2005 Stock Status of Cowcod in the Southern California Bight and Future Prospects

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Executive Summary

Stock.

Cowcod (*Sebastes levis*) in the Southern California Bight (SCB) is the “stock” described by the modeling. The SCB is at the southern end of the INPFC Conception management area and extends from the US-Mexio border north to Point Conception at about 34^{o} 30' N. Lat. Areas to the north and south of SCB were not included in the first assessment because of lack of data and possible differences in abundance trends. The SCB is the area where cowcod are most abundant, where adult habitat is most common and where catches are highest. Although larvae may spread across larger distances, we assume that the adults do not move beyond the stock boundary. This assumption, however, is untested and may very well be inaccurate.

Catches

Catches in this assessment were a combination of commercial and recreational fleets. Commercial catches were taken from the CALCOM database and recreational catches from the RecFIN database. The commercial fishery was made up primarily of set net gears, and to a lesser extent hook and line gears. The limited biological samples indicated commercial gears catch larger fish than recreational. Catches since 2001 have been very low due to management action, however catches in the 1980’s were substantially higher. Discard is not assumed except for a minimal discard in the years after the no-retention management.

Table of catches (1995-2005)

Year	Commercial catch (t)	Recreational catch (t)	Total (t)
1995.0	23.3	1.7	25.0
1996.0	24.6	5.4	30.0
1997.0	7.3	1.8	9.0
1998.0	1.2	2.8	4.0
1999.0	3.5	3.8	7.0
2000.0	0.4	4.5	5.0
2001.0	<1	<1	0.5
2002.0	<1	<1	0.5
2003.0	<1	<1	0.5
2004.0	<1	<1	0.5
2005.0	<1	<1	0.5

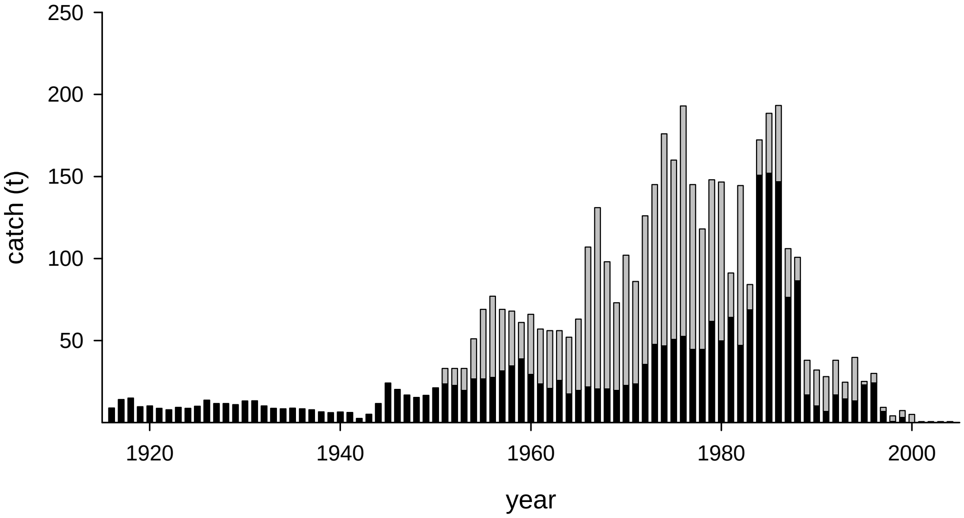

Figure of catch by fleet. Dark bars represent commercial catch and light bars recreational.

Data and Assessment

The last assessment of cowcod was completed in 1999. Data for this assessment include catch (1916-2005), CPFV recreational CPUE (1963-2000), and a single visual transect survey estimate (2002). The data were likelihood components in a Stock Synthesis (V 1.19) age-structured production model (Stock Reduction analysis). The assessment consists of 3 models that differ in the assumed steepness (h) of the Beverton and Holt Stock-Recruit relationship (h=0.4, 0.5, and 0.6). The models are not equally likely but range in probability from 30%, 40%, and 30% for h= 0.4, 0.5, and 0.6, respectively. Probabilities were assigned based upon expert opinion.

Unresolved Problems and Uncertainties.

The assessment suffers from a lack of quality and consistent data. The CPFV CPUE series ended in 2000 due to management actions, and a time series of relative abundance post 2000 is not currently available. Development of a quantitative measure of relative abundance is necessary to monitor this population. Both the steepness of the Beverton and Holt stock recruit relationship and the natural mortality rate are influential to the assessment and were assumed. The model with assumed *h*=0.5 was deemed the most likely by the review panel, although the actual *h* is not known.

Reference Points

The default PFMC harvest rate for rockfish is $F_{50\%SPR}$. The target spawning biomass is 40% of an unfished population. Species that are currently below 25% of an unfished state are overfished and catch rates above those specified by the $F_{50\%SPR}$ are considered overfishing. Currently (2005), cowcod spawning biomass is estimated to be between 14-21% of the unfished state indicating that cowcod are overfished. Catches in the most recent years have been minimal indicating that harvest levels are not sufficient to be currently overfishing the stock.

Table of Biological reference points

	H=0.4	h=0.5	h=0.6
Unfished age-1+ biomass (t)	3250	3191	3151
Unfished spawning biomass (t)	3101	3045	3007
Unfished age-0 recruit	60.6	59.6	58.8
Spawning biomass (t) at 40% unfished	1240	1218	1202
Exploitation rate (%) at $F_{50\%SPR}$	.033	.033	.033
2005 spawning biomass (t)	443	542	642

Stock Biomass

Spawning stock biomass is estimated to have declined from virgin estimates of 3101-3007 t (h=0.4-0.6, respectively) to 2005 estimates of 443-642 t (=0.4-0.6, respectively). A table of biomass for the last 10 years is given in the section **Exploitation Status**.

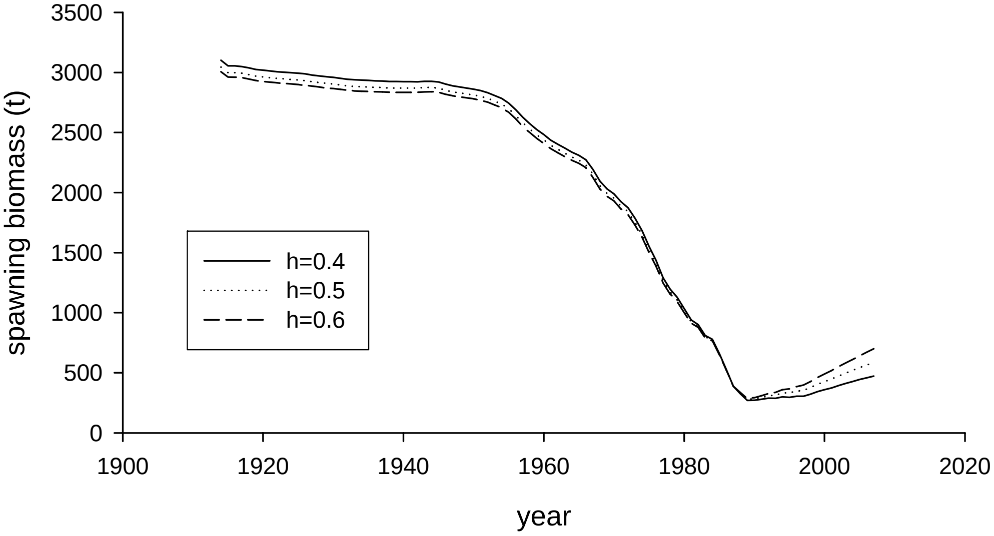

Figure of spawning stock biomass trajectory from all 3 models that used different levels of h.

Recruitment.

Because of the paucity of data, recruitment was modeled as the predicted from a specified stock recruit relationship. Only the level of virgin recruitment was estimated and the steepness of the relationship was fixed at 3 levels. Recruits in this constrained model are predicted to have increased in recent years. A table of biomass for the last 10 years is given in the section

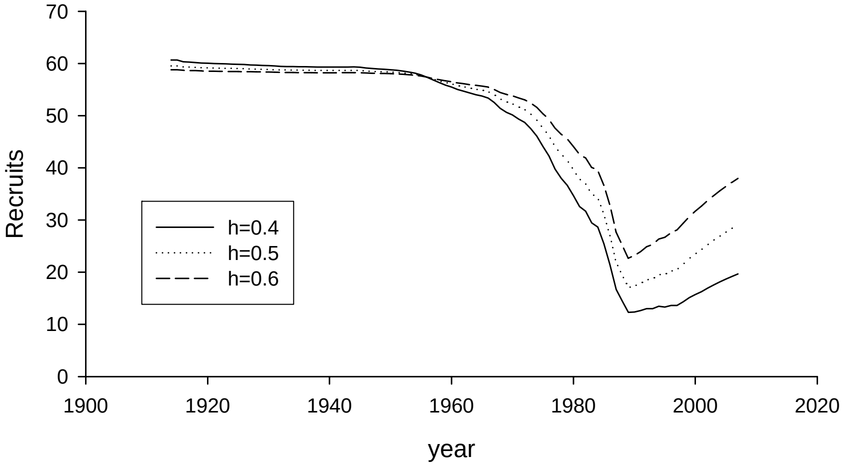

Figure of recruitment from all 3 models that used different assumed levels of h.

Exploitation Status

Currently, cowcod spawning biomass is estimated to be between 14-21% of the unfished state indicating that cowcod are overfished. Catches in the most recent years have been minimal indicating that harvest levels are not sufficient to be overfishing the stock.

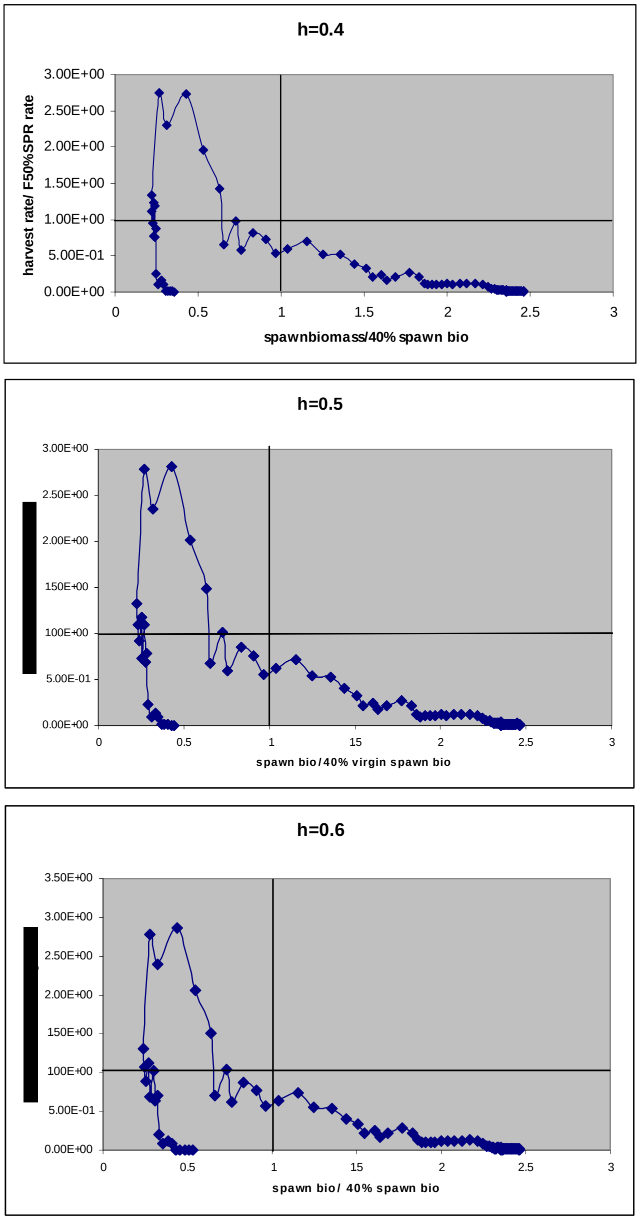

Figure of the ratio of harvest rate/F50%SPR rate vs spawning biomass/40% unfished spawning biomass.

Table of age1+biomass (t), spawning biomass (t), age-0 recruits, harvest rates (%) and depletion levels 1995-2005. Results are given for each level of assumed *h*.

	h=0.4					h=0.5					h=0.6				
year	age 1+	Spawn	recruit-0	Hrate	dep	age 1+	Spawn	recruit-0	Hrate	dep	age 1+	Spawn	recruit-0	Hrate	dep
1995	348	296	13.3	0.025	0.10	397	333	19.6	0.023	0.11	444	366	26.7	0.021	0.12
1996	350	304	13.6	0.029	0.10	405	346	20.2	0.026	0.11	457	385	27.5	0.023	0.13
1997	345	305	13.7	0.008	0.10	406	353	20.5	0.007	0.12	465	398	28.1	0.007	0.13
1998	359	323	14.4	0.003	0.10	426	378	21.5	0.003	0.12	492	428	29.4	0.003	0.14
1999	377	344	15.1	0.005	0.11	451	405	22.6	0.005	0.13	523	462	30.7	0.004	0.15
2000	392	359	15.7	0.004	0.12	472	426	23.5	0.003	0.14	551	490	31.7	0.003	0.16
2001	407	375	16.3	0.000	0.12	494	448	24.3	0.000	0.15	580	519	32.7	0.000	0.17
2002	426	394	16.9	0.000	0.13	520	473	25.2	0.000	0.16	613	550	33.7	0.000	0.18
2003	444	411	17.6	0.000	0.13	545	497	26.1	0.000	0.16	646	581	34.7	0.000	0.19
2004	461	428	18.1	0.000	0.14	569	520	26.9	0.000	0.17	678	612	35.6	0.000	0.20
2005	478	444	18.7	0.000	0.14	593	542	27.7	0.000	0.18	710	642	36.4	0.000	0.21

Management Performance

Since 2001, cowcod have been managed as a no retention fishery in California. The ABC has been 5 t and OY 2.4 t. Recent catches have been < 1t, and indicate that management has been effective at reducing landings unless there has been significant unreported fishing mortality. We have no information on significant unreported catches. The closure of prime cowcod habitat to fishing methods likely to take cowcod is assumed to have effectively reduced non-targeted catch.

Table of management performance. ABC, OY and Catch are given in (t).

year	ABC	OY	Catch
2001	5	2.4	<1
2002	5	2.4	<1
2003	5	2.4	<1
2004	5	2.4	<1
2005	5	2.1	<1

Regional Management

The stock is presently assumed to be a Southern California Bight population. We do not know if the areas north or south of the stock area may constitute additional fish in that population. We have no basis to recommend management on a different regional basis.

Forecasts.
Forecasts of OY catches (t) are given for all 3 levels of assumed S/R steepness. In each projection, catch in 2006 was assumed to be the same as 2005 catch.

Table of projections of OY (40-10 adjusted catch), age-1 biomass and depletion levels

year	h=0.4			h=0.5			h=0.6		
	Catch (t) age-1+ biomass depletion (t)			Catch (t) age-1+ biomass depletion (t)			Catch (t) age-1+ biomass depletion (t)		
2007	7.3	509	0.15	12.2	640	0.19	17.0	773	0.23
2008	7.8	518	0.15	12.9	651	0.20	17.9	788	0.24
2009	8.2	525	0.16	13.5	661	0.20	18.7	802	0.24
2010	8.6	531	0.16	14.1	671	0.20	19.5	815	0.24
2011	9.0	537	0.16	14.7	680	0.20	20.2	828	0.25
2012	9.3	543	0.16	15.2	688	0.20	20.9	840	0.25
2013	9.7	548	0.16	15.6	696	0.21	21.6	852	0.25
2014	10.0	553	0.16	16.1	705	0.21	22.2	864	0.26
2015	10.2	558	0.16	16.5	713	0.21	22.7	875	0.26
2016	10.5	562	0.17	16.9	721	0.21	23.3	887	0.26
2017	10.7	567	0.17	17.3	729	0.22	23.8	898	0.27

Decision Table

A decision table was constructed using the 3 levels of assumed steepness of the BH S/R relationship as different states of nature describing the resiliency of the population. The OY catch levels (40-10 adjusted) predicted for each state of nature were used as the catch in forecasting (2007-2016) age1+ biomass and depletion levels assuming those catches are taken in all 3 states of nature. **Series in bold font show decreasing population abundance**.

Table of estimated age 1+ biomass and depletion levels.

			State of nature: Catch used in the model with					
Management options:			Low resilience H=0.4 Prob=0.3		Medium resilience H=0.5 Prob=0.4		High resilience H=0.6 Prob=0.3	
Catch derived from:	Year	catch(t)						
Low resilience H=0.4	2007	7.3	509	0.15	639	0.19	773	0.23
	2008	7.8	518	0.15	655	0.20	798	0.24
	2009	8.2	525	0.16	670	0.20	821	0.25
	2010	8.6	531	0.16	685	0.21	845	0.25
	2011	9.0	537	0.16	699	0.21	868	0.26
	2012	9.3	543	0.16	713	0.21	891	0.27
	2013	9.7	548	0.16	727	0.22	914	0.27
	2014	10.0	553	0.16	741	0.22	936	0.28
	2015	10.2	558	0.16	754	0.22	959	0.29
	2016	10.5	562	0.17	768	0.23	982	0.30
Medium resilience H=0.5	2007	12.2	**509**	**0.15**	640	0.19	773	0.23
	2008	12.9	**512**	**0.15**	651	0.20	793	0.24
	2009	13.5	**515**	**0.15**	661	0.20	812	0.24
	2010	14.1	**516**	**0.15**	671	0.20	831	0.25
	2011	14.7	**517**	**0.15**	680	0.20	849	0.25
	2012	15.2	**517**	**0.15**	688	0.20	866	0.26
	2013	15.6	**517**	**0.15**	696	0.21	883	0.26
	2014	16.1	**516**	**0.15**	705	0.21	900	0.27
	2015	16.5	**516**	**0.15**	713	0.21	918	0.27
	2016	16.9	**515**	**0.15**	721	0.21	935	0.28
High resilience H=0.6	2007	17.0	**509**	**0.15**	639	0.19	773	0.23
	2008	17.9	**508**	**0.15**	646	0.19	788	0.24
	2009	18.7	**505**	**0.15**	651	0.19	802	0.24
	2010	19.5	**502**	**0.15**	656	0.20	815	0.24
	2011	20.2	**497**	**0.15**	659	0.20	828	0.25
	2012	20.9	**492**	**0.14**	663	0.20	840	0.25
	2013	21.6	**487**	**0.14**	666	0.20	852	0.25
	2014	22.2	**481**	**0.14**	668	0.20	864	0.26
	2015	22.7	**475**	**0.14**	671	0.20	875	0.26
	2016	23.3	**468**	**0.14**	673	0.20	887	0.26

Most Critical Research Need.

A consistent and synoptic measure of relative abundance is necessary to monitor the population biomass. Currently there is no dedicated survey operation meeting those criteria, and therefore future monitoring of population change will be difficult.

INTRODUCTION

Objectives

Cowcod (*Sebastes levis*) is a member of the family Scorpaenidae that is represented by 4 genera and 61 species, more species than any other marine fish family in the eastern North Pacific (Eschmeyer et al. 1983). Cowcod were an important part of both commercial and recreational fisheries in the INPFC Conception/Southern California (from the US-Mexico border, 32º 30.4’, N to 35º 30’ N). Cowcod may reach to 94 cm FL and 15 kg (Eschmeyer et al. 1983). Because of their large size and excellent food quality, anglers enthusiastically pursued cowcod. In the commercial fishery of the mid-1990’s cowcod ranked 24th in landings of rockfish species in California as a whole and 17th in the Conception management area.

This document is a follow up to the first ever assessment of cowcod by Butler et al. (1999) of the cowcod population status in the Southern California Bight (SCB). That assessment concluded that the cowcod population in 1998 was 7% of an unfished stock and that spawning biomass was under 250 t. During the intervening years, a major source of information (recreational CPUE) ended because of management actions taken to reduce catch. In 2002, an unpublished and independent assessment of cowcod abundance was performed using a survey method (Submersible Visual Transect Survey) new to the Pacific West Coast goundfish management. That estimate of biomass was > 3X higher than the previous assessment value. The difference between the estimates from the different assessment methods presents a somewhat conflicting estimate of stock status. The estimate from the visual transect survey was reviewed by an independent panel, chaired by the assessment team. Results of the review are included with the assessment. Because there is little new information beyond the data available to the last stock assessment except for the visual transect estimate, we have decided to maintain as much continuity with the past assessment as possible. We use the same data sources and build the data sets in the same manner as the previous assessment so that only new data (not new analyses) affect our view of how the cowcod population has changed since the 1998 assessment. This assessment will also allow a check that the methods, analysis and data used in that assessment were reasonable and replicable.

Appendix 1) of this document consists of the analysis intended to link the Butler et al. (1999) assessment with this subsequent effort. In appendix 1) We first update the previous assessment model in a manner consistent with an expedited assessment process (see STAR Terms of Reference). The assessment approach was the same, including assessment model (no code changes) and data (same years, same weightings etc). In effect, changes to the population dynamics consist exclusively of the addition of new years of data to the existing data streams. We analyze how our analysis of those data streams (example putting together a CPUE series following the describe methods in Butler et al. 1999) is affected by our reanalysis of the old data and their subsequent effects on the population dynamics. After establishing that the methods we are using to analyze the data are very similar to those of Butler et al. (1999), we examine the effects of the additional new years of data on the model. From this series of analytical steps, we can then describe the estimated condition of the cowcod stock, given the new years of data, through the analytical lens of the 1998 assessment.

In the modeling section of this assessment we explore age-structured models using the same data, and including new sources of data. We used the Stock Synthesis 2 code distributed by Richard Methot. This model is similar to the original SS code (Version 1.18), with the major modification coming from its use of ADMB as the modeling platform. This new modeling approach more easily accommodates different data sources and is designed to estimate the derived quantities specified by the Pacific Fishery Management Council and those quantities necessary to conduct a rebuilding analysis that conforms to the advice of the Science and Statistical Committee. The movement of the assessment from the original population model to the SS2 code will also put the cowcod assessment within the standard modeling platform recommended for groundfish assessments in 2005. Moving the assessment into a standardized modeling program, allows for a more seamless passing of assessments from one author to the next, easier inclusion of new data and removes the potential of individual assessment coding errors.

