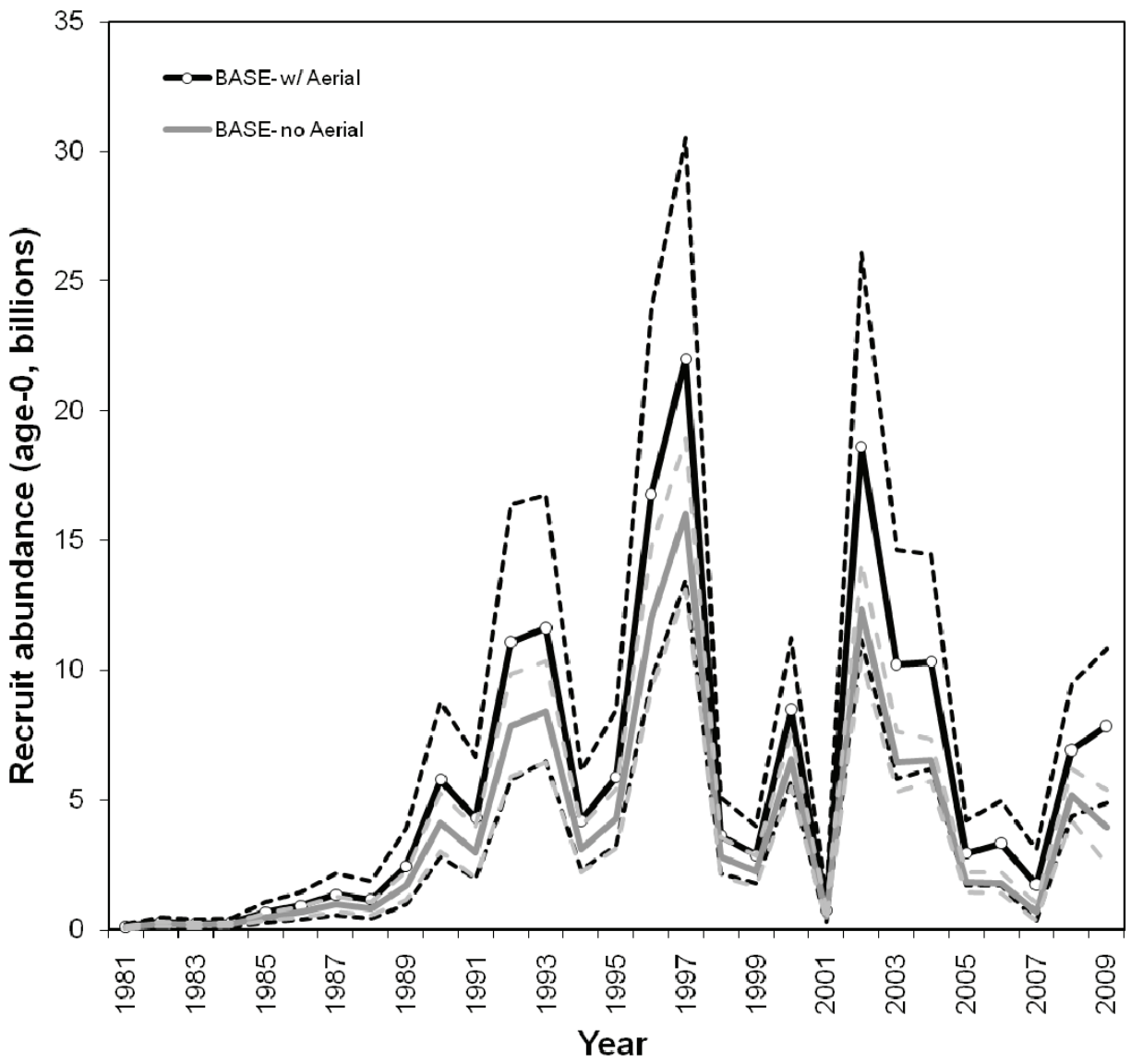


Figure 42b. Recruitments and ~95% asymptotic confidence intervals from the base model with the aerial survey (black line) and without the survey (gray line).

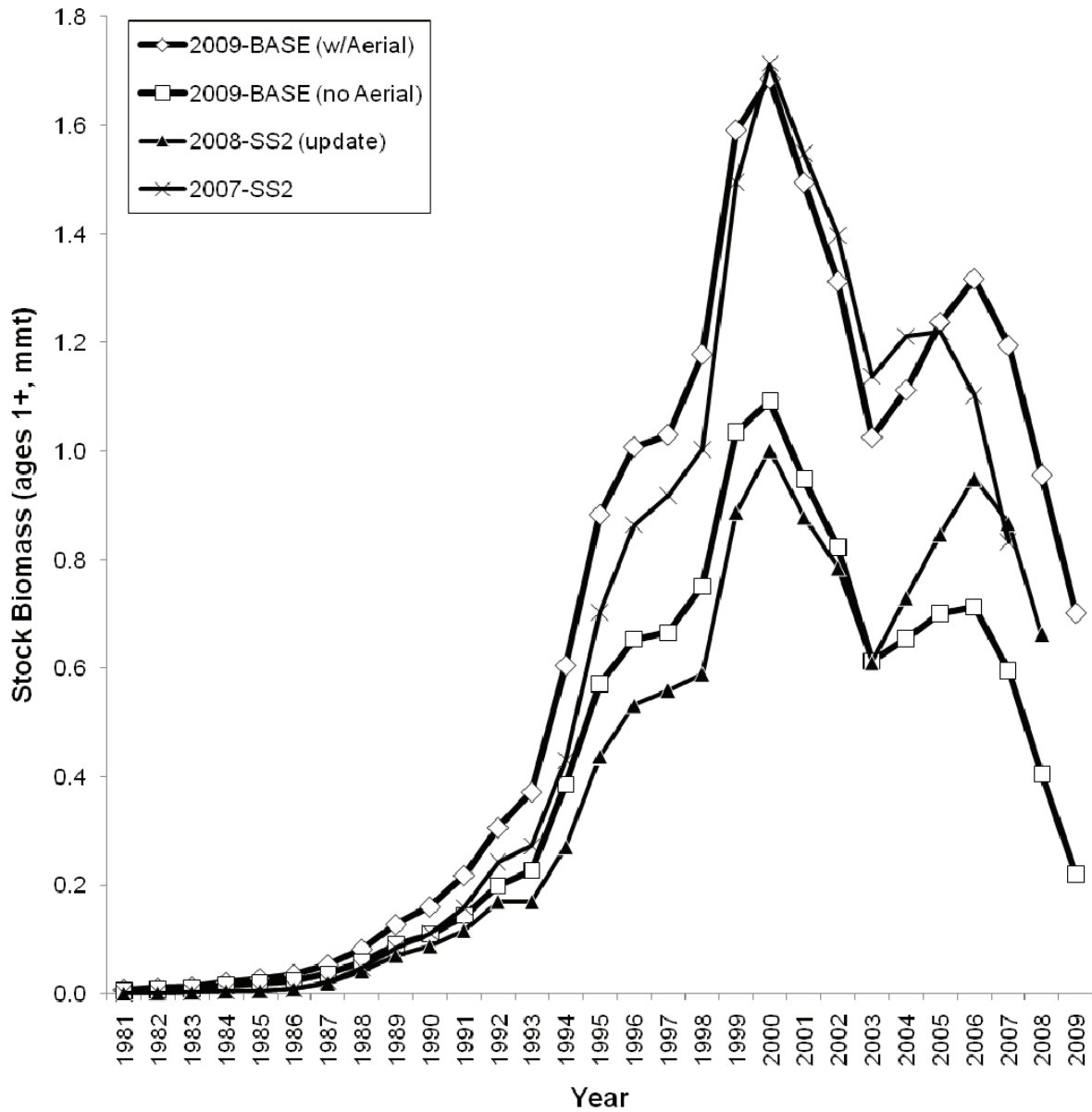


Figure 43a. Pacific sardine stock biomass (ages 1+) from the 2009 base model (with and without the 2009 aerial survey) compared to the 2008 update and 2007 final models.

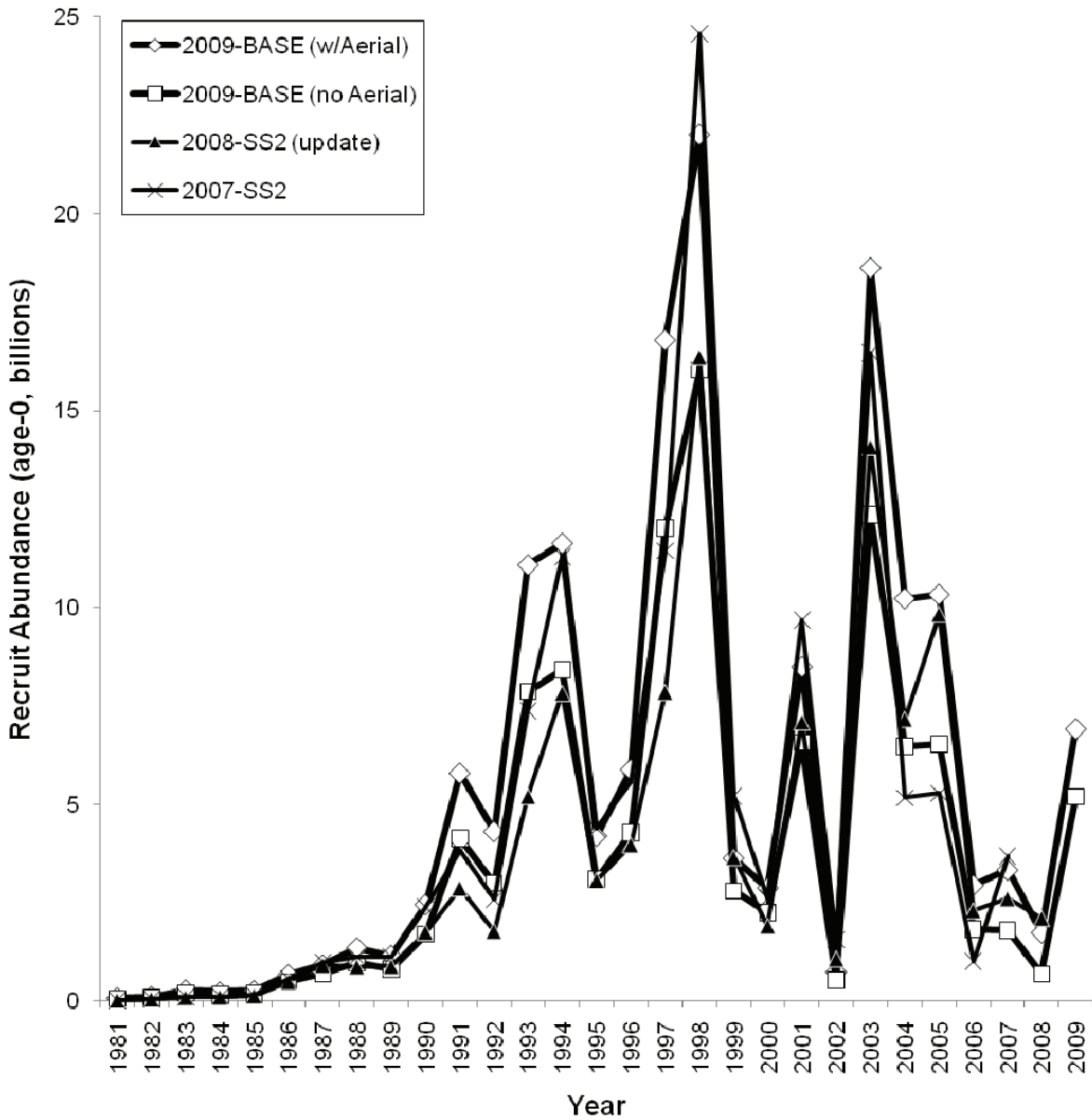


Figure 43b. Pacific sardine recruit (age-0) abundance from the 2009 base model (with and without the 2009 aerial survey) compared to the 2008 update and 2007 final models.

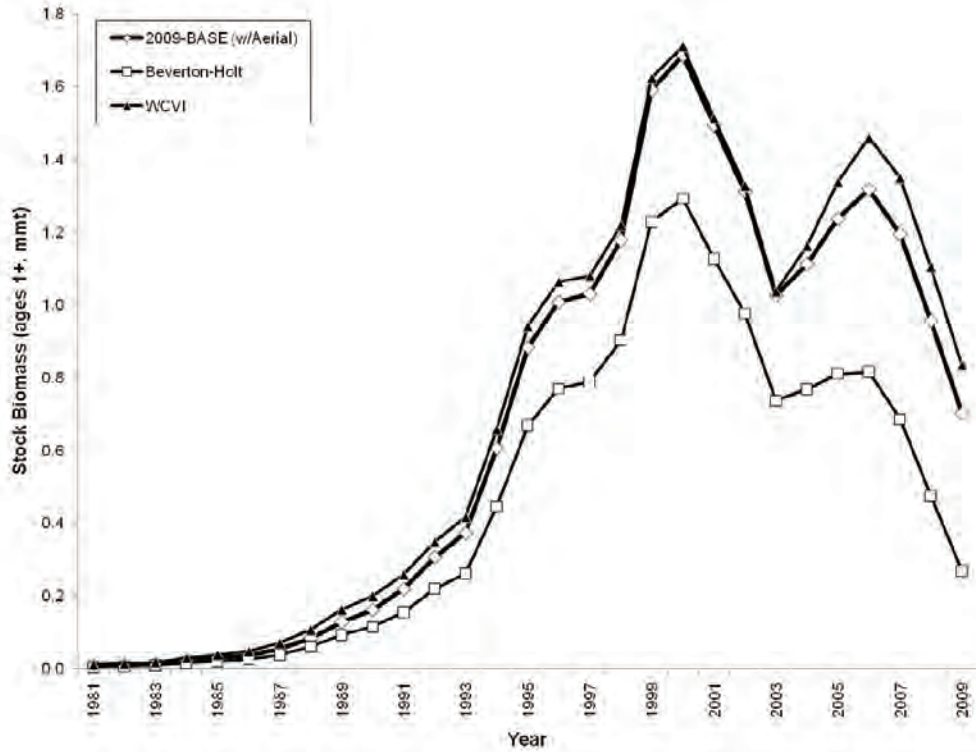


Figure 44a. Stock biomass (ages 1+) from the 2009 base model (w/ Aerial) compared to models fit with a Beverton-Holt S-R function and the WCVI survey.

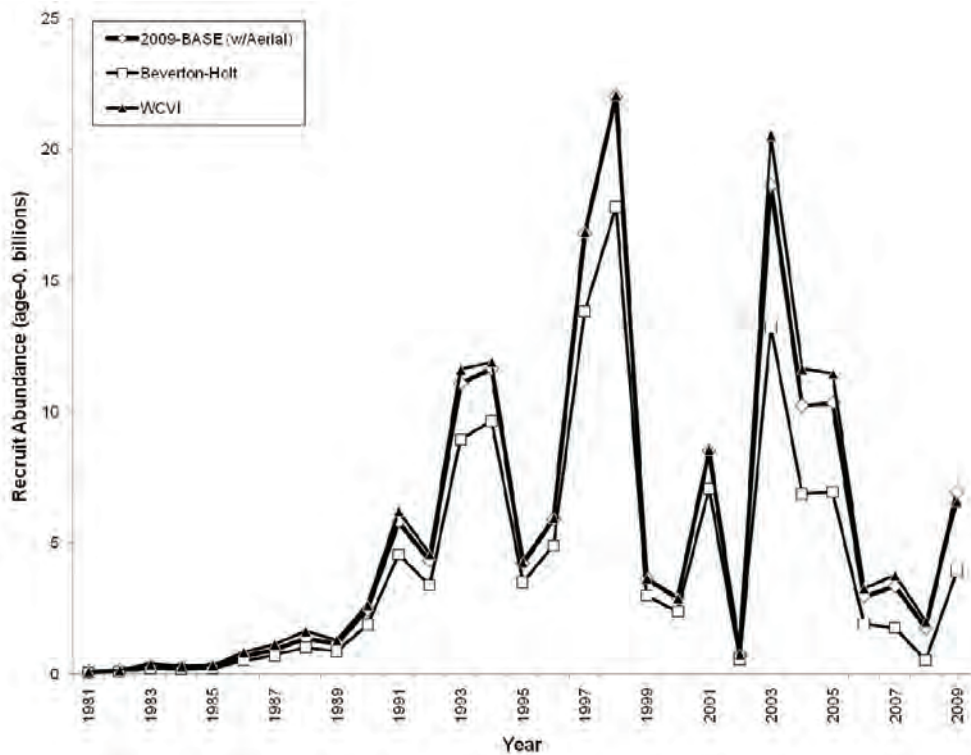


Figure 44b. Recruitment (age-0) from the 2009 base model (w/ Aerial) compared to models fit with a Beverton-Holt S-R function and the WCVI survey..

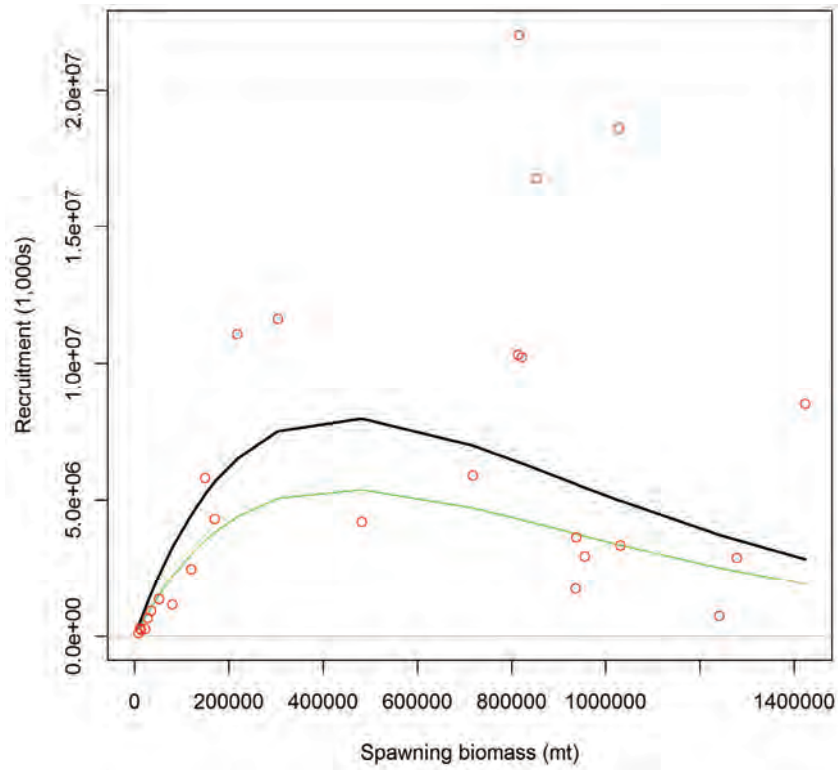


Figure 45a. Spawner-recruitment relationship for the base model, showing Ricker function fit with bias correction. Steepness ( $h$ ) = 2.32462.

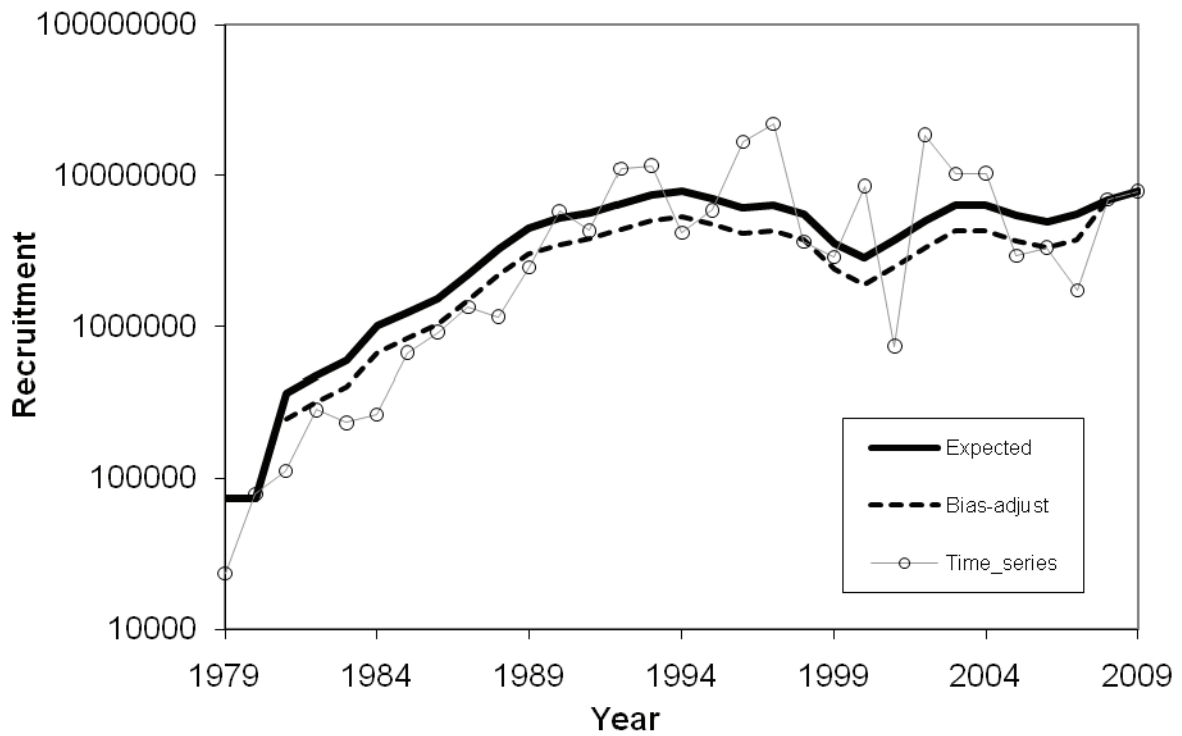


Figure 45b. Ricker model fit to the recruitment time series (base model).

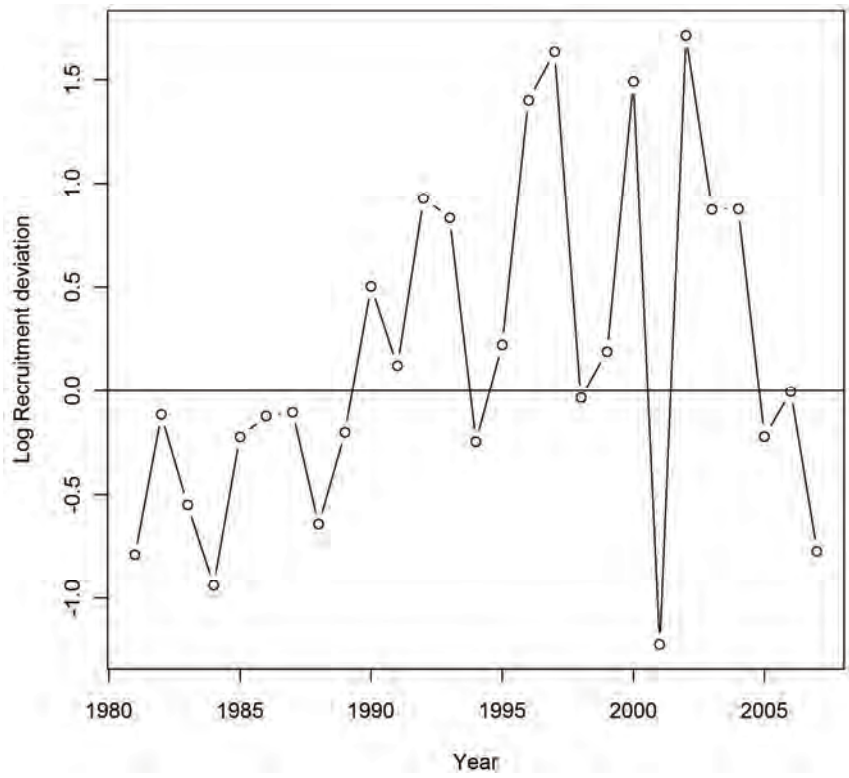


Figure 46a. Recruitment deviations estimated in the base model.

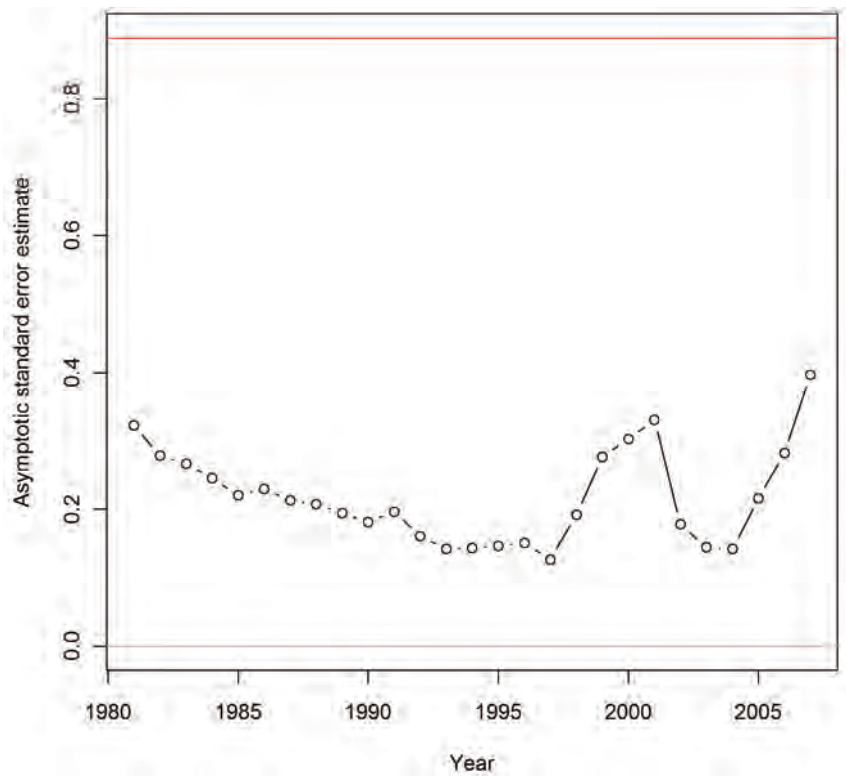


Figure 46b. Asymptotic standard errors for estimated recruitment deviations in the base model.