Section 1: Biology, Fisheries and Data

Biology

Distribution

Cowcod are found at 75–366 m (11–200 fm). It has long been argued that smaller are found at the shallow end of the depth range (Miller and Lea, 1972, Eschmeyer et al. 1983). More recent submersible work, however, indicates that cowcod size distribution may be more associated with structure than depth. Cowcod range from central Oregon (Mark Wilkins, NMFS, AFSC, pers. com.) to central Baja California and Guadalupe Island (Eschmeyer et al. 1983). They are rare off Oregon and Northern California (Figure 1); cowcod were taken in only 13 out of 3245 tows north of Cape Mendicino (40º 28’ N) during 1976–98 in the AFSC triennial shelf survey (Mark Wilkins, NMFS, AFSC, pers. com.). In a revision of the subfamily Sebastinae, Eigenmann and Beeson (1894) reported that cowcod were abundant off Southern California in the 1890s.

Life History

As with other species of *Sebastes*, fertilization is internal and females give birth to first-feeding stage planktonic larvae during the winter (Moser 1967, Boehlert and Yoklavich 1984). Gonad-somatic indices of females are highest from November through April (Love et al. 1990). Peak abundance of cowcod larvae is January through April, with some larvae present from November through August. Larvae spend about 100 days in the plankton and settle to the bottom as juveniles at about 50–60 mm length (Johnson 1997). In Monterey Bay, juveniles recruit to fine sand and clay sediments at depths of 40–100 m during the months of March–September (Johnson 1997). Adults are found at depths of 90–500 m (50–280 fm) usually on high relief rocky bottom.

Description of the Fishery

Estimated total removals peaked in mid 1970’s – 1980’s at 100-200 t. Prior to 1981, the recreational fishery accounted for most of the annual take. The post 1980 period, however, was characterized by a relatively brief but dramatic rise in the commercial set net fishery (Figure 2).

Hook-and-line, set nets and trawls were used to catch cowcod in the commercial fishery. Gear type varies with area; trawling is dominant north of the assessment boundary and set net gear and hook-and-line gear are used in the assessment area. Hook-and-line and set nets account for 92% of landings in the INPFC Conception area which contains the stock assessment boundaries. The majority of the cowcod taken (1978-2000) commercially were from setnet fisheries. The high catches of the mid to late 1980’s was ~70% set net catch. Set net fisheries were gradually eliminated during the 1990’s.

Cowcod reach the largest size of any rockfish in central and southern California, and are a highly prized trophy fish in the recreational fishery. Recreational fishers take cowcod with hook-and-line. Anglers may use as many as 10 baited hooks. Jigs with treble hooks are also a popular method of catching cowcod. The California record for sport caught cowcod is 21 lbs. 14 oz, but the recreational fishery has produced confirmed specimens as large as 34 lbs.

Recreational cowcod catches prior to 2000 were regulated as one component of the 15-fish daily bag limit for *Sebastes*, but cowcod catch rates are low and average only about 0.1 fish per angler day in the 1990's. Hence, recreational effort for cowcod was only limited when the 15-fish bag limit is attained for total *Sebastes*, which was an infrequent event in the Southern California Bight (about 1% of total bags). Cowcod recreational catch was limited to 1 cowcod per person in 2000. Discards were not thought to occur in the recreational fishery, as shown by survey results during 1985-87 (Ally et al.1991). If discarding does occur, cowcod might be subject to discard mortality because of the depth of capture and embolism at the surface.

Recreational effort is directed at cowcod from both private fishing boats and Commercial Passenger Fishing Vessels (CPFVs). Cowcod catch rates were low in the private boat fishery during 1975-76, when they accounted for only 179 out of 140,296 fishes sampled in a CDFG survey of private boats in the southern California sport fishery (Wine and Hoban 1976).

CPFV vessels include both charter boats (carrying a prearranged or closed group of anglers), and party boats (generally open to the general public, without prior reservation). The CPFV industry began in southern California around 1919, and by 1939 the fleet consisted of over 200 boats. CPFV operators targeted numerous species during the first half of the century, such as tuna, giant sea bass, marlin, swordfish, mackerel, California halibut, kelp and sand bass, bonito, barracuda, and yellowtail. However, early reports do not list *Sebastes* (rockfish) as a CPFV target group during the first half of the century (Young 1969).

Following World War II there was a notable expansion of the CPFV fleet, and by 1953 it totaled about 590 boats. By 1963 the statewide CPFV fleet had declined to 476 vessels, 450 of which operated out of central and southern California ports (Young 1969). The majority of the 1963 CPFV fleet (256 vessels) was based in the Southern California Bight (SCB). Species of preference for the southern California CPFV fleet in 1963 did not include *Sebastes*, although rockfish were listed as an important part of the catch (Young 1969). Young (1969) reports that "some [CPFV] fishermen would rather fish for yellowtail, and catch little or nothing, than to take home a sack of rockfish". Those who prefer rockfish to yellowtail are in a minority." However, by 1974 attitudes of the typical CPFV fisher had changed, and there was increased effort directed towards rockfish. With the decline in availability of "traditional" sportfish in the 1960-1970s, less lively "food" fish such as *Sebastes* were sought in order to maintain angler satisfaction (MacCall et al. 1975). In recent decades, cowcod seasonal catch has tended to peak in late autumn through early spring, which is the time of year when southern California CPFVs normally target offshore bottom fishes (Ally et al. 1991).

CPFVs in northern and central California typically have capacities of 6 to 50 anglers (Karpov et al. 1995), and in southern California they may range up to about 60 anglers. State law has required logbooks for every CPFV trip since 1935, but compliance is not complete. From 1981-1986 in central and northern California, CPFV logbook data was found to account for 38% to 62% of total effort, and 49% to 84% of total catch (Karpov et al.1995). Prior to 1963, cowcod were not reported separately on CPFV logbooks, but instead were combined with all other *Sebastes* as part of a "rockfish group." Since 1964, it has been common practice of CPFV skippers to itemize catches of large cowcod (>5 lbs.), but they may have continued to lump small cowcod with other rockfish.

The Los Angeles Times have reported catches from CPFVs from San Diego to Morro Bay. Butler et al. (1999) states that these reports are comparable to the logbook data for most common species, but give slightly higher numbers for the most desirable species (yellowtail and bonito). These species are included on logbook forms reported to CDFG, however, there is no category for cowcod, but rather a category for rockfish. Cowcod may be optionally reported on the logbooks as a separate entry. The Los Angeles Times reports many more cowcod than CPFV logbooks. This difference may be due to the advertising value of cowcod in the LA Times or to under reporting on the logbooks. As explained above logbook compliance is between 61% and 91% (Reilly et al. 1993) which may explain some of the difference.

Although highly sought in recent decades, cowcod have consistently composed < 1% of the CPFV rockfish catch since the 1960s. Cowcod were estimated to comprise >1% of the CPFV rockfish catch in 1961 (Miller and Gotshall 1965), 0.4% of the CPFV rockfish total during the 1970s (Collins and Crooke, MS), and 0.3% of the rockfish total during 1985-87 (Ally et al. 1991).

Multi-Species Aspects of Cowcod Fishing

Cowcod have been landed in 15 different CDFG market categories (used on commercial fish tickets), primarily in the red rockfish, Cowcod, and Unspecified Rockfish market categories. Fourteen species of *Sebastes* have been landed in the cowcod market category; of these, the bronzespotted rockfish, *Sebastes gilli*, is the most common.

Rockfish species landed in the Cowcod Market Category during 1980-97.

Common Name	Scientific Name	Metric Tons
Cowcod	*Sebastes levis*	380.19
Bronzespotted Rockfish	*Sebastes gilli*	92.36
Bocaccio	*Sebastes paucispinis*	15.27
Chilipepper Rockfish	*Sebastes goodei*	7.19
Canary Rockfish	*Sebastes pinniger*	3.34
Vermillion Rockfish	*Sebastes miniatus*	1.83
Widow rockfish	*Sebastes entomelas*	1.52
Pink Rockfish	*Sebastes eos*	1.08
Yelloweye Rockfish	*Sebastes ruberrimus*	0.78
Rougheye rockfish	*Sebastes aleutianus*	0.41
Splitnose rockfish	*Sebastes diploproa*	0.20
Greenspotted rockfish	*Sebastes chlorostictus*	0.18
Redbanded Rockfish	*Sebastes babcocki*	0.15
Flag Rockfish	*Sebastes rubrivinctus*	0.05

Species composition varies with gear type. In the trawl fishery, which is primarily in the Monterey management area, the main species taken with cowcod are chilipepper, bocaccio, and widow rockfish. In the hook-and-line and set net fishery, which is primarily in the Conception management area, bronzespotted rockfish, bocaccio, and vermillion rockfish are most important.

Discards

We assume no discard in the commercial or recreational fleets prior to the implementation of the no retention management measures in 2001. Cowcod were a prized fish, taken at large sizes and are therefore not likely to be discarded in either the recreational or commercial fishery. Any

discarding that existed may have resulted in mortality, because cowcod live deeper than 91 m (50 fm), and barotraumas is significant for this species. Some juveniles may not be reported as cowcod in the recreational fishery because of mis-identification, but it is unlikely that they are discarded.
In 2002, the total estimated discard of cowcod was 4 t from all California areas, including both recreational and commercial trawl sources. In 2003 that same discard was estimated to be only 0.1 t (pers comm.. Jim Hastie). The very small level of discard is too small to get a precise estimate. We assume a 0.5 t catch in years after 2000 inside the stock boundary to account for this unseen catch.

Prices
Cowcod were valuable in the commercial fishery. Prices (inflation adjusted) for fish in the nominal cowcod market category were higher (usually about double) than for unspecified rockfish. In general, cowcod landed by hook-and-line command higher prices than those landed by set net or by trawl. Unspecified rockfish caught by hook-and-line also command higher prices than set net or trawl-caught fish, but the prices for cowcod are more than double the price of unspecified rockfish .

Prices for cowcod ranked, on average, 11th out of 43 for California rockfish market categories in the 1990's. Prices for cowcod rockfish landings by hook-and-line gear during 1992–1997 were higher, for example, than for brown rockfish (*S. auriculatus*), starry rockfish (*S. constellatus*), vermillion rockfish (*S. miniatus*), kelp rockfish (*S. atrovirens*) and yelloweye rockfish (*S. ruberrimus*). Prices for nominal cowcod were lower than prices for grass rockfish (*S. rastrelliger*), treefish (*S. serriceps*), gopher rockfish (*S. carnatus*), china rockfish (*S. nebulosus*) and olive rockfish (*S. serranoides*) which are important in the live-fish fishery.

Management
Cowcod were once a part of the management unit defined as the *Sebastes* complex and often referred to as "remaining rockfish" (Rogers et al. 1996) in management literature because they were managed as a group without species-specific estimates of acceptable biological catch (ABC) and harvest guidelines (HG). For most of the lifespan of the fishery, cowcod had a similar status in the recreational fishery, no species specific limits applied.

The Pacific Fishery Management Council managed cowcod under regulations established annually for the *Sebastes* complex and remaining rockfish. During 1998, the allowable biological catch for the *Sebastes* complex in the southern management area (Eureka, Monterey and Conception management areas) was 8,999 MT. The corresponding harvest guideline was 8,439 MT. Beginning in 1990 the state of California (prop 132) authorized a buyout of set net fishers. The buyout nearly eliminated set net fisheries by 1994. Recreational cowcod catches prior to 2000 were regulated as one component of the 15-fish daily bag limit for *Sebastes.*

The 1998 assessment (Butler et al. 1999) provided the scientific guidance to manage this species as a separate management unit. The Allowable Biological Catch (ABC) of cowcod in 2000 was 5t, but the Optimum Yield (OY) target was only 2.4 t. The ABC remained constant through 2005, but the OY was lowered to 2.1 t in 2005. Cowcod are also managed using a reserve system. Beginning in 2001 areas of the Southern California Bight that were determined to be good cowcod habitat were closed to fishing strategies that could potentially take cowcod. Cowcod were also managed as a no retention fishery in the commercial and recreational sectors statewide. Catches after 2000 are < 1 t, indicating that the effort to eliminate cowcod catch has been effective.

Table. ABC, OY and catch levels (t) in the Southern California Bight 2001-2005.

year	ABC	OY	Catch
2001	5	2.4	<1
2002	5	2.4	<1
2003	5	2.4	<1
2004	5	2.4	<1
2005	5	2.1	

The two areas closed (Cowcod Conservation Areas) to bottom fishing due to concentrations of cowcod, include the "43-fathom spot," which lies 40 miles offshore of San Diego and extends northward and offshore to cover 100 square miles. A larger area was also designated (4,200 square), this area begins about 20 miles off the Palos Verdes Peninsula extending southward ~90 miles and westward another ~50 miles.

Stock Boundary

Cowcod in the Southern California Bight (SCB) is the “stock” described by the modeling. The SCB is at the southern end of the INPFC Conception management area and extends from the US-Mexio border north to Point Conception at about 34^{o} 30' N. Lat. Areas to the north and south of SCB were not included in the first assessment because of lack of data and possible differences in abundance trends. The SCB is the area where cowcod are most abundant where adult habitat is most common and where catches are highest. Although larvae may spread across larger distances, we assume that the adults do not move beyond the stock boundary. This assumption, however, is untested and may very well be inaccurate.

Data

Commercial Landings

This assessment is consistent with the previous assessment in that it constructed a time series of annual commercial cowcod landings from two different data sources. Total commercial estimates for 1978-present are available from CalCOM (Don Pearson, NMFS, SWFSC, pers. com.). Historical (pre 1978) catch estimates were derived by Butler et al. (1999). Prior to 1978, direct estimates of cowcod landings were not available because no port sampling was conducted to decompose the numerous rockfish “market categories” that may contain cowcod (see multispecies aspects). Consequently, Butler et al. (1999) used a ratio estimate to reconstruct historic annual cowcod landings in the SCB from total reported rockfish commercial catch in California (Heimann 1968). During the period of 1980-1997, annual cowcod landings from the assessment area comprised 0.00478 of total statewide rockfish landings. They report that no trend was apparent in the ratio time series although there was annual variability. They estimated the arithmetic scale standard deviation of this ratio estimate using log-scale residuals and the relationship given by Jacobson et al. (1994). Resulting annual estimates of commercial cowcod landings are given in FIG 2 and table 1. The associated confidence intervals are given in Butler et al. (1999). Data from the two sources provide an uninterrupted time series of landing estimates that cover almost 90 years (1916-2005). Cowcod catch in the most recent years has been <1 t, due to regulation. We assume a 0.25 t catch from 2001 to 2005 to account for incidental mortality.

Although catch (post 1978) was estimated using the same source and in a similar manner as the previous assessment, the year-specific catches were not identical to the previous assessment in the most recent (>1980) years. The differences between the two assessment estimates of catch are quite small. The cumulative catch during the period 1980-1997 were approximately 10% more in the most recent estimates relative to the prior assessment. The discrepancy in catches is largely in the mid-1980's. This is likely due to groupings of previously 'unspecified rockfish' being reapportioned into species-specific landing during the intervening years between the assessments. These new expansion are likely the result of borrowing species composition from other statistical cells to derive species-specific catch in unsampled cells. Catches in the unspecified rockfish group are not counted as species-specific until broken out into species-specific estimates based upon species proportion data. We assume that the most recent catch statistics (January, 2005) constitute the best available data.

Recreational Landings

We constructed a time series of annual recreational cowcod landings from three different data types (the same as Butler et al. 1999). Total recreational catches from both the CPFV fleet and private vessels have been estimated directly by Marine Recreational Fishery Surveys (MRFS) since 1980. The MRFSS program has traditionally relied on angler intercepts to get catch and random digit dialing (calling households randomly) to estimate effort. The CPFV fleet catches about 51% (± 28%) of the total recreational rockfish catch in southern California. We used results from the MRFSS surveys for 1980-2003, as tabulated and presented in the RecFIN database. For the historical (pre 1980) recreational catch we used the estimates from Butler et al. (1999). Those estimates were derived by expanding the reported CPFV and Los Angeles Times cowcod landings based by the ratio of CPFV and LA Times to RecFIN cowcod catch during 1980-1997. During those years (excluding 1991-93 when MRFSS was not conducted), the RecFIN catch averaged 4.2x the reported CPFV catch and 1.3X the LA Times catch for cowcod. Expanding each catch series results in similar estimates of recreational cowcod landings. Butler et al. (1998) estimated the arithmetic scale standard deviation of the ratio using log-scale residuals and the relationship given by Jacobson et al. (1994). Prior to 1964 (also taken from the previous assessment), recreational cowcod landings were estimated by Butler et al. (1999) using the fraction of total rockfish landings that were comprised of cowcod during 1965-1997. Data from the three sources provide an uninterrupted time series of recreational catch estimates in the 54 years 1950-2004 (Figure 2 and Table 1). Due to regulations, recreational landings in the most recent years have typically been <1 t. We assume a 0.25 t catch in those years to account for incidental mortality.

Recreational catch, similar to the commercial catch, varied slightly from the past assessment for the overlapping years. The difference was small (<10%) and could be due to many unknown sources. Given the relatively low catch of cowcod relative to other species we consider the difference to be well within the margin of uncertainty and not indicative of a major change in cowcod catches. As with commercial catches, the most recent estimates (February, 2005) of catch are assumed to be the best available estimates and are used in the modeling.

Age and Growth

Cowcod are one of the largest of rockfish species. The maximum size recorded is 94 cm FL (37 in) but larger specimens have been reported (Bob Lea, CDFG, Monterey, pers. com.). Butler et al. (1999) determined age from otoliths collected by the California Department of Fish and Game (CDFG). Otoliths from 131 cowcod were collected from the recreational fishery from April 1975 to June 1981 and from 129 cowcod from the commercial fishery during February 1982 to January 1986. These otoliths were sectioned and read by three readers for all otoliths or four readers for some specimens. Cowcod otoliths are easy to read relative to those of other deep water *Sebastes*. Age was the mean reading of three or four observers. The average percent error (Beamish and Fornier 1981) was 0.09 and the index of precision (Chang 1982) was 0.08.

Butler et al. (1999) determined that growth of cowcod did not drastically differ between sexes, thus the length-age relationship used combined data from both sexes and included specimens for which sex was not recorded. Growth was described by a von Bertalanffy equation:

$$L = L_{\infty}\left(1 - e^{\left(-k\left(Age - t_0\right)\right)}\right)$$

where L_{∞} is TL length, $L_{infinity}$ = 90 cm, k = 0.06, t is age in years and t_0 = -1.03 (Figure 3). Weight at age is also described by the von Bertalanffy equation

$$W = W_{\infty}\left(1 - e^{\left(-K\left(Age - t_0\right)\right)}\right)$$

Where W_{∞} = 35080 g, K = 0.00605, t_0 = 4.7.

Weight-at-length is given in Love et al. (2000) described by W (kg)=aTL^b (Figure 3). Where a=.0000101 and b=3.093.

The maturity at length was reported by Love et al. (2002) and is given in Figure (Figure 3)

Inserted Table of length TL and age of first, 50%, and 100% maturity for female cowcod, *S. levis.*

	Female	
Maturity	Length TL	Age
First	32	7
50%	43	11
100%	55	14

Estimates of Mortality

Estimates of total (natural plus fishing) mortality were derived by Butler et al. (1999; 2003) from samples of the fishery age composition. Reliable mortality estimates may be obtained from this source for fully recruited ages, providing there was no ageing error, sampling was random, recruitment was constant (or varied without trend), and mortality (natural and fishing) was constant (or varied without trend). Butler et al. (1999) tested these assumptions using Robson and Chapman's (1961) Chi^2 formula, and found that some or all were violated ($p < 0.05$). However, since no other data were available, we used the age composition data to obtain rough estimates of total mortality to serve as a starting place for sensitivity analyses in population modeling. The age composition samples were taken from recreational landings during the 1970s (n=129) and commercial landings during the 1980s (n=130). The youngest fish in the landings was age 7, and the oldest was age 55. Slopes of log-transformed data for fully recruited ages were similar from both sources, so data were pooled to increase sample size and reduce variance of mortality estimates (See below).

Four approaches were used to estimate mortality (Butler et al. 1998) from the age data. Because the age data were from an exploited stock, estimates were for total (natural plus fishing) mortality. Age at full recruitment was estimated from the pooled catch curve (Ricker 1975) to be age 17. The best choice for age at full recruitment was not obvious or easily identified from visual examination of the catch curve, but it appeared to fall somewhere within the range of age 10 to age 20. Age 17 was deemed the best estimate because it gave the highest coefficient of determination (r^2) from regression of log-transformed data.

Cowcod Total Mortality Estimates (Z) from Age Data

Method	*Result*
Linear Regression	0.055
Robson-Chapman (1961)	0.087
Heinke (1913)	0.065
Hoenig (1983)	0.075

The mean of the four estimates was $Z=0.071\ y^{-1}$.

Jensen (1997) examined relationships in life history parameters and found that natural mortality (M) = 1.5K, where K is the von Bertalanffy parameter for length. Given an estimate of K=0.056 for cowcod, the corresponding estimate for M=0.084. Since this estimate for M is greater than the age composition-based estimate for Z, it is apparent that there is a great deal of uncertainty in our mortality estimates; i.e. F=Z-M does not give a plausible solution for F. This is consistent with the finding that the catch curve assumptions were violated. One possible implication of similar values for F and M is that M is the major component of Z, and F is significantly less than M. Butler et al. (1999) used M=0.055 and with the lack of new information, this assessment will continue that tradition, noting that the estimate is uncertain.

Indices of Abundance.

Three indices of relative abundance were used in the previous assessment and we updated each time series for use in the current assessment. Table 2 lists the sample sizes used in the construction of the indices.