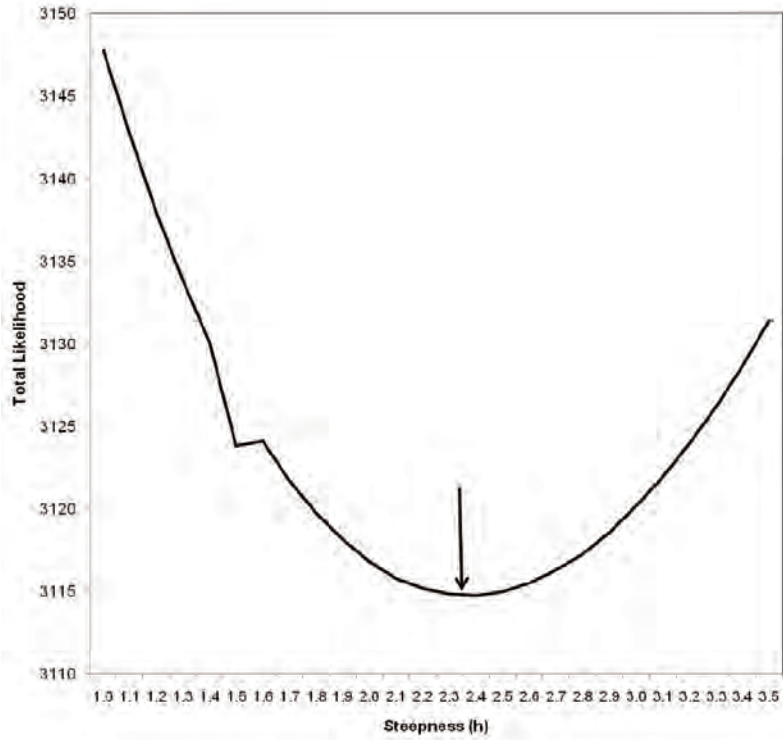


Figure 47a. Likelihood profile over a range of steepness values fixed in the base model. Arrow indicates base model estimate (2.32462).

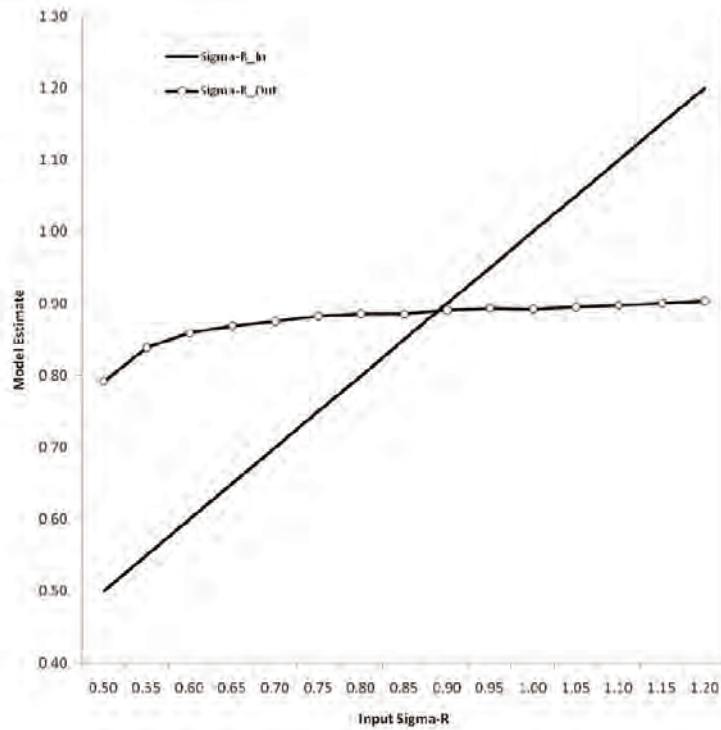


Figure 47b. Root mean square error estimates for recruitment deviations for a range of  $\sigma_R$  inputs in the base model ( $\sigma_R = 0.88789$  in base model).

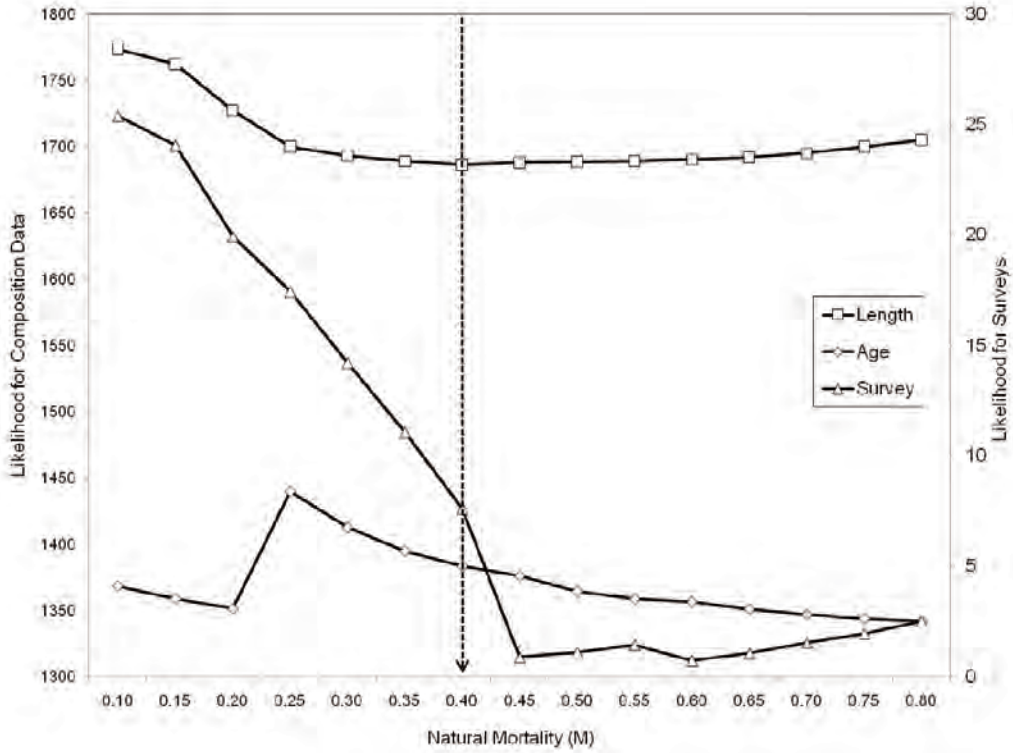


Figure 48a. Component likelihood profiles over a range of natural mortality rates fixed in the base model including the aerial survey.

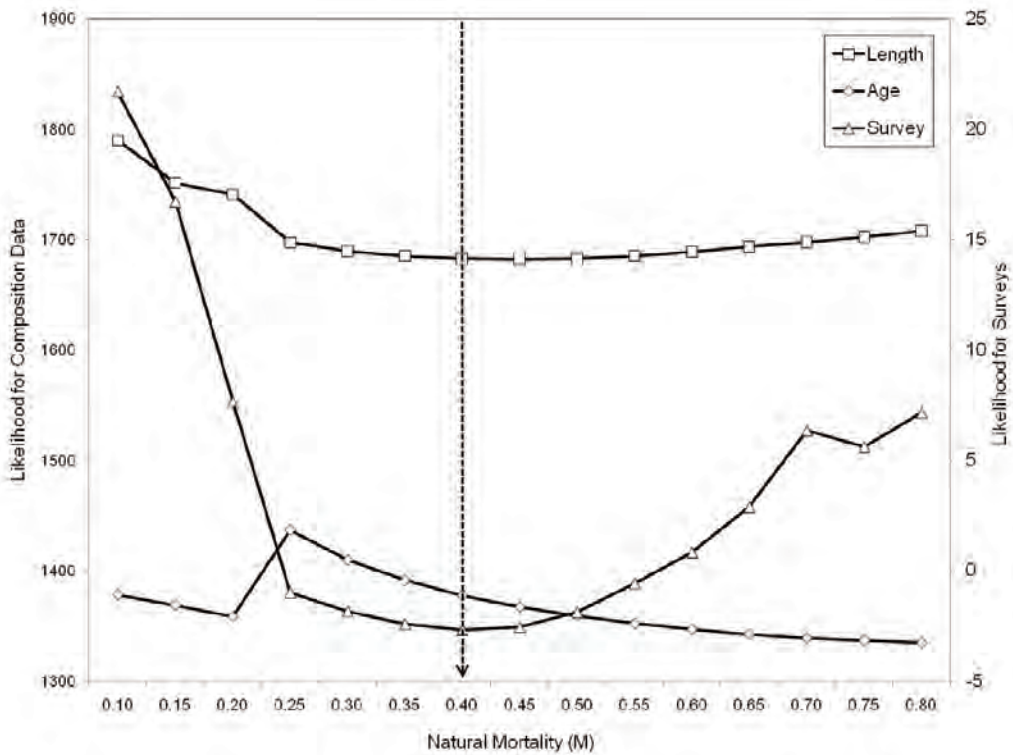


Figure 48b. Component likelihood profiles over a range of natural mortality rates fixed in the base model excluding the aerial survey.

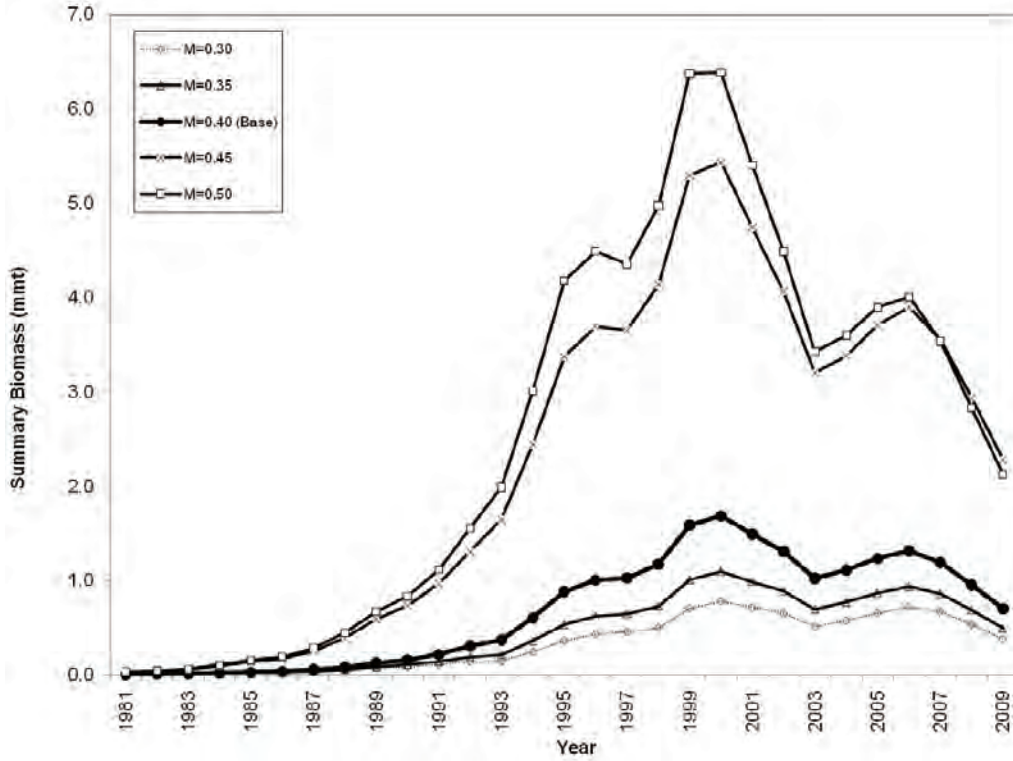


Figure 49a. Uncertainty around stock biomass (age 1+) estimates based on natural mortalities ranging 0.3-0.5 for the base model including Aerial-‘09.

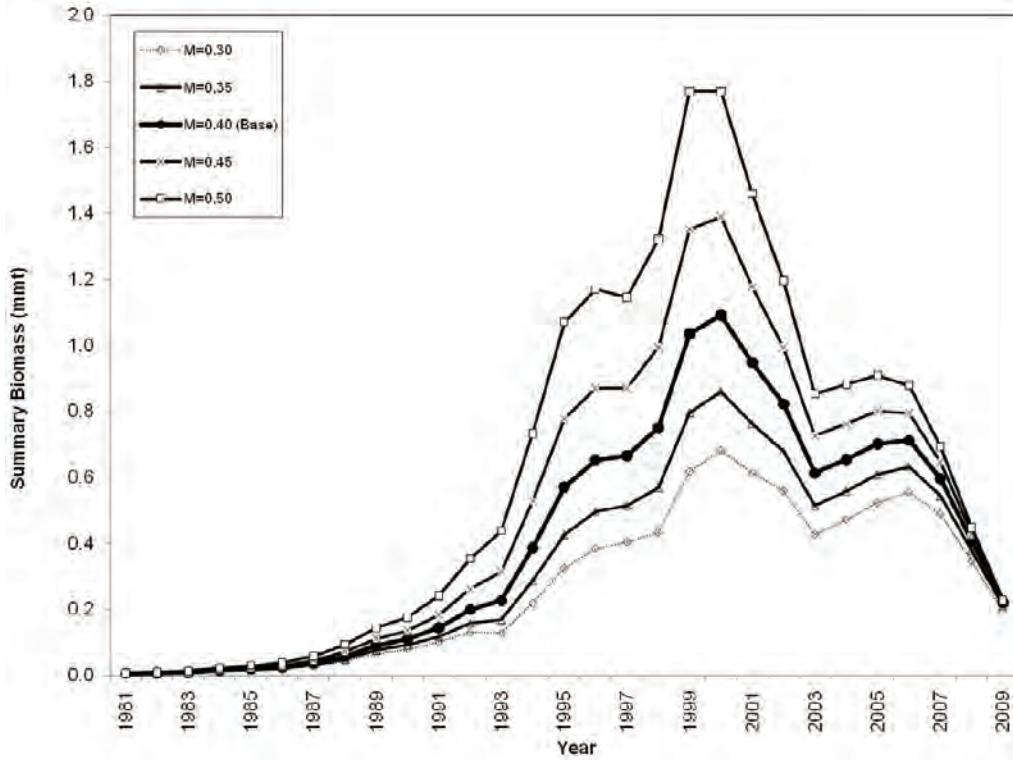


Figure 49b. Uncertainty around stock biomass (age 1+) estimates based on natural mortalities ranging 0.3-0.5 for the base model excluding Aerial-‘09.

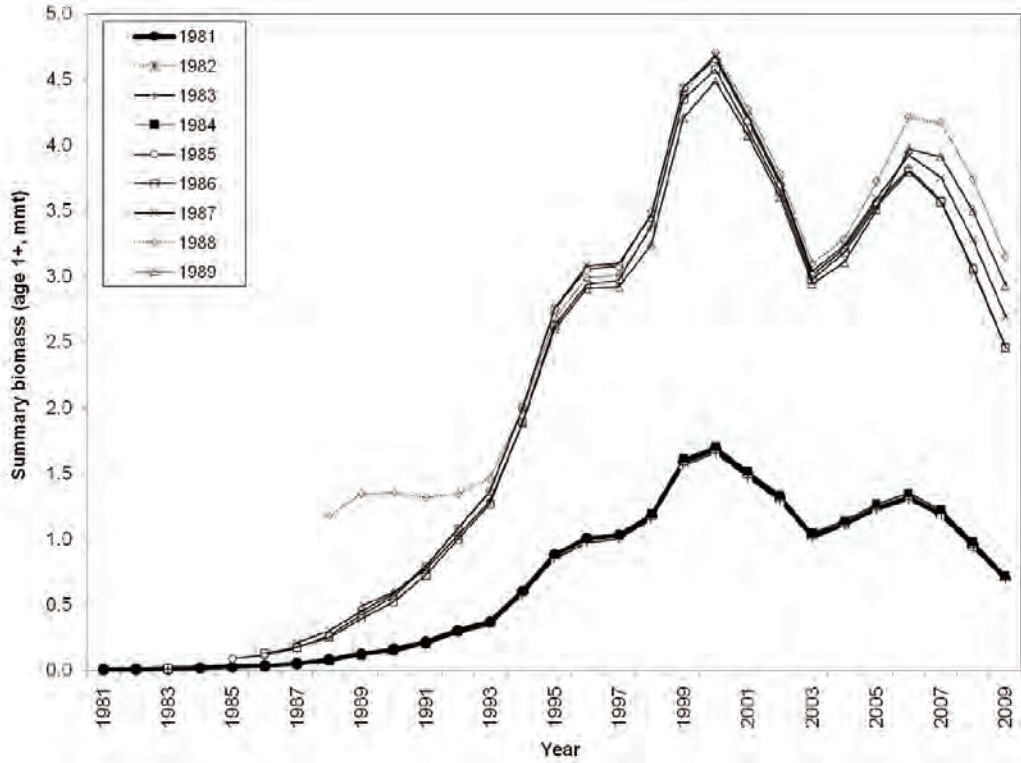


Figure 50a. Prospective analysis of biomass from the base model including the aerial survey.

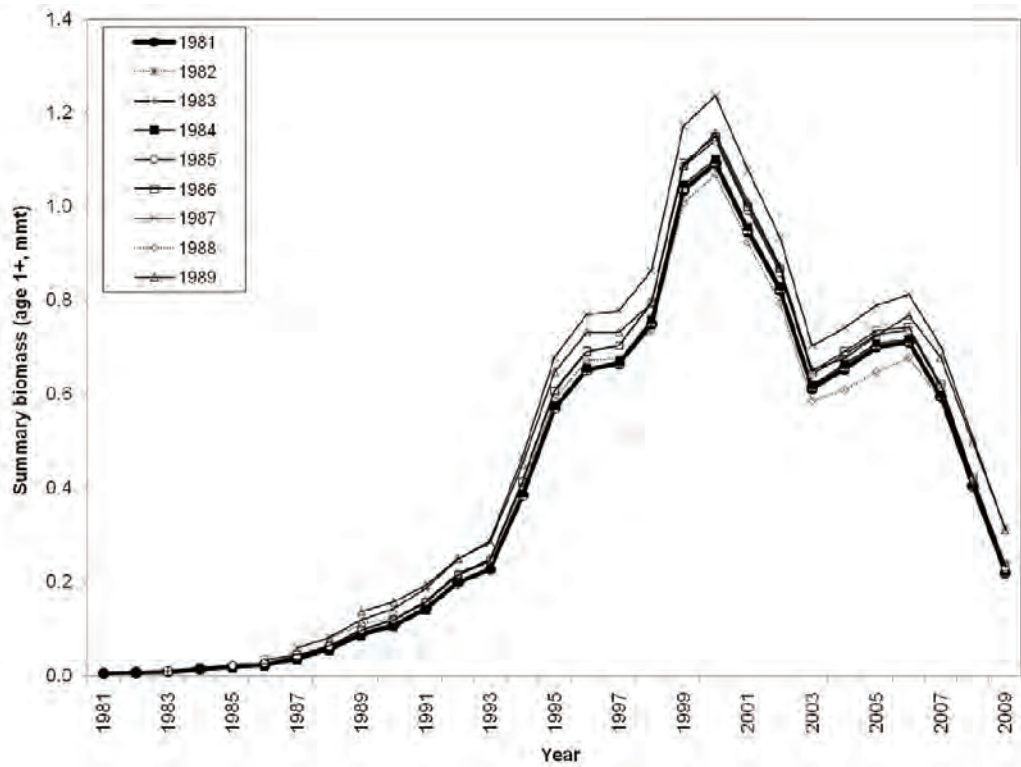


Figure 50b. Prospective analysis of biomass from the base model excluding the aerial survey.

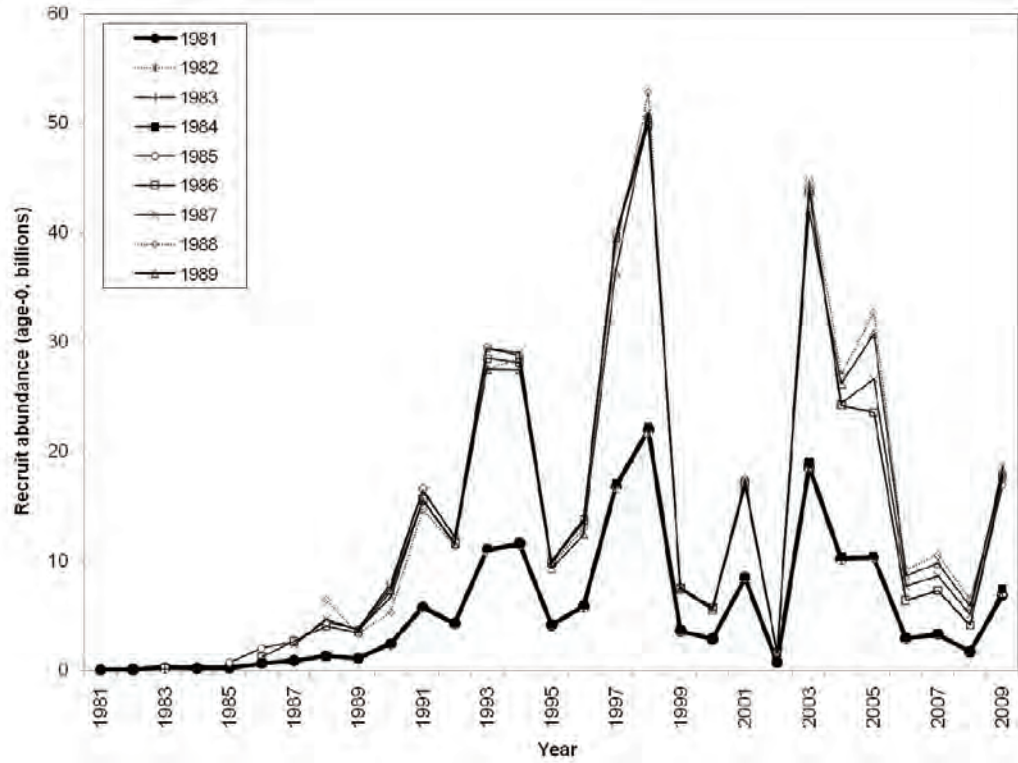


Figure 51a. Prospective analysis of recruitments from the base model including the aerial survey.

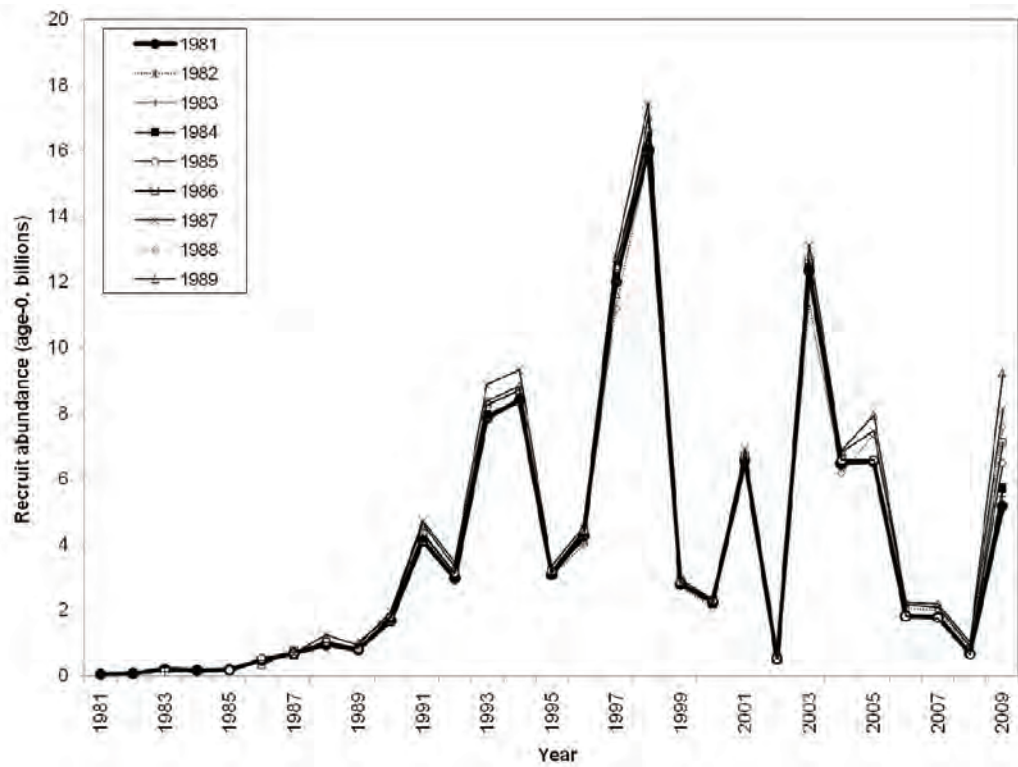


Figure 51b. Prospective analysis of recruitments from the base model excluding the aerial survey.

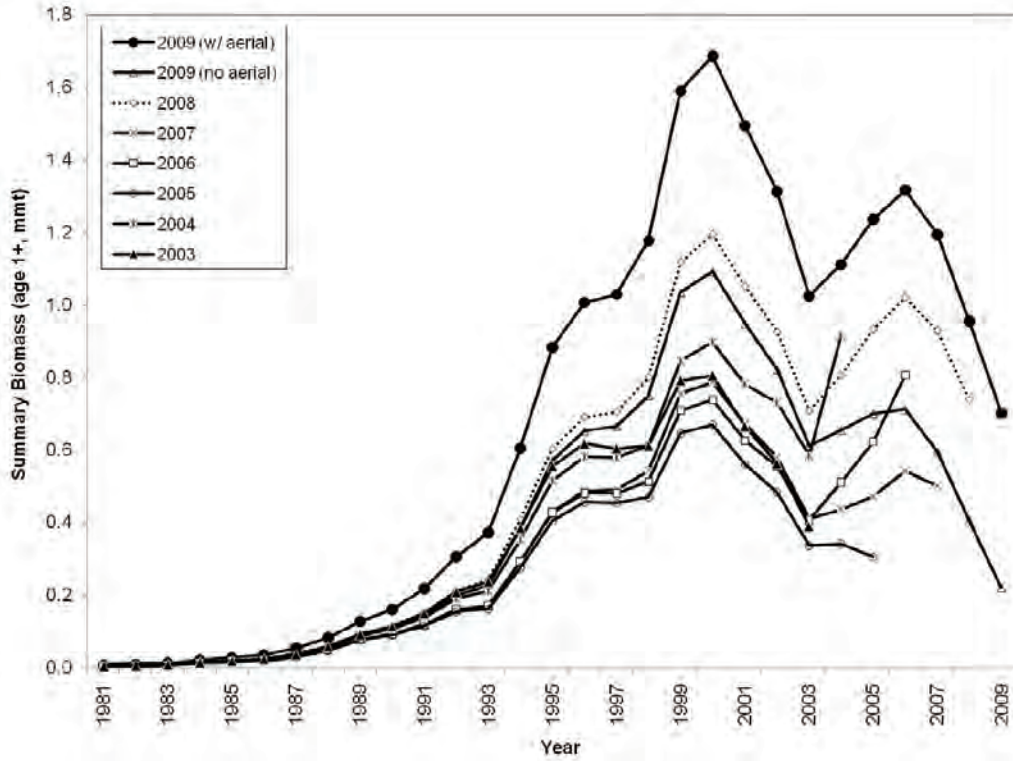


Figure 52a. Retrospective analysis of biomass from the base model.

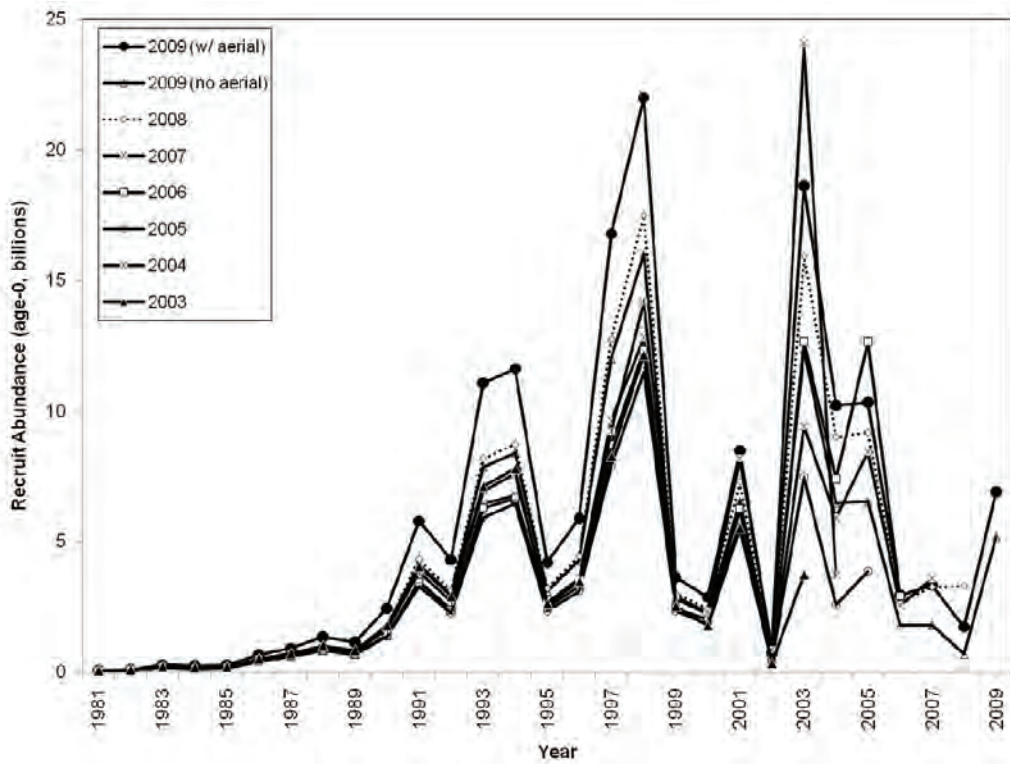


Figure 52b. Retrospective analysis of recruitments from the base model.

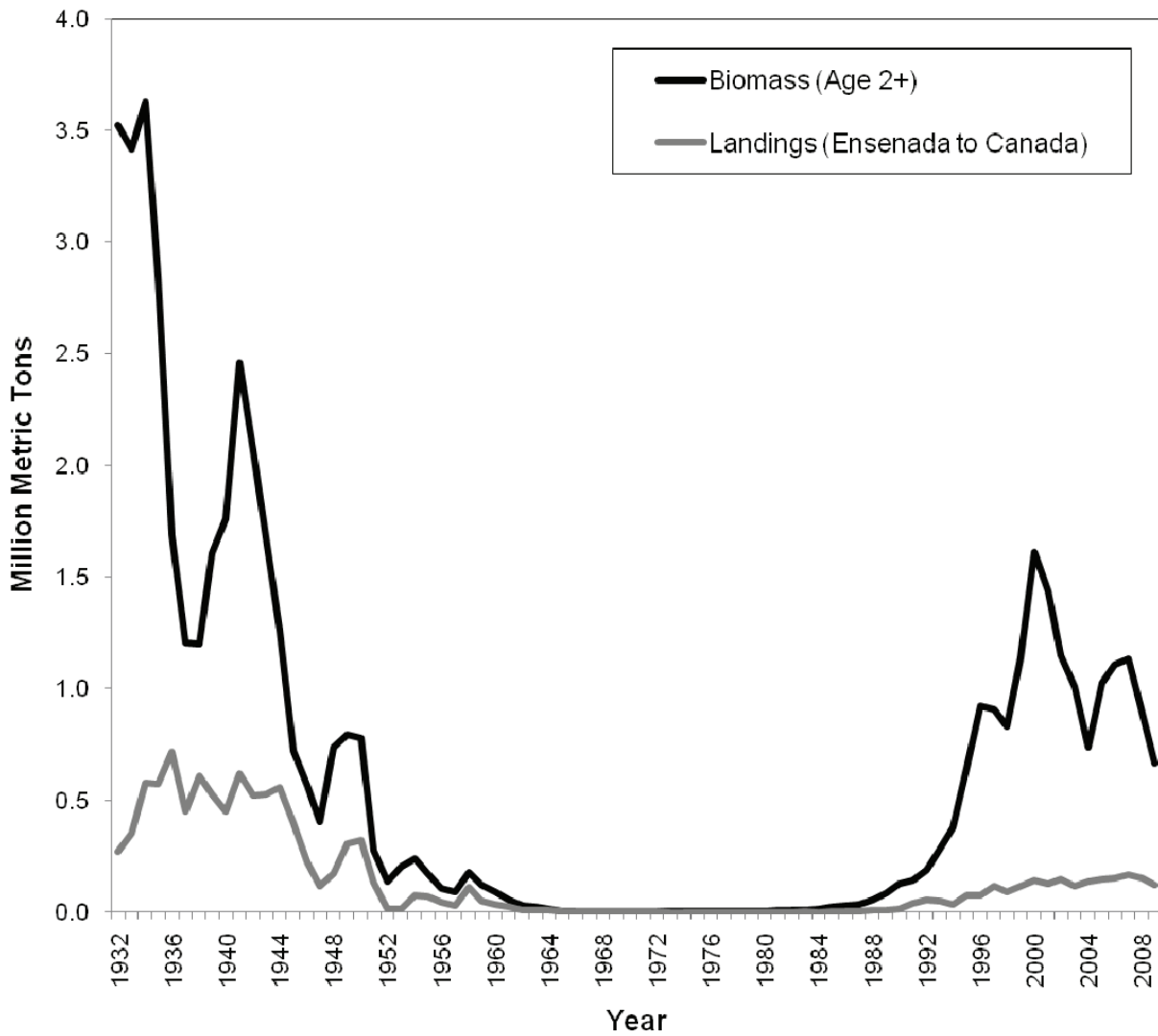


Figure 53. Historic sardine biomass (age 2+) from Murphy (1966) and the base model.

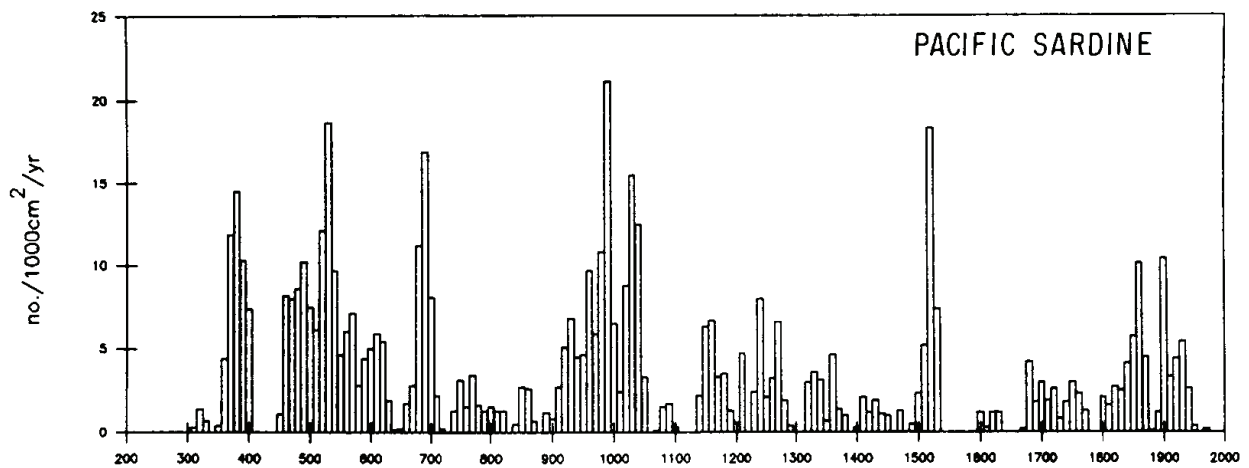


Figure 54. Sardine scale-deposition rates in the Santa Barbara Basin from approximately 300 to 1970 AD. Bars represent decades (reproduced from Baumgartner et al. 1992).

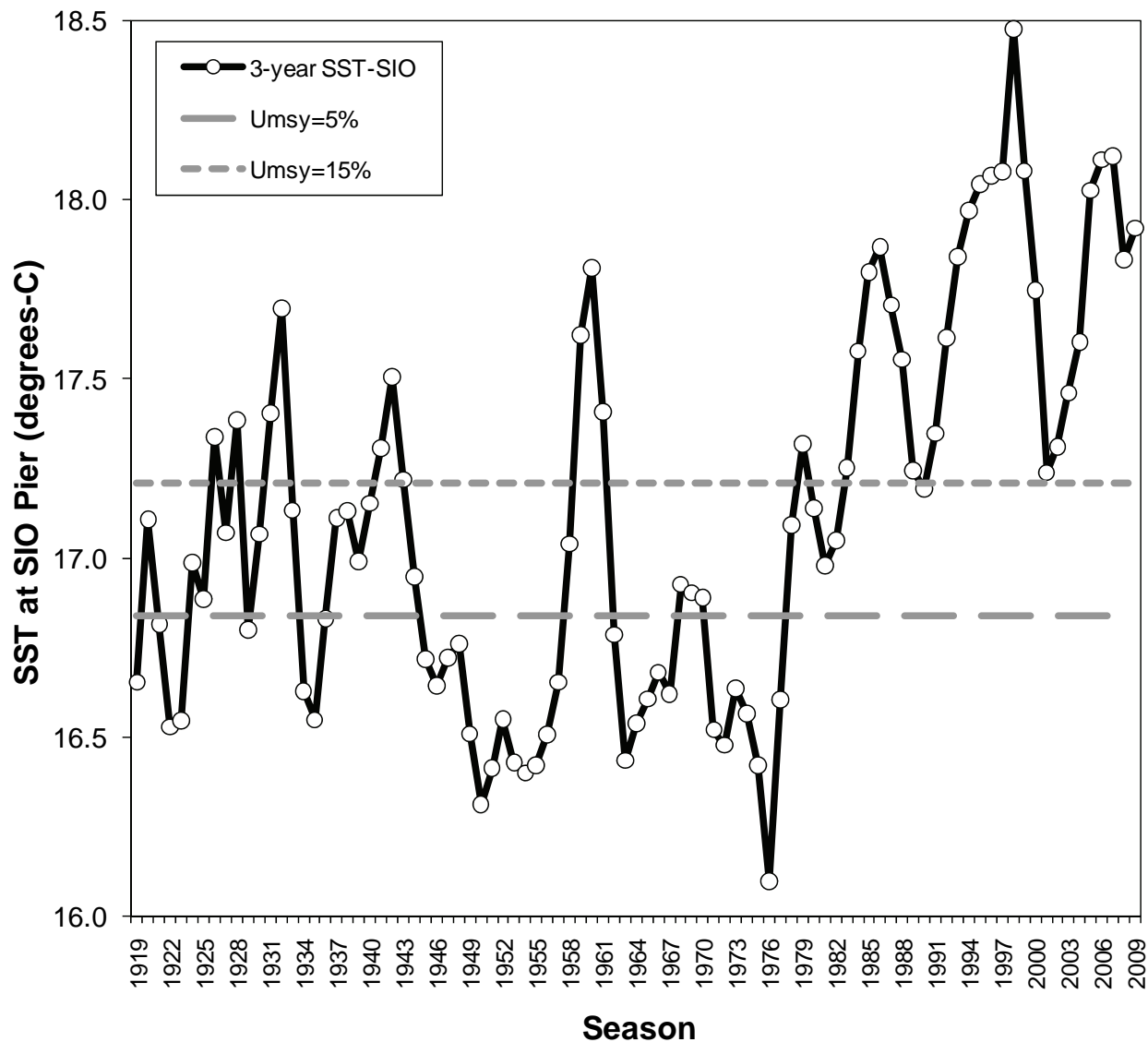


Figure 55. Three-season running average of sea surface temperature (SST) data collected daily at Scripps Institution of Oceanography pier since 1916. For any given season, SST is the running average temperature during the preceding three seasons (July-June), e.g. the 2009 estimate is the average from July 1, 2006 through June 30, 2009. The 2009 value used for management in 2010 was calculated to be 17.92 °C, so a 15% exploitation fraction ( $F_{msy}$ ) should be applied in the harvest control rule.



## **APPENDICES**

## APPENDIX I

### Revised estimation of spawning biomass of Pacific sardine (*Sardinops sagax*) using the Daily Egg Production Method

Nancy Lo, Beverly Macewicz, and Kevin Hill  
NOAA Fisheries  
Southwest Fisheries Science Center  
8604 La Jolla Shores Dr.  
La Jolla CA 92037  
USA

#### Abstract

Per requests of the 2009 May STAR panel, we examined the estimates of spawning biomass based on the weighted average for each of the parameters:  $P_0$  and four adult parameters: female weight ( $W$ ), sex ratio ( $R$ ), batch fecundity ( $F$ ) and daily spawning fraction ( $S$ ), where the weight was the estimated spawning biomass in each of two regions. The resulting estimates of spawning biomass were imprecise. Our exercise indicated that the total spawning biomass was best estimated by the sum of the two regional spawning biomasses. We revised the estimate of the daily spawning fraction ( $S$ ) by using the average of females spawning the night before capture (day-1) and those spawning two nights before capture (day-2) for the number of spawning females to replace females spawning the night of capture (day-0) with the total number of mature females adjusted accordingly. We computed the female spawning biomass (or the population egg production) for years when adequate adult samples were available: 1986, 1987, 1994, 2004, 2005, and 2007-2009. Estimates of spawning biomass and the female spawning biomass (fs. biomass) were recalculated for 1986, and 1987 using the recent estimation procedure. In addition, we also provided a time series of total egg production for years when not all the adult parameter estimates were available or few trawls were taken: 1988, 1996-2003, and 2006. Two time series were summarized in two separate tables similar to Table 4 in Lo et al. (2007 and 2008). The year of 1995 was excluded from the stock assessment because the survey area was the quarterly CalCOFI area (CalCOFI lines 77-95) and not the standard daily egg production method survey area (CalCOFI lines 60-95).

#### Introduction

The 2009 May STAR panel made suggestions to revise the original estimation procedure of computing the spawning biomass of Pacific sardine for the upcoming Pacific sardine STAR panel meeting in September, 2009 (Punt et al. 2009):

1. Estimate the adult reproductive parameters using the same high and low production regions identified by the pelagic egg sampling survey. The estimates will be weighted by their relative adult abundance in each of two strata (regions 1 and 2). The daily egg production method (DEPM) estimates should be input to the stock assessment in the form of the biomass of spawning females (or the population egg production, i.e. ignore the sex-ratio of mature animals when computing the estimates)

2. The estimates of spawning biomass for 1986-1988 should be re-calculated using a statistical system that is consistent with the more recent DEPM estimates.

3. A complete and annotated table similar to Table 4 in the 2008 report (Lo et al. 2008), including the information from the 1980s CDFG surveys, should be available (and included in the stock assessment report) for the upcoming sardine assessment

And

4. The data for 2006 should be used in the assessment as an estimate of Total Egg Production (TEP) rather than as part of the DEPM series. Estimates of abundance based on the 1995 survey should not be included in the stock assessment at all and re-specify the SS model accordingly.

In this report, we examined four issues of the DEPM spawning biomass (s. biomass) in response to the requests by the May STAR panel: 1. Compare three estimates of s. biomass: stratified estimates with weights being spawning biomass (recommended by the STAR panel) or area size in each region, and the original estimates which were based on unstratified estimates of adult parameters; 2. Reexamine the estimates of spawning fraction (S); 3. Revise the estimates of spawning biomass and estimate female spawning biomass (fs. Biomass) of Pacific sardine for 1994, 2004, 2005, and 2007-2009; and 4.. Revise the spawning biomass and estimate female spawning biomass of Pacific sardine in 1986-1988 to be consistent with the current procedure. We presented two time series from the DEPM surveys for the stock assessment.

## Method

The spawning biomass (s. biomass) was computed according to the daily egg production method (DEPM)

$$B_s = \frac{P_0 A C}{R S F / W_f} \quad [1]$$

where  $A$  is the survey area in units of  $0.05\text{m}^2$ ,  $S$  is the daily spawning fraction (fraction of females spawning per mature female per day),  $F$  is the batch fecundity (number of eggs per mature female released per spawning),  $R$  is the fraction of mature female fish by weight (sex ratio),  $W_f$  is the average weight of mature females (g), and  $C$  is the conversion factor from grams (g) to metric tons (mt).  $P_0 A$  is the total daily egg production in the survey area, and the denominator ( $R S F / W_f$ ) is the daily specific fecundity (number of eggs/population weight (g)/day).

The variance of the spawning biomass estimate ( $\hat{B}_s$ ) was computed from the Taylor expansion in terms of the coefficient of variation (CV) for each parameter estimate and covariance for adult parameter estimates (Parker 1985):

$$\text{VAR}(\hat{B}_s) = \hat{B}_s^2 \left[ \text{CV}(\hat{P}_0)^2 + \text{CV}(\hat{W}_f)^2 + \text{CV}(\hat{S})^2 + \text{CV}(\hat{R})^2 + \text{CV}(\hat{F})^2 + 2\text{COVS} \right] \quad [2]$$

The last term, involving the covariance term, on the right-hand side is

$$COVS = \sum_i \sum_{i < j} sign \frac{COV(x_i, x_j)}{x_i x_j}$$

where  $x$ 's are the adult parameter estimates, and subscripts  $i$  and  $j$  represent different adult parameters; e.g.,  $x_i = F$  and  $x_j = W_f$ . The sign of any two terms is positive if they are both in the numerator of  $B_S$  or denominator of  $B_S$  (equation 5); otherwise, the sign is negative. The covariance term is

$$cov(x_i, x_j) = \frac{[n/(n-1)] \sum_k m_k (x_{i,k} - x_i) g_k (x_{j,k} - x_j)}{\left( \sum_k m_k \right) \left( \sum_k g_k \right)}$$

where  $k$  refers to  $k^{th}$  tow, and  $k = 1, \dots, n$ . The terms of  $m_k$  and  $g_k$  are sample sizes and  $x_{i,k}$  and  $x_{j,k}$  are sample means from the  $k^{th}$  tow for  $x_i$  and  $x_j$  respectively.

For each survey, the area was post-stratified into two regions based on the presence of sardine eggs: region 1 (high density area) and region 2 (low density area). Equation (1) can be applied to the whole survey area or to each of the two regions depending on the availability of data. For the female spawning biomass (fs. biomass), the sex ratio ( $R$ ) was excluded from equations (1) and (2). For details of the post-stratification and estimation procedures for each parameters, please see Lo et al (1996) and Lo et al. (2001)

## Results

### 1. Three estimators of the spawning biomass using 2007 and 2008 data

Method 1. The estimate of spawning biomass (s. biomass) was based on estimates of  $P_0$  and adult parameters, each of which was a weighted mean with the weight being the estimate of s. biomass in each of two regions.

Method 2. The estimate of s. biomass was the sum of the estimate of the s. biomass in each region

Method 3. The original estimate, which was based on a weighted estimate of  $P_0$  with weights being the area size and unstratified estimates of adult parameters.

The analysis indicated that the estimates of the spawning biomass based on Method 1 had the highest cv (Table 1). The estimates from Method 2 have cvs slightly lower than those of the original estimates. The reason for the large cv from Method 1 was because the variance of weighted mean for the  $i$ th adult parameter,  $var(x_{iw}) = var(x_{i1} * a_1 + x_{i2} * a_2)$ , is a function of the  $var(x_{i1}), var(a_1), var(a_2), var(x_{i2})$  and  $cov(a_1, a_2)$  where  $a_j = sb_j / (sb_1 + sb_2)$  and  $sb_j$  is the estimate of the spawning biomass in the  $j$ th region for  $j = 1, 2$ . The variance of s. biomass is a function of  $var(P_{0w}),$  and  $var(x_{iw}), i = 1, \dots, 4$ , for the  $i$ th adult parameter: mature female weight ( $W_f$ ), sex ratio

( $R$ ), batch fecundity ( $F$ ) and daily spawning fraction ( $S$ ), and  $\text{cov}(x_{i'w}, x_{i'w})$ . The  $\text{cov}(x_{i'w}, x_{i'w})$  is a function of  $\text{cov}(x_i, x_i)$  within each region,  $\text{var}(a_1), \text{var}(a_2)$ ,  $\text{cov}(a_1, a_2)$ , and estimates of each adult parameter (appendix 1). For this exercise, the spawning fraction ( $S$ ) was based on the original method following Northern anchovy procedures based on day-1 mature females (Picquelle and Hewitt, 1983). The estimates of adult parameters based on Method 1 for 2007 were given in Appendix 2.

The point estimates of  $P_0$  using Method 1 in 2007 and 2008 were higher than those using area sizes as the weights, so were the estimates for the s. biomass (Table 1). Method 1 produced estimates with highest cv, while Method 2 produced estimates with the lowest cv. We chose to use method 2 to recalculate the spawning biomass and female spawning biomass for years when both  $P_0$  and adult parameter estimates within each region were available. Otherwise, Method 3 would be used, e.g. 2004

## 2. The spawning fraction ( $S$ )

The daily spawning fraction ( $S$ ) is the fraction of females spawning per mature female per day and day is a 24h time-period and not a calendar day. Sardine spawn and were collected at night, and our 'day' used the 24 hours from 18:01-18:00. For these exercises, females spawning the night of capture were categorized as day-0, those spawning the night before capture (about 24 hours ago) as day-1, those spawning two nights before capture (about 48 hours ago) as day-2, and remaining mature females as mature-non-spawners. When we estimated daily spawning fraction in the past, we used the number of day-1 females and followed the procedure set up for Northern anchovy to replace the number of day-0 females with that of day-1 females to adjust the number of total mature females ( $m.\text{females}_1$ ); and  $S_1$  is the daily spawning fraction by this original method (Picquelle and Hewitt, 1983). In recent years much data on Pacific sardine spawning rates have been accumulated, and we compared the mean number of day-0, day-1, and day-2 spawning females based on data from 2005, 2007 and 2008. The number observed in the trawls was analyzed with possible effect of region, year, with region nested within year. The analysis of variance indicated that there was no significant difference among all three day groups while the region and year effect were significant (Table 2). The overall mean number of each day category in the trawl samples was 1.68 (cv = 0.80), 1.86 (cv = 0.46), and 1.82 (cv = 0.39) for day-0, day-1 and day-2 females respectively (Figure 1). Thus, the variance of the number of day-0 fish is much greater than those of other two day categories. As suggested by the STAR panel, we examined an alternative estimator of daily spawning fraction ( $S_{12}$ ) using the mean number of day-1 and day-2 spawning females for each trawl and replacing day-0 females by this mean to adjust the number of total mature females, which was termed the adjusted total number of mature females ( $m.\text{female}_{12}$ ).

We compared these two estimates:  $S_{12}$  and  $S_1$  without stratification of regions using data from four years: 2004, 2005, 2007 and 2008 (Table 3). The results indicated that  $S_{12}$  was more precise than  $S_1$ . Thus, we opt to use  $S_{12}$  in computing the spawning biomass and female spawning biomass. This pooled estimate of spawning fraction based on day-1 and day-2 mature females was used for Peruvian anchovy (Alheit et al. 1984), sardine off Spain (Garcia et al. 1992) and Portugal (Cunha et al. 1992).

### **3. Estimates of spawning biomass and female spawning biomass of Pacific sardine for 1994, 2004, 2005, and 2007-2009.**

We recalculated spawning biomass and the female spawning biomass of Pacific sardine for 1994 (Lo et al. 1996), 2004, 2005, 2007-2009 as the sum of biomass in each region (Fig 2-7). Egg production, adult parameters including the new estimates of daily spawning fraction,  $S_{12}$ , the spawning biomass and the female spawning biomass (the population egg production) were estimated for each region. The total spawning biomass was the sum of the spawning biomass in each of the two regions (Table 4). For 1994, the original estimation procedure  $S_1$  based on day-1 females was used because data on day-2 females was not available. Region 1 was the area where sardine eggs were caught with embedded zero and the rest of the survey area was region 2. Because most adult collections were in region 1, the spawning biomass of 1994 was based on data from region 1 only. Since 1996, the CUFES egg density was used to post stratify the survey area. For 2004, because trawls were taken only in stratum 1, Method 3 was used to estimate spawning biomass and female spawning biomass where  $P_0$  was weighted by the area in each region and the adult parameters were unstratified. Since 2005, trawls were taken in each region and Method 2 was used for both the spawning biomass and female spawning biomass.

### **4. Estimates of spawning biomass and female spawning biomass of Pacific sardine for 1986, 87 and 88 based on CDFG DEPM surveys and CalCOFI surveys.**

The California Department of Fish and Game (CDFG) conducted annual ichthyoplanton-adult fish surveys for Pacific sardine in 1985-1988 (Wolf and Smith, 1985; Wolf 1988a and 1988b; Scannel et al. 1996). Sample sizes were small in 1985 (Wolf and Smith 1986). Here we reexamined CDFG surveys in 1986-1988 (Fig 8-10). Surveys in these three years were conducted in different months: August, July and May in each year respectively (8608, 8707 and 8805). The area occupied was small compared to recent DEPM surveys: from US-Mexico boarder to Point Conception for 1986 and 1987, and to Monterey in 1988. Survey area extended west to 28 nautical miles (nm), 75 nm, and 120 nm off shore respectively for each of the three years. For all surveys adult sardine were caught by purse-seine and only CalVET net tows were taken as the CUFES was not launched off California till 1996. We included data of yolk-sac larvae (larvae  $\leq 5$  mm in preserved length) from CalCOFI cruises closest to the CDFG surveys together with egg data from CDFG surveys to model the embryonic mortality curve. We were able to do so for 1987 and 1988 but not for 1986 as no larvae were caught by the closest CalCOFI surveys in 1986 (8605). Therefore the embryonic mortality curve for 1986 was based on CalVET egg data only.

For each survey, the whole area was stratified: region 1 where one or more sardine eggs were caught (with embedded zero tows) and region 2 was the rest of the survey area. For 1988, two vessels were employed (Fig 10): one vessel, *Shana Rae*, surveyed the area north of CalCOFI line 75 ( $\sim 35.3^{\circ}\text{N}$ ) and the other vessel, *Yellowfin*, surveyed the southern area. Because no eggs were observed in the north aboard *Shana Rae*, the analyses were carried out only for data collected aboard the *Yellowfin* in the area south of CalCOFI line 81.5 ( $\sim 34.3^{\circ}\text{N}$ ).