CalCOFI Index Abundance Data

We used California Cooperative Fisheries Investigations (CalCOFI) data (i.e. catch of cowcod larvae in bongo and ring nets) to construct an index of larval production (reproductive output) for cowcod. CalCOFI data were collected prior to the first west coast bottom trawl survey and in southern areas not often sampled by bottom trawl survey gear. Thus, CalCOFI data provide crucial historical information and information about southern areas not covered by bottom trawl surveys. We have used the same methods to develop a time series as Butler et al. (1999).

Larval, rather than egg, densities were used for cowcod because rockfish are live bearers that give birth to larvae rather than eggs. Rockfish larvae are "cryptic" and many species can be identified only to genus. Cowcod can, however, be reliably identified to species (Moser et al. 1977) by trained staff (G. Moser, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA). We used data from bongo and ring nets because they are relatively effective at capturing larval fish. Changes in sampling gear and protocols are accommodated in calculation of larval densities (number larvae 0.05 m^{-2}) based on larvae counted in samples, volume of water strained and other factors (Stevens et al. 1990).

Abundance indicies based CalCOFI data are used routinely for northern anchovy (*Engraulis mordax*, Jacobson et al. 1994), Pacific sardine (*Sardinops sagax,* Deriso et al. 1996) and Pacific mackerel (*Scomber japonicus*, Hill et al. 1998) and for groundfish. (Ralston et al. 1996, Jacobson et al. 1996, Brodziak et al. 1997 and Cope et al. 2004). The use of CalCOFI in groundfish assessments suffers from a lack of overlap between the CalCOFI survey pattern (which is centered on southern California) and the fisheries which operates primarily on more northern grounds.

As shown below, problems in using CalCOFI data for Dover sole and bocaccio rockfish have been eliminated or do not not exist for cowcod. In particular, the distribution of spawning, the fishery for cowcod and the CalCOFI survey pattern coincide. Furthermore, cowcod (and every other species that can be identified as larvae) have been identified in CalCOFI samples collected during 1951 to 2003 so that a longer and relatively current time series of data are available. The identification of cowcod from 2004 samples has not been completed, therefore that data is not included in the analysis.

Indices of relative abundance for pelagic fishes (and probably cowcod) based on CalCOFI data track long term trends but are imprecise for any one year. Ability to track trends is probably due to long term (1951 to present), consistent (other than as described below), and relatively intense sampling (Hewitt et al. 1988). Imprecision is probably due to the "patchy" and highly variable nature of fish eggs and larvae in the ocean, as well as effects of weather, climate, location, and oceanographic features (e.g. El Nino, PDO) on their seasonal and spatial distribution. CalCOFI data track trends most accurately when the CalCOFI sampling pattern and distribution of the spawning stock coincide, icthyoplankton (fish eggs and larvae) are abundant and uniformly distributed, and the relationship between fecundity and spawning biomass is constant over time.

CalCOFI data were collected from a grid of lines and stations off the west coast (mainly central and southern California) from 1951 to the present (Hewitt 1988). Beginning in 1986, the coverage of the CalCOFI survey was reduced to the "current" CalCOFI survey pattern that is almost entirely within the Southern California Bight. Butler et al. (1999) confirmed Moser et al.'s (1994) results that indicate cowcod larvae are more common in the Southern California Bight than in areas to the south and north. The rest or our analysis is uses CalCOFI data for 1951-2003 from the current CalCOFI sampling pattern in the Southern California Bight.

Based on Moser et al. (1994) and Butler et al. (1999), we defined spawning "seasons" for cowcod. The 1993 spawning season was, for example, June 1993-May 1994.

Inserted table. Sampling gear and procedures for bocaccio larvae taken during CalCOFI cruises (Moser et al. 1993).

Years	Net Frame	Net Material	Mesh Size (mm)	Target Haul Depth (m)	Mean Volume Filtered / m depth (m^3)
1951-1968	1 m ring	silk bolting cloth	0.55	140	3.6
1969-1975	1 m ring	nylon	0.505	210	3.3
1978-1984	0.71 m bongo	nylon	0.505	210	2.0

The CalCOFI index is assumed to represent changed in spawning biomass. The index was compiled in the methods described in the previous assessment. The previous assessment produced an index of the proportion of positive stations, and we have done the same. The data were constrained stations inside line 67.5 and to the months January- June. These constraints limited the number of possible samples to roughly one-third the original numbers, but also constrained the stations to the ones most likely to have a positive tow because cowcod are primarily nearshore and winter spawners. The previous assessment modeled estimates of proportion positive using a logistic regression. Independent variable include year, month and station (inshore/offshore). We have done the same analysis and a comparison of old versus new is given in Figure 4. The year-specific estimates are also given in Table 3 along with the associated CV. As expected, given we have analyzed the data using the same approach, the new estimates and the previous assessments estimates are nearly identical.

CPFV Recreational CPUE

Logbook data from commercial passenger fishing vessels (CPFV or “partyboats”) provided by CDFG (K. Hill, Southwest Fisheries Science Center, pers. comm.) were for fishing trips off southern California during January 1964 to March 1998. The “raw” data used in our analysis were monthly summaries of logbook records for individual CDFG sardine blocks (Figure CPFV-1). Each record contained total numbers of rockfish and cowcod caught in addition to total angler hours for a particular month and block. Data for trips before 1963 were not available because cowcod catches were combined with rockfish prior to 1963. Young (1969) and Golden (1992) give additional information about the CPFV fishery

Following the methods described in Butler et al. (1999), we assigned CPFV data to July-June years (e.g. the 1981 year was 1 July 1981 to 31 June 1982). We used CPFV logbook records for November-April in each year because the CPFV fishery tends to target rockfish during the winter when migratory game fish (e.g. barracuda, tunas, yellowtail, etc.) are seldom caught. We excluded all years after 2000 because of the effects of the 1999 assessment on management (no retention, no bottom fishing in the CCA).

We used data for data from blocks 560-897 and 916 because cowcod are taken almost entirely from the area between Pt. Piedras Blancas and U.S.-Mexico border. We excluded records for blocks 600, 699, 700, 799, 800 and 899 because these codes are used for data of uncertain origin. We excluded a few records that reported cowcod catches larger total rockfish catches and records with high catches from blocks with no cowcod habitat as likely errors.

To be consistent with the previous assessment, we assumed total angler hours reported on CPFV logs for blocks with rockfish catches during November-April was a measure of relative fishing effort for cowcod (see below). We used the logbook data to estimate catch rates measured as catch-per-unit-effort (CPUE, with adjustments described below) in units of numbers of fish per angler hour (fish hr^{-1}).

Changes in angler's gear likely had little effect on catch rates for cowcod because angler's gear used on CPFV vessels has changed little since the early 1960's. Anglers typically use one or two poles with 1-10 hooks per pole that are baited with live or dead bait.

Changes in the percent of fish that are identified to species and reported on logbooks as cowcod (rather than as rockfish) would also effect catch rates. We are not, however, aware of any changes in catch reporting until after the end our time series.

Changes in "effectiveness" of fishing effort may have changed catch rates for cowcod from CPFV logbook data. Catch rates tend to show optimistic trends if fishing effort has become more effective over time and pessimistic trends if fishing effort has become less effective over time. Aprior, we would expect that the advent of new technologies (gps etc.) would tend to favor more effective fishing effort .Butler et al. (1999), based upon knowledgeable sources, indicated that recreational fishing effort for rockfish may have moved from inshore areas to offshore areas during the 1960-1980's and that initially, fishing effort during November-April in offshore areas was probably concentrated in relatively shallow areas around islands and bottom features.

Stratification for Modeling

Butler et al. (1999) stratified CPFV data spatially based on "pseudo-blocks" prior to fitting models and estimating trends in relative abundance. They found differences among blocks in CPUE trends because of differences among blocks in habitat quality. They designed a spatial stratification scheme based on CDFG sardine blocks that would accommodate differences in abundance trends among areas while reducing the number of strata (and model parameters) to a manageable number. We use the same area stratification.

Psuedo-Block 1=651 658 664 665 666 667 668 682 684 685 686 690 691 704 705 706 708
711 712 714 719 723 726 736 737 738 741 761 767 802 803 814 816 821 823 845 865
Psuedo-Block 2= 696 707 709 710 721 725 727 729 730 739 740 744 745 746 751
758 759 760 762 765 768 812 813 833 847 849 850 852 866 878 891
Psuedo-Block 3=827 829 678 683 815 897 678 866 724 728 742 743 747 748 749 750 763 764
766 769 770 806 807 808 809 820 825 826 834 835 836 840 846 853 854
855 856 861 863 864 867 868 871 872 882 883 889 890

The previous assessment used a General Additive Model to estimate CPUE from the California Commercial Passenger Fishing Vessel fleet. In this assessment, we have instead used a GLM approach to estimate CPUE. A logistic regression was used to estimate the proportion positive and a General Linear Model (gamma error assumption) was used to estimate the CPUE for only the positive tows. LSMEANS were calculated for the factor year. Separate estimates were produced for each pseudo-block incorporating month as an explanatory variable in the model. Similar to Butler et al. (1998,) we produced the SCB index by weighting the contribution to the overall index by the pseudo-blocks based upon the area inside each pseudo-block. Area in each block was based on the number of California reporting blocks that made up each pseudo-block.

The estimates from the new CPUE series are very similar to that from the previous assessment (Figure 5 and Table 3). Only 3 new points were calculated and those are low relative to the series mean.

Outfall index of recruitment

Both Los Angeles County and Orange County, Ca. sanitation departments routinely monitor the effects of outflow from their sewage treatment through the use of standardized trawls at fixed stations. Two other outfall data sets were considered (LA City and SD City). Consistent with the previous assessment, those series were not used because of a lack of cowcod catch and shorter time span. The trawls used by the sanitation departments are otter trawls with a 7.6 m headrope with a 1.25-1.3cm cod end mesh. Trawl speed was 1.5-2.5 knots and durations were ~10min. The outfall survey primarily catches very small/young (~ age 3) cowcod. The previous assessment used an arithmetic estimate of proportion positive as a measure of relative abundance of pre-recruit animals. We have analyzed the data in the same way. Our new series includes new data from 1998-2004 that was not included in the previous assessment as well as data 1970-1972 that was also not included. The 1970-1972 data are only from LA county, and is likely the reason those years were not included in the previous assessment. The index of recruitment is given in Figure 6 and Table 3. The values are identical in the overlapping years to those in Butler et al. (1999). The recruitment index is low throughout the 1980's and 1990's. There is evidence, however, of larger recruitment in recent years that will begin to contribute to the spawning biomass.

Additional data not used in the previous assessment: (Data potentially used in the fully age-structured model. See Section 2)

Length composition

Length composition information from port sampled cowcod is relatively sparse. Cowcod have rarely been encountered in samples after the early 1980s. In order to provide the model with demographic information on the recreational catch, we produced year-specific length composition from a composite of 2 data sources. Recreational length information (1980-1989 and 1993-2002) was taken from the RecFIN website. These lengths were taken primarily as part of the MRFSS intercept sampling program used to estimate recreational catch. Additional recreational length observations (1975- 1979 and 1986-1989) were taken from a CPFV observer program in the SCB (per. Comm. Deb Wilson-Vandenberg CDF&G). Because cowcod are caught infrequently (sample size is generally small: see table 4) and all fish taken on a trip are usually sampled (in effect catch weighted), we assumed each length observation was random and representative of the recreational catch. The proportion at length from each year is given in Figure 8 and Table 5.

Commercial length samples of cowcod are nearly non-existent. The only samples taken are from the late 1980's, at the height of the set net fishery. Commercial fleet length information was taken from CalCOM (1986-1989 and 1995-1997). Port samplers collected individual lengths (FL) at unloading docks and the proportion at length data had been expanded based on catch by gear at the port and month level. The lengths were then converted (Love et al. 2001) to TL before binning. All lengths were binned in 2cm intervals from 10cm to 100cm TL. The commercial proportion at length is given in Figure 9 and Table 5. Although relatively few samples were taken, the commercial samples were much larger than the recreational samples (Figure 10). This is consistent with the knowledge that set net type gears, are likely to take large fish.

Manned Submersible Visual Transect Survey.

A single survey of the Cowcod Conservation Area (CCA) was completed using a manned submersible (Yoklavich et al. unpublished data). Transects were placed within a series of 1.5 x 1.5 km squares that were randomly chosen from a grid of squares overlying each bank. The results presented were from a 2002 sampling effort over eight rocky banks inside the CCA. Those banks were chosen because they were previously evaluated to be cowcod habitat (mixed sediment or rocky substrate at depths between 75 to 300 m). The survey platform was a two-person *Delta* submersible capable of operating at depths up to 365 m and for speeds up to 1.5 knots. Safety considerations prevented the submersible from operating down steep slopes. A total of 95 dives were completed and the numbers of cowcod on all banks estimated using direct visual counts and one-sided line transect methods. Cowcod numbers were converted to biomass using recorded fish lengths and a length-weight relationship. The survey estimated 940 t (CV =25%) of cowcod in the study area within the CCA.

The assessment team hosted an independent-internal panel (with outside reviewers from CIE and University) to review and advise the assessment team on the potential use of the new data in the assessment (see supplied materials on the review). Although advice from the review panel indicated that expanding the transect survey results to the entire SCB was not scientifically defensible, we estimated what fraction of the stock was not inside the CCA to develop a prior around the q. Preliminary expansion results indicate that the visual transect survey q=0.75 (essentially 1/3 of the stock lies outside the CCA- see Appendix IV and V). The estimate of q is uncertain because of potential biases in the survey method as well as expansion analysis. This expanded estimate may also serve as alternative assessment of cowcod abundance in 2002.

Acoustic in combination with Remotely Operated Vehicle (ROV) Survey

Another version of a fishery independent survey aimed at rockfish like cowcod is presently being developed. This survey involves the use of acoustic sampling methods and a remotely operated vehicle (ROV) to monitor size and species composition. The ROV may also be used to estimate density in areas the acoustic signal is uninformative due to bottom echo. The survey has been conducted since 2004, but has not yet developed formal protocols and has not been peer reviewed (pers. Comm. John Butler). Thus this survey is not used in this assessment. It may be a source of information for future assessments.

Cowcod Intensive Sampling

Because of the low stock abundance and the low encounter rate of cowcod in the CalCOFI survey, a more intensive ichthyoplankton survey was developed. This survey is designed to monitor decadal changes in spawning biomass. The survey sampled more intensely in a limited geographical area to monitor rebuilding inside the CCA using the same methods as the CalCOFI survey. The intensive sampling began in 2000, but only two years of samples have been identified to species. Because of the limited temporal series and lack of a formal review of the survey methods it is not used in this assessment. However it may be a source of decadal changes in future assessments.

Hook and Line Survey

The NWFSC began conducting a hook and line survey of rockfish in the SCB. The survey initially began in 2003 and was continued in 2004. Several cowcod have been recorded in this survey, but due to the limited time scale, lack of formal survey protocols and the lack of peer review, it has not been included in this assessment. It may be a source of information in future assessments.

RecFIN recreational Fishery CPUE

We considered creating a separate index of recreational CPUE for private boats and party boats using the RecFIN port intercept data and the Steven and MacCall (2004) approach. The party boat index is drawn from the same sampling universe as the CPFV logbook index. Because of the overlap with the logbook data and few samples, the RecFIN index was not used in the modeling. The RecFIN private boat index was based on very sparse sampling and was unusually noisy, therefore it was not considered a realistic assessment of population abundance changes. Both indices were produced using a standard a delta glm approach with season as an explanatory variable. The RecFIN based indices are given in Figure 7 and Table 3.

(*The next section presents our analysis of the population using a fully age structure model.*)

SECTION 2: Assessment Model

Previous Assessment

The previous assessment was conducted in 1998 using a delay-difference model (Butler et al. 1999). In that previous assessment, the stock boundary was identical to the boundary used in this assessment. The analytical team chose the delay difference model because they believed there was not enough length/age information to do a more complex analysis. They assumed that the fishable biomass was comprised of fish > 40 cm FL, because that size also corresponded to the approximate size at maturity (fishable biomass= spawning biomass). The assessment assumed the fishable biomass was proportional to the CPFV recreational CPUE and the CalCOFI larval survey. The assessment assumed that recruitment was proportional to the Outfall index lagged by seven years and controlled by a random walk process. The previous assessment concluded that the fishable biomass was under 250 t and ~7% of unfished in 1998. For more specific information on the previous assessment and for our update of that assessment see appendix 1.

Current Assessment approach

In this section we explore the use of an age-structured analysis. Structural changes to the assessment include the assumption of a Beverton Holt spawner-recruit function (S/R) and that we model numbers at age. The assumption of an underlying S/R relationship is a traditional fishery assumption and its shape will be critical to rebuilding analysis. We address 2 important questions with this model. What is the ending biomass and associated depletion level (ending biomass/ virgin biomass)? What is the expected productivity of the stock as assumed by the BH S/R steepness parameter (h)?

Star Panel Data Considerations
The STAR panel considered all the data sources and in discussion with the STAT team decided that only the CPFV CPUE series and the Visual transect estimate were justified for use in the current assessment. Both the Outfall and CalCOFI indices were series with too few positive tows, and the abundance of the zero catch years were problematic for the lognormal error assumption. Likewise, the proportion at length information was not used because of its general noisy nature and that the assessment model had difficulty in fitting to the data. Both STAR panel and STAT team agreed that the visual survey should be treated as a measure relative abundance with prior information about q (see Appendix IV and V).

Model Components.
The following models use the likelihood components listed below:
Fishery catch 1916-2005 (recreational and commercial)
CPFV recreational fishery CPUE 1963-2000
Visual Transect Survey estimate of biomass (2002)

This following data were not part of the Butler et al. (1999) assessment:
Fishery catch 1999-2005

CPFV recreational CPUE years (1998-2000)

Visual transect survey estimate (2002)

The following assumptions apply to the base case model described below: The population can be described by a single sex life history. Catch is known without error. Natural mortality is assumed =0.055 Recruitment process is described by a Beverton-Holt Stock-Recruit relationship. Selectivity patterns of the fishery and CPUE series were assumed. Selectivity for the fishery, CPFV and CPUE are length based. The CV of the length-at-age relationship is assumed =0.05. A diffuse normal prior (sd=1000) is assumed for each estimated parameter (except visual transect survey q). All models begin in 1916 with the population in equilibrium assuming a total catch of 2 t. The base cases and sensitivity analysis were performed in SS2 Version 1.19. Complete data and control files are given in Appendix III.

Base Case . Simple stock reduction
Base case 1 is a stock reduction model that is essentially an age-structured production model, where lnR0 (initial recruitment) is the carrying capacity and *h* is analogous to the intrinsic rate of increase. The model assumes a single fishery (combined recreational and commercial). A total of 4 parameters are estimated (lnR0, initial F of the combined recreational/commercial fishery, and 2 survey *q* parameters). This model is conceptually close to the delay difference of the previous assessment. The model uses CPFV CPUE, and visual transect survey information. Length information is not used. Selectivity patterns of the single fishery and the CPFV CPUE series is assumed to be the same as the female maturity ogive. In other words, the vulnerable biomass is the mature biomass. This assumption is essentially the same assumption used by Butler et al. (1999), where they modeled knife edge recruitment into the fishery at 40 cm (FL). The visual transect survey is treated as a relative index with some information about its catchability (*q*) because the survey was designed to be an absolute estimate; a normal prior around *q*=0.75 and a CV=0.5. This prior comes from a recommendation of error bounds by the independent survey review panel and considerations of the STAR Panel. The prior is however, subjective. The CV associated with the visual survey estimate is assumed to be the reported 0.25. Selectivity of the visual survey is 1 for all ages, because the visual survey method assumed that all fish are seen along the transect line. Recruitment is constrained to a BH S/R curve with *h* fixed at 3 levels (h=0.4, 0.5 and 0.6) and lnR0 estimated. The inputted CV associated with each survey time series (except the visual transect survey) was iteratively adjusted by a multiplicative scaling factor to achieve internal model consistency.

Base Case Model Results

Models using all 3 levels of *h* depict similar pictures of a population that declined to very low levels during the 1990's and remains below the overfished threshold in 2005 (14-21% of unfished spawning biomass). All models indicate that the population reached very low stock sizes in the 1990's and has since increased. Spawning stock biomass in 2005 was estimated to be 444-642 (t), for *h*=0.4-0.6, respectively. The likelihoods of all individual components, parameter estimates and values of important fixed parameters from all three models are given in Table 6.

Figure 11 depicts observed and predicted values for each survey from *h*=0.4.
Figure 12 depicts observed and predicted values for each survey from *h*=0.5.
Figure 13 depicts observed and predicted values for each survey from *h*=0.6.
Figure 14 depicts the assumed selectivity pattern (same as female maturity ogive).

Table 7 depicts the estimated time series of spawning biomass, recruitment and harvest rates from all 3 levels of *h*. Estimates of the population numbers at age for the most likely model are given in Appendix VI.

Uncertainty and Sensitivity

For each of the three potential base case models, we performed sensitivity analysis to determine the effects of data, and assumptions on model performance. We performed sensitivity analysis to the assumed levels of M and *h*. We also examined the effects of changing the visual survey *q* and associated CV. The results are presented in Table 8. In the original document (prior to STAR Panel), we examined the effects of doubling and halving pre-1970 catch on a similar model. Although not presented in this post-STAR panel document, the changes in historical catch did not drastically alter our perception of stock status. At the STAR panel meeting, we also estimated a power coefficient relating the CPFV CPUE series q and the population abundance. Estimating this power coefficient improved the fit to the CPFV CPUE series and indicated that the series may show hyperdepletion (coefficient =1+0.6). However, there was no biological/fishery justification for estimation of this parameter at this time. It may be useful to investigate this phenomenon in subsequent assessments. We also did a sensitivity analysis that removed all priors and the model estimates were not greatly different as the prior on visual survey q was the only informative prior and it was only somewhat informative.

Harvest Projections and Decision Tables

Forecasted yields using the $F_{50\%SPR}$ proxy for MSY (both 40-10 adjusted and not adjusted) were calculated. The harvest projections using an $F_{50\%SPR}$ rate for the years 2006-1017 are given in Table 9.