#### **1986 (8608)**

Only egg data from the CDFG-cruise CalVET tows were used to estimate the daily egg production because no larvae were caught by bongo and CalVET net tows during CalCOFI cruises, 8605 and 8609. The nonlinear regression on the individual egg data points could not run well, so we obtained the mean egg production for five half-day group up to 2.5 day old.

The survey area was post-stratified into a north and south area due to the difference in egg densities and the spatial distribution of eggs: the dividing line was CalCOFI line 85.4 (~33.8°N) in the Santa Monica Bay (Scannell et al. 1996) (Fig 8). Within each of the two areas, we further stratified into region 1 and 2. As the number of tows were small (133 in the north and 197 in the south) and no larvae data were available, the nonlinear regression produced poor estimate of  $P_0$ , in particular for the north with positive mortality rate ( $Z$ ). Therefore, for the northern area, an average of egg production in three egg day categories (day-1, 2, and 3) were used as the estimate of  $P_0$ . The estimates of  $P_0$  were different between the south and north: 1.48 (cv = 1) and 0.32 (cv = 0.25) with 1.74 (cv = 1) and 0.38 (cv = 0.25) in region 1 within each area. For the entire survey area, the area for region 1 was 10141.55 km<sup>2</sup> out of the total area of 11811.73 km<sup>2</sup> (Table 4). The estimate of  $P_0$  and  $z$  for the region 1 were 0.56 (cv = 0.66) and -0.18 (2.17). The weighted  $P_0$  was 0.95 (cv = 0.84), where the weights were the area size for northern and southern area. All the above regression estimates were corrected from bias from the weighed group data:  $P_{0,c} = P_0 (1+0.14) = (Lo 2001)$ .

### **1987 (8707)**

Egg data from CDFG 8706 (Wolf 1988a, Fig 9) and yolk-sac larval data from bongo and CalVET from CalCOFI cruises: 8705 and 8709 were used to model the embryonic mortality curve. The daily egg production ( $P_0$ ) and the instantaneous mortality rate ( $z$ ) for region 1 were 1.11 (cv = 0.5) and 0.66 (cv = 0.4) for an area of 22259.94 km<sup>2</sup> out of the entire survey area of 37702.26 km<sup>2</sup>. The overall  $P_0$  was 0.66 (cv = 0.5). All adult sardines were caught by purse-seine gear in region 1.

### **1988 (8805)**

Because no eggs were observed north of CalCOFI line 81.5, egg data from CDFG 8805 survey south of CalCOFI line 81.5 (~34.2°N) (Wolf 1988b, Fig 10) and yolk-sac larval data from CalVET and Bongo tows of CalCOFI 8805 surveys were used to model the embryonic mortality curve. Estimates of  $P_0$  and  $z$  were 0.55 (cv = 0.36) and 0.39 (cv = 0.25) for region 1 of 31788.18 km<sup>2</sup> out of the southern survey area of 44040.73 km<sup>2</sup>. Because few eggs and non adult samples were taken in the region 2, we prorated  $P_0$  from region 1 to the whole southern survey area after the correction of relative bias:  $P_{0c,w} = P_{0c} * A1/A$  where  $P_{0c}$  is the bias corrected  $P_0$  in region 1,  $A1$  and  $A$  are area sizes of region 1 and the whole southern survey area. The relative bias (RB) is -0.04 and -0.14 for the weighted nonlinear regression based on individual data points and the group data respectively and  $P_{0c} = P_0 (1-RB)$  (Lo 2001).

The  $P_0$  for the southern survey area and the entire survey area (71940 km<sup>2</sup>) was 0.39 (cv = 0.36) and 0.24 respectively. For the past spawning biomass estimation, the batch fecundity-fish weight relationship for 1988 was based on 1986 and 1987 data because no batch fecundity data was available for 1988 and females in 1988 were similar in size to those in 1986 and 1987; For the 2009 stock assessment,  $P_0$  from 1988 was included in the total egg production (TEP) time series

and spawning biomass was not included due to this lack of an 1988 batch fecundity-fish weight relationship.

## 5. Two time series from DEPM surveys for the stock assessment

We constructed two time series for the stock assessment. The first time series includes the estimates of female spawning biomass (fs. biomass) for 1986, 1987, 1994, 2004, 2005, and 2007-2009 as described in the previous sections (Table 4). For the batch fecundity estimates (F), the mean fecundity for a given fish weight:  $F=a+bW$  was used in the past. Because the fecundity was estimated for each individual female, to account for the variation among individual fish, we added an error term to the fecundity-fish weight equation as  $F = a + bW + e$  where  $e$ , the error term, follows a normal distribution with mean 0 and variance of the residual from the equation. Therefore we expect an increase of variance of the batch fecundity estimate for the fs. biomass and s. biomass. The second time series includes the total egg production (TEP) for years when not all adult parameters were estimated primarily due to lack of adults collections, no spawning fraction (S), and/or the lack of fecundity-fish weight equations: 1988, 1996-2003 and 2006 (Table 5; Lo et al. 2008)). The TEP is proportional to  $P_0 * A$  where  $P_0$  is the egg production/0.05m<sup>2</sup>, and A is the survey area in km<sup>2</sup>. The year of 1995 was excluded from either time series because data of that year came from CalCOFI survey only.

## Discussions

All the exercises provided slightly more precise estimates of spawning biomass and the female spawning biomass using new estimates of spawning fraction ( $S_{12}$ ), the average of day-1 and day-2 females. We only provided survey maps for years when the female spawning biomass was obtained. For years when only the total egg production was provided, readers can go to Southwest Fisheries Science Center website (<http://swfsc.noaa.gov/>) for most of the survey maps.

The point estimates of spawning biomass are similar to the original estimates. One drawback of using females spawning two nights before capture (day-2 females) is that at high temperatures, e.g. >16°C, postovulatory follicles degenerate faster than at cool temperatures. It is important to establish temperature-dependent identification criteria to obtain an unbiased estimate of spawning fraction. Otherwise at high temperature fish may be misclassified as mature non-spawner (did not spawn in previous 60 hours) and the spawning fraction may be underestimated and vice versa for low temperature. Even though we had not encountered extreme temperature in the most years, in 1994 and 1987, sardine females spawning more than 48 hours before capture were recorded as 'day-2' and we restricted spawning fraction to only sardine females categorized as day-1 spawners.

## References

Alheit, J., Alarcon, V.H. and Macewicz, B.J. (1984). Spawning frequency and sex ratio in the Peruvian anchovy, *Engraulis ringens*. California Cooperative Oceanic Fisheries Investigations Report 25, 43–52.



- Cunha, E.M., Figueiredo, I., Farinha, A. and Santos, M. (1992) Estimation of sardine spawning biomass off Portugal by the daily egg production method. *Boletín del Instituto Español de Oceanografía* 8, 139–153.
- García, A., Pérez, N., Lo, N.C.H., Lago de Lanzos, A. and Sola, A. (1992) The Egg Production Method applied to the spawning biomass estimation of sardine, *Sardina pilchardus* (Walb.) on the North Atlantic Spanish coast. *Boletín del Instituto Español de Oceanografía* 8, 123–138.
- Goodman, L.A. 1960. On the exact variance of products. *JASA*, 55(292):708-713
- Lo, N. C. H. 2001. Daily egg production and spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2001. Southwest Fisheries Science Center, National Marine Fisheries Service, SWFSC Admin. Rep. La Jolla, LJ-01-08. 32 pp.
- Lo, N. C. H., Y. A. Green Ruiz, M. 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. *Calif. Coop. Oceanic. Invest. Rep.* 37:160-174.
- Lo, N.C.H., J. R. Hunter, and R. Charter. 2001. Use of a continuous egg sampler for ichthyoplankton survey: application to the estimation of daily egg production of Pacific sardine (*Sardinops sagax*) off California. *Fish. Bull.* 99:554-571.
- Lo, N. C. H. and B. J. Macewicz, and R. L. Charter. 2007. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2007. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-411. 31 pp.
- Lo, N. C. H. and B. J. Macewicz, D. A. Griffith and R. L. Charter. 2008. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2008. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-430. 33 pp.
- Parker, K. 1985. Biomass model for egg production method. *In* An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy, *Engraulis mordax*, R. Lasker, ed. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 36, pp. 5-6.
- Picquelle, S.J. and R. P. Hewitt 1983: The northern anchovy spawning biomass for the 1982-83 California fishing season. *CalCOFI Rep.*, Vol. 24:16-28.
- Punt, A. , O. Hamer, G. Melvin, A. MacCall, and K. Burham. 2009. Daily egg production methods for Pacific Sardine, Report of STAR Panel Meeting. Agenda Item H.2.a Attachment 4. 9pp.
- Scannel, C. L., T. Dickerson, P. Wolf, and K. Worcester. 1996. Application of an egg production method to estimate the spawning biomass of Pacific sardines off southern California in

1986. Southwest Fisheries Science Center, National Marine Fisheries Service, SWFSC Admin. Rep. La Jolla, LJ-96-01. 37 pp.
- Wolf, P. 1988a. S. Status of the spawning biomass of the Pacific sardine, 1987-88. Calif. Dep. Fish Game, Mar. Res. Div., Rep. to the legislature, 9 pp.
- Wolf, P. 1988b. Status of the spawning biomass of the Pacific sardine, 1988-1989. Calif. Dep. Fish Game, Mar. Res. Div., Rep. to the legislature, 8 pp.
- Wolf, P and P.E. Smith. 1985. An inverse egg production method for determining the relative magnitude of Pacific sardine spawning biomass of California. Calif. Coop. Oceanic Fish Invest. Rep. 26:130-138.

Table 1 Estimates of daily egg production ( $P_0/0.05\text{m}^2$ ) and spawning biomass based on three methods (see text), and their cv in parentheses for 2007 and 2008 of the standard DEPM area off California. Method 1a provided estimates of spawning biomass assuming the cv of the estimates of regional spawning biomass is zero for comparison purposes.

$P_0/0.05\text{m}^2$

Year	Method	Whole (cv)	region 1 (cv)	region 2 (cv)
2007	1	1.14( <b>0.29</b> )	1.32(0.2)	0.56(0.46)
	2		1.32(0.2)	0.56(0.46)
	3	0.86(0.26)	1.32(0.2)	0.56(0.46)
Area (km <sup>2</sup> )		356,159	142,403	213,756
2008	1	0.54( <b>0.64</b> )	1.45(0.18)	0.202(0.32)
	2		1.45(0.18)	0.202(0.32)
	3	0.43(0.21)	1.45(0.18)	0.202(0.32)
Area(km <sup>2</sup> )		297,949	53,514	53,514

**Spawning biomass**

Year	Method	Whole (cv)	Region 1 (cv)	Region 2 (cv)
2007	1	539852 ( <b>0.64</b> )	311774 (0.45)	96819 (0.82)
	1a	539852 (0.41)	311774 (0)	96819 (0)
	2	408593 (0.39)	311774 (0.45)	96819 (0.82)
	3	392,492 (0.45)		
2008	1	137310 ( <b>1.26</b> )	27037 (0.23)	71323 (0.49)
	1a	137310 (0.24)	27037 (0)	71323 (0)
	2	98360 (0.36)	27037 (0.23)	71323 (0.49)
	3	117426 (0.43)		

Table 2. Analysis of variance of mean number of spawning day-0, day-1 and day-2 mature female fish based on data from region 1 and region 2 in 2005, 2007 and 2008.

Coefficients:

	Value	Std. Error	t value	Pr(> t )	Note
(Intercept)	0.1614	0.4361	0.3700	0.7123	
day.group.factor1	0.123	0.0975	1.2664	0.2090	<b>compare day-0 and day-1</b>
day.group.factor2	0.0611	0.0563	1.0862	0.2806	<b>compare (day-0 and day-1) with day-2</b>
years	0.0017	0.0008	2.2705	0.0258	
reg %in% years	-0.0006	0.0002	-2.6871	0.0087	

Residual standard error: 0.7425 on 82 degrees of freedom

Multiple R-Squared: 0.1171

F-statistic: 2.718 on 4 and 82 degrees of freedom, the p-value is 0.03517

Correlation of Coefficients:

(Intercept)	day.group.factor1	day.group.factor2	years	
day.group.factor1	0.0			
day.group.factor2	0.0	0.0		
years	-0.8	0.0	0.0	
reg %in% years	0.1	0.0	0.0	-0.56

Table 3. Unstratified estimates of daily spawning fraction: ( $S_1$ ) by the original and ( $S_{12}$ ) by alternative criteria with cv in the parenthesis for 2004,2005,2007 and 2008.

Survey Year	$S_1$		$S_{12}$	
	Numerator	Denominator	day-1 females m.female <sub>1</sub>	(day-1 + day-2)females/2 m.female <sub>12</sub>
2004			0.13 (0.17)	0.13 (0.11)
2005			0.12 (0.31)	0.10 (0.28)
2007			0.11 (0.33)	0.12 (0.25)
2008			0.12 (0.31)	0.11 (0.29)

m.female<sub>1</sub> = the adjusted total number of mature females with day-0 by replaced by day-1 females.

m.female<sub>12</sub> = the adjusted total number of mature females with day-0 replaced by the average number of day-1 and day2 females

Table 4. The spawning biomass related parameters: daily egg production/ $0.05\text{m}^2$  ( $P_0$ ), daily mortality rate ( $z$ ), survey area ( $\text{km}^2$ ), two daily specific fecundities: (RSF/W), and (SF/W);  $s$ : biomass, female spawning biomass, total egg production (TEP), and sea surface temperature for 1986, 1987, 1994, 2005 and 2007-2009

Calendar year	Season	Region	$^1P_0/0.05\text{m}^2$ (cv)	Z (CV)	$^2\text{RSF/W}$ based on $S_1$	$^3\text{RSF/W}$ based on $S_{1,2}$	$^3\text{FSW}$ based on $S_{1,2}$	$^4\text{Area}$ ( $\text{km}^2$ )	$^5\text{S. biomass}$ (cv)	S. biomass females (cv)	S. biomass females (Sum of R1 and R2) (cv)	Total egg production (TEP)	Mean temperature ( $^{\circ}\text{C}$ ) for positive eggs	Mean temperature ( $^{\circ}\text{C}$ ) from Calvet
1986(Aug)	1986	$^6\text{S}$	1.48(1)	1.59(0.5)	38.31	43.96	72.84	6478	4362 (1.00)	2632 (1)		9587.44		
		N	0.32(0.25)		8.9	13.34	23.89	5333	2558 (0.33)	1429 (0.28)		1706.56		
		whole	0.95(0.84)		23.61	29.89	49.97	11811	7767 (0.87)	4491 (0.86)	4061 (0.66)	11220.45	18.7	18.5
1987(July)	1987	1	1.11(0.51)	0.66(0.4)	38.79	37.86	57.05	22259	13050 (0.58)	8661 (0.56)		24707.49		
		2	0				15443		0	0		0		
		whole	0.66(0.51)		38.79	37.86	57.05	37702	13143 (0.58)	8723 (0.56)	8661 (0.56)	25637.36	18.9	18.1
1994	1993	1	0.42(0.21)	0.12(0.91)	11.57	11.42	21.27	174880	128664 (0.30)	69065 (0.30)		73449.6		
		2	0(0)				205295		0	0		0		
		whole	0.193(0.21)		11.57	11.42	21.27	380175	128531 (0.31)	68994 (0.30)	69065 (0.30)	73373.775	14.3	14.7
2004	2003	1	3.92(0.23)	0.25(0.04)	27.03	26.2	42.37	68204	204118 (0.27)	126209 (0.26)		267359.68		
		2	0.16(0.43)				252416		30833 (0.45)	19065 (0.44)		40386.56		
		whole	0.96(0.24)		27.03	26.2	42.37	320620	234958 (0.28)	145297 (0.27)	145274 (0.23)	307795.2	13.4	13.7
2005	2004	1	8.14(0.4)	0.58(0.2)	31.49	25.6	46.52	46203	293863 (0.45)	161685 (0.42)		376092.42		
		2	0.53(0.69)		3.76	3.2	7.37	207417	686168 (0.86)	298258 (0.89)		109931.01		
		whole	1.92(0.42)		15.67	12.89	27.11	253620	755657 (0.52)	359209 (0.50)	459943 (0.60)	486950.4	14.21	14.1
2007	2006	1	1.32(0.2)	0.13(0.36)	12.06	13.37	27.54	142403	281128 (0.42)	136485 (0.36)		187971.96		
		2	0.56(0.46)		24.48	23.41	38.94	213756	102998 (0.67)	61919 (0.62)		119703.36		
		whole	0.86(0.26)		15.68	16.17	31.52	356159	380601 (0.39)	195279 (0.36)	198404 (0.31)	306296.74	13.7	13.6
2008	2007	1	1.45(0.18)	0.13(0.29)	57.4	53.89	68.54	53514	29798 (0.20)	22642 (0.19)		77595.3		
		2	0.202(0.32)		13.84	12.6	22.57	244435	78359 (0.45)	43753 (0.42)		49375.87		
		whole	0.43(0.21)		21.82	20.31	32.2	297949	126148 (0.40)	79576 (0.35)	66395 (0.28)	128118.07	13.1	13.1
2009	2008	1	1.76(0.22)	0.25(0.19)	19.50	20.37	36.12	74966	129520 (0.31)	73048 (0.29)		131940.16		
		2	0.15(0.27)		14.25	16.26	22.97	199929	36884 (0.38)	26114 (0.38)		29989.35		
		whole	0.59(0.22)		17.01	17.53	29.11	274895	185084 (0.28)	111444 (0.27)	99162 (0.24)	162188.05	13.6	13.5

1:  $P_0$  for the whole is the weighted average with area as the weight.

2: The estimates of adult parameters for the whole area were unstratified and RSF/W was based on original  $S_1$ , data of day-1 spawning females. For 2004, 27.03 was based on sex ratio= 0.618 while past biomass used RSF/W of 21.86 based on sex ratio = 0.5. (Lo et al. 2008)

3: The estimates of adult parameters for the whole area were unstratified. Batch fecundity was estimated with error term. For 1987 and 1994, estimates were based on  $S_1$  using data of day-1 spawning females. For 2004, all trawls were in region 1 and value was applied to region 2.

4: Region 1, since 1997, is the area where the eggs/min from CUFES  $\geq 1$  and prior to 1997, is the area where the eggs/ $0.05\text{m}^2 > 0$  from CalVET tows

5: For the spawning biomasses, the estimates for the whole area uses unstratified adult parameters

6: 1986: Within southern and northern area, the survey area was stratified as region1 (eggs/ $0.05\text{m}^2 > 0$  with embedded zeros) and region 2 (zero catch)

Table 5 Time series of total egg production (TEP) for years when not all estimates of adult parameter were available for 1988, 1996-2003 and 2006.

Calendar year	Season	$P_0/0.05m^2$	CV( $P_0$ )	Z(CV)	Area(km <sup>2</sup> )	Total egg production (TEP)	Mean temperature for positive eggs(°C)	Mean temperature from Calvet (°C)
1988	1987	0.240	0.36	0.390 (0.25)	71,940	17,266	14.81	13.8
1996	1995	0.415	0.42	0.105 (4.15)	235,960	97,923	14.50	15.0
1997	1996	2.770	0.21	0.350 (0.14)	174,096	482,246	13.70	13.9
1998	1997	1.280	0.34	0.255 (0.37)	288,311	369,038	14.38	14.6
1999	1998	1.092	0.35	0.100 (0.60)	304,191	332,177	12.50	12.6
2000	1999	4.235	0.40	0.420 (0.73)	295,759	1,252,539	14.10	14.4
2001	2000	2.890	0.39	0.370 (0.21)	321,386	928,806	13.30	13.2
2002	2001	0.728	0.17	0.400 (0.15)	325,082	236,660	13.60	13.6
2003	2002	1.520	0.18	0.480 (0.08)	365,906	556,177	13.70	13.8
2006	2005	1.936	0.256	0.310 (0.25)	336,774	651,994	14.95	14.5

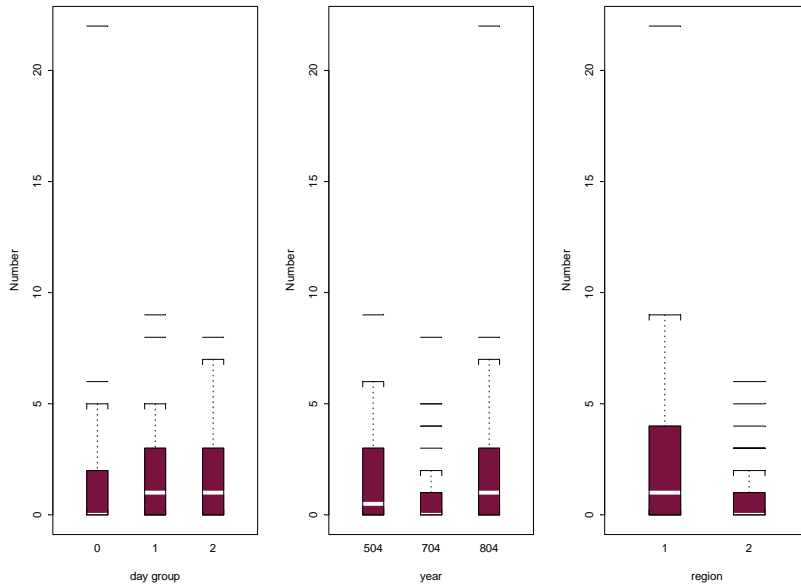
$P_0$  is the weighted average from  $P_0$  in region 1 and region 2 (See Table 4)

TEP=  $P_0$  \* area

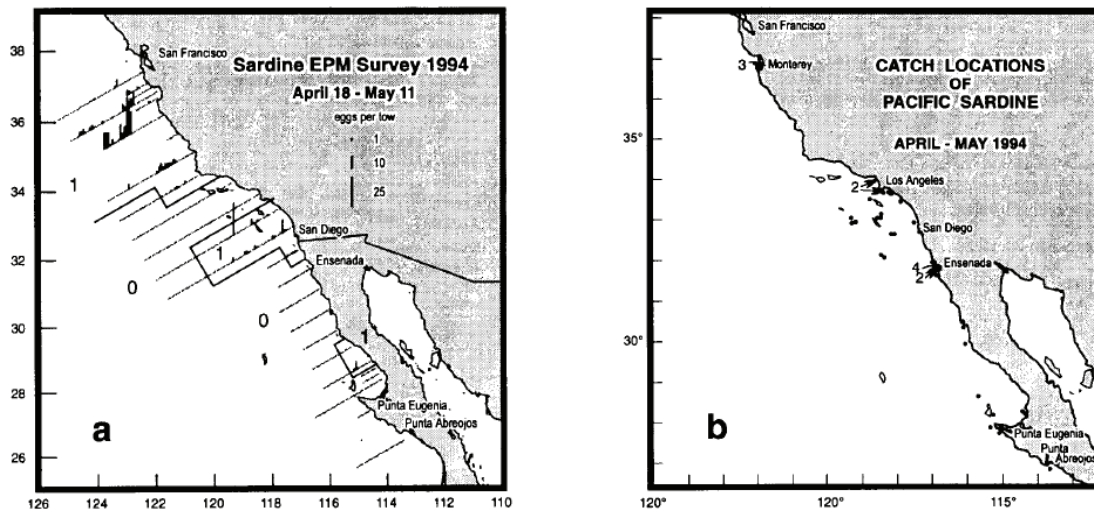
No adult samples were taken in 1996. For 1988, 1997-2003, fecundity-fish weight equation was not available for each year .

In 1997, 2001, and 2002, few opportunistic trawl samples were taken

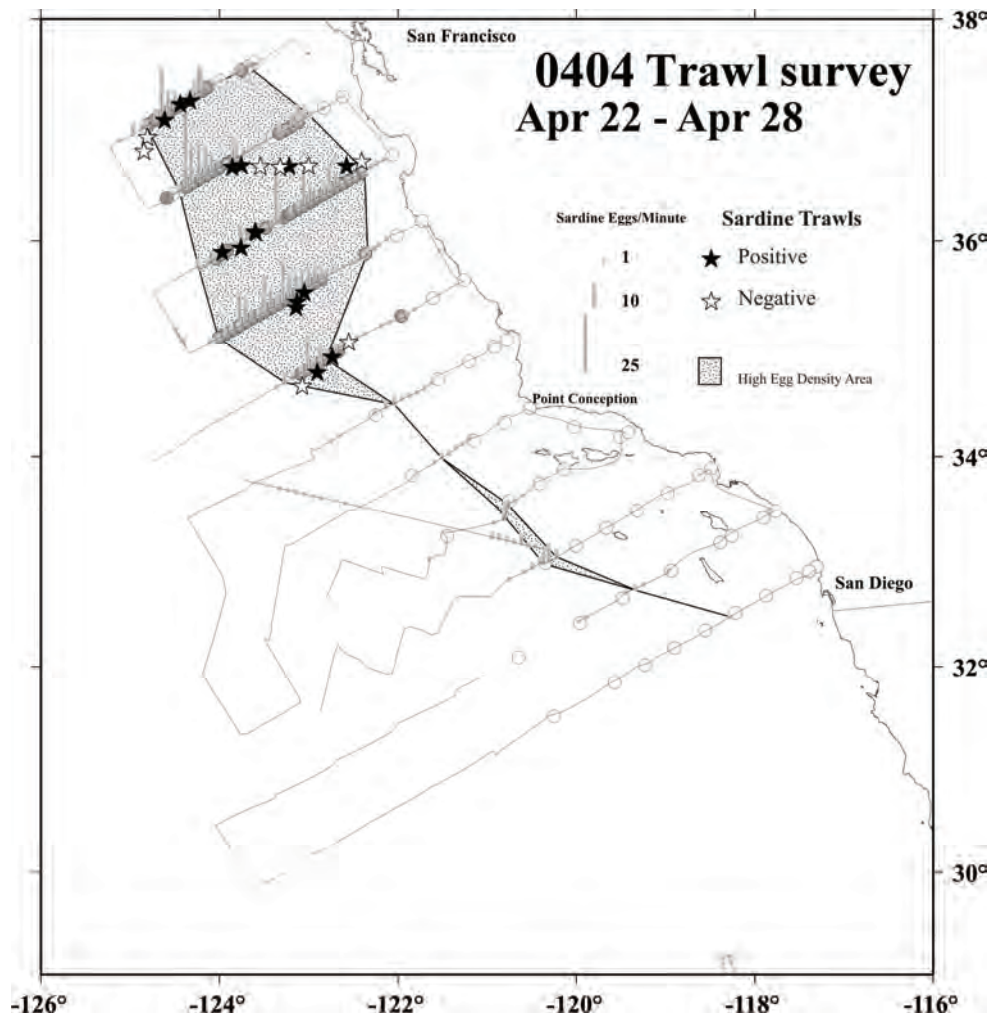
For 2006, TEP was used because trawl samples and egg samples were not synchronized during the survey. Thus adult data collected in 1997, 2004, 2005, and 2007 were used to compute spawn fraction in the original analysis.