A decision table was constructed that evaluates the effects of choosing an OY catch from any one of the levels of assumed *h* to base management action if one of the other base cases is actually a better population representation The decision table is given in Table 10. Because cowcod are overfished the quotas will be set by a separate rebuilding analysis and not based upon the forecasts in this document. Forecasts and decision tables in this document are for entertainment purposes only.

Rebuilding parameters and Reference Points

In the PFMC groundfish group, a stock is considered overfished if the current spawning biomass is less than 25% of the unfished biomass. At the current abundance, the cowcod population remains overfished. Overfishing (different from being overfished) occurs if the actual harvest rate exceeds the harvest rate at MSY or its proxy ($F_{50\%SPR}$). With almost no catch occurring since 2001, overfishing is not presently occurring. Reference Parameters and quantities needed for rebuilding are given in Table 11. A separate rebuilding analysis has not yet been completed.

General Comments about all models

All models indicate that cowcod in the SCB are still below the overfished threshold (spawning biomass <25% of unfished). All models indicate that the population has been stable to increasing over the last 10 years. This is not surprising because catch has dropped to near zero, and the data sources that extended beyond 2000 have generally been more positive. Over the range of models explored, the ratio of 2005 spawning biomass/virgin spawning biomass ranged from 14-21%. No matter the model configuration, it is clear that management action was necessary to protect the stock in 1999. Although the level of *h* was assumed in each model run, the STAR panel recommend that *h*=0.5 be considered the base model configuration with the highest probability of being true (40% probability) and that *h*=0.4 and *h*=0.5 are less likely (30%).

The overall view of the population status is not greatly affected by estimates of historical catch. Previous STAR panels have acknowledged that historical catch is uncertain and that its effects on population trends should be considered. Information on catch prior to the mid 1970's is not generally available. Butler et al. (1999) made good use of available information to determine estimates of historical catch going back more than 50 years, and the estimates have subsequently been accepted by both review panels and journal review. However, those estimates are still very uncertain. It is likely that errors of omission of catch are greater than addition, but the sensitivity analysis indicates that even doubling pre 1970 catch does not greatly affect estimates of terminal spawning biomass or depletion. Other assessment issues are probably a larger source of uncertainty.

Another question that needs to be asked is if the assumed curvature of the BH S/R relationship (*h*) is reasonable? Estimates of *h* from more data rich rockfish assessments include canary rockfish *h*=0.29 (Methot and Piner 2002) and yelloweye rockfish h=0.4 (Methot et al. 2003). Both are large rockfish species that showed a similar magnitude of decline as cowcod. However those estimates of *h* are much smaller than the meta-analysis estimate from Dorn (2002). We do not know if the assumed levels of *h* (0.4-0.6) are appropriate, but they are likely a reasonable range to base management action until we understand productivity of this species better.

The outside assessment of cowcod abundance from the Visual Transect survey by Yoklavich et al. (unpublished data), presents the most optimistic picture of the cowcod population. Their independent assessment methodology indicates that the cowcod population in the CCA was roughly twice the 2002 biomass estimated by this stock assessment. We do not know if direct observation using transect theory is more realistic than the traditional stock assessment method presented in this document. It does appear to support the larger estimates of biomass from this assessment relative to the Delay Difference modeling used previously. Despite the support for higher biomass from the visual survey, there appears a general mis-match between the population dynamics implied by the CPFV cpue series and the visual transect estimate. The more fitting power (less freedom in the visual *q* parameter) given to the visual transect estimate, the poorer the fit to the CPUE series. If the transect survey is an unbiased and reasonably precise estimate of abundance, then the assessment results presented here are likely too pessimistic. We also do not fit the CPFV CPUE series well, with the population abundance underestimating the cpue decline. If the CPFV CPUE series is an accurate depiction of population change, this assessment is likely too optimistic. At this time, we do not know with certainty which picture is correct.

Conclusions

The analytical team asked itself if any of the models presented in this document are realistic? The answer is probably no. All the data sources used have their problems and are likely biased, although we do not know the magnitude or direction of that bias. It is not clear if recreational CPUE is truly proportional to biomass, especially with the likely undocumented changes the fleet has made and the improvements the industry has made in technology. It is hard to believe that over the 40 years the series spans, the fishing power, reporting rates and targeting practices have not changed. Finally, the visual survey has its own questions regarding sampling and the magnitude/direction of the associated error, and that availability of only a single estimate makes evaluating its reliability as an absolute estimate difficult. Even if the transect estimate is an unbiased and relatively precise measure of stock abundance, we are not sure that pinning the model to the estimate when it may be somewhat conflicting with other series is the best solution to produce management advice. However, it is clear that alternative (to trawl based methods) methods of surveying, such as transect surveys, are necessary to monitor cowcod populations. This is an area of research that will be needed to adequately address cowcod management.

The results of this assessment corroborate the 1999 assessment in that cowcod are very likely at a small fraction of their hypothetical unfished state and below the overfished threshold. Although the stock status in this assessment is more optimistic than in the previous assessment, this is due in part to the different assumptions in this assessment. Estimates of harvest rates near MSY are similar to those described by Jacobsen et al. (2001) using surplus production models (schaefer and ASPIC). Catch levels seen throughout the 1980s are clearly too high and it is may be that the Pacific Fishery Management Council default harvest rate of $F_{50\%SPR}$ is too aggressive for this species. However, the available information indicates that the population may have stabilized and that it is increasing in the most recent years. Given that reported catch has been near zero for close to a decade, this is not unexpected. If the population does not increase with the level of catches assumed in the model, then it is likely no reasonable management strategy will be successful.

Most troubling to the assessment team is what future assessment will do. It is not clear that any of the new survey methods discussed in the data section will be both useful (quantitative, synoptic coverage etc.) and repeated in the near future. Very little new data was available for this assessment beyond what was available for the 1999 assessment, and the future of survey information is not certain. Survey type information will be most useful if it is done consistently and often. A more directed and consistent measure of abundance that can be done at least biannually is sorely needed.

Research Needs

1. Consistent and synoptic monitoring of relative/absolute biomass. This new survey should cover areas both inside and outside the CCA.
2. Work on defining stock boundary. The choice of stock boundary in the assessment was based on historical definitions, but may not be accurate. Does Mexico or the Monterey INPFC area harbor a portion (substantial?) of the stock.
3. Determine if fish move in response to environmental signals. There is some indication that fish may have moved from the assessed area during regime type environmental changes.
4. Collection and analysis of biological data. Better define growth, mortality and maturity.
5. As habitat classification maps are developed for the SCB, these will likely be useful to construct the CPUE and Survey time series.
6. Establish different criteria (reference points, rebuilding strategies) for truly data poor species that do not have the quality or quantity of data needed to estimate the current suite of assessment/management quantities. It is unknown if trying to provide the detailed advice currently requested by the PFMC may contribute to erroneous advice relative to maybe much simpler assessment advice (ie. Abundance is increasing/decreasing).

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Table 1. The landings of cowcod in the Southern California Bight by year and fishery. Units are metric tones rounded to the nearest tenth.

year	commercial	recreational	TOTAL
1916.0	8.8		8.8
1917.0	14.1		14.1
1918.0	14.9		14.9
1919.0	9.7		9.7
1920.0	10.2		10.2
1921.0	8.6		8.6
1922.0	7.8		7.8
1923.0	9.2		9.2
1924.0	8.6		8.6
1925.0	9.9		9.9
1926.0	13.6		13.6
1927.0	11.6		11.6
1928.0	11.6		11.6
1929.0	10.9		10.9
1930.0	13.1		13.1
1931.0	13.2		13.2
1932.0	10.2		10.2
1933.0	8.7		8.7
1934.0	8.3		8.3
1935.0	8.7		8.7
1936.0	8.3		8.3
1937.0	7.8		7.8
1938.0	6.6		6.6
1939.0	6.0		6.0
1940.0	6.5		6.5
1941.0	6.2		6.2
1942.0	2.6		2.6
1943.0	5.0		5.0
1944.0	11.6		11.6
1945.0	24.0		24.0
1946.0	20.2		20.2
1947.0	16.7		16.7
1948.0	15.3		15.3
1949.0	16.5		16.5
1950.0	21.1		21.1
1951.0	24.0	9.0	24.5
1952.0	23.0	10.0	32.5
1953.0	20.0	13.0	33.6
1954.0	27.0	24.0	50.3
1955.0	27.0	42.0	69.0
1956.0	28.0	49.0	76.4
1957.0	32.0	37.0	69.4
1958.0	35.0	33.0	68.1
1959.0	39.0	22.0	61.2
1960.0	30.0	36.0	66.1
1961.0	24.0	33.0	56.5
1962.0	21.0	35.0	56.0
1963.0	26.0	30.0	55.9
1964.0	18.0	34.0	51.6
1965.0	20.0	43.0	63.0
1966.0	22.0	85.0	107.0
1967.0	21.0	110.0	130.8
1968.0	21.0	77.0	97.7
1969.0	20.0	53.0	72.8
1970.0	23.0	79.0	102.2
1971.0	24.0	62.0	86.0
1972.0	36.0	90.0	125.8
1973.0	48.0	97.0	145.4
1974.0	47.0	129.0	175.9
1975.0	51.0	109.0	160.5
1976.0	53.0	140.0	193.9
1977.0	45.0	100.0	144.9
1978.0	45.0	73.0	117.6
1979.0	62.0	86.0	147.7
1980.0	50.2	96.4	147.0
1981.0	64.6	26.6	91.0
1982.0	47.4	97.0	144.0
1983.0	69.1	15.1	84.0
1984.0	151.1	21.2	172.0
1985.0	152.4	36.0	188.0
1986.0	147.3	46.0	193.0
1987.0	76.8	29.1	106.0
1988.0	86.8	13.9	101.0
1989.0	17.4	20.6	38.0
1990.0	10.4	21.6	32.0
1991.0	7.1	20.9	28.0
1992.0	17.3	20.7	38.0
1993.0	14.9	9.7	24.0
1994.0	13.7	26.0	39.0
1995.0	23.3	1.7	25.0
1996.0	24.6	5.4	30.0
1997.0	7.3	1.8	9.0
1998.0	1.2	2.8	4.0
1999.0	3.5	3.8	7.0
2000.0	0.4	4.5	5.0
2001.0			0.5
2002.0			0.5
2003.0			0.5
2004.0			0.5
2005.0			0.5

Table 2. The number of stations and the number of positive stations (collected at least 1 cowcod) for each survey and CPUE index used in assessment.

	CalCOFI		CPFV		Outfall		RecFIN party boat		RecFIN private	
year	# obs	# positive	# obs	# positive	# obs	# positive	# obs	# positive	# obs	# positive
1950	94	6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1951	137	3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1952	177	4	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1953	181	10	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1954	142	4	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1955	156	2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1956	142	3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1957	171	8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1958	187	3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1959	195	9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1960	73	3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1961	64	4	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1962	77	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1963	109	3	141	31	n/a	n/a	n/a	n/a	n/a	n/a
1964	112	3	252	53	n/a	n/a	n/a	n/a	n/a	n/a
1965	169	6	273	73	n/a	n/a	n/a	n/a	n/a	n/a
1966	23	1	317	86	n/a	n/a	n/a	n/a	n/a	n/a
1967	71	4	308	76	n/a	n/a	n/a	n/a	n/a	n/a
1968	144	17	279	73	n/a	n/a	n/a	n/a	n/a	n/a
1969	116	9	329	70	n/a	n/a	n/a	n/a	n/a	n/a
1970	n/a	n/a	327	58	32	4	n/a	n/a	n/a	n/a
1971	n/a	n/a	333	84	31	6	n/a	n/a	n/a	n/a
1972	197	6	349	96	32	9	n/a	n/a	n/a	n/a
1973	n/a	n/a	351	170	60	18	n/a	n/a	n/a	n/a
1974	n/a	n/a	340	157	57	5	n/a	n/a	n/a	n/a
1975	215	0	358	205	59	16	n/a	n/a	n/a	n/a
1976	n/a	n/a	369	151	55	2	n/a	n/a	n/a	n/a
1977	n/a	n/a	365	114	66	6	n/a	n/a	n/a	n/a
1978	171	0	126	47	56	1	n/a	n/a	n/a	n/a
1979	n/a	n/a	301	98	79	4	n/a	n/a	n/a	n/a
1980	n/a	n/a	450	178	81	4	700	12	319	8
1981	141	0	442	179	80	2	630	24	171	2
1982	n/a	n/a	387	107	81	1	470	13	269	7
1983	n/a	n/a	399	133	80	1	539	19	n/a	n/a
1984	67	0	431	123	82	2	675	19	n/a	n/a
1985	68	0	364	70	66	0	668	18	183	2
1986	70	0	347	69	82	5	646	9	113	2
1987	72	0	419	58	80	1	n/a	n/a	74	4
1988	72	0	408	70	80	3	240	2	240	2
1989	67	1	418	75	80	0	n/a	n/a	n/a	n/a
1990	68	1	409	78	80	1	n/a	n/a	n/a	n/a
1991	67	1	426	100	94	0	n/a	n/a	n/a	n/a
1992	72	0	376	57	106	0	n/a	n/a	n/a	n/a
1993	71	0	374	36	112	1	138	4	140	5
1994	69	0	378	43	100	2	218	8	131	7
1995	69	0	409	43	95	0	n/a	n/a	n/a	n/a
1996	68	0	445	54	80	1	n/a	n/a	112	4
1997	70	0	419	17	82	0	n/a	n/a	41	3
1998	71	1	465	43	82	0	327	2	66	4
1999	81	3	386	12	99	3	949	10	191	3
2000	70	2	150	5	83	9	528	4	n/a	n/a
2001	70	0	n/a	n/a	84	5	n/a	n/a	n/a	n/a
2002	71	5	n/a	n/a	91	3	n/a	n/a	n/a	n/a

Table 3 . The survey and CPUE estimates used in the assessment of cowcod.

	CalCOFI		CPFV		Outfall		RecFIN Party boat		RecFIN private boat	
year	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV
1951	5.0	0.41								
1952	2.2	0.52								
1953	1.9	0.47								
1954	4.4	0.33								
1955	2.4	0.47								
1956	1.0	0.59								
1957	1.8	0.52								
1958	3.8	0.36								
1959	1.2	0.52								
1960	3.4	0.35								
1961	2.7	0.54								
1962	3.9	0.49								
1963	0.1	1.02	7.15	0.37						
1964	2.0	0.53	5.75	0.32						
1965	2.4	0.53	5.51	0.29						
1966	2.7	0.40	5.93	0.23						
1967	13.0	0.90	4.08	0.21						
1968	5.9	0.50	2.70	0.19						
1969	8.1	0.28	4.83	0.24						
1970			3.40	0.25	12.50	0.33				
1971			3.83	0.22	19.35	0.40				
1972	4.4	0.36	2.92	0.29	28.13	0.45				
1973			3.05	0.13	30.00	0.46				
1974			2.61	0.13	8.77	0.28				
1975	2.5	0.41	4.83	0.11	27.12	0.44				
1976			2.32	0.11	3.64	0.19				
1977			2.31	0.15	9.09	0.29				
1978	0.1	1.01	2.30	0.32	1.79	0.13				
1979			1.44	0.24	5.06	0.22				
1980			1.17	0.11	4.94	0.22	0.05	0.35	0.02	0.38
1981	0.1	1.01	2.50	0.17	2.50	0.16	0.04	0.22	0.01	0.77
1982			0.71	0.19	1.23	0.11	0.03	0.31	0.03	0.46
1983			1.29	0.11	1.25	0.11	0.03	0.24		
1984	0.1	1.01	1.00	0.11	2.44	0.15	0.03	0.23		
1985	0.1	1.02	0.48	0.14	0.10	0.22	0.03	0.25	0.01	0.71
1986	0.1	1.02	0.78	0.15	6.10	0.24	0.01	0.34	0.01	0.72
1987	0.1	1.02	0.38	0.15	1.25	0.11			0.05	0.51
1988	0.1	1.02	0.81	0.22	3.75	0.19	0.01	0.71	0.04	0.87
1989	0.1	1.02	0.85	0.16	0.10	0.22				
1990	1.1	0.74	0.85	0.16	1.25	0.11				
1991	0.9	0.73	0.72	0.13	0.10	0.22				
1992	1.0	0.74	0.56	0.18	0.10	0.22				
1993	0.1	1.02	0.58	0.24	0.89	0.09	0.04	0.53	0.01	0.46
1994	0.1	1.02	0.36	0.14	2.00	0.14	0.04	0.35	0.03	0.41
1995	0.1	1.02	0.19	0.13	0.10	0.22				
1996	0.1	1.02	0.24	0.13	1.25	0.11			0.04	0.55
1997	0.1	1.02	0.25	0.23	0.10	0.22			0.06	0.62
1998	0.10	1.02	0.23	0.22	0.10	0.22	0.01	0.71	0.03	0.61
1999	1.04	0.74	0.01	0.26	3.03	0.17	0.01	0.33	0.02	0.80
2000	3.01	0.54	0.01	0.39	10.84	0.31	0.01	0.55		
2001	2.13	0.62			5.95	0.24				
2002	0.10	1.02			3.30	0.18				
2003	4.53	0.46								

Table 4. The numbers of fish collected and used to create the fishery proportion-at length of cowcod in the Southern California Bight.

	Recreational		Commercial	
year	# fish	# trips	# fish	# trips
1975	291	76	n/a	n/a
1976	363	120	n/a	n/a
1977	453	73	n/a	n/a
1978	354	66	n/a	n/a
1979	n/a	n/a	n/a	n/a
1980	45	10	n/a	n/a
1981	30	12	n/a	n/a
1982	24	10	n/a	n/a
1983	21	6	n/a	n/a
1984	19	10	n/a	n/a
1985	26	9	n/a	n/a
1986	63	18	246	57
1987	60	26	134	28
1988	34	18	41	10
1989	50	20	34	6
1990	n/a	n/a	n/a	n/a
1991	n/a	n/a	n/a	n/a
1992	n/a	n/a	n/a	n/a
1993	11	3	n/a	n/a
1994	13	6	n/a	n/a
1995	n/a	n/a	32	6
1996	7	3	21	4
1997	3	2	42	8
1998	5	5	n/a	n/a
1999	19	7	n/a	n/a
2000	6	3	n/a	n/a
2001	3	2	n/a	n/a
2002	3	3	n/a	n/a

Table 5. Recreational proportion at length data.

Tl (cm)	1975	1976	1977	1978	1980	1981	1982	1983	1984	1985	1986	1987
10	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
20	0.0034	0	0	0	0	0	0	0	0	0	0	0
22	0	0.0028	0	0	0	0	0	0	0	0	0	0
24	0	0.0028	0	0.0028	0	0	0	0	0	0	0	0.0333
26	0	0.0055	0	0	0	0	0.0417	0	0	0	0	0
28	0	0.0028	0.0022	0	0	0	0	0	0	0	0	0.0167
30	0.0137	0.022	0.0088	0.0028	0	0	0	0.0476	0	0	0	0
32	0.0241	0.0193	0.0132	0.0028	0	0	0	0.0476	0	0	0	0.0667
34	0.0206	0.0358	0.0397	0	0	0.0333	0	0	0	0.0385	0	0.0333
36	0.0447	0.0303	0.0442	0.0198	0.0222	0.0333	0.0417	0.0476	0	0	0	0.0333
38	0.0515	0.0468	0.0486	0.0311	0.0444	0.1	0.0833	0.0952	0.0526	0	0	0
40	0.0619	0.0523	0.0309	0.0339	0.0667	0.0333	0	0	0	0	0	0.0333
42	0.0653	0.0689	0.0684	0.0339	0.0889	0	0	0.0476	0	0	0.0159	0.0167
44	0.0893	0.0579	0.1192	0.0339	0.0222	0.0333	0	0	0.0526	0	0.0635	0.0167
46	0.0653	0.0468	0.1038	0.0226	0.0444	0	0.0833	0	0.1053	0.0385	0.0635	0
48	0.0687	0.0579	0.1369	0.0113	0.0222	0.0667	0.0833	0.0476	0	0.0385	0.0635	0.0333
50	0.0653	0.0496	0.0993	0.0311	0.0444	0.1333	0.0417	0	0	0	0.0794	0.0333
52	0.0997	0.0523	0.0574	0.0226	0.0444	0.0667	0	0.0476	0	0	0.1111	0.05
54	0.0722	0.0441	0.0353	0.0452	0.0222	0.0333	0.0417	0.0476	0	0.0769	0.0635	0
56	0.0619	0.0523	0.0375	0.0424	0.0222	0.0333	0.0417	0	0.0526	0	0.0635	0.05
58	0.0309	0.0468	0.0309	0.0537	0.0444	0	0.0833	0	0	0.0385	0.0794	0.1167
60	0.0172	0.0275	0.0155	0.0367	0.0444	0.0667	0.125	0.0476	0.0526	0.0385	0.0476	0.05
62	0.0137	0.0275	0.0132	0.0537	0.0222	0.1333	0	0.0952	0.1053	0.0769	0.0635	0.1
64	0.0206	0.0358	0.0066	0.0565	0.1333	0.1	0.0833	0.0476	0.0526	0	0.0635	0.0833
66	0.0241	0.0468	0.0132	0.0424	0.0222	0.0333	0.0417	0.0952	0	0.1154	0.0476	0.0333
68	0.0103	0.0275	0.0066	0.0508	0.0444	0.0333	0.0833	0.0476	0.1053	0.0769	0.0476	0.0833
70	0.0206	0.0193	0.0044	0.0424	0.0444	0	0.0417	0	0.0526	0.1154	0.0317	0.0167
72	0.0206	0.0303	0.0155	0.0763	0.0222	0.0333	0.0417	0.0952	0.1053	0.0769	0	0.0167
74	0.0103	0.0165	0.011	0.0621	0.0222	0	0	0	0	0.1538	0.0476	0
76	0.0034	0.0165	0.0088	0.0367	0.0222	0	0	0.0476	0	0	0	0
78	0	0.022	0.0088	0.0311	0.0444	0	0	0.0476	0.1579	0.0385	0	0
80	0.0034	0.0193	0.0088	0.0367	0.0444	0	0	0	0	0	0.0159	0.0333
82	0.0034	0.0055	0.0044	0.0056	0.0444	0.0333	0	0	0.0526	0.0385	0	0
84	0	0	0.0022	0.0282	0	0	0	0	0.0526	0	0	0.0167
86	0.0034	0	0.0022	0.0169	0	0	0.0417	0	0	0	0	0.0333
88	0.0034	0.0028	0	0.0169	0	0	0	0	0	0.0385	0	0
90	0.0034	0.0028	0.0022	0.0085	0	0	0	0	0	0	0.0159	0
92	0.0034	0	0	0.0085	0	0	0	0	0	0	0.0159	0
94	0	0.0028	0	0	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0.0476	0	0	0	0