**Figure 1.** Box plot for the number of mature female fish of day-0, day-1 and day-2 by day group, year, and region.



**Figure 2** Area sampled during April-May 1994 daily egg production survey for Pacific sardine. Calvet stations and egg catches (left graph) and locations for adult samples (right graph) (Lo et al. 1996)



**Figure 3:** April 2004 trawl start locations. Solid stars are trawls that contained at least one sardine. Background is CUFES track lines and sardine egg abundance, pairvet tows (circles: solid are positive for sardine eggs; open are negative). The high egg density area is Region 1.



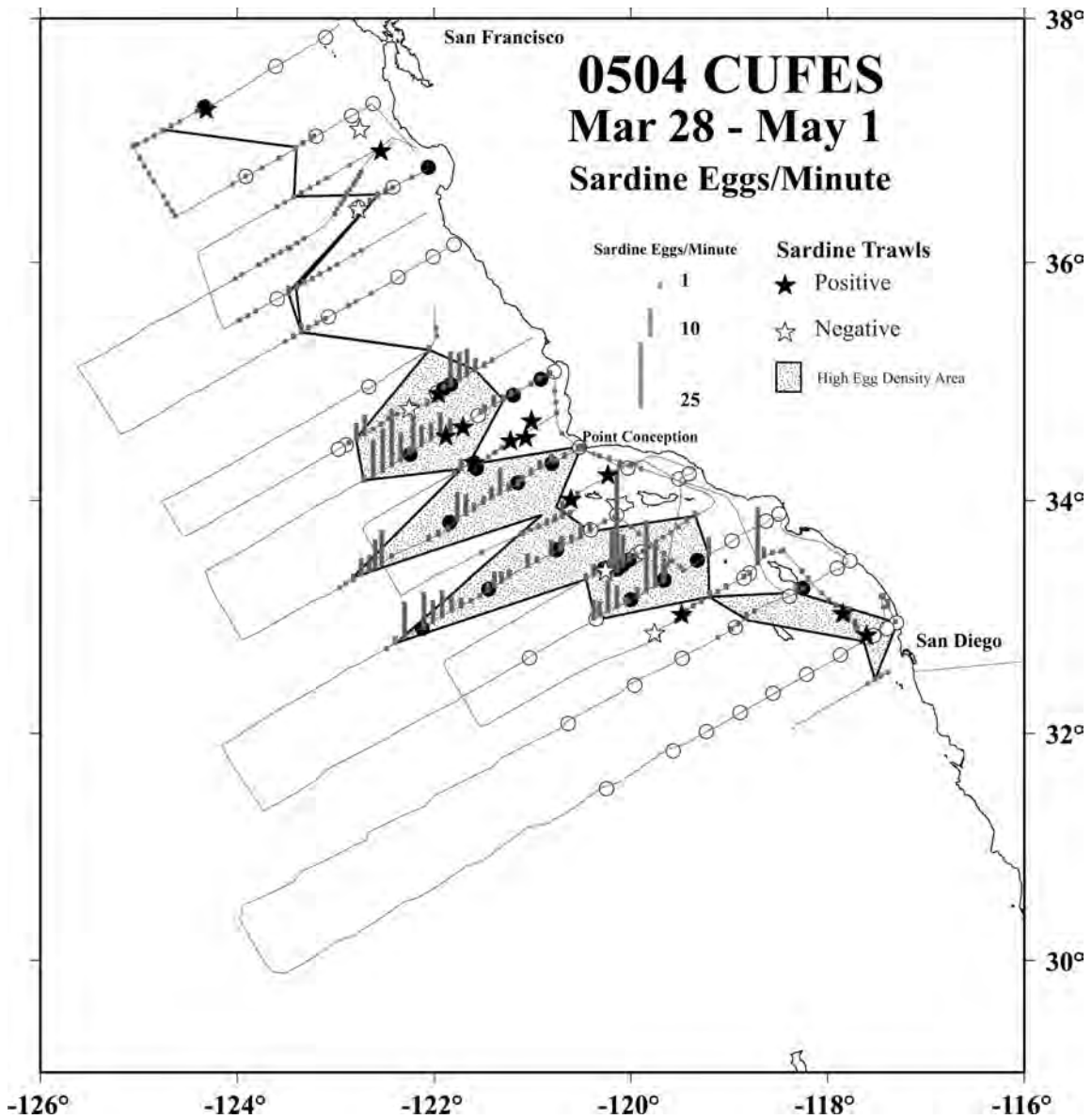


Figure 4. March-April 2005 trawl start locations. Solid stars are trawls that contained at least one sardine. Background is CUFES track lines and sardine egg abundance, pairvet tows (circles: solid are positive for sardine eggs; open are negative). The high egg density area is Region 1.

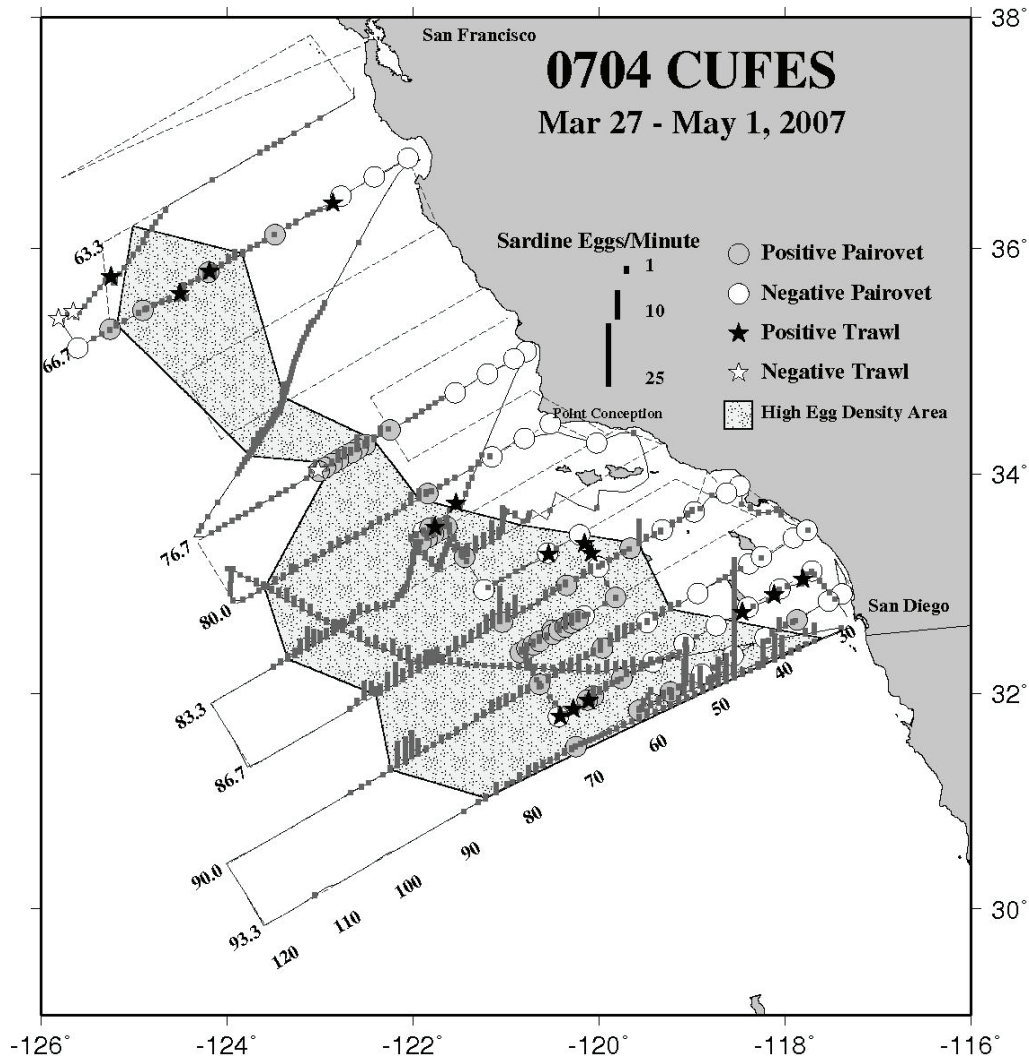


Figure 5. March-April 2007 trawl start locations. Solid stars are trawls that contained at least one sardine. Background is CUFES track lines and sardine egg abundance, pairovet tows (circles: solid are positive for sardine eggs; open are negative). The high egg density area is Region 1.

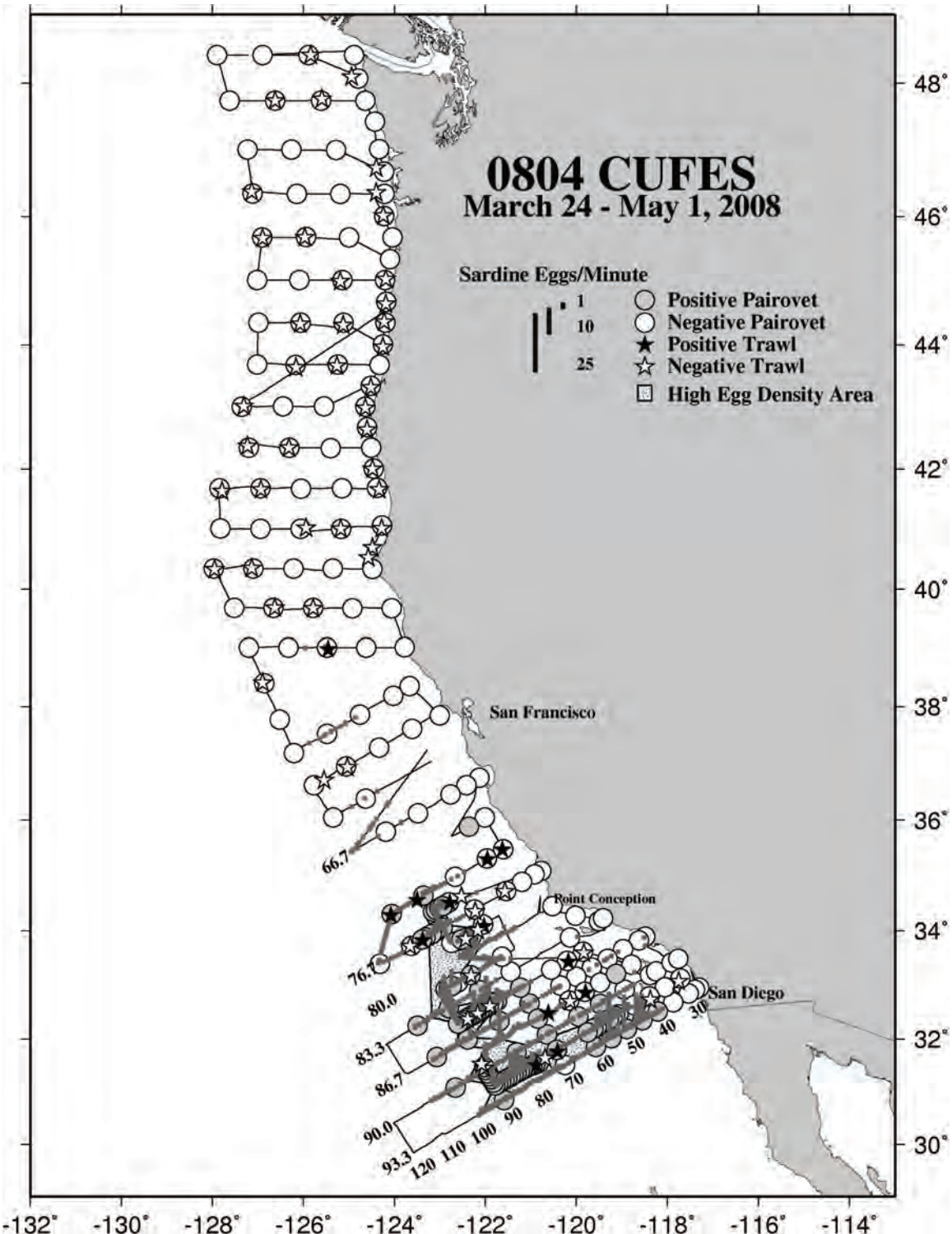


Figure 6. Location of sardine eggs collected from CalVET, a.k.a. Pairovet; (solid circle is a positive catch and open circle is zero catch) and from CUFES (stick denotes positive collection), and trawl locations (solid star is catch with sardine adults and open star is catch without sardines) during the 2008 survey. Region 1 is high density area. Dates of cruises refer to the first and last tow.

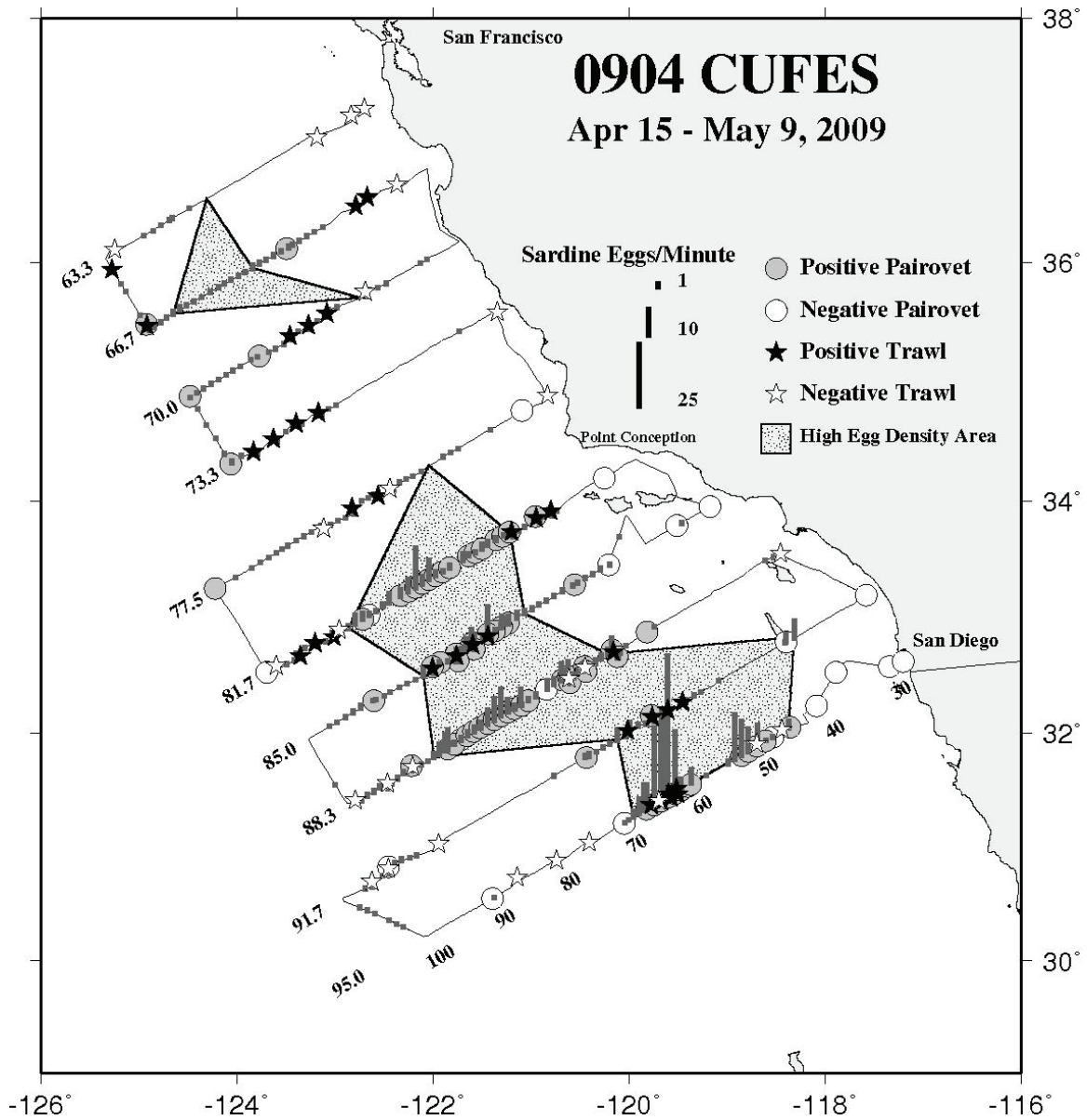


Figure 7. April-May 2009 trawl start locations. Solid stars are trawls that contained at least one sardine. Background is CUFES track lines and sardine egg abundance, pairovet tows (circles: solid are positive for sardine eggs; open are negative). The high egg density area is Region 1.

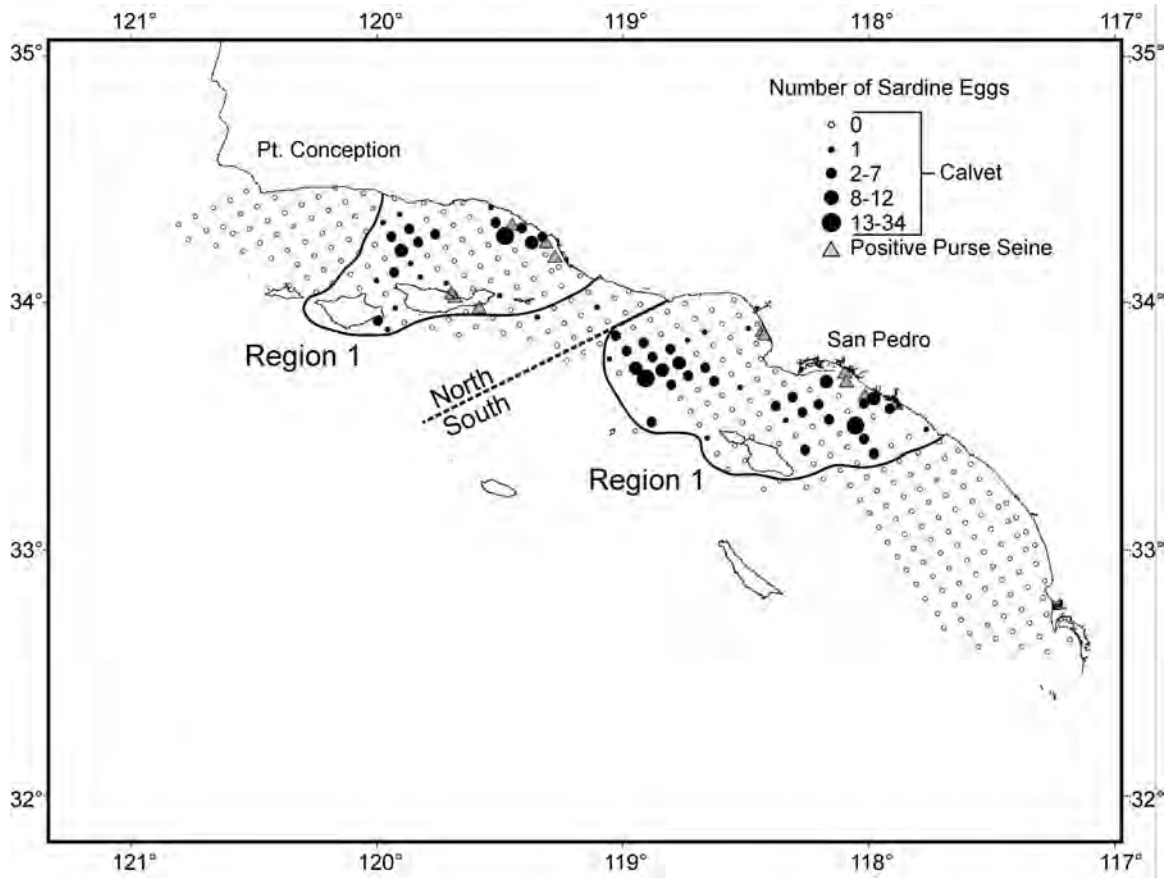


Figure 8. California Department of Fish and Game Pacific sardine ichthyoplankton-purse-seine surveys in August, 1986. Area in side the contours is region 1. Adult collections were purse seine sets (only 1 trawl)

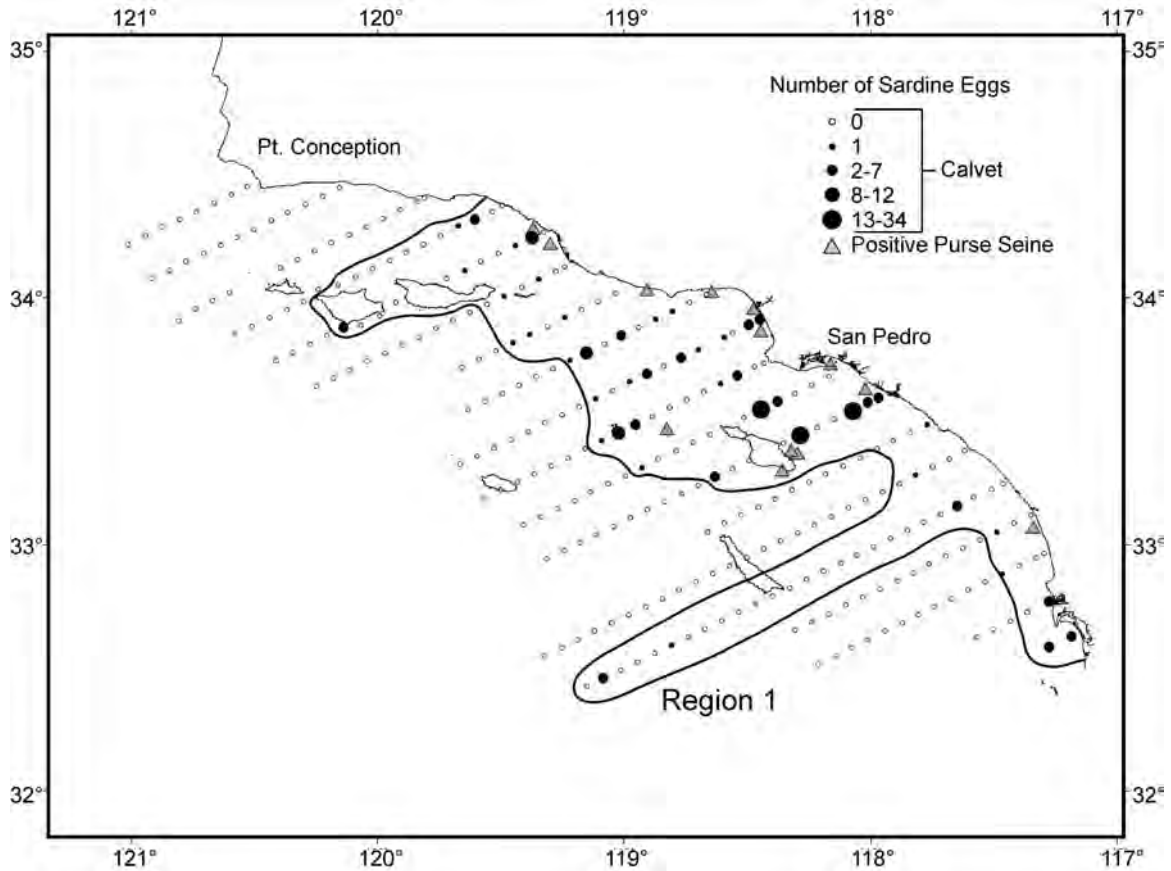


Figure 9. California Department of Fish and Game Pacific sardine ichthyoplankton-purse-seine surveys in July, 1987. Area inside the contour is region 1.

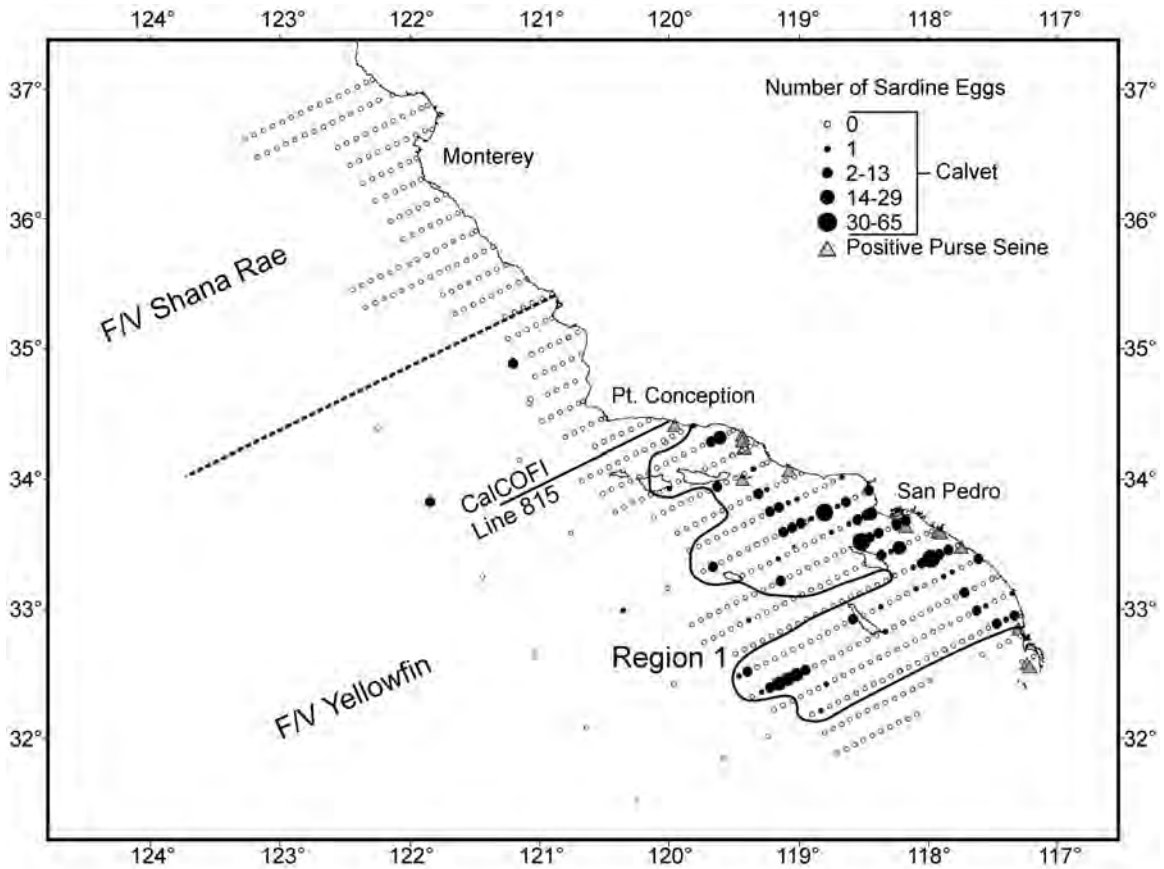


Figure 10. California Department of Fish and Game Pacific sardine ichthyoplankton-purse-seine surveys in May, 1988. Area inside the contour is region 1. Adult collections were purse seine and hook-n-line. Offshore stations south of Point Conception were occupied by CalCOFI survey.