Table 5 continued Recreational proportion at length continued

1988	1989	1993	1994	1996	1997	1998	1999	2000	2001	2002
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0.0526	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0.04	0	0	0	0.3333	0.2	0	0	0	0
0	0.02	0	0	0	0	0	0	0	0.3333	0
0.0294	0.02	0	0	0.1429	0	0	0.0526	0	0.3333	0
0.0588	0.06	0	0	0.1429	0	0	0.1053	0	0	0
0.0588	0.02	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0.08	0.0909	0	0.1429	0	0	0.0526	0	0	0
0.0588	0.08	0	0	0	0	0.2	0	0	0	0
0.0588	0.02	0	0	0.1429	0	0	0	0	0	0
0.0294	0.04	0	0	0	0	0.2	0	0	0	0
0.0588	0	0.0909	0.0769	0	0	0	0	0	0	0
0.0588	0	0	0.0769	0	0	0	0.0526	0	0	0
0.0588	0	0	0.0769	0	0.3333	0.2	0.0526	0	0	0.3333
0	0.04	0	0.1538	0	0	0	0	0	0	0
0.0294	0.04	0	0	0	0	0	0.0526	0	0.3333	0
0	0.04	0.0909	0	0.1429	0	0	0.2105	0	0	0
0.0294	0.06	0	0	0	0	0	0.0526	0.1667	0	0
0.0294	0.04	0	0	0	0	0	0.0526	0.1667	0	0
0.0294	0.04	0.1818	0.0769	0	0	0	0.1053	0	0	0
0.1471	0.02	0.3636	0	0	0	0	0.1579	0	0	0.3333
0.0882	0.04	0.1818	0.0769	0.1429	0.3333	0.2	0	0.3333	0	0
0	0.06	0	0.0769	0	0	0	0	0	0	0
0.0294	0.06	0	0.2308	0	0	0	0	0	0	0.3333
0	0.04	0	0.0769	0	0	0	0	0	0	0
0.0588	0.02	0	0.0769	0	0	0	0	0.3333	0	0
0.0588	0.02	0	0	0.1429	0	0	0	0	0	0
0	0.06	0	0	0	0	0	0	0	0	0
0.0294	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0.02	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0.02	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0

Table 5 continued Commercial fleet proportion at length data

Tl (cm)	1986	1987	1988	1989	1992	1995	1996	1997
10	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
26	0	0	0	0	0.01	0	0	0
28	0	0	0	0	0.01	0	0	0
30	0	0	0	0	0	0	0	0
32	0	0.01	0	0	0.01	0	0	0
34	0	0	0	0	0.02	0	0	0
36	0	0	0	0	0.06	0.18	0	0
38	0	0.01	0	0	0.1	0.02	0	0
40	0.01	0.01	0	0	0.02	0	0	0.01
42	0.03	0	0	0	0	0	0.05	0
44	0.01	0	0	0	0.05	0.09	0	0
46	0.03	0	0	0	0.26	0.03	0	0
48	0.05	0	0	0	0	0	0.08	0
50	0.05	0.01	0	0	0.05	0	0.08	0
52	0.02	0.01	0	0	0	0	0.02	0.14
54	0.01	0.02	0	0.02	0.03	0.01	0.04	0
56	0.05	0.11	0.03	0	0	0.09	0.03	0.02
58	0.05	0.02	0	0	0.03	0.15	0.22	0
60	0.03	0.02	0.05	0.02	0.05	0	0.03	0
62	0.05	0.11	0.03	0.06	0	0	0.03	0.01
64	0.04	0.03	0	0.08	0	0.07	0.27	0.13
66	0.08	0.08	0.05	0.07	0.03	0	0.08	0.14
68	0.05	0.1	0.12	0.04	0.03	0	0.04	0
70	0.03	0.01	0.03	0.04	0.05	0.07	0	0
72	0.11	0.05	0.05	0.2	0.05	0.15	0	0.13
74	0.04	0.1	0.15	0.16	0.11	0.07	0	0.13
76	0.05	0.1	0.12	0.12	0.03	0.07	0	0.13
78	0.07	0.08	0.19	0.12	0	0	0.03	0
80	0.05	0.03	0.06	0.02	0	0	0	0.13
82	0.04	0.05	0.03	0.06	0	0	0	0
84	0.03	0.06	0.03	0	0	0	0	0
86	0.01	0	0.07	0	0	0	0	0
88	0	0	0	0	0	0	0	0
90	0.01	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0
96	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0

Table 6. Base Model Results. Columns are model and rows are likelihood and parameter values

Likelihood Component/ estimate	h=0.4	h=0.5	h=0.6
Likelihood compontents			
Total Likelihood	12.91	13.43	14.03
CPFV CPUE	11.15	12.23	13.21
Visual survey	0.35	0.22	0.14
Parm priors	1.39	0.91	0.58
Parameter estmates			
Ln (R0)	4.10	4.086	4.07
Initial F			
CPFV CPUE q	0.0000149	.00000146	.00000143
Visual q	1.75	1.49	1.30
M (for all ages)	0.055 assumed	0.055 Assumed	0.055 Assumed

Table 7. Estimates of age 1+ biomass, spawning biomass, recruitment (age-0) and harvest rates and depletion (1914-2005) from all 3 levels of h.

	h=0.4					h=0.5					h=0.6				
year	age 1+	SpawnBio	recruit-0	Hrate-	dep	age 1+	SpawnBio	recruit-0	Hrate-1	dep	age 1+	SpawnBio	recruit-0	Hrate-1	dep
1914	3250	3101	60.7	--	1.00	3191	3045	59.6	--	1.00	3151	3007	58.8	--	1.00
1915	3204	3055	60.7	0.000	0.99	3144	2998	59.6	0.000	0.98	3105	2961	58.8	0.000	0.98
1916	3204	3055	60.3	0.000	0.99	3144	2998	59.3	0.000	0.98	3105	2961	58.7	0.000	0.98
1917	3197	3049	60.3	0.001	0.98	3138	2992	59.3	0.001	0.98	3098	2954	58.6	0.001	0.98
1918	3186	3037	60.2	0.001	0.98	3126	2981	59.2	0.001	0.98	3087	2943	58.6	0.001	0.98
1919	3174	3025	60.1	0.000	0.98	3115	2969	59.2	0.000	0.98	3075	2931	58.6	0.000	0.97
1920	3167	3019	60.0	0.000	0.97	3108	2962	59.1	0.000	0.97	3069	2924	58.5	0.000	0.97
1921	3161	3012	60.0	0.000	0.97	3101	2955	59.1	0.000	0.97	3062	2918	58.5	0.000	0.97
1922	3155	3007	60.0	0.000	0.97	3096	2950	59.1	0.000	0.97	3057	2913	58.5	0.000	0.97
1923	3151	3003	59.9	0.000	0.97	3092	2946	59.1	0.000	0.97	3053	2909	58.5	0.000	0.97
1924	3146	2998	59.9	0.000	0.97	3087	2941	59.0	0.000	0.97	3047	2903	58.5	0.000	0.97
1925	3141	2993	59.9	0.000	0.97	3082	2937	59.0	0.000	0.96	3043	2899	58.5	0.000	0.96
1926	3135	2988	59.8	0.001	0.96	3076	2931	59.0	0.001	0.96	3037	2893	58.4	0.001	0.96
1927	3126	2979	59.7	0.001	0.96	3067	2922	58.9	0.001	0.96	3028	2884	58.4	0.001	0.96
1928	3119	2972	59.7	0.001	0.96	3060	2915	58.9	0.001	0.96	3021	2878	58.4	0.001	0.96
1929	3112	2965	59.6	0.001	0.96	3054	2909	58.9	0.001	0.96	3015	2871	58.4	0.001	0.95
1930	3106	2959	59.6	0.001	0.95	3048	2903	58.8	0.001	0.95	3009	2865	58.3	0.001	0.95
1931	3098	2951	59.5	0.001	0.95	3040	2895	58.8	0.001	0.95	3001	2858	58.3	0.001	0.95
1932	3091	2944	59.5	0.000	0.95	3032	2888	58.8	0.000	0.95	2994	2850	58.3	0.001	0.95
1933	3086	2939	59.4	0.000	0.95	3028	2883	58.7	0.000	0.95	2989	2846	58.3	0.000	0.95
1934	3083	2936	59.4	0.000	0.95	3025	2880	58.7	0.000	0.95	2987	2843	58.3	0.000	0.95
1935	3080	2933	59.4	0.000	0.95	3022	2878	58.7	0.000	0.95	2984	2841	58.3	0.000	0.94
1936	3077	2930	59.4	0.000	0.94	3020	2875	58.7	0.000	0.94	2982	2839	58.2	0.000	0.94
1937	3074	2928	59.3	0.000	0.94	3017	2873	58.7	0.000	0.94	2980	2836	58.2	0.000	0.94
1938	3072	2926	59.3	0.000	0.94	3015	2871	58.7	0.000	0.94	2978	2835	58.2	0.000	0.94
1939	3071	2925	59.3	0.000	0.94	3015	2871	58.7	0.000	0.94	2978	2835	58.2	0.000	0.94
1940	3070	2924	59.3	0.000	0.94	3015	2871	58.7	0.000	0.94	2978	2835	58.2	0.000	0.94
1941	3070	2924	59.3	0.000	0.94	3014	2870	58.7	0.000	0.94	2978	2835	58.2	0.000	0.94
1942	3069	2923	59.3	0.000	0.94	3014	2870	58.7	0.000	0.94	2978	2835	58.2	0.000	0.94
1943	3072	2926	59.3	0.000	0.94	3017	2873	58.7	0.000	0.94	2981	2839	58.2	0.000	0.94
1944	3072	2926	59.3	0.001	0.94	3018	2874	58.7	0.001	0.94	2982	2840	58.2	0.001	0.94
1945	3066	2920	59.3	0.001	0.94	3013	2869	58.7	0.001	0.94	2977	2834	58.2	0.001	0.94
1946	3048	2903	59.1	0.001	0.94	2995	2851	58.6	0.001	0.94	2960	2817	58.2	0.001	0.94
1947	3034	2889	59.0	0.001	0.93	2982	2838	58.5	0.001	0.93	2947	2804	58.1	0.001	0.93
1948	3024	2879	59.0	0.001	0.93	2972	2829	58.4	0.001	0.93	2938	2795	58.1	0.001	0.93
1949	3016	2871	58.9	0.001	0.93	2965	2821	58.4	0.001	0.93	2930	2788	58.1	0.001	0.93
1950	3007	2861	58.8	0.001	0.92	2956	2812	58.3	0.001	0.92	2922	2779	58.0	0.001	0.92
1951	2993	2848	58.7	0.001	0.92	2943	2799	58.3	0.001	0.92	2909	2767	58.0	0.001	0.92
1952	2977	2831	58.6	0.002	0.91	2927	2783	58.2	0.002	0.91	2894	2751	57.9	0.002	0.91
1953	2953	2808	58.4	0.002	0.91	2904	2760	58.1	0.002	0.91	2871	2728	57.8	0.002	0.91
1954	2929	2784	58.2	0.003	0.90	2880	2737	57.9	0.003	0.90	2848	2705	57.7	0.003	0.90
1955	2890	2745	57.8	0.004	0.89	2842	2698	57.7	0.004	0.89	2809	2667	57.6	0.004	0.89
1956	2833	2689	57.4	0.004	0.87	2786	2643	57.4	0.004	0.87	2754	2612	57.4	0.004	0.87
1957	2772	2627	56.8	0.004	0.85	2725	2582	57.0	0.004	0.85	2693	2551	57.1	0.004	0.85
1958	2718	2574	56.3	0.004	0.83	2672	2529	56.7	0.004	0.83	2641	2499	56.9	0.004	0.83
1959	2668	2524	55.9	0.004	0.81	2622	2479	56.3	0.004	0.81	2592	2450	56.7	0.004	0.81
1960	2626	2482	55.5	0.004	0.80	2581	2438	56.1	0.004	0.80	2550	2409	56.5	0.004	0.80
1961	2580	2437	55.0	0.003	0.79	2535	2393	55.8	0.003	0.79	2506	2364	56.3	0.004	0.79
1962	2545	2402	54.7	0.003	0.77	2501	2359	55.5	0.003	0.77	2472	2330	56.1	0.004	0.77
1963	2511	2369	54.4	0.003	0.76	2468	2327	55.3	0.004	0.76	2439	2298	55.9	0.004	0.76
1964	2478	2337	54.0	0.003	0.75	2436	2295	55.1	0.003	0.75	2408	2267	55.8	0.003	0.75
1965	2450	2310	53.8	0.004	0.74	2409	2269	54.9	0.004	0.75	2382	2242	55.7	0.004	0.75
1966	2412	2273	53.4	0.007	0.73	2372	2233	54.6	0.007	0.73	2346	2206	55.5	0.007	0.73
1967	2333	2195	52.5	0.009	0.71	2294	2155	54.0	0.009	0.71	2268	2129	55.0	0.009	0.71
1968	2232	2096	51.4	0.007	0.68	2195	2057	53.2	0.007	0.68	2170	2031	54.5	0.007	0.68
1969	2166	2031	50.6	0.006	0.65	2130	1993	52.6	0.006	0.65	2106	1967	54.1	0.006	0.65
1970	2125	1991	50.2	0.008	0.64	2091	1954	52.3	0.008	0.64	2067	1930	53.8	0.008	0.64
1971	2057	1924	49.3	0.007	0.62	2024	1888	51.6	0.007	0.62	2002	1865	53.4	0.007	0.62
1972	2006	1874	48.7	0.011	0.60	1975	1840	51.2	0.011	0.60	1954	1817	53.0	0.011	0.60
1973	1918	1786	47.5	0.013	0.58	1888	1754	50.3	0.013	0.58	1868	1732	52.4	0.014	0.58
1974	1812	1682	46.1	0.017	0.54	1784	1651	49.2	0.017	0.54	1766	1630	51.6	0.018	0.54
1975	1679	1550	44.1	0.017	0.50	1653	1521	47.6	0.018	0.50	1636	1502	50.4	0.018	0.50
1976	1563	1436	42.3	0.023	0.46	1539	1408	46.2	0.024	0.46	1524	1390	49.3	0.024	0.46
1977	1417	1291	39.8	0.020	0.42	1395	1266	44.1	0.020	0.42	1381	1249	47.6	0.021	0.42
1978	1320	1197	38.0	0.018	0.39	1301	1173	42.6	0.018	0.39	1289	1157	46.4	0.019	0.38
1979	1251	1129	36.7	0.024	0.36	1234	1108	41.4	0.025	0.36	1224	1094	45.5	0.026	0.36
1980	1153	1034	34.7	0.027	0.33	1139	1015	39.7	0.028	0.33	1131	1002	44.1	0.029	0.33
1981	1056	940	32.6	0.019	0.30	1046	923	37.8	0.020	0.30	1040	912	42.5	0.020	0.30
1982	1014	901	31.7	0.032	0.29	1007	887	37.0	0.034	0.29	1003	877	41.9	0.034	0.29
1983	921	811	29.5	0.022	0.26	917	799	35.0	0.023	0.26	915	792	40.1	0.023	0.26
1984	885	779	28.7	0.047	0.25	885	770	34.3	0.049	0.25	886	765	39.5	0.050	0.25
1985	763	662	25.5	0.065	0.21	766	656	31.2	0.067	0.22	771	652	36.7	0.068	0.22
1986	624	528	21.4	0.091	0.17	631	525	27.1	0.093	0.17	638	524	32.9	0.095	0.17
1987	478	387	16.7	0.076	0.12	489	387	21.9	0.078	0.13	500	389	27.7	0.079	0.13
1988	414	327	14.5	0.091	0.11	429	331	19.5	0.092	0.11	443	335	25.3	0.092	0.11
1989	352	270	12.3	0.044	0.09	371	278	17.1	0.044	0.09	389	285	22.7	0.043	0.09
1990	350	272	12.4	0.037	0.09	373	283	17.3	0.036	0.09	395	294	23.2	0.036	0.10
1991	353	279	12.7	0.031	0.09	381	294	17.8	0.031	0.10	407	309	23.9	0.029	0.10
1992	358	289	13.0	0.041	0.09	391	309	18.5	0.039	0.10	422	328	24.9	0.037	0.11
1993	352	288	13.0	0.026	0.09	390	314	18.7	0.024	0.10	426	337	25.3	0.023	0.11
1994	358	300	13.5	0.039	0.10	402	331	19.5	0.036	0.11	443	359	26.4	0.034	0.12
1995	348	296	13.3	0.025	0.10	397	333	19.6	0.023	0.11	444	366	26.7	0.021	0.12
1996	350	304	13.6	0.029	0.10	405	346	20.2	0.026	0.11	457	385	27.5	0.023	0.13
1997	345	305	13.7	0.008	0.10	406	353	20.5	0.007	0.12	465	398	28.1	0.007	0.13
1998	359	323	14.4	0.003	0.10	426	378	21.5	0.003	0.12	492	428	29.4	0.003	0.14
1999	377	344	15.1	0.005	0.11	451	405	22.6	0.005	0.13	523	462	30.7	0.004	0.15
2000	392	359	15.7	0.004	0.12	472	426	23.5	0.003	0.14	551	490	31.7	0.003	0.16
2001	407	375	16.3	0.000	0.12	494	448	24.3	0.000	0.15	580	519	32.7	0.000	0.17
2002	426	394	16.9	0.000	0.13	520	473	25.2	0.000	0.16	613	550	33.7	0.000	0.18
2003	444	411	17.6	0.000	0.13	545	497	26.1	0.000	0.16	646	581	34.7	0.000	0.19
2004	461	428	18.1	0.000	0.14	569	520	26.9	0.000	0.17	678	612	35.6	0.000	0.20
2005	478	444	18.7	0.000	0.14	593	542	27.7	0.000	0.18	710	642	36.4	0.000	0.21

Table 8. Sensitivity analysis over a range of M, h, and transect survey q and CV.

h	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.5	0.5	0.5
M	0.045	0.055	0.065	0.045	0.055	0.065	0.045	0.055	0.065	0.045	0.055	0.065	0.055	0.055	0.055
visual *q*	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.75	0.75
CV on visual *q*	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.75	0.5	0.75
likelihood value															
total	13.12	13.501	14.27	13.258	13.91	15.12	13.41	14.43	15.87	13.65	14.88	16.74	13.1	13.43	12.85
cpfv CPUE	10.59	11.208	12.61	10.92	12.27	13.94	11.52	13.24	15.08	12.13	14.08	16.11	12.16	12.23	12.15
visual transect	0.5	0.456	0.31	0.466	0.311	0.195	0.376	0.222	0.09	0.286	0.11	0.07	0.08	0.22	0.058
priors	2.02	1.82	1.24	1.82	1.3	0.98	1.5	0.97	0.6	1.2	0.68	0.5	0.85	0.97	0.64
derived quantity															
virgin spawn bio	3288	3103	2976	3208	3046	2917	3163	3008	2878	3135	2980	2853	3041	3045	3040
ending spawn bio	446	464	556	475	546	684	541.4	644	774	593	742	892	535	564	534
2005spwnbio/unfished	0.14	0.15	0.19	0.15	0.18	0.23	0.17	0.21	0.27	0.19	0.25	0.31	0.18	0.19	0.18
est visual q	1.7	1.67	1.53	1.69	1.4	1.2	1.53	1.25	1.07	1.37	1.14	0.94	1.61	1.49	1.64

Table 9. Projections of OY (40-10 adjusted catch), age-1 biomass and depletion levels (40-10 adjusted)

	h=0.4			h=0.5			h=0.6		
year	Catch (t) age-1+ biomass depletion (t)			Catch (t) age-1+ biomass depletion (t)			Catch (t) age-1+ biomass depletion (t)		
2007	7.3	509	0.15	12.2	640	0.19	17.0	773	0.23
2008	7.8	518	0.15	12.9	651	0.20	17.9	788	0.24
2009	8.2	525	0.16	13.5	661	0.20	18.7	802	0.24
2010	8.6	531	0.16	14.1	671	0.20	19.5	815	0.24
2011	9.0	537	0.16	14.7	680	0.20	20.2	828	0.25
2012	9.3	543	0.16	15.2	688	0.20	20.9	840	0.25
2013	9.7	548	0.16	15.6	696	0.21	21.6	852	0.25
2014	10.0	553	0.16	16.1	705	0.21	22.2	864	0.26
2015	10.2	558	0.16	16.5	713	0.21	22.7	875	0.26
2016	10.5	562	0.17	16.9	721	0.21	23.3	887	0.26
2017	10.7	567	0.17	17.3	729	0.22	23.8	898	0.27

Table 9 continued. Projections of ABC, age-1 biomass and depletion levels (not 40-10 adjusted)

	H=0.4			H=0.5			H=0.6		
	Catch (t)	age-1 biomass	depletion	Catch (t)	age-1 biomass	depletion	Catch (t)	age-1 biomass	depletion
2007	15.8	509	0.15	19.1	639	0.19	22.3	773	0.23
2008	16.1	509	0.15	19.6	644	0.19	23.0	783	0.24
2009	16.4	508	0.15	20.0	647	0.19	23.6	792	0.24
2010	16.6	507	0.15	20.4	651	0.19	24.2	801	0.24
2011	16.7	505	0.15	20.7	654	0.19	24.7	809	0.24
2012	16.8	504	0.15	20.9	657	0.19	25.1	817	0.24
2013	16.9	502	0.15	21.1	660	0.20	25.5	825	0.25
2014	16.9	500	0.15	21.3	663	0.20	25.8	833	0.25
2015	16.9	499	0.15	21.4	666	0.20	26.2	841	0.25
2016	16.8	498	0.15	21.6	670	0.20	26.5	850	0.25
2017	16.8	497	0.15	21.7	674	0.20	26.7	858	0.25

Table 10

Table of estimated age 1+ biomass and depletion levels assuming 3 states of nature (h) and harvest (OY) predicted by those states of nature.

			State of nature: Catch used in the model with					
Management options:			Low resilience H=0.4 Prob=0.3		Medium resilience H=0.5 Prob=0.4		High resilience H=0.6 Prob=0.3	
Catch derived from:	Year	catch(t)						
Low resilience H=0.4	2007	7.3	509	0.15	639	0.19	773	0.23
	2008	7.8	518	0.15	655	0.20	798	0.24
	2009	8.2	525	0.16	670	0.20	821	0.25
	2010	8.6	531	0.16	685	0.21	845	0.25
	2011	9.0	537	0.16	699	0.21	868	0.26
	2012	9.3	543	0.16	713	0.21	891	0.27
	2013	9.7	548	0.16	727	0.22	914	0.27
	2014	10.0	553	0.16	741	0.22	936	0.28
	2015	10.2	558	0.16	754	0.22	959	0.29
	2016	10.5	562	0.17	768	0.23	982	0.30
Medium resilience H=0.5	2007	12.2	**509**	**0.15**	640	0.19	773	0.23
	2008	12.9	**512**	**0.15**	651	0.20	793	0.24
	2009	13.5	**515**	**0.15**	661	0.20	812	0.24
	2010	14.1	**516**	**0.15**	671	0.20	831	0.25
	2011	14.7	**517**	**0.15**	680	0.20	849	0.25
	2012	15.2	**517**	**0.15**	688	0.20	866	0.26
	2013	15.6	**517**	**0.15**	696	0.21	883	0.26
	2014	16.1	**516**	**0.15**	705	0.21	900	0.27
	2015	16.5	**516**	**0.15**	713	0.21	918	0.27
	2016	16.9	**515**	**0.15**	721	0.21	935	0.28
High resilience H=0.6	2007	17.0	**509**	**0.15**	639	0.19	773	0.23
	2008	17.9	**508**	**0.15**	646	0.19	788	0.24
	2009	18.7	**505**	**0.15**	651	0.19	802	0.24
	2010	19.5	**502**	**0.15**	656	0.20	815	0.24
	2011	20.2	**497**	**0.15**	659	0.20	828	0.25
	2012	20.9	**492**	**0.14**	663	0.20	840	0.25
	2013	21.6	**487**	**0.14**	666	0.20	852	0.25
	2014	22.2	**481**	**0.14**	668	0.20	864	0.26
	2015	22.7	**475**	**0.14**	671	0.20	875	0.26
	2016	23.3	**468**	**0.14**	673	0.20	887	0.26

Table 11 Rebuilding and Reference parameters

Model Rebuilding param	H=0.4	h=0.5	h=0.6
SPB0 (SPR*R0) (t)	3101	3045	3007
B40% (PFMC proxy) (t)	1241	1218	1203
Mean Generation (years)	39	39	39
Exploitation rate (%) At F50%SPR (Yield/biomass)	0.033	0.033	0.033
2005 Depletion (2005 spwn biom/ virgin spwn biom)	0.14	0.18	0.21

Figure 1 Map of Pacific West Coast showing state, INPFC

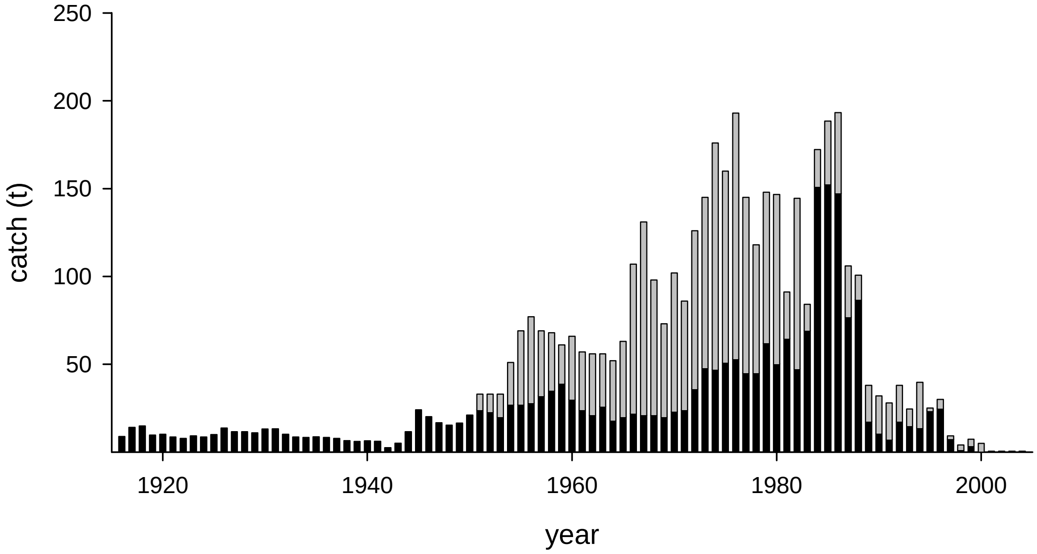


Figure 2. The landing of cowcod in the Southern California Bight in the recreational and commercial fleets. Black bars are commercial and grey bars recreational catches.

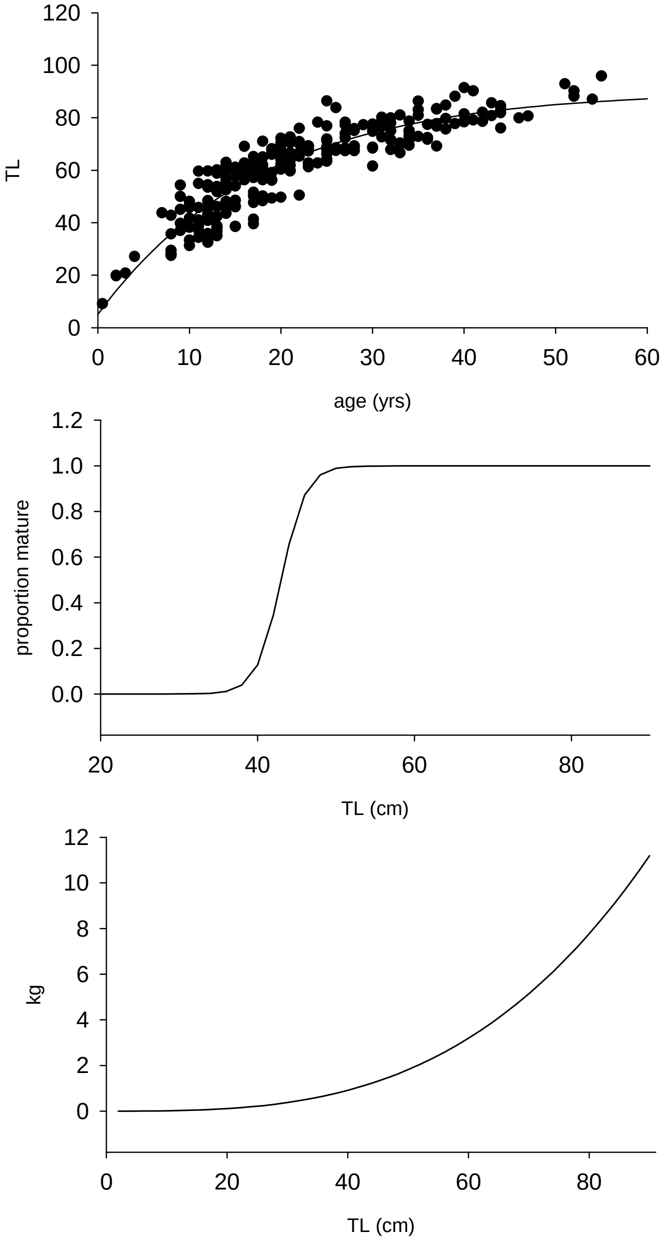


Figure 3. The length-at-age, maturity ogive and length weight relationships used in the cowcod stock assessment.

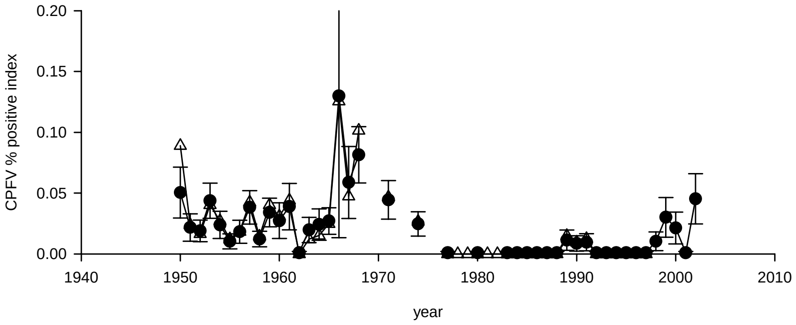


Figure 4. The proportion of tows estimated to be positive in the CalCOFI survey (1951-2003). New estimates are given with filled symbols and the previous assessments estimates are depicted with open symbols.

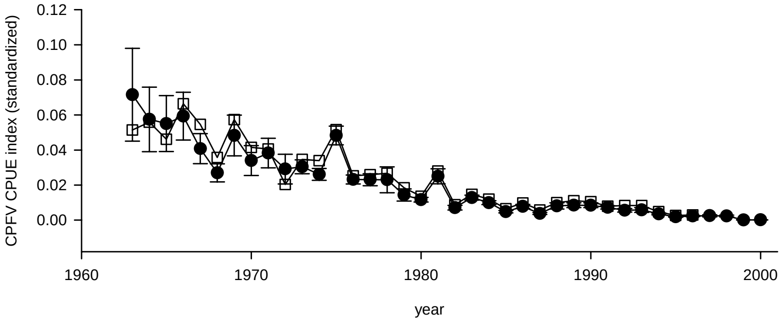


Figure 5. Estimate of the CPUE of the California Passanger Fishing Vessles 1961-2000. New estimates (●) are plotted against the estimates from the previous assesment (☐).

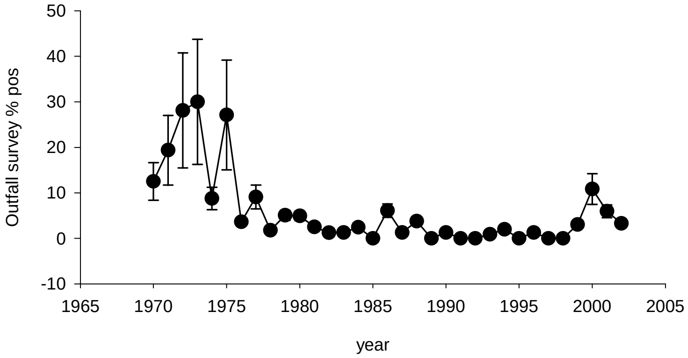
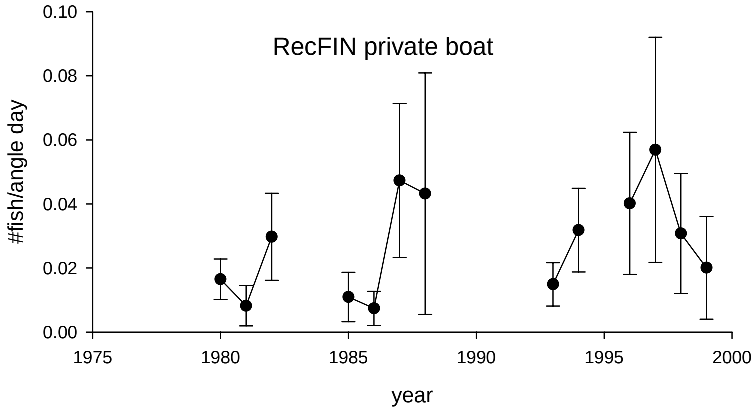


Figure 6. The arithmetic estimate of the precentage of Las Angeles and Orange County Sanitation department tows that were positive 1973-2002.



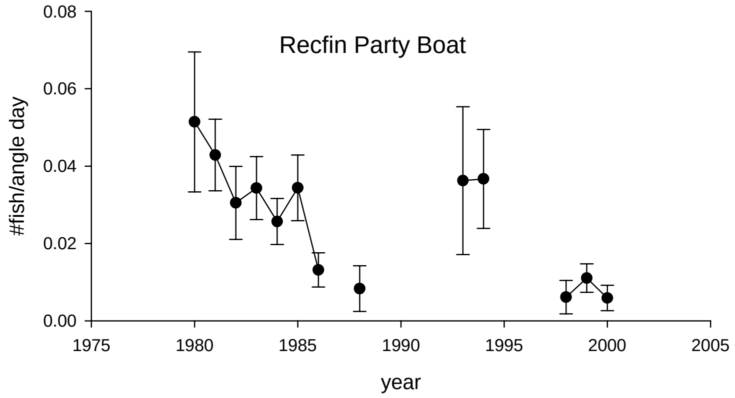


Figure 7. Recreation CPUE series derived from the RecFIN database (1980-2000) for both the private boat and party boat (CPFV) fleets. Error bars are 1 SE.

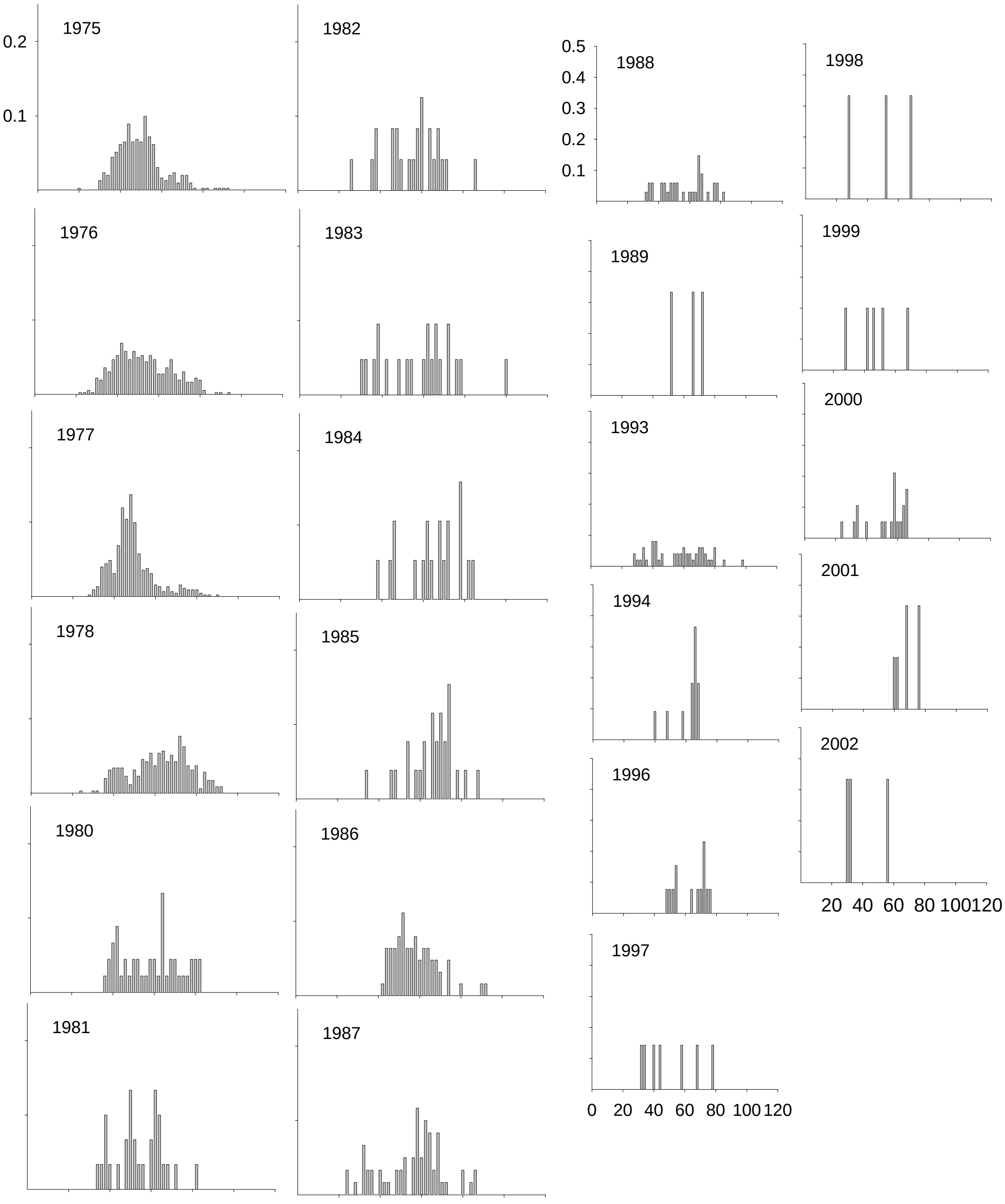


Figure 8. Length composition of cowcod in the recreational fleet operating in the Southern California Bight 1975-present. Missing years indicated no samples.

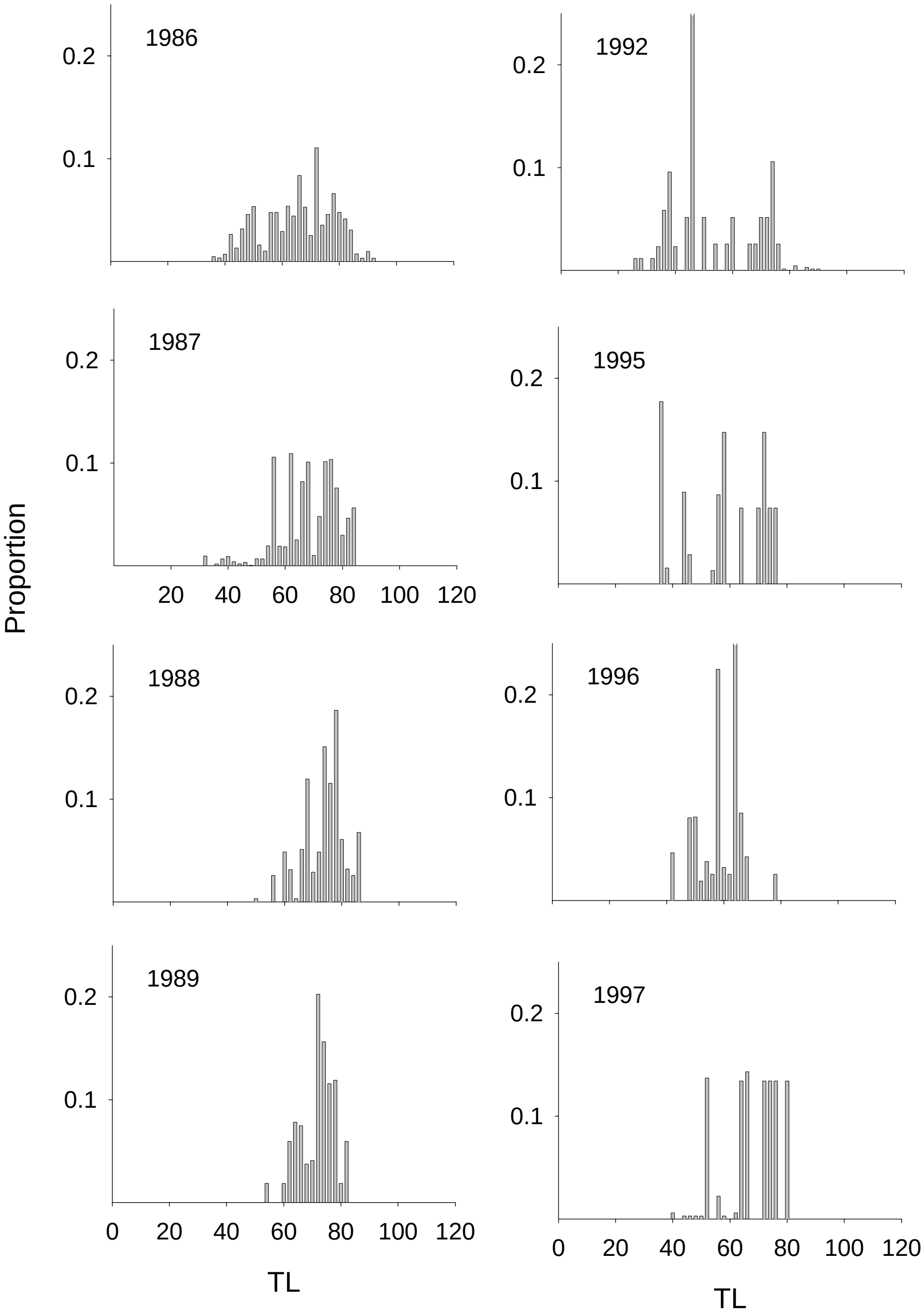


Figure 9. The length compositon of the cowcod catch in the commercial fisheries in the Southern California Bight 1986- present. Many years have no sample information.