### Appendix I - Adjunct 1

Estimates of variance of each adult parameter and the covariance of any two adult parameters where each adult parameter was weighted by s. biomass in each area

1. Estimate of variance of estimate of the  $i$ th adult parameter weighted by relative s. biomass:

$$\bar{x}_{iw} = \bar{x}_{i1} a_1 + \bar{x}_{i2} a_2 \quad i=1, \dots, 4 \quad a_1 + a_2 = 1$$

$$\begin{aligned} \text{var}(\bar{x}_{iw}) &= \text{var}(\bar{x}_{i1} a_1 + \bar{x}_{i2} a_2) = \text{var}(\bar{x}_{i1} a_1) + \text{var}(\bar{x}_{i2} a_2) + 2 \text{cov}(\bar{x}_{i1} a_1, \bar{x}_{i2} (1 - a_1)) \\ &= \text{var}(\bar{x}_{i1} a_1) + \text{var}(\bar{x}_{i2} a_2) - 2 \bar{x}_{i1} \bar{x}_{i2} \text{var}(a_1) \end{aligned}$$

assuming the covariance of the  $i$ th adult parameter in each region is zero.

$$\text{var}(\bar{x}_{ij} a_j) = \bar{x}_{ij}^2 \text{var}(a_j) + a_j^2 \text{var}(\bar{x}_{ij}) - \text{var}(\bar{x}_{ij}) \text{var}(a_j)$$

(Goodman, 1960)

where  $\bar{x}_{ij}$  is the  $i$ th adult parameter and

$$a_j = (\text{s. biomass in the } j\text{th region}) / \text{total s. biomass}, \quad i=1, \dots, 4 \text{ and } j=1, 2.$$

2. Estimate of covariance of the two weighted adult parameters estimated by ratio estimates:  $\bar{x}_{1w}, \bar{x}_{2w}$ :

$$\bar{x}_{1w} = \bar{x}_{11} a_1 + \bar{x}_{12} a_2, \quad \bar{x}_{2w} = \bar{x}_{21} a_1 + \bar{x}_{22} a_2$$

$$\text{cov}(\bar{x}_{1w}, \bar{x}_{2w}) = E(\bar{x}_{1w} \bar{x}_{2w}) - E \bar{x}_{1w} E \bar{x}_{2w}$$

$$\begin{aligned} E(\bar{x}_{1w} \bar{x}_{2w}) &= E(\bar{x}_{11} a_1 + \bar{x}_{12} a_2)(\bar{x}_{21} a_1 + \bar{x}_{22} a_2) \\ &= [\text{cov}(\bar{x}_{11}, \bar{x}_{21}) + E \bar{x}_{11} E \bar{x}_{21}] [\text{var}(a_1) + (E a_1)^2] + \\ &\quad (E \bar{x}_{11} E \bar{x}_{22} + E \bar{x}_{12} E \bar{x}_{21}) [E a_1 - (E a_1)^2 (1 + \text{cv}(a_1)^2)] \\ &\quad + [\text{cov}(\bar{x}_{12}, \bar{x}_{22}) + E \bar{x}_{12} E \bar{x}_{22}] [\text{var}(a_2) + (E a_2)^2] \end{aligned}$$

$$\text{Note : } \text{cov}(x, y) = E(xy) - E x E y$$

$$\text{and } \text{var}(x) = E x^2 - (E x)^2$$

where

$\bar{x}_{11}$  and  $\bar{x}_{21}$  are estimates of any two adult parameters, say, sex ratio and batch fecundity in region 1 and  $\bar{x}_{12}$  and  $\bar{x}_{22}$  are sex ratio and batch fecundity estimates in region 2.  $a_j$  is the weighting factor for region  $j$  and is the s. biomass estimate in each region.



**Appendix I - Adjunct 2**

Variance and covariance of the adult parameter estimates based on method 1 estimate of each adult parameter as the weighted mean for 2007 data.

Weighted mean:

	Estimate	variance	CV
Sex ratio (R)	0.51	6.780021e-002	0.098
Fish weight (W)	81.72	1.748073e+003	0.082
Fecundity (F)	21764.96	1.237309e+008	0.081
Spawning fraction (S)	0.11	5.068447e-003	0.316

Covariance of weighted means

	Fish weight (W)	Fecundity (F)	Spawning fraction (S)
Sex ratio (R)	0.095	24.84	0.098
Fish weight (W)		13440.88	-0.0219
Fecundity (F)			-6.082

## **APPENDIX II**

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

- A) Report of the STAR Panel held September 21-25, 2009, in La Jolla, CA
- B) Report of the Scientific and Statistical Committee meeting held November 1, 2009, in Costa Mesa, CA.
- C) Reports of the Coastal Pelagic Species Management Team and Advisory Subpanel meetings held November 1-2, 2009, in Costa Mesa, CA.

## **Pacific Sardine**

### **STAR Panel Meeting Report**

NOAA / Southwest Fisheries Science Center  
La Jolla, California  
September 21-25, 2009

#### **STAR Panel Members:**

André Punt (Chair), Scientific and Statistical Committee (SSC), Univ of Washington  
Selina Heppell, SSC, Oregon State University  
Dvora Hart, External Reviewer, Northeast Fisheries Science Center  
John Wheeler, Center for Independent Experts (CIE)

#### **Pacific Fishery Management Council (Council) Representatives:**

Briana Brady, Coastal Pelagic Species Management Team (CPSMT)  
Mike Okoniewski, Coastal Pelagic Species Advisory Subpanel (CPSAS)  
Mike Burner, Council Staff

#### **Pacific Sardine Stock Assessment Team:**

Kevin Hill, NOAA / SWFSC  
Nancy Lo, NOAA / SWFSC  
Beverly Macewicz, NOAA / SWFSC  
Paul Crone, NOAA / SWFSC

#### **Aerial Survey Team**

Tom Jagielo, Tom Jagielo Consulting  
Ryan Howe, West Coast Sardine Survey  
Doyle Hanan, Hanan and Associates, for California Wetfish Producers Association  
(CWPA)

## 1) Overview

The Pacific Sardine Stock Assessment and Review (STAR) Panel (Panel) met at the Southwest Fisheries Science Center, La Jolla, CA Laboratory from September 21-25, 2009 to review a draft assessment by the Stock Assessment Team (STAT) for Pacific Sardine. The Panel also reviewed the results of the 2009 industry-sponsored aerial survey (aerial survey) for Pacific sardine. Introductions were made (see list of attendees, Appendix 1), and Mike Burner reviewed the Terms of Reference for CPS assessments with respect to how the Panel would be conducted. A draft assessment document and background materials were provided to the Panel in advance of the meeting on the Council FTP site.

In addition to a review of the data inputs and assessment results, the Panel reviewed a report presented by Tom Jagielo on the 2009 aerial survey. The main text of this report outlines the discussions relative to the stock assessment itself, while Appendix 2 outlines the discussions related to the 2009 aerial survey. Both the main text and Appendix 2 list relevant research recommendations.

Kevin Hill (SWFSC) presented the assessment methodology and the results from a draft assessment utilizing the Stock Synthesis Assessment Tool, Version 3.03a (SS3). The model on which the draft assessment was based differed from that on which the 2007 assessment was based in several respects: (a) the use of bi-annual (semester; S1 (July-Dec) and S2 (Jan-June)) rather than quarterly time-steps, (b) separation of the California fishery into central and southern California fisheries, (c) the use of weighted rather than unweighted length-frequencies and conditional ages-at-length for all fisheries rather than just the California fishery, (d) the use of different population length-bins, (e) the use of the hybrid option to estimate  $F$ , (f) different assumptions regarding selectivity, and (g) the use of revised estimates of spawning biomass from the daily egg production method (DEPM) as an index of relative abundance. The draft assessment treated the early (1981-1990; EAR) and more recent (1991+; LAT) data for the Ensenada and southern California fisheries as separate fisheries. The review and subsequent explorations of the model through sensitivity analyses were primarily motivated by the marked temporal changes in the biomass time series evident from the retrospective analysis, very high estimates of fishing mortality ( $F$ ) in some years, poor residual patterns in the fits to the age- and length-composition data for some fleets and years, concern over environmentally-driven and/or density-dependent changes in biological parameters, and seasonal effects on selectivity generated by shifts in fish distribution.

The Panel reviewed the DEPM and TEP time series which had been updated based on the recommendations of the May STAR 2009 Panel. The final DEPM time series was based on the sum of the DEPM spawning biomass estimates for each of two regions rather than on the approach recommended by the STAR Panel because the recommended approach led to estimates with very high variance. The Panel endorsed the use of the revised DEPM and TEP estimates for use in the assessment.

The Panel endorsed the use of the 2009 aerial survey data as the basis for an estimate of absolute abundance after revising the method used to model the relationship between

school weight and school area and the method used to quantify uncertainty. The 2009 aerial survey is a key source of information about the stock status of Pacific sardine. The final version of the document describing the aerial survey, the data collected, and the analysis of those data needs to be provided along with the final assessment report to the November 2009 Council meeting and included in the CPS Stock Assessment and Fishery Evaluation (SAFE).

The Panel and STAT revised the model in the draft assessment by: (a) allowing growth to differ between 1981-90 and 1991+, (b) changing the time-blocking for the selectivity pattern for the central California fishery, (c) combining the early and later fisheries for Ensenada and southern California, (d) fitting the California fisheries in semesters one and two with separate selectivities, (e) including the 2009 aerial survey estimate of absolute abundance, and (f) not bias-correcting the 2008 and 2009 recruitments. The STAR panel concluded that this final base model constitutes the best available scientific information on the status of Pacific sardine off the west coast of North America and recommends that it be used for status determination and management in the Council process.

The Panel reviewed a proposal for a research set-aside for 2010 (Appendix 3). It agreed that how well different research set-asides improve the precision of the relationship between school weight and school area was an appropriate scientific basis for contrasting alternative research set-asides. However, the Panel noted that there is no way to specify the ideal number of point sets because larger numbers of point sets will lead to more precise estimates. The Panel therefore recommended that the proponents evaluate the trade-off between the number of point sets [and design of school sizes within the set-aside] and the precision of the relationship between school size and school area (e.g., in the form of a Coefficient of Variation (CV)) and present this information to the SSC at the November 2009 Council meeting. The SSC could then provide a recommendation regarding a research set-aside based on this trade-off (e.g., the point at which the rate of change of CV with set-aside indicates diminished returns from extra sampling). The Panel noted that a bootstrap approach along the lines of Adjunct 2 to Appendix 2 could be used to construct the needed trade-off relationship.

This assessment is the first to make use of an estimate of absolute abundance for Pacific sardine, although, as noted below, the uncertainty associated with that 2009 aerial survey is not fully quantified. The need for a STAR Panel review of the Pacific sardine assessment before 2012 depends on whether any major new sources of data (such as estimates of absolute abundance from acoustic surveys or based on satellite images) or substantial revisions to the methodology on which current data sources are based become available. Similarly, a STAR Panel would be warranted if further major changes to the assessment are needed because the revised process for update assessments limits the scope of changes to assessments during “update years”. In addition, the estimate of total catch by the U.S., Mexico, and Canada combined for 2008 exceeded that implied by the harvest guideline for the entire stock based on the 2008 assessment. A more thorough review of stock status may be needed if this continues.

The STAR Panel thanked the STAT for their hard work and willingness to respond to Panel requests, and the staff at the SWFSC La Jolla laboratory for their exceptional support and provisioning during the STAR meeting.

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

The fisheries modelled and referred to in this and the following sections are:

- Ensenada (ENS)
- Southern California (SCA) – south of Point Conception
- Central California (CCA) – Point Conception to San Francisco
- Pacific Northwest (PNW)

The following acronyms are used as well:

- DEPM = Daily Egg Production Model (fishery independent survey)
- WCVI = West Coast Vancouver Island Survey (fishery independent survey)
- TEP = Total Egg Production
- PFFS = Predator Forage Fish Survey (fishery independent survey)
- S1 = First season (July – Dec)
- S2 = Second season (Jan – June)
- MLE = Maximum likelihood estimate
- EFP = Exempted Fishing Permit

**A: Plot the selectivity and growth curves for each retrospective run and perform a sensitivity analysis to assess the influence of different data inputs by doubling the weights on the index, and age- and length-composition data for the four fisheries one at a time.**

*Rationale:* To identify why there were significant deviations in the biomass estimates for the retrospective runs, particularly a large change between 2007 and 2008.

*Response:* The growth curves were comparable for all retrospective runs, but the selectivity curves were affected by the influx of the large 2003 cohort into the PNW fishery. The sensitivity analysis showed no effect of the DEPM and TEP survey data, but revealed some influence of the age- and length-composition data for the ENS and SCA fisheries on biomass scaling. All the runs showed a similar pattern of decline since 2006.

**B: Identify the effects of age- and length-composition data from each fishery on the likelihood profiles for natural mortality ( $M$ ).**

*Rationale:* The likelihood profile for  $M$  suggested an MLE much larger than the base value for  $M$  and inconsistencies between the  $M$ -values supported by the age- and length-composition data.

*Response:* The  $M$ -value at which the fishery-specific likelihood profiles were minimized varied substantially among data sources, with the SCA fishery data supporting a higher  $M$ . The inconsistency in likelihood profile patterns across fisheries and between the age-composition and length-composition data led to additional scrutiny of age- and length-composition residuals and the possible effects of aging error or environmental variability such as El Niño.

**C: Determine the effects of aging error on model results by adding a linear bias to the age compositions.**

*Rationale:* The age-frequency data for the PNW suggested a “spillover” effect by the 2003 cohort, and aging error could affect model fitting for the later years in the time series due to that large cohort.

*Response:* The suggested (semi-arbitrary) aging bias pattern (a linear increase in expected age from expected age 0.5 at true age 0.5 to expected age 5.5 at true age 6.5 and then a constant bias of 1 year thereafter) resulted in a slightly poorer fit to the data (negative log-likelihood increase from 3341 to 3374), a higher biomass peak and a lower ending biomass. No problems were solved with this analysis, although the level of aging error may have been set too high.

**D: Re-run the assessment assuming a Beverton-Holt stock-recruitment relationship.**

*Rationale:* The stock-recruitment plot showed a large amount of variability with large recruitments in four years: 1994, 1997, 1998, and 2003, which are El Niño years. With those points removed or treated separately, there was little obvious (visual) justification for a Ricker curve.

*Response:* Assuming a Beverton-Holt rather than a Ricker stock-recruitment relationship led to a nearly identical fit (negative log-likelihood = 3330, slightly below that for the base model) and a slightly greater biomass peak, but the population did not appear to grow fast enough during the early part of the time series. This Beverton-Holt curve did not solve the problem of unrealistic  $F$  estimates.

**E: Add the new aerial survey results to the assessment and examine the sensitivity of the assessment to a range of (assumed) coefficients of variation for the biomass estimate; estimate selectivity for the aerial survey.**

*Rationale:* The 2009 aerial survey can be used to calculate a fishery-independent biomass estimate that provides critical information on stock size and distribution. The methods and analysis on which this estimate was based were reviewed and improved through consultation with the Panel (Appendix 2).

*Response:* The addition of the aerial survey biomass estimate (1.4 million metric tons) increased the expected age-1 biomass and did not drastically alter the residuals for other survey data (DEPM, TEP). The expected current age-1 biomass doubled with a CV of 0.49 and increased as the CV decreased. The selectivity pattern for the aerial survey was dome-shaped, and the model fit the aerial survey length-composition data reasonably well. Additional evaluation of the effects of the aerial survey on the model results was postponed until a new base model was completed.

**F: Explore the effects of blocking growth and/or selectivity curves.**

*Rationale:* The residuals for the age- and length-composition data strongly suggested that growth and selectivity were not constant over time, potentially due to strong year classes and two years of data from the ENS and SCA fisheries with particularly high proportions of older fish. There was also biological evidence of shifts in fish distribution that would affect selectivity in the south between the two semesters.

*Response:* Adding semesters to the selectivity curve estimation improved the model fit, supporting the seasonal shift in fish distribution and age-composition hypothesis.

Removing the length and age data for ENS and SCA in 1990 and 1991 led to a surprisingly large reduction in negative log-likelihood; a similar result was obtained by blocking these data sets for the two years separately from the prior and proceeding years. Efforts to block selectivities by El Niño years and as a function of sea surface temperature patterns were not successful (i.e., deterioration of model fit to data). There was strong support for a shift in growth rates in 1991, with slower growth in the more recent years. The predicted change in the growth parameter  $k$  was large  $-0.84 \text{ yr}^{-1}$  in years prior to 1991, but only  $0.40 \text{ yr}^{-1}$  in 1991-2009. This may reflect a shift in life history tactics following expansion of the stock into northern waters; additional evaluation of correlated life history parameters, such as length at maturity, is warranted. Improvement to the overall model fit, before adjusting the weights, was over 100 likelihood points and the revised model provided much better fits to the length- and age-composition data. The Panel recommended development and analysis of a new base model that included a change in growth after 1990 and three selectivity time blocks (1981-1991, 1992-1998, and 1999-2009) based on the improvement in negative log-likelihood and data fits. The negative log-likelihood for this new base model was 3151 with 107 parameters.

**G: Explore alternative time blocking on selectivities.**

*Rationale:* Residuals from the length- and age-composition data suggest substantial shifts have occurred in catch composition over time and among fisheries, but the number and years needed for optimal blocking are not clear. Time-specific selectivities are supported by observations of a shift in fish distribution by size over time (more and larger fish in the north).

*Response:* An alternative blocking on selectivity was explored based on observed shifts in the age- and length- compositions in the different fisheries: ENS status quo; SCA 1981-1989, 1990-1991, 1992-1998, 1999-2009; CCA 1981-1992, 1993-1998, 1999-2009; PNW status quo. The negative log-likelihood for this model was 3146 and the model showed minor improvement to age-composition residuals. The analysis indicated that the new base model did not react strongly to isolating 1990 and 1991, years with large numbers of older fish in the catch. The Panel approved the decision by the STAT to use the new split for CCA, but retain the status quo for the other fisheries, based on improved age-composition residuals for that fishery.

**H: Add seasonal (semester) selectivities to California fisheries.**

*Rationale:* Observations and length composition data suggest that large fish are present in the southern part of the range in spring (S2) but not in summer (S1), when they move northward.

*Response:* The overall negative log-likelihood improved with seasonal selectivity for the two California fisheries: 131 parameters, overall negative log-likelihood = 3122. This model showed noteworthy improvements to the fits to the age-compositions for the CA fisheries without degradation in the fit to the ENS and PNW age- and length-composition data. The new model showed shifts in selectivity patterns that conformed to observations of a shift in age structure through time, season, and years. The final age-1 biomass estimate for this model, before adding the aerial survey data, was 0.6 million mt. Fishing mortality estimates were still high for some years and were unrealistically high for 2009.



The residuals on the age compositions for most fisheries were improved, but the model was still struggling to fit the PNW age distribution due to 2003 and possibly 2004 year classes, which recruited in greater numbers to this area.

**I: Identify the effects of age- and length-composition data from each fishery on the likelihood profiles for natural mortality ( $M$ ).**

*Rationale:* The likelihood profiles for  $M$  from the original base model indicated a conflict among the different data sets; it was hoped that the new base model would be more consistent.

*Response:* The new base model showed a change in the point estimate of  $M$  from  $0.8 \text{ yr}^{-1}$  to  $0.6 \text{ yr}^{-1}$ , which is more biologically reasonable for sardine. The likelihood profiles by fishery and composition types were also more consistent. However, the length composition data indicated a best estimate for  $M$  of  $0.65 \text{ yr}^{-1}$ , while the age-composition data still preferred higher  $M$  estimates.

**J: Conduct a sensitivity analysis accounting for aging error.**

*Rationale:* The new base model still had problems fitting the large 2003 year class, with residual patterns that suggested possible “spillover” of fish from the strong 2003 cohort into the 2004 cohort and hence that fish ages may be underestimated.

*Response:* Similar to request C, this sensitivity test increased expected age linearly with true age, but so that the expected age at true age  $n$  was age  $n-0.5$  from age 6. The negative log-likelihood for this model was 3112, indicating a marginally better fit and providing some support for aging error. However, the residual pattern evident for the PNW was not resolved. The results indicate a need for further investigation of aging error.

**K: Re-run the assessment assuming a Beverton-Holt stock-recruitment relationship.**

*Rationale:* The stock-recruitment plot showed a large amount of variability, with large recruitments in four years: 1994, 1997, 1998, and 2003, which are El Niño years. With those points removed or treated separately, there was little obvious (visual) justification for a Ricker curve.

*Response:* The negative log-likelihood for this model was 3128, a minor improvement overall; the peak biomass and final biomass were both slightly higher. The estimate of steepness was 0.89. The Panel agreed that there was no need to change the base model at this time.

**L: Explore the influence of high British Columbia catch in 2008 on model results.**

*Rationale:* There is a need to determine if the British Columbia (BC) fishery should be treated independently from PNW, particularly in light of the large catch reported for 2008.

*Response:* A sensitivity test was run omitting the 2008 length-composition data for the PNW (where the BC data would have heaviest influence), but not the catch itself. Unlike the 2008 update assessment, reducing the influence of the PNW length and conditional age-composition data for the most recent year had little effect on model results and the shape of the biomass trajectory through time, although the biomass estimates were scaled lower. This result re-emphasized the need for estimates of absolute abundance to scale the population estimates.

**M: Estimate  $M$  separately for the same time blocks used for growth.**

*Rationale:* Natural mortality is correlated with growth in many studies of fish populations. The large predicted difference in growth rate for the two periods (von Bertalanffy growth parameter  $k = 0.85 \text{ yr}^{-1}$  for 1981-1990 and  $0.42 \text{ yr}^{-1}$  for 1991-2009) suggests that  $M$  may also have been different for these two periods.

*Response:* The resulting  $M$  values for this sensitivity analysis were  $1.22 \text{ yr}^{-1}$  for the early period and  $0.45 \text{ yr}^{-1}$  for the late period. An  $M$  of  $1.22 \text{ yr}^{-1}$  is unrealistic for Pacific sardine given the ages encountered in the fishery data, and must include the effects of both natural mortality and emigration during the years 1981-1990. The Panel's conclusion after reviewing the residual patterns was that length and age data for 1981-90 are leading to the high estimate of  $M$  for the early years. This analysis provides a partial explanation for why  $M$  has a minimum at values larger than  $0.4 \text{ yr}^{-1}$  in the likelihood profile for the base model. This result warrants further investigation. However, the model did not lead to the expected stock trajectory in the 1980s (recovery), and the results may be caused by local minima in the fitting process.

**N: Add aerial survey data to the model and run a sensitivity on the coefficient of variation of the biomass estimate.**

*Rationale:* The 2009 aerial survey can be used to calculate a fishery-independent estimate of biomass that provides critical information on stock size and distribution. The survey methods and analysis for the aerial survey were reviewed and improved through consultation with the Panel (Appendix 2 Adjunct).

*Response:* The addition of the biomass estimate from the aerial survey (1.35 million mt with a CV = 0.52, Appendix 2) approximately doubled the current expected age 1+ biomass and did not drastically alter the residuals for the other survey data (DEPM, TEP). The selectivity pattern for the aerial survey was dome-shaped, and the model fit the fishery age- and length-compositions reasonably well. The expected biomass increased as the CV decreased, but maintained the same pattern. There was a major increase in the estimate of current (2009) age 1+ biomass (from 0.88 million mt to 2.53 million mt) as the survey CV was decreased from 0.5 to 0.45. The addition of the aerial survey data decreased the peak estimates for fishing mortality, with a maximum  $F$  estimate of  $0.6 \text{ yr}^{-1}$  for ENS in 2009. The fit to the DEPM data was not inconsistent with that for models, which ignored the aerial survey data. The model prediction for the 2009 aerial survey is only 114,000 mt (biomass selected by the survey gear), only slightly higher than the biomass estimated from the observed transects (approximately 96,000 mt). The model fits the data adequately and gives a higher biomass estimate than the base model, but not as high as the point estimate of absolute abundance based on the aerial survey. With a CV of 0.55, the model is essentially putting more emphasis on fitting other data sources; this will change if the CV of the estimate of abundance from the aerial survey can be reduced or with the addition of more years of data. A lower CV (0.4) increased age 1+ biomass to 3 million mt, but the model estimate corresponding to the aerial survey estimate was still only 430,000 mt. The catchability coefficients for the DEPM and TEP time-series were markedly lower when the aerial survey data were included in the assessment (e.g., 0.16 for DEPM compared to 0.34 for the previous base model). The Panel concluded that the aerial survey provides important data for estimating absolute population size, and

recommended that it should be included in the assessment, and that the aerial survey should be continued.

**O: Run final base model with Beverton-Holt stock-recruitment relationship.**

*Rationale:* There is still uncertainty about the form of the stock-recruitment relationship, so the Beverton-Holt curve should be run as a sensitivity on the final base model.

*Response:* The fit for this model was similar (no improvement in log-likelihood), but with biomass scaled up. Recruitment variance needs to be adjusted to improve the fit. Due to abrupt changes in biomass caused by tension between the age- and length-composition data and the aerial survey estimate of absolute abundance, the Panel recommended that the sensitivity analysis be completed by including the Beverton-Holt stock-recruitment relationship in the model and tuning the effective sample sizes prior to adding the aerial survey data. This sensitivity analysis should be included in the final assessment report.

**P: Add WCVI night estimates (2006, 2008, 2009) to the model as a sensitivity analysis.**

*Rationale:* The WCVI survey is an important source of abundance information from Canada, and methods for this survey are consistent for 2006 onwards. However, the data cannot be formally added to the base model until an analysis of methods has been presented and reviewed; therefore the data were treated as the basis for a sensitivity analysis.

*Response:* The length compositions from the WCVI survey caused a marked increase in the estimate of current biomass, including high biomass (500,000mt) prior to stock recovery in the 1980s. As with the Beverton-Holt sensitivity analysis (see request O), the Panel recommended that the model be tuned using these data before adding the aerial survey data. This sensitivity analysis should be included in the final assessment report.

**Q: Run a likelihood profile on the aerial survey catchability ( $q$ ).**

*Rationale:* The assumption  $q = 1$  for the aerial survey may not be correct. The Panel also wished to further explore the extent to which the aerial survey data were consistent with the remaining data sources

*Response:* The likelihood profile showed a decrease in negative log-likelihood as  $q$  increased (Figure 1), with, as expected, the lowest negative log-likelihood at high  $q$  (effectively ignoring the aerial survey data). This further supports the need for additional survey data to scale abundance and provide a time-series of abundance estimates.

**R: Document response of the model to “Jitter” analysis to avoid local minima.**

*Rationale:* The sensitivity of the model results to seemingly small changes to assumptions pointed to the possibility of local minima. Repeat the estimation for the base model with 2-5% “jitter” of starting values.

*Response:* Up to a 4% change in starting values for all parameters caused no major changes in model results.

**S: The draft document should be modified to include a more thorough description of the analysis on which PFFS index is based.**

*Rationale:* The document only includes the results of the analyses.

*Response:* This information will be included in the final report.