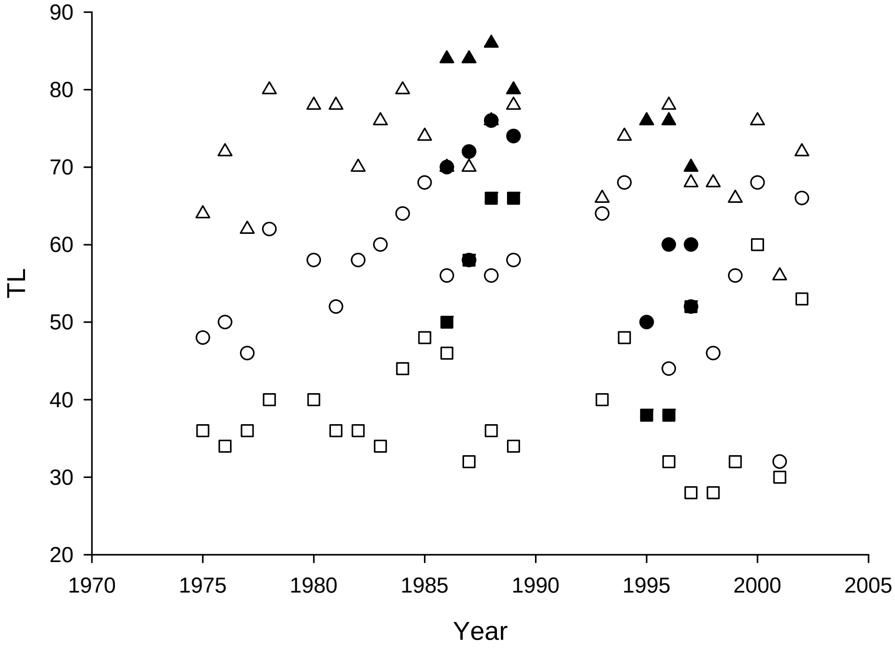


Figure 10. The percentiles (10th, 50th and 90th) of the length distribution for commercial and recreational proportion at length data. Open symbols depict recreational data, and filled the commercial. Squares represent the 10th percentile, circles the 50th and triangles the 90th.

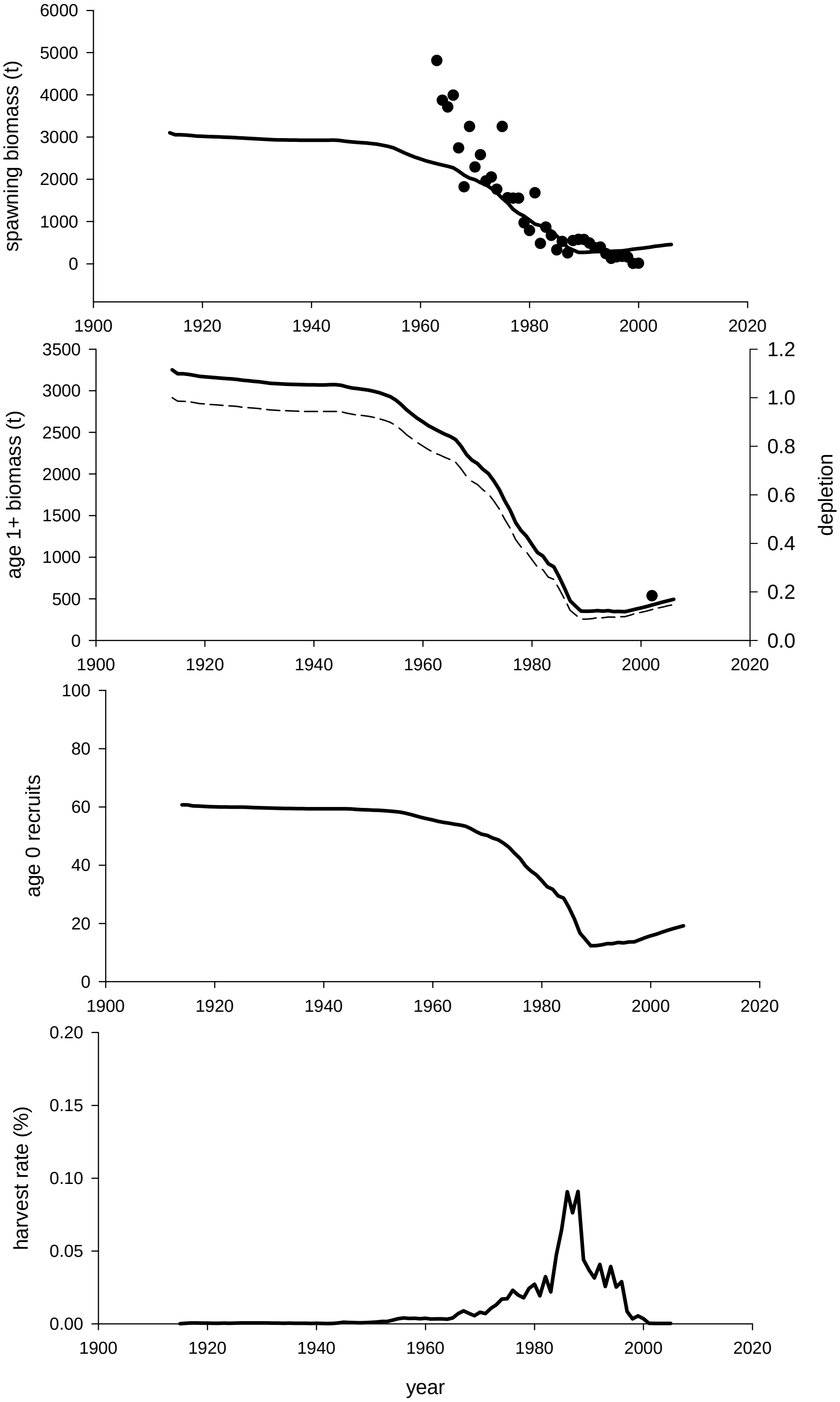


Figure 11 h=0.4.
Upper panel depicts spawning biomass (solid line) and estimated CPFV CPUE (circles) q adjusted. The second panel depicts age 1+ biomass (solid line) and q adjusted estimate of the visual transect survey (circle). Depletion level is given by the dashed line and corresponds to the right axis. The 3rd panel depicts age 0 recruitment. The 4th panel depicts the harvest rate.

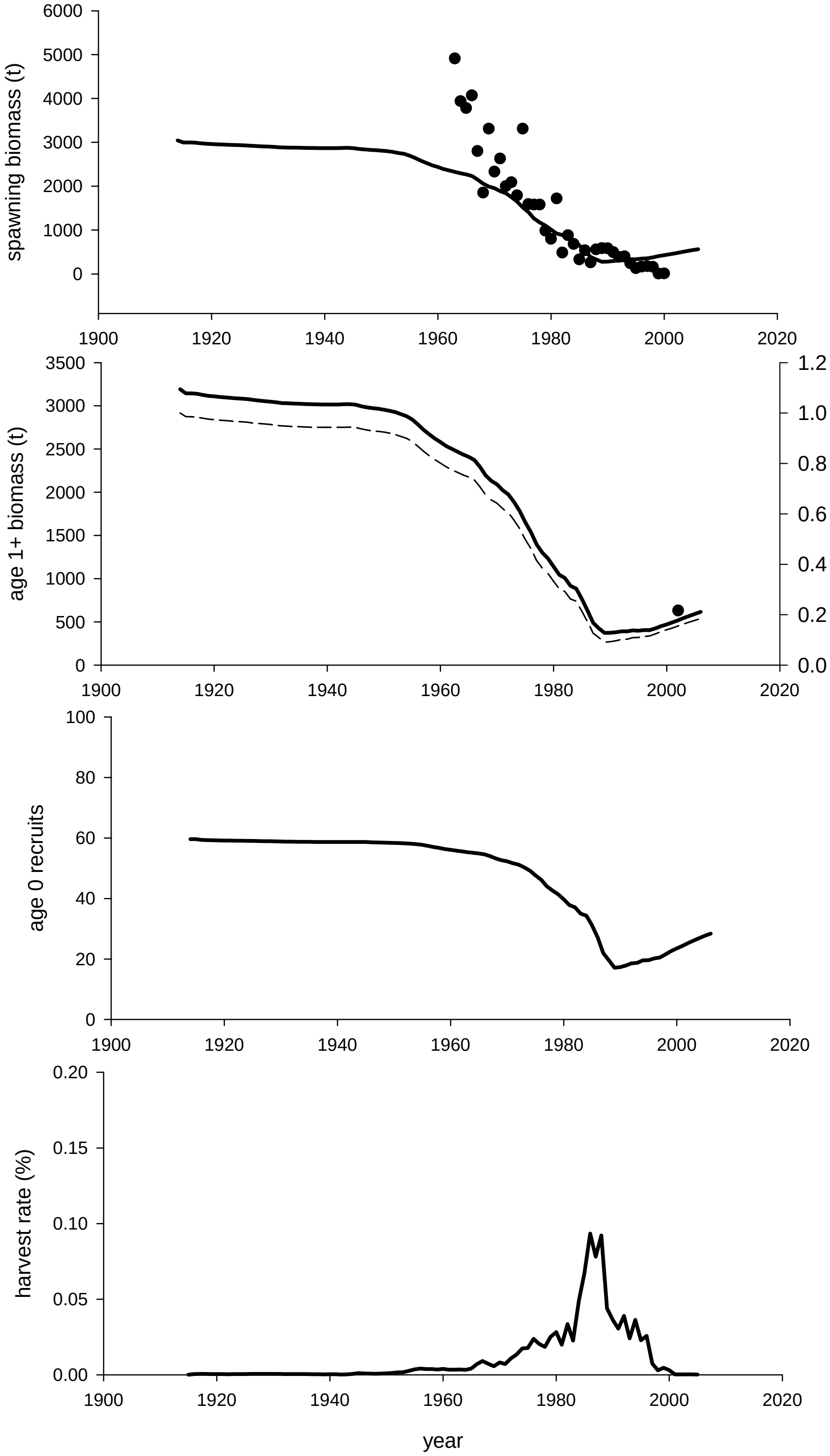


Figure 12 h=0.5.

Upper panel depicts spawning biomass (solid line) and estimated CPFV CPUE (circles) q adjusted. The second panel depicts age 1+ biomass (solid line) and q adjusted estimate of the visual transect survey (circle). Depletion level is given by the dashed line and corresponds to the right axis. The 3rd panel depicts age 0 recruitment. The 4th panel depicts the harvest rate.

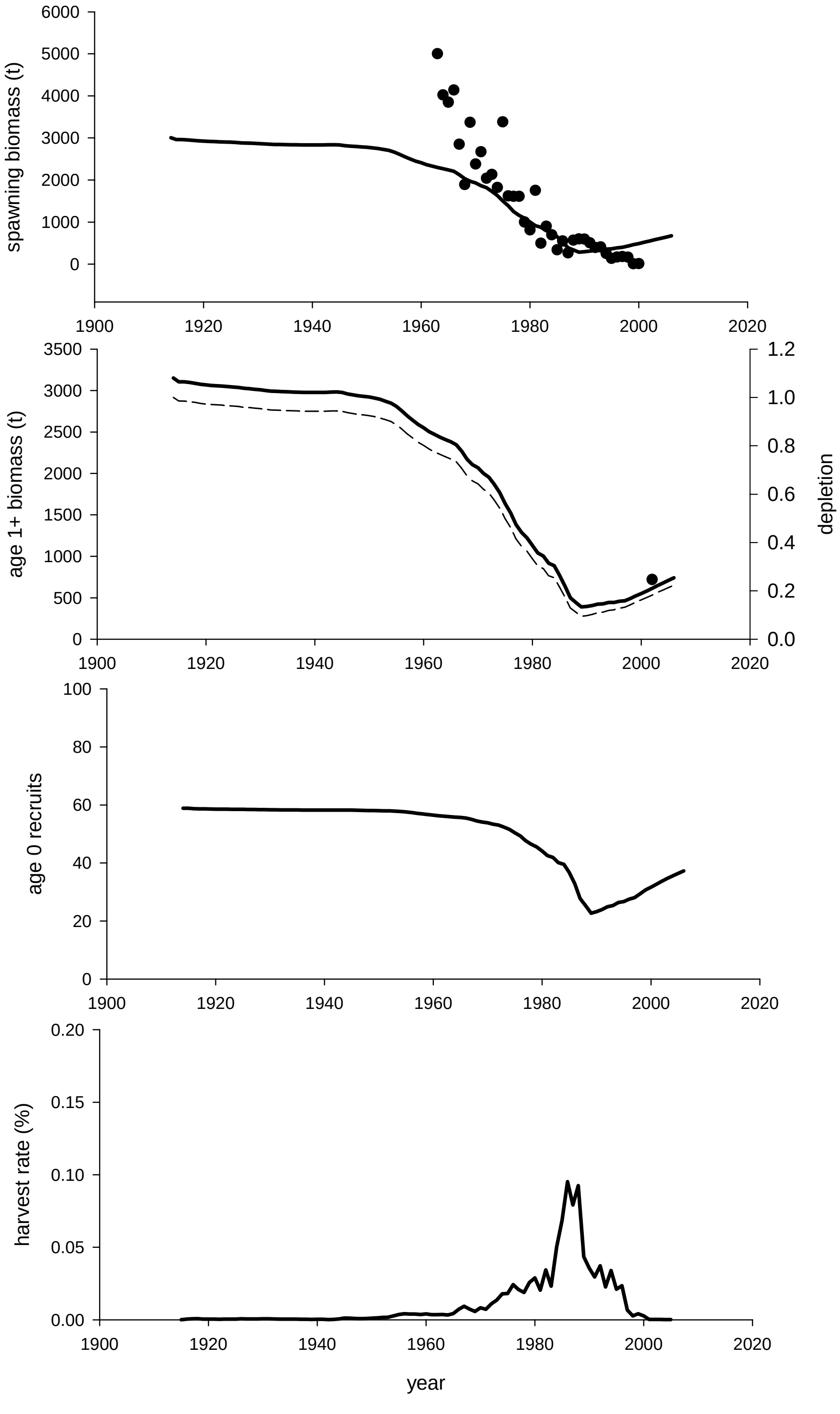


Figure 13 h=0.6.
Upper panel depicts spawning biomass (solid line) and estimated CPFV CPUE (circles) q adjusted. The second panel depicts age 1+ biomass (solid line) and q adjusted estimate of the visual transect survey (circle). Depletion level is given by the dashed line and corresponds to the right axis. The 3rd panel depicts age 0 recruitment. The 4th panel depicts the harvest rate.

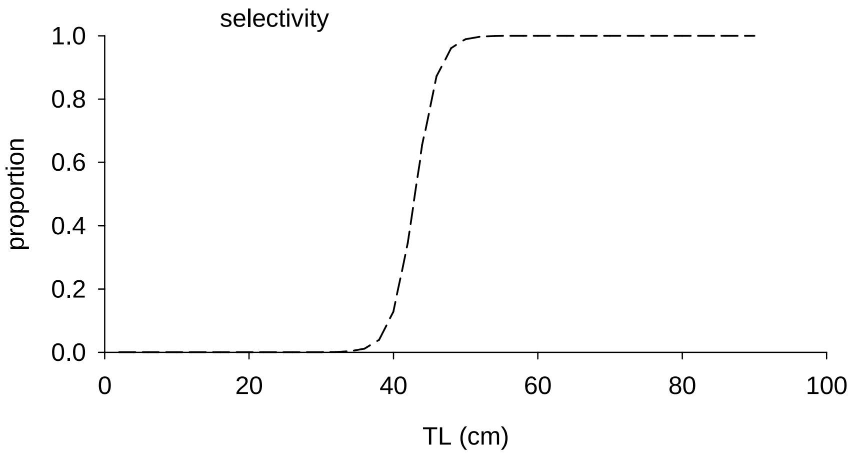


Figure 14. The selectivity ogive from base case (same as female maturity).

Appendix 1

Updated ASSESSMENT- Delay Difference Model

This reanalysis of the previous assessment method was designed to address the same two questions as the previous assessment. What is the current spawning biomass relative to historical or virgin levels? Is recruitment sufficient to maintain current catches? Furthermore a third question was addressed. Has the re-analysis of the times series (cpue series, CalCOFI, outfall, and catch) substantially changed the assessment results. This section of the assessment document is included to act as a bridge between the previous assessment model and the modeling presented in the next section. We do not intend for this modeling to be the basis for management decisions, but will base our recommendations on the SS2 assessment models. In this section, we show with the use of the previous model the effects of the new years of data on the population assessment method used previously. The exact same model formulation given by Butler et al. 1999 was used, and the description of the model as well as the ADMB code taken directly from Butler et al. (1999) is given in appendix 1.

Three data sources were used in this modeling effort. The CalCOFI (1951-2003) time series was used as an index of relative abundance of the fishable/spawning biomass. The CPFV CPUE series (1963-2000) was used as an index of relative abundance of the fishable/spawning biomass. The fishable biomass was made up of fish 40cm FL and larger. The 40 cm (FL) size was chosen as it approximates the knife edge cutoff between mature and immature fish. The Outfall survey was a recruitment index (1973-1998), with a seven year lag before recruiting to the fishable biomass. Individual recruitments (post 1950) were estimated as a random walk process.

The model for cowcod was broken in into two time periods. The "recent" period in the model was 1951-2005 and included all years with abundance information for cowcod (CalCOFI data begins in 1951). The "historical" period was 1916-1951 and included the year with catch but no abundance data.

The assessment model for cowcod rockfish was a C++ program (calculations in double precision arithmetic) implemented using AD-Model Builder (Otter Software Ltd.). Parameters were estimated from the Hessian and the delta method by AD Model Builder's AutoDIF library routines.

Model Results

The first step in the analysis was to check if our use of the new data analysis (not including data post 1998) within the same dynamic model produced different results from the 1998 assessment (Butler et al. 1998). Comparison of spawning biomass trajectories show similarities but that the new catch data (~10% higher 1990-1998) scales the biomass trajectory higher (Appendix Figure 1). When we sequentially add in only one piece of data (new meaning new catch or new index method up to 1998), there is very little change with the ending ratio of spawning biomass/ unfished biomass ranging from 7-10% (Appendix Figure 1) which is nearly identical to the original assessment.

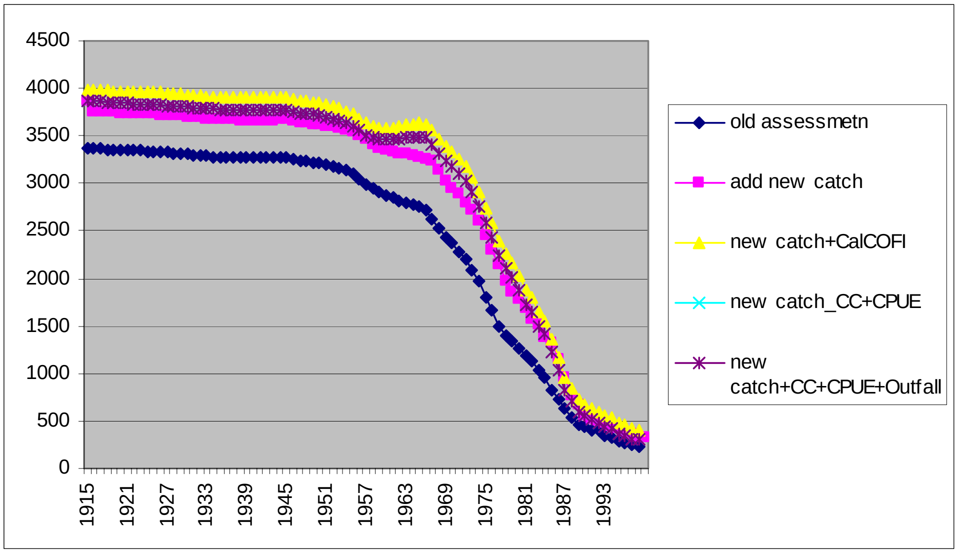
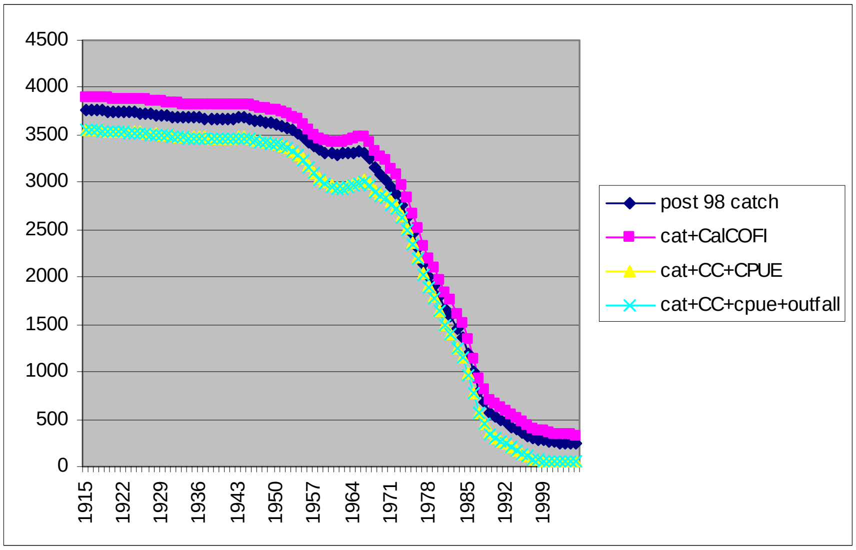


Figure Appendix 1. The timeseries of fishable/spawning abundance from the DD model that covered the time period 1915-1998. Each series incorporates the updated or new analysis of information used in the previous assessment. Example new catch+ CalCOFi indicates that the model was run with the 2005 estimates of catch (1916-1997) and includes estimates of the reanalysis of the CalCOFI survey (1951-1997).

Satisfied that the assessment model and data analysis up to 1998 are essentially the same as the previous assessment (with the exception of catch) we sequentially updated each time series through the most recent data point (Figure Appendix 2). The results of the update of the previous assessment indicated that the population is approximately 1.5 % of unfished with a spawning biomass near 50mt in the SCB. This is somewhat less than reported in 1998, but does not indicate further decline relative to the 1998 spawning biomass. The population has been stable to increasing since 1998 to present, which is to be expected as fishery removals have been largely eliminated. The smaller ratio of ending to unfished spawning biomass is a result of 3 low CPUE points at the end of the timeseries and the inability of the assessment model to incorporate potentially larger recruitment events towards the end of the time series. Also this assessment significantly downweights the CalCOFI series post 1980, thus the positive change in this series is largely ignored. The small changes between this assessment and the previous one are likely within the substantial noise of the data and we believe that the view of the population has not been changed from the last assessment, and that it is too early to monitor significant population change with this model. We do believe, however that the assessment is likely underestimating cowcod abundance in the most recent time period. Abundance of 50 t seems unlikely and the model results of a fully age-structured analysis that indicates that the population is likely larger.