### **3) Technical Merits and/or Deficiencies of the Assessment**

The final base model incorporates the following specifications:

- Two seasons (Jul-Dec and Jan-Jun) (assessment years 1981 to 2009).
- Four fisheries (ENS, SCA, CCA, PNW), with annual selectivity patterns for ENS and PNW and seasonal selectivity patterns for SCA and CCA.
- Fishery-specific time-blocking of selectivity (1981-91, 1992-98, 1999+ for ENS and SCA; 1981-92, 1993-98, 1999+ for CCA; 1981-2003, 2004+ for PNW)
- Ricker stock-recruitment relationship with estimated “steepness”.
- $M = 0.4 \text{ yr}^{-1}$ ;  $\sigma_R = 0.89$  (tuned value).
- Initial recruitment estimated; recruitment residuals estimated for 1975-2007.
- Two growth periods (1981-90 and 1991+).
- Length-frequency and conditional age-at-length data for all fisheries.
- Length-frequency data for the 2009 aerial survey, taken from point-set samples.
- DEPM and TEP measures of spawning biomass (1986, 1987, 1993, 2003, 2004, and 2006-08 for DEPM, and 1987, 1995-2002 and 2005 for TEP) and the 2009 aerial survey estimate of abundance.

In contrast to past assessments, the current assessment is based on a more thorough evaluation of time-trends in growth and selectivity, which resulted in better fits to all of the available data sources. The current assessment also considered more potential indices of abundance. While not all of these were included in the base model the potential remains that these sources of data could be used in the future, following review of the analysis techniques on which they were based and of the available data.

The final base model differs markedly from that in the draft assessment in terms of current stock size. This is due primarily to the inclusion of the estimate of abundance from the 2009 aerial survey. Other information in the assessment is not markedly informative about absolute abundance. Therefore, while uncertain, even a fairly imprecise estimate of absolute abundance is informative for scaling biomass.

### **4) Areas of Disagreement**

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

### **5) Unresolved Problems and Major Uncertainties**

#### *a) Lack of information on absolute abundance*

Most of the data sources used in the final base model provide information, which reliably determine trends in abundance. However, as shown by the retrospective analyses (and the 2008 assessment update), relatively “minor” changes to the input data can lead to major changes to the model estimates of absolute abundance. The 2009 aerial survey estimate of abundance provides the first measure of the absolute abundance of Pacific sardine off the U.S. west coast. Inclusion of this estimate in the assessment increased the model estimate of current abundance substantially, and was not in major conflict with the trends in abundance from the DEPM and TEP estimates. While this estimate is likely to be an

underestimate (e.g., the whole range was not surveyed and schools would be missed if they were too deep to be observed from the air), it provided a means to “anchor” the assessment.

The CV used to weight the aerial survey has a major impact on the final outcome of the assessment, but the Panel was not able to evaluate all sources of uncertainty. A CV of 0.55 was assigned to the aerial survey estimate to reflect quantifiable (and some currently unquantifiable) sources of uncertainty. One major source of unquantified uncertainty is the relationship between school area and biomass. In particular, the estimated biomass from the aerial survey is highly sensitive to the estimated biomasses of large (~ >10,000m<sup>2</sup>) schools. The conversion of area to biomass for these schools is especially uncertain, due to the lack of point-set data for large schools.

The model estimate corresponding to the 2009 aerial survey estimate of selected abundance is outside of the lower 99%+ confidence interval for the estimate. Furthermore, relatively small changes to the weights assigned to the data can lead to marked changes in current abundance. For example, re-tuning the weights assigned to the age- and length-composition data while fixing the CV to 0.55 for the aerial survey leads to much higher estimates of current stock size. This problem should become less of an issue as more data from aerial surveys become available and it becomes possible to tune the weights assigned to the aerial survey data in the same manner as for other data sources. Sensitivity to selectivity assumptions (e.g. domed vs. asymptotic form) should be more thoroughly explored in the future.

*b) Lack of information on population structure*

Stock identification continues to be an issue for Pacific sardine; genetic analysis currently indicates one subpopulation from Ensenada to British Columbia, with overlap between the northern and southern subpopulations off Baja. This creates a potential uncertainty in the Mexican and SCA catches as well as the DEPM estimates that may be difficult to resolve. Also, the complex population structure within the northern subpopulation makes coastwide extrapolation of the data difficult. An unknown proportion of older, larger fish migrate north each summer. This leads to unexplained inconsistencies in the data, such as a strong 2003 cohort that can be seen in the PNW age-compositions but not the CA age-compositions.

*c) Continuing lack of data from the Mexican fishery*

The Mexican fishery for Pacific sardine is a major source of mortality. Abundance and compositional information for this fishery is lacking since 2002 as is the catch for 2009. The lack of the 2009 catch was consequential for the current assessment because this catch led to the very high fishing mortality rates for first semester of 2009 in the original base model, which was a focus of Panel discussion.

*d) Residual patterns for the Pacific northwest fishery*

The STAT and this and previous Panels have considered a variety of ways (mainly selectivity blocks) to remove the residual pattern for the PNW (the model underestimates the numbers of fish from the 2003 and 2004 year-classes in the PNW). This residual pattern is probably due to fish in these cohorts recruiting in larger proportions to the

PNW than to the CA fisheries, a factor that SS3 cannot model explicitly without many additional assumptions. Aging error may be a factor as well. For example, it is unclear at present whether the 2004 year-class was strong or if the large number of animals in this year-class in the data reflects under-aging of fish from the large 2003 year-class because the 2004 year-class is not apparent as 2-year-olds in PNW or CCA.

*e) Canadian West Coast Surveys*

The Panel reviewed information on a series of mid-water surveys that have been conducted by the Canadian Department of Fisheries and Oceans off the west coast of Vancouver Island from 1992 to the present. These surveys are designed to examine the distribution and relative abundance of Pacific sardines. Survey results, including length compositions and variance estimates for some years, were available. Unfortunately, raw data were not available to the STAT.

Biomass estimates from WCVI survey were available for 1997, 1999 – 2001, 2004, 2006, 2008, and 2009. Estimates to 2004 were derived from surveys conducted during daytime. In 2006, 2008, and 2009, surveys were conducted at night. This change was made based upon research conducted in 2005, which indicated that sardine schools tend to aggregate in the daytime with catches being fewer, but larger. At night, the fish tend to disperse with many smaller schools being encountered. A calibration factor was developed in 2005 for day / night catch ratios and applied to the 2006, 2008, and 2009 data to standardize the time series to daytime catches. The Panel was concerned with recent nighttime survey results as they were much larger (by almost an order of magnitude) from the last daytime survey in 2006. However, there was insufficient information available to evaluate the calibration factor that was used. Moreover, variance estimates were not available for the biomass estimates from this survey for 2008 and 2009. Continued collaboration with Canadian biologists and the STAT is needed to assure that these data can be incorporated in future assessments.

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

*a) CPSMT concerns*

The CPSMT Representative noted that the Panel thoroughly reviewed the stock assessment and the industry-collected aerial survey data. The CPSMT Representative expressed concern in regards to incorporating new data into the stock assessment that did not span multiple years; but agreed that the aerial survey and point-set data were statistically scrutinized in a rigorous manner. Historically, sardine are known to fluctuate on a multi-decadal time-scale and currently appear to be in the downward aspect of the cycle, therefore the CPSMT Representative supported the increase to the nominal CV for the aerial survey to account for the unmodelled uncertainty that the Panel applied to the aerial survey data. The CPSMT Representative also expressed concern that the aerial survey and point set research process is establishing a fishery exclusive of the federally- and state-permitted fisheries, and noted that the calibration point sets can be conducted during the directed fishery as an alternative to research set-asides. The CPSMT Representative requested: 1) the Panel make a clear recommendation regarding the EFP research set aside for the 2010 management cycle, 2) the EFP operating guidelines application be revised by the November Briefing Book deadline to include an updated

sample design that reflects the discussion points that were brought up during the Panel (e.g., distance from shore for EFP point sets), 3) the final Industry Research report include all of the data collected from the PNW and CA, and identify which data were not included in the analyses and why, and 4) the use of hydroacoustics be explored as an additional aspect to the industry research.

*b) CPSAS concerns*

The CPSAS representative commended the Panel and STAT for their willingness to look at a new scientific data source and use that information in a credible and meaningful manner, noting that the modeling process for sardines had needed a new data source for years. This has been pointed out by previous Panels, the CPS Advisory Bodies, and the SSC. Past modeling results were derived from DEPM, TEP, and at one time a spotter index, and attempted to account for all fish as various modeling platforms were employed and rejected. Now the same modeling structure predicts a crashing sardine population. The CPS industry embarked in 2008 on a mission of discovery after years of living under a scientific status quo that signaled a declining population. This pilot effort was the starting point for the NW aerial survey.

He noted that the 2009 aerial survey established an absolute biomass estimate of 1.4 million tons for approximately 660 miles of coastline (less than 25 percent of the range of this species) using 40+ transects. This was based on a 2009 CV of 0.49. Only one replicate was achieved during 2009, but results of three replicates during the 2008 pilot effort indicated a CV of 0.23. CPS industry representatives expected to see a range of 0.23 to 0.49 not the 0.55 that the Panel selected and the Panel's rationale for this decision is not fully understood.

He further noted that the density values of the larger schools in 2009 (10,000 m<sup>2</sup>) could not be quantified using point sets because there was too much fish in these schools to practice safe capture by a vessel. The lowest density evidenced in 2008 and 2009 was used to estimate the weight of the larger school sizes. This appeared to be the most conservative approach possible. This was still deemed inappropriate by the Panel. This logic does not appear valid from fishing observations or the aerial survey. While larger schools may be less dense (or more), fishermen have "diagonally-cut set" on large schools for years and there has been no evidence of drastic density differentials. Extrapolating the graph line to equate very large sardine schools into very low relative weights seems contradictory to everything the fishery and other observations indicate. Perhaps this is the statistically correct approach, but the treatment appears artificial compared to what the aerial survey portrays and fishing-based knowledge indicates. Either way it dramatically influenced the outcome.

In relation to the total biomass, the CPSAS representative noted that Pacific sardine schools were observed from Ensenada, Mexico to northern Canada while the aerial survey was being conducted; both Canada and Ensenada were landing fish at this time. Also, although the aerial survey encountered difficulties with weather and could not survey in the Monterey, CA area, fish were readily landed and seen in the Monterey area at the same time. It is difficult to accept that the entire coast biomass from Ensenada to Sitka, Alaska is only 700,000mt.

The CPSAS representative recommended that yearly STAR Panels may be needed for Pacific sardine and that there is a need to continue, promote and enhance the aerial survey. To that end, he recommended that a smaller pilot project south of Monterey be started next year. He noted that the SWFSC is willing to employ sonar arrays in conjunction with aerial survey and point sets. This experimental approach should be encouraged. It is likely that research set-asides and exempted fishing permits will be required to conduct these enhanced aerial survey efforts in 2010.

#### **7) Research Recommendations (not in priority order)**

- A. Future assessments should consider the fishery-independent midwater trawl surveys off the west coast of Vancouver Island. This data set is potentially valuable as it provides abundance information for a large area within Canadian waters. However, it needs to be analysed further before it can be included in a future assessment. The STAT should confer with the lead investigator for the WCVI survey to obtain further information, including raw data. If necessary, the lead investigator should be invited to attend the next STAR Panel to present results for this time series.
- B. Further review the sampling protocols and analysis methods for other potential indices of abundance (such as the SWFSC juvenile rockfish survey and the acoustic surveys, which have been conducted in conjunction with egg surveys since 2003) and consider inclusion of such data in future assessments.
- C. Density-dependent changes in growth or reproduction have not been identified nor evaluated. Maturity at length is variable from year to year, although adult sampling has not been consistent, and young fish may be under-represented. Available maturation ogives could be compared to biomass estimates to identify possible density-dependent effects, although environmental variation is likely to be a major factor in growth and maturation so inference may be weak.
- D. Fecundity at age is based on weight and does not account for the total number of batches of eggs produced during a season (annual fecundity). While the spawning frequency during the peak season does not appear to be age-dependent, the length of the spawning season may be longer in older fish. This may affect the stock-recruitment relationship. Whether visual estimates of activity (presence of developed gonads) from port-collected samples can be used to estimate length-specific timing and duration of spawning across the stock's range should be explored.
- E. There continues to be uncertainty in the DEPM survey as a key indicator of spawning stock biomass trends coastwide. Expand coastwide sampling of adult fish to further refine the estimate of the proportion spawning.
- F. Temperature at catch could provide insight in stock structure and the appropriate catch stream to use for assessments, because the southern subpopulation is thought to prefer warmer water. Conduct sensitivity tests to alternative assumptions regarding the fraction of the ENS and SCA catch that comes from the northern subpopulation.
- G. The assessment would benefit not only from data from Mexico and Canada, but also from a joint assessment, which includes assessment team members from these countries.
- H. Re-evaluate the magnitude of discards in each fishery, and account for discards in future assessments.
- I. Otolith and microchemistry studies are useful tools for evaluating stock structure. Results should be evaluated to determine if the spatial distribution is purely age-



dependent or due to an alternate life history strategy. These evaluations could be combined with a traditional tagging study (which has not been done since the 1940s) to provide useful information about fish migration and distribution.

- J. The relationship between environmental correlates and abundance should be examined. In particular, the relationship between environmental covariates and recruitment deviations should be explored further.
- K. Further evaluate the appropriate form of stock-recruitment relationship for Pacific sardine, including appropriate environmental covariates.
- L. Consider spatial models for Pacific sardine, which can be used to explore the implications of regional recruitment patterns and region-specific biological parameters. These models could be used to identify critical biological data gaps.
- M. Re-estimate age-reading error matrices and include them in updated assessments.

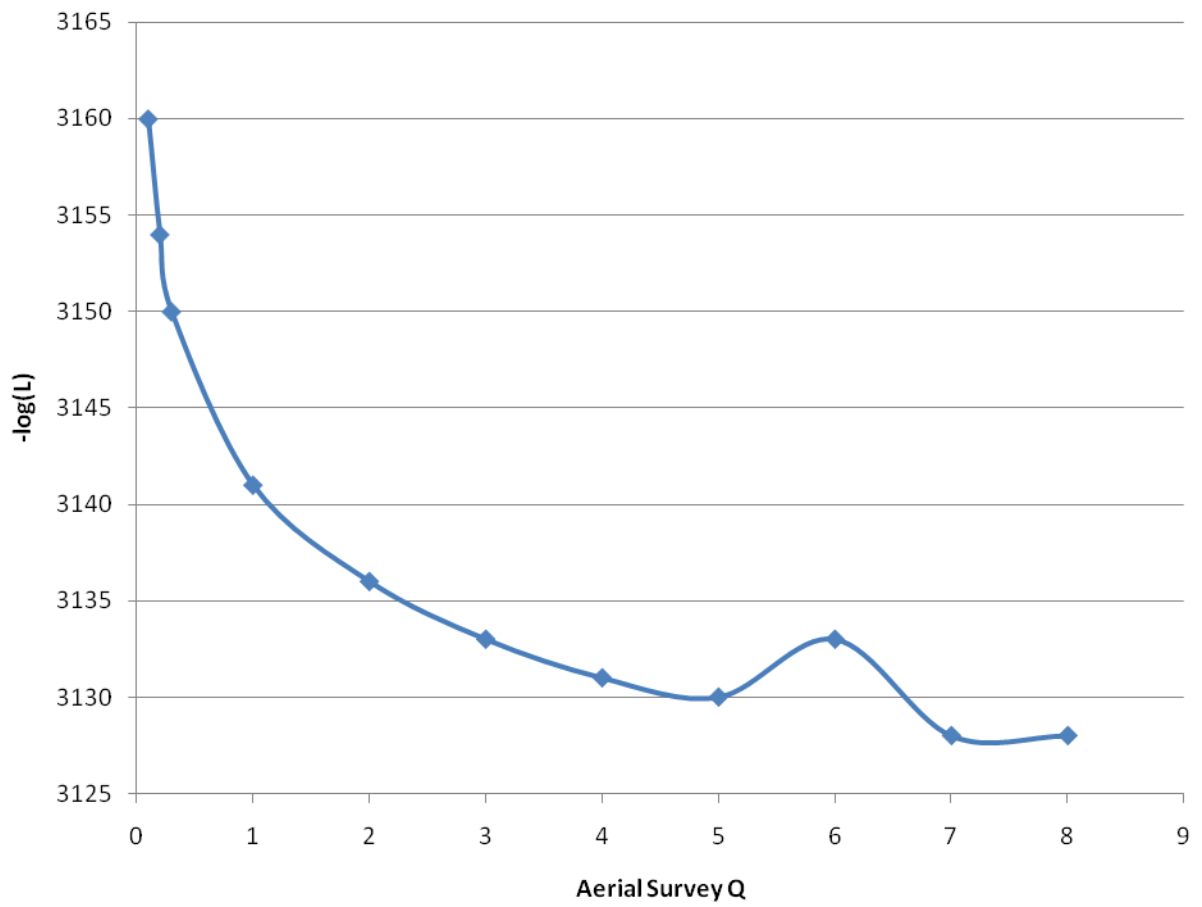


Figure 1. Likelihood profile for the aerial survey  $q$  parameter.

## Appendix 1

### **STAR Panel Members:**

André Punt (Chair), Scientific and Statistical Committee (SSC), Univ of Washington  
Selina Heppell, SSC, Oregon State University  
Dvora Hart, External Review, Northeast Fisheries Science Center  
John Wheeler, Center for Independent Experts (CIE)

### **Pacific Fishery Management Council (Council) Representatives:**

Briana Brady, Coastal Pelagic Species Management Team (CPSMT)  
Mike Okoniewski, Coastal Pelagic Species Advisory Subpanel (CPSAS)  
Mike Burner, Council Staff

### **Pacific Sardine Stock Assessment Team:**

Kevin Hill, NOAA / SWFSC  
Nancy Lo, NOAA / SWFSC  
Beverly Macewicz, NOAA / SWFSC  
Paul Crone, NOAA / SWFSC

### **Aerial Survey Team**

Tom Jagielo, Tom Jagielo Consulting  
Ryan Howe, West Coast Sardine Survey  
Doyle Hanan, Hanan and Associates, for CWPA

### **Others in Attendance**

John Butler, NMFS, SWFSC, La Jolla, CA  
Richard Carroll, Ocean Gold Seafoods  
Ray Conser, NMFS, SWFSC, La Jolla, CA  
David Haworth, Fisherman, San Diego, CA  
Jime Humphrys, Marine Stewardship Council, Seattle, WA  
Steve Joner, Makah Tribe  
Darrell Kapp, Astoria Pacific Seafoods  
Greg Krutzikowsky, Oregon Dept. of Fish and Wildlife, Newport, OR  
Hui-hua Lee, NMFS, SWFSC, La Jolla, CA  
Josh Lindsay, NMFS, Southwest Regional Office  
Mark Maunder, Inter-American Tropical Tuna Commission (IATTC), La Jolla, CA  
Sam MccClatchie, NMFS, SWFSC, La Jolla, CA  
Jenny Mc Daniel, NMFS, SWFSC, La Jolla, CA  
Kevin Piner, NMFS, SWFSC, La Jolla, CA  
Diane Pleschner-Steele, CWPA  
Bob Seidel, Astoria Holdings, Inc.  
Alexandre Silva, IATTC, La Jolla, CA  
Christina Show, NMFS, SWFSC, La Jolla, CA  
Kevin Steinhof, NMFS, SWFSC, La Jolla, CA  
Dale Sweetnam, California Dept. of Fish and Game, La Jolla, CA  
Andrew Thompson, NMFS, SWFSC, La Jolla, CA

Jerry Thon, Astroia Holdings, Inc.  
Russ Vetter NMFS, SWFSC, La Jolla, CA, Fisheries Research Division, Director  
Rob Zuanich, Purse Seine Vessel Owners Association

## **Appendix 2**

### **Summary of Discussions Related to the 2009 Aerial Survey**

#### ***Summary***

Mr. Tom Jagielo outlined the 2009 aerial survey for Pacific sardine. The design for the aerial survey was reviewed by a STAR Panel during May 2009 and considered by the SSC at its June 2009 meeting, and the implemented survey followed most of the protocols established during that Panel. A key modification to the aerial survey protocol was that the flights were conducted from 4000ft rather than 8000ft. This reduced the width of transects, but it also increased the number of sampling days when conditions could permit clear visibility of sardine schools on the ocean surface.

The aerial survey involved two stages. The first stage aimed to collect data on the number of sardine schools on three sets of 52 transects and the second stage aimed to collect 52 point-sets in the north and the south strata (separated at Oregon-California border) to determine the relationship between school area and weight (or density) of sardine. Various factors, including weather and survey protocols, meant that it was not possible to achieve the target number of transects (156) and point sets (104). A total of 41 transects (of which 16 recorded sardine schools) and 28 point sets, which could be used for abundance estimation were collected during the aerial survey. The lack of replicate sets of transects precluded the use of replicate surveys as the basis for variance estimation. Instead the variance estimate was based on among-transect variation in density. The final estimate of abundance was 1,403,504 mt with a standard error of 698,284 mt. It was noted that there are various reasons why this estimate should be expected to be negatively biased, including schools that are missed by the aerial photographs (e.g., because they are too deep to be seen) and a survey area that excludes some areas in which sardine would be expected to be found.

The Panel welcomed the aerial survey, noting that several previous STAR Panels have recognized the need for new indices of abundance for Pacific sardine, particularly those which pertain to the Pacific Northwest. The Panel reviewed the document describing the 2009 aerial survey and had access to the data on which the estimate of abundance was based (suggested changes to the survey document are listed in Adjunct 1). The Panel noted that the lateness of the document describing the survey was due primarily to the timing of the aerial survey and that of the Panel meeting and that this lateness is to be expected if the aerial survey continues to be conducted during August-September and assessment reviews continue to occur in late September.

The Panel discussed the aerial survey as it had been implemented in 2009 and identified several recommendations for further work. The Panel noted that the CV was very large compared to that for the 2008 aerial survey, which was based on replicate sets of transects, and hence that it was likely (though not definite) that some of the variance estimate of 698,284 mt is associated with spatial variation in density rather than sampling variation. The Panel included the 2009 aerial survey estimate of abundance in the stock assessment by assuming that it provided an estimate of the absolute abundance of the component of the population selected by the gear used during the point sets.

The Panel was concerned with the approach proposed to model the relationship between school weight and school area because it implied zero density at infinite school area. It therefore explored an alternative formulation for this relationship. The Panel also identified, and worked with the analysts to implement, a method for estimating the variance of the estimates of biomass, which accounts for more (but not all) of the uncertainty.

The Panel endorsed the use of the 2009 aerial survey estimate for use in the Pacific sardine stock assessment. The aerial survey provides a basis for scaling the abundance of Pacific sardine, something which was not available in the past. However, efforts should continue to refine the survey design and to enhance the precision of the estimate by collecting additional data to quantify the relationship between school weight and school area. Specifically, the Panel notes that collection of data for schools with sizes between 4,000 and 10,000m<sup>2</sup> should allow this relationship to be refined.

The Panel was advised that consideration was being given to extending the aerial survey into Canada and using information of, for example, school area, from satellites. It agreed that there would be no need for a STAR Panel to review the survey estimate for an extension to include Canada as long as the methods used to conduct an aerial survey off Canada are the same as those used during the 2009 aerial survey. However, use of satellite data as the basis for abundance estimation would require a thorough review by a STAR Panel. Similarly, in-depth review would be needed if acoustic methods were to form the basis for assigning weights to schools which are too large to be sampled using point sets.

### ***Requests***

#### **A. Annotate the school density and weight data by the years concerned.**

*Reason:* To check whether there are year-specific patterns in the data.

*Response:* The data from 2008 tended to correspond to the largest surface areas. The Panel explored this further through request F.

#### **B. Compute the variances of the estimates of abundance from the 2008 aerial surveys using a between-transect estimator.**

*Reason:* The estimate of variance for the 2009 aerial survey was based on among-transect variation in density, but this may confound spatial variation with sampling variation. Comparing the between-replicate variation for the 2008 aerial survey with the average between-transect variation for that aerial survey provides information on the potential bias in the current method of variance estimation.

*Response:* The CV for the biomass in the 90-mile stretch of coast during 2008 was 0.23 based on the between-transect variation while the CVs for each set based on the spatial variation in density were 0.29, 0.16, and 0.27 respectively. The Panel concluded that these results provided no basis to modify the CV from the 2009 aerial survey

#### **C. Estimate abundance (and its CV) using only the data for the northern stratum.**

*Reason:* A sensitivity test is to be conducted using only the aerial survey estimate for the northern stratum because most of the detected biomass (>90%) and transects were in the northern stratum.

*Response:* The estimate for the northern stratum was 1,361,012 mt (CV 0.49). The abundance estimate and CV were sufficiently close to the estimate and CV for the whole coast, so the Panel deemed it unnecessary to conduct a sensitivity test based on the northern transects only.

**D. Compute the confidence and prediction intervals for the relationship between school area and weight.**

*Reason:* The uncertainty associated with this relationship needs to be quantified because it impacts how the estimate of abundance is to be used in the stock assessment.

*Response:* The prediction and confidence intervals were wide for the lowest and highest school areas. See request H for further considerations of this matter.

**E. Plot the weighted and raw length frequency data from the 2009 aerial survey.**

*Reason:* The Panel wanted to check that weighting the length-frequency distribution did not unduly impact the distribution.

*Response:* The plots of the weighted and unweighted length-frequencies were essentially identical.

**F. Fit the school weight and surface area data for 2008 and 2009, and test whether the data are consistent with pooling the data.**

*Reason:* The data from 2008 tended to correspond to the large surface areas.

*Response:* The two data sets were fitted separately using the model used in the survey analysis report and the fits compared with that of a fit to all of the data pooled using a likelihood ratio test. This test found no reason ( $P=0.38$ ) to reject the hypothesis that the data for the two data sets cannot be pooled and analysed together.

**G. Explore the sensitivity of the biomass estimate to using the relationship between school surface area and school density to estimate the weight of all schools rather than using the lowest density for schools that are larger than schools with the largest surface areas, which were sampled for density.**

*Reason:* Data on density are not available for schools larger than 9,500 m<sup>2</sup> and the assumption was made that the density for these schools equalled the lowest density.

*Response:* The predicted density from the model implies an unrealistic zero density at very high surface area. However, the approach used in the survey analysis report could be argued to be arbitrary because it assumes that the density of all schools larger than the maximum observed in the point sets is equal to the lowest density. The Panel identified an alternative model for the relationship between school weight and school area (see Request H).

**H. Fit the data on school weight and school size to a Michaelis-Menten model assuming log-normal error, i.e.,  $\ln(\text{Density}) = (a + b \cdot \text{Area}) / (c + \text{Area})$ .**

*Reason:* The log-transformed quadratic regression model used to convert school area to density is not ideal because, by its structure, it incorrectly predicts that the density would tend to zero as area tends to infinity. The solution proposed to this problem by the analysts was to put a floor on the predicted density equal to the lowest observed density. The Panel was concerned that this floor is somewhat *ad hoc*, and depends on the quantity of data collected. The Michaelis-Menten model has the advantage of allowing a non-zero

asymptote  $b$ . This parameter functions similarly to the floor in the original model, but is estimated rather than fixed.

*Response:* A least-squares fit of this model to the point-set data, using the `nls` function in R, gave estimates of  $a = -8667$ ,  $b = -5.00$ , and  $c = 2795$ . Although there is considerable scatter, the resulting curve leads to a reasonable fit to the data, which is similar to the fit of the original model (Figure A1). The estimated asymptotic density,  $\exp(b) = 0.00676$ , is slightly lower than the density floor (0.0077). The estimate of abundance using the new relationship was 1,353,170 mt. The Panel, survey analysis team, and STAT agreed to base further analyses on this estimate.

**I. Quantify the uncertainty associated with the 2009 estimate of abundance taking account of both the between-transect variation and the uncertainty related to the relationship between school density and school area.**

*Reason:* The measures of uncertainty in the draft document related only to between-transect variation in density.

*Response:* A bootstrap procedure was developed to estimate a CV for the abundance estimate. However, numerical problems related to non-convergence of the non-linear minimization method precluded accounting for the uncertainty due to the relationship between school density and school area. The Panel rounded the CV up from 0.52 to 0.55 to account to some extent for this unmodelled uncertainty based on between-transect variation. While not a formal estimate of unmodelled uncertainty, it reflects the fact that there are sources of unmodelled uncertainty (an “extra” CV of approximately 0.2).

***Research Recommendations***

The Panel noted that most of the short-term recommendations of the May 2009 Panel had been implemented and identified a number of additional recommendations (not in priority order).

1. Further attempt to quantify (and then account for) the impact of “edge effects” on photographs, including the effect of calculating school weight for an estimate of school area, in which only part of a school is visible in a photograph.
2. Further attempt to calibrate the scheme used to estimate surface area from photographs. Specifically, calibration experiments should consider objects which do not have a regular shape (e.g., a baseball field was identified as a possible “target”) and explore whether there are “analyst effects” and/or “photograph effects” by analysing existing and future calibration data.
3. Future research should consider methods that can be used to determine the proportion of sardine schools that are visible from aircraft. Acoustics (e.g., from fishing vessels) was identified as one potential method to achieve this goal.
4. Continue to refine the approach used to identify sardine schools in photographs. The use of mosaicing and recording lines on the images were identified as possible areas of investigation.
5. Examine the trade-offs associated with different flight heights between area surveyed and the ability to fly transects.
6. Estimate the variation in the perceived size of sardine schools using multiple photographs of the same schools.



7. Refine the method of variance estimation to account for all sources of uncertainty. Specifically, identify methods (e.g., based on bootstrapping; see Adjunct 2) that can take into account: (a) inter-transect variation in density, (b) uncertainty about the school weight – school area relationship, (c) variation for individual schools about the school weight – school area relationship, and (d) uncertainty arising from attempting to estimate the size of schools.
8. Consider the use of geostatistical methods to estimate sardine abundance and the uncertainty of the estimate, especially if the likelihood of obtaining multiple replicates within a single aerial survey is likely to remain low.
9. Consider further stratification of the area surveyed during the aerial survey. In particular, consider the benefits of offshore strata. Such strata could have lower coverage, consistent with likely lower density.
10. Consider whether it is possible to use acoustics to calculate the density associated with schools that are too large to be sampled using point sets. Consideration must be given to the impact of vessel avoidance in the analysis of such data.
11. Collect data on environmental conditions from point sets (e.g., using onboard loggers) and explore whether environmental covariates explain some of the variation about the school weight – school area relationship.
12. Refine how photographs are analysed to account for pitch and roll.
13. Provide all of the data on which the aerial survey estimate is based (including the original photographs and details regarding school size identification and quantification) to the STAT.

Additional recommendations from the May 2009 STAR Panel:

- Record qualitative information related to processing photographs, and the difficulty in assigning species and calculating school areas.
- Observer effects when viewing photographs could be evaluated using double-blind comparisons and similar techniques.

***Adjunct 1: Suggested modifications to the document***

- A. Add a table that lists all of the point sets, including location; include reasons if point sets were not included in the density vs surface area relationship.
- B. Add latitude to table 4.
- C. Discuss the results related to maturity and the impact of predators of sardine.

***Adjunct 2: A bootstrap method for assessing the uncertainty associated with the aerial survey***

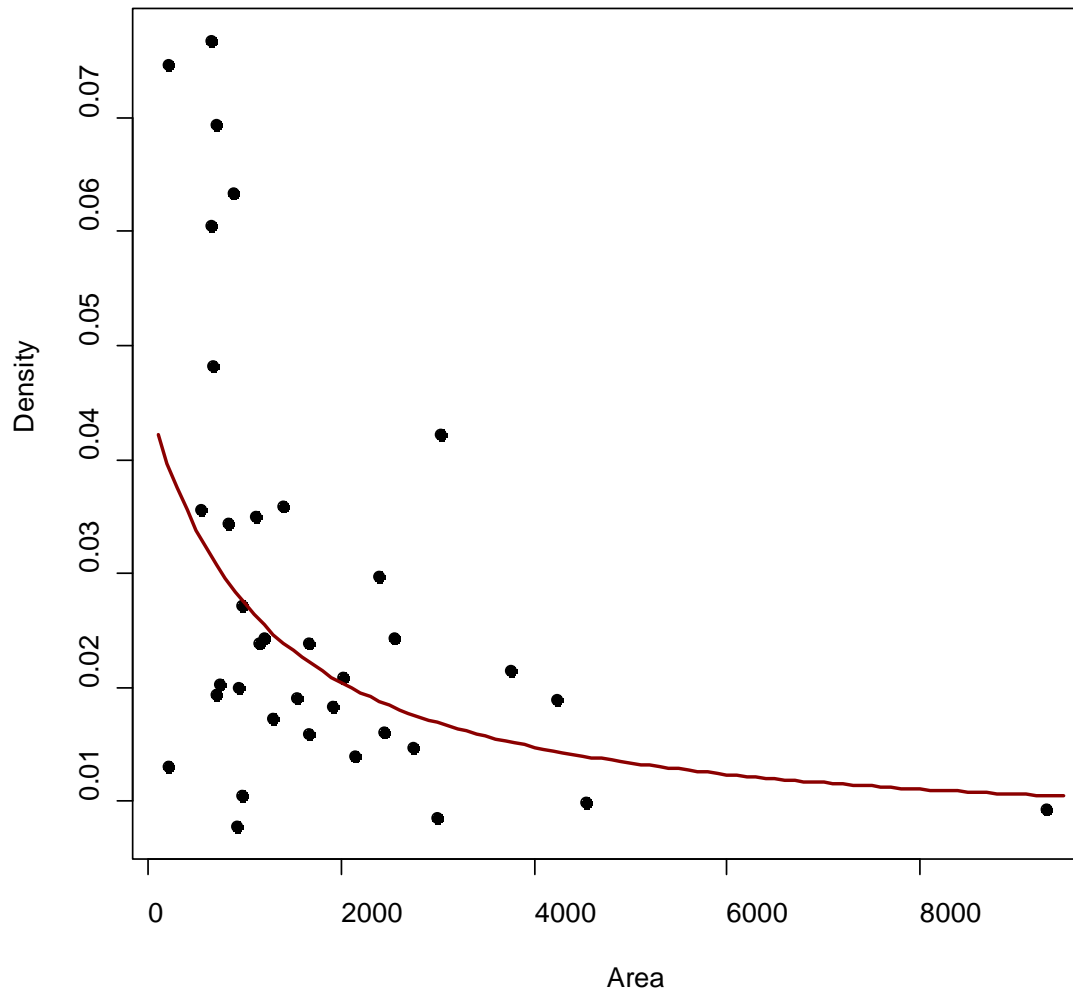
The confidence intervals for the biomass from the aerial survey should not be constructed assuming a normal distribution because of the high variability associated with the aerial survey relative to its mean. Instead, the Panel recommended using a bootstrap approach. Ideally, both the point set data and the transect data should be bootstrapped so as to capture uncertainty in both the area/biomass conversion as well as in the aerial survey itself. Each bootstrap replicate would involve sampling transects at random and with replacement from the 41 transects while the residuals about the area/biomass relationship would be permuted and added to the model predictions to generate a pseudo area/biomass data set, which is “balanced” and is conditioned on the observed school sizes observed during the point sets.

However, there were difficulties in bootstrapping the point-set data because the non-linear model fitted to the bootstrapped point-set data would occasionally fail to converge. For this reason, only the transect data were bootstrapped. Biomass on each transect was computed based on the observed school areas, converted to biomass using the fixed area to biomass conversion, and then summed over all schools on the transect. The 41 transects were then resampled with replacement 10,000 times, and the total estimated biomass was calculated for each bootstrap replicate. The 95% confidence interval was calculated using the 2.5% and 97.5% quantiles, and the mean, median and standard error of the mean biomass of the 10,000 runs were also computed (Table A1).

It should be noted that this analysis underestimates the total uncertainty associated with the aerial survey. In particular, uncertainty associated with the conversion of school area to biomass is not included in this analysis.

**Table A1 – Bootstrapped biomass estimates (mt) of sardines from the aerial survey**

Mean	1,343,754
Median	1,277,557
S.E.M.	659,138
90% C.I.	(384670, 2545251)
95% C.I.	(271558, 2792850)



**Appendix 3**  
**Proposed Point Set Sampling for 2010**  
**Tom Jagielo**

In developing a recommendation for the number of point set samples needed for the aerial sardine survey in 2010, consideration was given to obtaining more data points for the area-biomass regression in the region between 2,000 and 10,000 m<sup>2</sup> (Figure 1). The purpose of getting more data points in this size range is to better determine the asymptote of the relationship and thus to better estimate the biomass of the largest schools observed. In order to distribute the samples across the full range of size categories, and to sample the larger schools with an adequate sample size (e.g., n = 32 for the 2,000-10,000 m<sup>2</sup> size range), an overall sample size of n=56 point sets is proposed. This sampling schedule would require a catch allowance of 2,100 mt per area (north and south), and thus a total EFP set-aside of 4,200 mt coastwide.

The Panel has identified the need to reduce the variance of the area-biomass relationship in order to reduce the estimate of total biomass from the aerial sardine survey. The addition of 56 new data points per region (assuming that any new data points obtained for 2010 could be pooled with the 2008-2009 dataset) should help to reduce the overall uncertainty of the area-biomass relationship.

Another consideration for 2010 point set sampling is the number of vessels to be permitted in the EFP fishery. The aerial survey team found that being limited to two vessels per region had the effect of constraining the project such that it was difficult to complete the project effectively in the time available for the EFP fishery. We recommend that 4 vessels per region be granted EFP permits in 2010.

Figure 1. Relationship of surface area (m<sup>2</sup>) (x axis) vs. density (y axis) determined from point sets sampled in 2008 and 2009. Obs: actual point-set data; Pred: model-estimate of density.

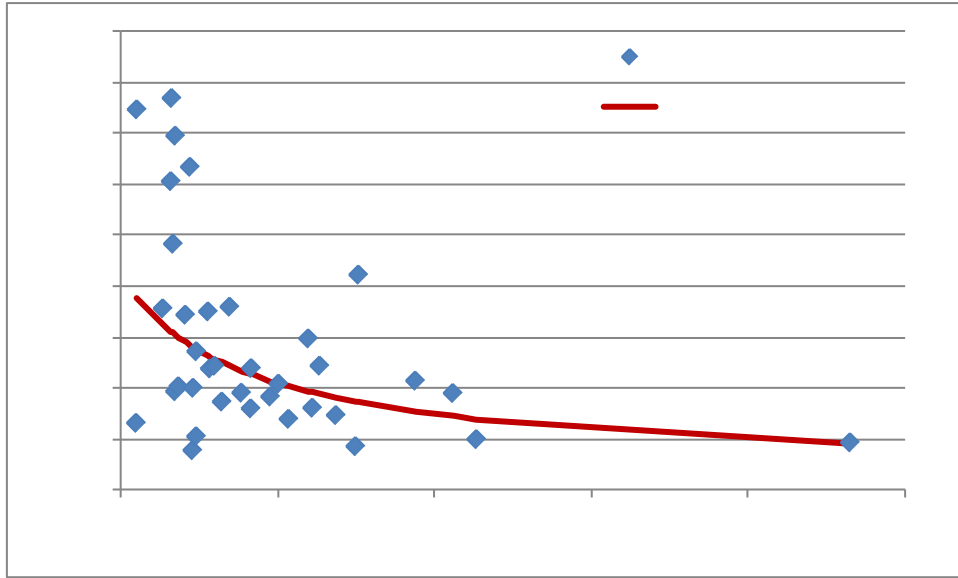


Table 1. Distribution of point set sizes proposed for each region (north and south) for the 2010 Aerial Sardine Survey.

Size (m <sup>2</sup> )	Weight (mt)	Total Weight	Number of Point Sets
100	3.8	31	8
500	10.6	85	8
1000	17.0	136	8
2000	26.5	212	8
4000	51.9	415	8
8000	70.5	564	8
10000	82.1	657	8
		2099	56

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

Mr. Tom Jagielo presented the 2009 sardine aerial survey results and Dr. Kevin Hill summarized the Pacific sardine assessment for the Scientific and Statistical Committee (SSC). Dr. André Punt summarized the Stock Assessment Review (STAR) Panel report on the 2009 aerial survey and the 2009 Pacific sardine assessment, held in La Jolla, California, September 21-25, 2009.

The 2009 aerial survey was designed and executed based on recommendations stemming from the Survey Methodology Review panel held in May 2009. Results from the survey provide the first estimate of the absolute biomass of Pacific sardine off the U.S. west coast. The estimate of abundance used in the assessment was 1.35 million mt, with a coefficient of variation of 0.55. It was noted that this estimate could well be negatively biased due to a variety of reasons, such as schools that are missed by the aerial photographs (e.g., because they are too deep to be seen) and a survey area that excludes regions in which sardine would be expected to be found.

The previous assessment of Pacific sardine was conducted in 2007, transitioning from the ASAP model into the Stock Synthesis model (version 2). In the new 2009 assessment, changes are made in several model components, new data are added, and the Stock Synthesis 3 (version 3.03a) assessment model was utilized. However, the most notable change in the 2009 assessment is the use of an absolute abundance estimate from the aerial survey, which is a key source of information about the size of the Pacific sardine stock.

The SSC discussed and noted the difficulty in quantifying uncertainty in the aerial survey abundance estimate. The CV of the aerial survey abundance was estimated to be 0.52 using a bootstrapping procedure, while a value of 0.55 was used in the assessment model to include between-transect variation. The value of 0.55 means the model put more emphasis on the other data sources than the aerial survey abundance estimate. The main source of uncertainty in the abundance estimate is the conversion of school area to school biomass, especially for schools sizes between 4,000 and 10,000 m<sup>2</sup>, which is due to a paucity of point-set data in that range. This problem should be solved as the aerial survey continues and more data become available.

The dome-shaped selectivity curve for the aerial survey implies an absence of large fish in the survey. Although this selectivity specification was estimated in the model, it should be more thoroughly explored in the future in order to explain the deficit of large fish.

The catchability coefficient ( $q$ ) of the aerial survey could not be estimated in the model because there is only one data point. It was therefore fixed at  $q = 1$ . Discussion and rationalization of this value is warranted. To do so, additional survey data may be needed and, in addition, further consideration of developing a  $q$  prior is also recommended.

- A concern about correctly identifying the species composition of aerially spotted schools was raised. However, anchovy were infrequently observed in 2009 and there was a lack

of valid point-sets in the southern portion of the survey where anchovy are typically more abundant.

- Other data sources that could be used to estimate coast-wide sardine biomass, e.g., satellite images and acoustics, should be considered in the future. These new data sources need to be thoroughly examined by a methodology review panel before their actual use in the assessment.
- A later start of the fishery would allow more time to conduct and finalize the stock assessment.
- The assessment would benefit by including data from Mexico and Canada.
- Efforts should continue to refine the aerial survey design and to enhance the precision of the estimate by collecting additional data to quantify the relationship between school weight and school area.
- The 2009 EFP point-set set-aside was useful and valuable information was collected.

The SSC endorsed the 2009 Pacific sardine assessment as the best available science for status determination and Council management. The SSC recommends an ABC for the 2010 fishery of 72,039 mt. The 2010 assessment is recommended to be an update.

PFMC  
11/02/09

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

The Coastal Pelagic Species Management Team (CPSMT) received a presentation from Dr. Kevin Hill regarding the Pacific sardine stock assessment conducted in 2009 and a presentation from Tom Jagielo regarding the results of the aerial survey conducted in 2009 that was incorporated into the Pacific sardine assessment. The CPSMT recommends that the Council adopt the assessment and the resulting harvest guideline. The biomass (ages 1+) estimate is 702,024 mt, and the acceptable biological catch (ABC) for the 2010 fishing year is 72,039 mt. This represents a 7 percent increase from the 2009 ABC/harvest guideline (HG) adopted by the Council (November 2008). The CPSMT agrees with the Stock Assessment Team, the Stock Assessment and Review Panel, and the Scientific and Statistical Committee approved base model.

*Set asides and incidental load allowance*

The CPSMT recommends that the incidental catch amounts for all three allocation periods should be set to 1,000 mt. To account for management uncertainty, 4,000 mt should be reserved for the 3<sup>rd</sup> period (Table 1). The CPSMT recommends that the incidental landing allowance be no more than 30 percent Pacific sardine by weight. The CPSMT recommends setting the sardine research set aside at 5,000 mt, which should be used solely for aerial point sets in 2010.

**Table 1. Allocation scheme for 2010 Pacific Sardine HG.**

HG = 72,039 mt Research set aside = 5,000 mt Adjusted HG = 67,039 mt				
	Jan 1- Jun 30	Jul 1- Sep 14	Sep 15 – Dec 31	Total
Seasonal Allocation (mt)	23,463	26,816	16,760	67,039
Incidental Set Aside (mt)	1,000	1,000	1,000	3,000
Management Uncertainty			4,000	4,000
Adjusted Allocation (mt)	22,463	25,816	11,760	60,039

*Future work*

The CPSMT agrees with the SSC to schedule the 2010 assessment as an update.

The CPSMT recognizes the challenges involved with conducting the aerial survey field work, especially during the first one or two years of data collection. The industry outlined improvements for the 2010 Aerial Survey Methodology in November 2009 Public Comment. The CPSMT is providing additional guidance for the applicants submitting the 2010 EFP application (Attachment 1).



The CPSMT recommends the Council encourage National Marine Fisheries Service (NMFS) to continue to fund comprehensive coastwide annual CPS research. 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. The CPSMT supports further exploration of innovative survey techniques for assessing the stock.

## **Attachment 1**

The CPSMT has concerns with the oversight of the EFP point set data collection in 2009. The CPSMT recommends that the EFP application for 2010:

1. Specify the procedure for submitting aerial photograph data for each point set
2. Specify the procedure to determine if the point set data and corresponding aerial photographs are acceptable.
3. Document point set / aerial photos review process
  - a. Date data were submitted for review with date received
  - b. Date data were reviewed
  - c. Date data were approved or denied
  - d. Describe next phase (e.g., sample again OR make corrections and sample again)

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

The Coastal Pelagic Species Advisory Subpanel (CPSAS), along with the Coastal Pelagic Species Management Team (CPSMT), received presentations on the 2009 Pacific Coast Aerial Survey from Tom Jagielo and the aerial research team; and the 2009 Pacific Sardine Stock Assessment from Dr. Kevin Hill. The CPSAS thanks Dr. Hill and the Stock Assessment Team for their hard work to incorporate the point estimate from the summer aerial survey as recommended in the September STAR Panel meeting. The CPSAS appreciates the support accorded by the STAR Panel and Science and Statistical Committee (SSC) in both recognizing the importance of this new sardine survey method and including the data in the 2009 base model.

With the aerial survey included as a minimum estimate of absolute biomass, in a precautionary manner to address uncertainty, the assessment resulted in a biomass (ages 1+) estimate of 702,024 mt. After applying the harvest control rule, the assessment produced an acceptable biological catch (ABC) for the 2010 fishery of 72,039 mt.

### **Management Measures**

As occurred in 2009, the directed seasonal allocation of the recommended 2010 HG (72,039 mt) will be reached prematurely in each time period. The CPSAS agrees with the CPSMT on the need for (1) a set aside of 7,000 mt (to account for incidental catch and management uncertainty), and (2) a set aside of 5,000 mt for industry-supported research, to be deducted from the HG before it is allocated.

Further, the CPSAS recommends that the first two incidental catch amounts should each be set to 1,000 mt and that the last amount should be set to 5,000 mt total to account for management uncertainty in addition to incidental sardine catch in other fisheries. This means that any overage in the directed sardine fishery in the third period would be deducted from the 5,000 mt incidental set aside in the third period.

The CPSAS is in agreement with the CPSMT regarding the in-season automatic actions that should be taken to deal with surpluses or shortages that may occur for the direct and incidental seasonal allocations. 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 Incidental Set-Aside from Period 1 or Period 2 rolls into the next period's directed fishery.
- Any overage of the third period's allocation to the directed fishery will be deducted from that period's set-asides.

- If both the seasonal allocation to the directed fishery and the Incidental Set-Aside are reached or exceeded in any period, the retention of Pacific sardine will be prohibited.
- Any set-aside for research that is not included in an exempted fishing permit (EFP) will be rolled into the third period's directed fishery.
- Any research set-aside attributed to an EFP designed to be conducted prior to September 15, but not utilized, will roll into the third period's directed fishery.
- Any research set-aside attributed to an EFP designed to be conducted after September 15, but not utilized, will not be re-allocated.

The CPSAS also recommends the incidental landing allowance be no more than 30 percent Pacific sardine by weight, increased by 10 percent from 2009 to allow more opportunity to fish on other CPS after the directed fishery has closed.

### **Research Set Aside and EFP Request**

After successful completion of the 2009 Aerial Survey, the first under the EFP, the CPSAS again asks the Council for an EFP set aside for the 2010 summer Sardine survey to continue and improve the survey as recommended by the STAR Panel. After STAR Panel review, the data collected was added to the assessment model, resulting in a harvest guideline of 72,039 mt vs. 9,100 mt without the survey. This difference averted a complete collapse of the sardine industry.

The CPSAS requests that the Council set aside 5,000 mt of the 2010 quota allocation to be utilized by the Principal Investigators, Tom Jagielo and Dr. Doyle Hanan, to increase the point set database with the goal to target larger schools, and to perform photographic and acoustical documentation of the Sardine population during the summer and fall of 2010.

The CPSAS also expresses the need for two STAR Panels in 2010 to review new data sources. These include the Canadian trawl survey data and analysis first discussed at the 2009 STAR Panel, and replicated satellite photography and measurement of sardine schools. These photographs will be developed and enhanced using the same methods as in the 2009 West Coast Sardine Survey. In order to utilize these new data sources in the model, STAR Panel reviews will be required. The benefits include: (1) improved scientific understanding of the overall sardine population dynamics (reproductive patterns, stock range, and migratory behavior), (2) achievement of a survey that is truly synoptic, (3) reduction of the CVs (coefficient of variation), and (4) the potential for significant increase of economic benefit to the sardine industry and coastal communities.

The CPSAS strongly recommends that the Council support the EFP research and our request for STAR Panels as a continuation and expansion of the 2009 aerial survey. The CPSAS encourages the National Marine Fisheries Service (NMFS) to continue to support and fund comprehensive coast-wide annual coastal pelagic species research to improve understanding of the spawning biomass and migration patterns; and to encourage similar cooperative surveys in Canada and Mexico.

The CPSAS continues to advocate for coordinated international management of coastal pelagic species fisheries, to avoid the potential for coastwide overfishing. The CPSAS encourages the Council, NMFS and the State Department to continue working to achieve timely receipt of biological research data from Mexico.

## RECENT TECHNICAL MEMORANDUMS

SWFSC Technical Memorandums are accessible online at the SWFSC web site (<http://swfsc.noaa.gov>). Copies are also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 (<http://www.ntis.gov>). Recent issues of NOAA Technical Memorandums from the NMFS Southwest Fisheries Science Center are listed below:

- NOAA-TM-NMFS-SWFSC-442 Ichthyoplankton and station data for surface (Manta) and oblique (Bongo) plankton tows for California Cooperative Oceanic Fisheries Investigations Survey Cruises and California Current Ecosystem Survey in 2006.  
N.M. BOWLIN, W. WATSON, R.L. CHARTER, and S.M. MANION  
(April 2009)
- 443 Testing and validation of automated whistle and click detectors using PAMGUARD 1.0.  
T.M. YACK, J.P. BARLOW, S. RANKIN, and D. GILLESPIE  
(May 2009)
- 444 Predictive modeling of cetacean densities in the eastern Pacific ocean.  
J. BARLOW, M.C. FERGUSON, E.A. BECKER, J.V. REDFERN,  
K.A. FORNEY, I.L. VILCHIS, P.C. FIEDLER, T. GERRODETTE, and  
L.T. BALLANCE  
(May 2009)
- 445 AMLR 2008/09 field season report: Objectives, Accomplishments,  
and Tentative Conclusions.  
A.M. VAN CISE, Editor  
(May 2009)
- 446 Life history aspects of greenspotted rockfish (*Sebastes chlorostictus*)  
from central California.  
D.L. BENET, E.J. DICK, and D.E. PEARSON  
(July 2009)
- 447 What caused the Sacramento River Fall Chinook stock collapse?  
S.T. LINDLEY, C.B. GRIMES, M.S. MOHR, W. PETERSON, J. STEIN  
J.T. ANDERSON, L.W. BOTSFORD, D.L. BOTTOM, C.A. BUSACK,  
T.K. COLLIER, J. FERGUSON, J.C. GARZA, A.M. GROVER, D.G. HANKIN  
R.G. KOPE, P.W. LAWSON, A. LOW, R.B. MacFARLANE, K. MOORE,  
M. PALMER-ZWAHLEN, F.B. SCHWING, J. SMITH, C. TRACY, R. WEBB,  
B.K. WELLS, and T.H. WILLIAMS  
(July 2009)
- 448 Estimation of population size with molecular genetic data.  
E.C. ANDERSON and J.C. GARZA  
(September 2009)
- 449 Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2009.  
N.C.H. LO, B.J. MACEWICZ, and D.A. GRIFFITH  
(October 2009)
- 450 Review of the evidence used in the description of currently recognized  
cetacean subspecies.  
W.F. PERRIN, J.G. MEAD, and R.L. BROWNELL, JR.  
(December 2009)
- 451 Climate change in California: Implications for the recovery and protection  
of Pacific salmon and steelhead.  
F. SCHWING, S. LINDLEY, E. DANNER, and D. BOUGHTON  
(December 2009)