Appendix Figure 2. The timeseries of fishable/spawning abundance from the DD model that covered the time period 1915-2005. Each series incorporates the updated or new analysis of information used in the previous assessment. Example new catch+ CalCOFi indicates that the model was run with the 2005 estimates of catch (1916-2005) and includes estimates of the reanalysis of the CalCOFI survey (1951-2003).

Description of the delay difference model used by Butler et al. (1999)

Population Dynamics

Population dynamics calculations in the assessment model used Schnute's (1985) delay-difference equation:

$$B_{t+1} = (1 + p) L_t B_t - p L_t L_{t-1} B_{t-1} + R_{t+1} - p L_t J R_t.$$

where B_t was fishable (not total, see below) cowcod biomass in the SCB at the beginning of year t; p was Ford's growth coefficient (see below); $L_t=\exp(-Z_t)=\exp[-(F_t+M_t)]$ was the fraction of the stock that survived in year t; Z_t, F_t, and M_t were instantaneous rates for total, fishing and natural mortality; and R_t was the biomass of recruits at the beginning of year t. The term $J = w_{k-1} / w_k$ was the ratio of mean weight one year before recruitment (age k-1) and mean weight at recruitment (age k). Fishing mortality rates (F_t) were calculated from catch data and biomass based on Baranov's catch equation and Sim's (1982) algorithm.

Ford's growth model:

$$w_a = w_{k-1} + (w_k - w_{k-1}) (1 + p^{1+a-k}) / (1-p)$$

is mathematically the same as von Bertalanffy's more familiar growth model $\{W_a = W_{max} [1 - \exp(-K(a-t_{zero})]$ where W_{max}, K and t_{zero} are parameters$\}$. The Ford and Von Bertalanffy equations are the same (Schnute 1985) because $W_{max} = (w_k - p\, w_{k-1})/(1-p)$, $K = -\ln(p)$ and $t_{zero} = \ln[(w_k - w_{k-1})/(w_k - p\, w_{k-1})] / \ln(p)$.

There was too little information (i.e. no age composition data) to estimate year-to-year variation in recruitment as a series of independent annual recruitment parameters but, as described below, recruitment probably changed over time and trends in recruitment are important for cowcod. As described below, recruitment to the fishable stock in our model is made up of many age groups and, like a weighted average, probably relatively smooth and consistent from year to year with extended periods of either higher or lower than average values. We chose an autocorrelated random walk approach to model annual recruitment variation for cowcod that accommodates these features:

$$R_t = \mathrm{P}e^{\Omega_t}$$

where P was average recruitment and Ω_t was the sum of annual log-scale recruitment deviations ω_i:

$$\Omega_t = \sum_{i=1950}^{t} \omega_i$$

Recruitment deviations ω_i were defined such that their sum (and average) over the whole time series (1950-1998) was zero.

The delay-difference model gives the same results as more complicated age structured models if recruitment to stock is "knife-edged" at age k and occurs at the beginning of the year, natural mortality is the same for all age groups, and the Ford growth model holds. In Schnute's (1985) original description of the delay-difference model, knife-edged recruitment means that fish recruit to the fishery *en-masse* on their kth birthday so that total biomass B_t includes all fish age k and older. These assumptions hold to varying degrees for cowcod (see below) but Butler et al. (1999) believed the data were insufficient to support a more complex and realistic model.

Assumptions about knife-edged recruitment could be relaxed in the model for for cowcod because it tracks fishable biomass, rather than total biomass. Fishable biomass is the portion of total stock biomass that is fully vulnerable to fishing mortality. This has an important implications related to interpreting selectivity patterns and interpreting model results. Firstly, recruitment in any year to the fishable stock includes cowcod of many ages. The actual age of recruiting fish and selectivity at age is irrelevant. It is not necessary to specify body weights at and prior to recruitment (parameters v and V in Schnute 1985), although it is necessary to specify the growth parameter J, which is a ratio of weights. They report that their approach reduces problems in specifying fishery selectivities at the cost of measuring fishable biomass *in lieu* of total biomass. See Butler et al. (1999) for more details.

Historical Calculations

Preliminary model runs, like the abundance data, all showed declining trends in SCB cowcod abundance but two distinctly different hypotheses explained the data almost equally well (see below). Under the "high initial biomass/low recruitment" hypothesis, the SCB cowcod stock was initially at a very high level and declined because average recruitment was very low (in extreme scenarios, even lower than losses to natural mortality). Under the alternative "lower initial biomass/higher fishing mortality" scenario, the cowcod stock was at a lower initial abundance level, recruitment was higher and the stock declined because catches exceeded recruitment (in extreme cases catch and recruitment were almost equal and the stock was composed almost entirely of new recruits). The purpose of historical calculations was to help choose between these alternate extreme hypotheses.

The purpose of historical calculations was to identify a plausible model, develop a picture of trends in the cowcod stock during historical years (1916-1950), and provide a way for managers to compare current stock size to the virgin condition. Historical biomass calculations use average recruitment to estimate a "near virgin" biomass level (see below) in the SCB during 1916. Near-virgin biomass is fished down during the historical period (based on historical catches) to a biomass level at the beginning of the recent period (1951) and trend that matches abundance data for the recent period. Thus, average recruitment from the model and historical catch data are the links used to choose a model with plausible near-virgin, historical and recent biomass estimates. Historical calculations are based on Stock Reduction Analysis (Kimura and Tagart 1982; Kimura et al. 1984; Kimura 1985). Butler et al.(1998) used a similar idea for blackgill rockfish (*S. melanostomus*).

Model runs covering the historical period (1916-1950) assumed a constant level of average recruitment prior to 1951 (R_{hist}) that was estimated (by constraint, see below) in the model. Constant recruitment was assumed during the historical period because there was no historical abundance information to use in estimating recruitment trends.

The first step in historical modeling was to calculate virgin biomass for SCB cowcod as equilibrium biomass from the delay-difference equation given constant historical recruitment R_{hist} and no fishing. The second step was to calculate near-virgin biomass as the equilibrium biomass given constant recruitment R_{hist} and a constant level of historical fishing mortality F_{hist}. Near virgin biomass was a crude proxy for B_{1916} (cowcod biomass in the first year with catch data) and used to start the delay-difference model for the historical period. F_{hist} was set at a low level based on preliminary runs and inspection of trends in catch after 1916. The third step was to use estimates of near virgin biomass (B_{1916}), recruitment (R_{hist}) and catch data in the delay difference model to calculate biomass and fishing mortality during the historical period, 1916-1951. As described below, a constraint was used to make sure biomass estimates from historical and recent calculations for 1951 agreed and to link the two series of estimates.

Parameters From Auxiliary Data

The natural mortality rate (M) in for cowcod was assumed to be the same for all ages and years in the model. We used a range of values for M (0.04-0.07 y^{-1}) for sensitivity analysis and the mid-range value 0.055 y^{-1} for basecase runs to accommodate uncertainty about this important parameter. The range used for modeling was lower than the range of total mortality rate estimates (0.055-0.087 y^{-1}, see above) because the latter included some fishing mortality.

We used $p=e^{-K}=0.994$ where $K=0.00605\ y^{-1}$ was the von Bertalanffy growth parameter for round weight and sexes combined (see above).

For modeling, we assumed recruitment to the fishable stock in the SCB at about 40 cm FL or about 10 years of age (age estimate based on the Von Bertalanffy growth curves). As described above, age at recruitment is not very important in our model but the assumed size at recruitment might be because it effects calculation of a growth parameter J. Length composition data show that cowcod begin to recruit to commercial fishing gear used in SCB (set nets and hook-and-line gear) at about 30 to 40 cm FL or about 6-10 years of age (Figure 13). Length frequency data for CPFV trips (Figure 27) shows recruitment beginning at about 30 cm FL or about 6 years of age. Limited age composition data from the SCB shows recruitment to commercial and recreational fisheries at about 6-15 years of age. We calculated $J_k=w_{k-1}/w_k$ for ages k=6-15 years based on the von Bertalanffy model (see below). For base case runs, we used J=0.811 (corresponding to k=10, the midpoint of the range). Sensitivity analysis (see below) was used to determine how this affected results.

Age at Recruitment (k)	$J=w_{k-1}/w_k$
6	0.179
10	0.811
15	0.905

Parameter Estimation and Tuning

The assessment model for cowcod included process and observation parameters. Process parameters control population dynamics and biomass calculations. Observation parameters are used to statistically compare trends in model results with trends in data. Process parameters estimated in the delay-difference model for cowcod were for recruitment (P and ω_t) and initial biomass (B_{1951}). Runs covering the historical period also estimated a parameter for average historical recruitment biomass (R_{hist}) and included an assumed equilibrium fishing mortality before 1916 (F_{hist}). Other process parameters (e.g. for growth and natural mortality) were estimated outside the assessment model. There were 53 parameters to estimate when the model was run with recent years only and 54 parameters to estimate when the model was run with historical years turned on. Most (49) were process parameters for recruitments during the recent period.

We tuned the assessment model for cowcod in the SCB to three abundance indices: 1) CPUE from CPFV logs; 2) CalCOFI proportion positive; and 3) LA&OCSD proportion positive tows (proportion positive bottom trawl tows). CPFV and CalCOFI data were assumed to measure relative abundance of the total fishable/spawning stock. As described above, these abundance indices were for SCB cowcod.

LA&OCSD data were used as a recruitment index for cowcod. Recruitment to the fishable stock starts at about age ten (see above) so comparisons between data and model predictions were lagged by 10-3=7 years. For example, we compared recruitment of three-year-old cowcod in 1980 with model estimates of recruitment in 1987. LA&OCSD data were particularly important because they gave information about future recruitment. For example, data for 1993-1994 contain information about recruitment to the fishable stock in the years 2000-2001.

Predicted values for abundance indices were calculated:

$$\hat{I}_{K,t} = Q_K B_t$$

where $I_{K,t}$ is abundance index kind K (either CPUE in units of fish h^{-1} or CalCOFI and LACSD in units of proportion) for year t, hats "^" denote model estimates, and Q_K is an observation parameter that converts from units of biomass to units of the abundance index.

Goodness-of-fit for observed and predicted CPUE data was computed assuming log-normal measurement errors and the negative log-likelihood:

$$L_{CPUE} = 0.05 \sum_{I=1}^{N_{CPUE}} Ln\left(\frac{I_{CPUE}}{\hat{I}_{CPUE}}\right)^2$$

where N_{CPUE} was the number of observations.

Goodness of fit for proportions (CalCOFI and LACSD data) assumed binomial measurement errors. For example, the negative log-likelihood for CalCOFI of data was:

$$L_{CalCOFI} = -\lambda_{CalCOFI} \left\{ \sum_{i=1}^{N_{CalCOFI}} \left[I_{CalCOFI,i} \ln\left(\hat{I}_{CalCOFI,i} \right) + \left(1 - I_{CalCOFI,i} \right) \ln\left(1 - \hat{I}_{CalCOFI,i} \right) \right] - A \right\}$$

where A $_{\text{CalCOFI}}$ was a constant (see below), λ_{CalCOFI} was an assumed "effective" sample size (see below), and observed and predicted index values were proportions. In effect, the effective sample size was used as a weighting factor that determined how much emphasis was placed on CalCOFI data in the model (relative to CPUE and LACSD data and constraints, see below) in estimation of parameters.

The constant for CalCOFI data was calculated:

$$A = \sum_{i=1}^{N_{CalCOFI}} D_i \left[I_{CalCOFI,i} \ln\left(I_{CalCOFI,i} \right) + \left(1 - I_{CalCOFI,i} \right) \ln\left(1 - I_{CalCOFI,i} \right) \right]$$

where the dummy variable D_i is one if $0 < I_{\text{CalCOFI},i} < 1$ and zero otherwise. The constant depends only on the data (not the fit) and is the minimum possible log-likelihood (if observed and predicted values match exactly). It has no effect on biomass estimates but makes the adjusted log-likelihood (scaled likelihood) easier to interpret, plot and understand (Methot 1989).

For simplicity, effective sample size was assumed constant for CalCOFI data during 1951-1986. Effective sample size for CalCOFI data during 1987-1998 was also constant but set at one-third the value for 1951-1986 to accommodate reductions in CalCOFI sampling effort (Hewitt 1988). Effective sample size for LA&OCSD data was constant in all years. We assumed that precision of the CalCOFI and LA&OCSD data as indices of abundance for cowcod would be less than expected based on sample size and and sampling theory (see below). This often occurs when binomial or multinomial proportions are used to monitor biological characteristics of fish stocks (e.g. age composition of catches) and sample size is large (Fournier and Archibald 1982).

As described above, effective sample sizes were set manually to single values in our model. Reasonable choices for effective sample size were approximated from the variance of residuals in a preliminary model run (Methot 1989). This "iterative re-weighting" approach was repeated once or twice until assumed and calculated values were roughly equal. For example, the expected variance of a predicted CalCOFI value based on standard formulas for proportions and n tows is:

$$Var(\hat{p}) = \frac{\hat{p}(1-\hat{p})}{\lambda_y}$$

so that:

$$\lambda_y = \frac{\hat{p}_y(1-\hat{p}_y)}{Var(p_y)}$$

The variance $Var(p_y)$ of residuals in one year was calculated by using another, equivalent, standard formula:

$$Var\left(p_y\right)=\frac{\{(p_y-\hat{p}_y)^2+[(1-p_y)-(1-\hat{p}_y)]^2\}}{n-1}=2(p_y-\hat{p}_y)^2$$

To estimate an effective sample size for the time series as a whole, we calculated the geometric mean (roughly equal to the median) of the effective sample sizes for each year:

$$\lambda = e^{\Lambda}$$

where Λ was the average $\log(\lambda_y)$ value.

Recruitment deviations were penalized based on changes between successive time steps:

$$L_{\omega}=\sum_{y=1951}^{1998}\left[\frac{\left(\omega_y-\omega_{y-1}\right)}{\sigma}\right]^2$$

where $\sigma=0.5$ was an assumed standard deviation.

Likelihood components used to penalize model fits with absurdly high fishing mortality rates were calculated:

$$L_{F1}=0.5\sum_{y=1916}^{y=1950}\left(F_y-3\right)^2$$

if Fy ≥3, zero otherwise

$$L_{F2}=0.5\sum_{y=1951}^{y=1998}\left(F_y-3\right)^2$$

if Fy ≥3, zero otherwise

Penalties on high F values were not important for cowcod and always zero except in sensitivity analysis with vary low biomass levels.

The constraint used to make recent and historical recruitment calculations agree was calculated:

$$L_{HB}=0.5\left(b_{1951}-B_{1951}\right)^2$$

where b_{1951} and B_{1951} were estimates of cowcod biomass from historical and recent calculations. Choice of average recruitment for historical calculations is important. For example, if R_{hist} was fixed at some very large value, then b_{1951} and B_{1951} would probably be too large.

The constraint used to estimate historical recruitment was:

$$L_{HR} = 0.5\left(R_{hist} - \mu\right)^2$$

where μ was the average of recruitments for a user-specified range of years during the recent model period. It would have been possible to set $R_{hist}=\mu$ without using a constraint and in practice, R_{hist} and μ were usually equal. However, the constraint adds some flexibility because the model was able estimate R_{hist} values slightly different from μ to achieve a better bit between b_{1951} and B_{1951} without distorting fit to abundance data in recent years. In addition, the constraint contributes a degree of uncertainty that was captured in variance calculations. This is a topic for future research.

After diagnostic and sensitivity runs based results for recent years only, we turned historical years on and made decisions about historical fishing mortality rates (F_{hist}) and years to use in calculating the constraint for historical recruitment (R_{hist}). The decisions, based on intermediate model runs and the data, were subjective but reasonable. The goal was to develop a set of historical and recent estimates that were plausible.

Population dynamics and observation parameters estimated in the model were chosen to minimize the total negative log-likelihood:

$$\Xi = \lambda_{CPUE} L_{CPUE} + \lambda_{CalCOFI} L_{CalCOFI} + \lambda_{LA\ \&\ OCSD} L_{LA\ \&\ OCSD} + \lambda_{\omega} L_{\omega} + \lambda_{F1} L_{F1} + \lambda_{F2} L_{F2} + L_{HIST}$$

where the λ's were weighting factors (usually one). L_{HIST} was the negative log-likelihood for historical calculations:

$$L_{HIST} = \lambda_{HB} L_{HB} + \lambda_{HR} L_{HR}$$

with weighting factors zero except in runs including historical biomass calculations.

Appendix II.

GMT Tables Based upon the h=0.5 model (model deemed most probable).

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Total Catch	25	30	9	4	7	5	0.5	0.5	0.5	0.5	0.5
Discards (assumed)											
Landings	25	30	9	4	7	5					
ABC						5	5	5	5	5	5
OY* (if different from ABC)						2	2	2	2	2	2
F or SPR (specify which)											
Exploitation Rate	0.023	0.026	0.007	0.003	0.005	0.003	0.000	0.000	0.000	0.000	0.000
Summary Age Biomass (B) at the beginning of the year	397	405	406	426	451	472	494	520	545	569	593
Spawning Stock Biomass (*SB*) at the beginning of the year – include uncertainty estimates	333	346	353	378	405	426	448	473	497	520	542
(CV)	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.11
Recruitment at the beginning of the year - include uncertainty estimates	20	20	22	23	23	24	25	26	27	28	20
(CV)	0.10	0.10	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.07	0.10
Depletion level at the beginning of the year - include uncertainty estimates	0.11	0.11	0.12	0.12	0.13	0.14	0.15	0.16	0.16	0.17	0.18

Summary GMT Table based upon the h=0.5 model.

	Estimates including uncertainty when possible
Unfished Spawning Stock Biomass (SB_0)	3044.6
Unfished Summary Age Biomass (B_0)	3191
Unfished Recruitment (R_0)	59.6
Spawning Stock Biomass at MSY (SB_{msy})	1218
Basis for SB_{msy} (i.e $SB_{40\%}$proxy)	SB40% proxy
SPR_{msy} or F_{msy} (specify which)	SPRmsy
Basis for SPR_{msy} or F_{msy} (i.e. $F_{40\%}$ proxy)	$F_{50\%SPR}$
Exploitation Rate corresponding to SPR_{msy} or F_{msy} (if available)	0.033
MSY	N/A

Appendix III. data and control file for cowcod h=0.5

Data file

```
1916 #start year
2006 # end year
1
 12
1 #_spawn_seas
1 #_Nfleet
4 #_Nsurv
fishery1%survey1%survey2%survey3%survey4
 0.5 0.5 0.5 0.5 0.5#_surveytiming_in_season
1 #_Ngenders
80 #_Nages
 2 #_init_equil_catch_for_each_fishery
#_catch_biomass(mtons):_columns_are_fisheries,_rows_are_year*season
 8.8
14.06
14.9
9.7
10.19
8.61
7.8
9.21
8.58
9.92
13.64
11.56
11.61
10.92
13.071
13.16
10.19
8.66
8.32
8.73
8.32
7.76
6.57
6.02
6.45
6.16
2.57
4.99
11.61
24.03
20.19
16.7
15.29
16.48
21.14
24.45
32.52
33.6
50.31
69.04
76.39
69.43
68.06
61.19
66.07
56.53
55.96
55.92
51.64
63
107.01
130.77
97.72
72.78
```

```
102.15
85.97
125.84
145.36
175.91
160.54
193.87
144.9
117.64
147.66
147
91
144
84
172
188
193
106
101
38
32
28
38
24
39
25
30
9
4
7
5
0.5
0.5
0.5
0.5
0.5
0.5

117 # numb survey points followed by survey data
1951    1    2    5      0.8292
1952    1    2    2.2    1.041
1953    1    2    1.9    0.9348
1954    1    2    4.4    0.6616
1955    1    2    2.4    0.9408
1956    1    2    1      1.1892
1957    1    2    1.8    1.036
1958    1    2    3.8    0.7178
1959    1    2    1.2    1.0376
1960    1    2    3.4    0.6912
1961    1    2    2.7    1.0778
1962    1    2    3.9    0.9824
1963    1    2    0.1    2.0336
1964    1    2    2      1.0568
1965    1    2    2.4    1.0686
1966    1    2    2.7    0.8064
1967    1    2    13     1.795
1968    1    2    5.9    1.006
1969    1    2    8.1    0.5684
1972    1    2    4.4    0.7144
1975    1    2    2.5    0.81
1980    1    2    0.1    2.0184
1981    1    2    0.1    2.0218
1984    1    2    0.1    2.0244
1985    1    2    0.1    2.0428
1986    1    2    0.1    2.0424
1987    1    2    0.1    2.045
1988    1    2    0.1    2.043
1989    1    2    0.1    2.0442
1990    1    2    1.1    1.4808
1991    1    2    0.9    1.469
```

1992	1	2	1	1.474
1993	1	2	0.1	2.0422
1994	1	2	0.1	2.038
1995	1	2	0.1	2.046
1996	1	2	0.1	2.0406
1997	1	2	0.1	2.0412
1998	1	2	0.1	2.0438
1999	1	2	1.04	1.478
2000	1	2	3.01	1.0828
2001	1	2	2.13	1.233
2002	1	2	0.1	2.0394
2003	1	2	4.53	0.913
1963	1	3	0.071542523	1.953799094
1964	1	3	0.05748274	1.689772189
1965	1	3	0.055060397	1.531356046
1966	1	3	0.059308434	1.214523761
1967	1	3	0.040768441	1.108912999
1968	1	3	0.027003596	1.003302237
1969	1	3	0.04826441	1.267329142
1970	1	3	0.03402068	1.320134523
1971	1	3	0.038283529	1.16171838
1972	1	3	0.029175205	1.531356046
1973	1	3	0.030455837	0.686469952
1974	1	3	0.026091295	0.686469952
1975	1	3	0.048316544	0.58085919
1976	1	3	0.023169089	0.58085919
1977	1	3	0.023090242	0.792080714
1978	1	3	0.02303154	1.689772189
1979	1	3	0.014366307	1.267329142
1980	1	3	0.011653262	0.58085919
1981	1	3	0.025012452	0.897691475
1982	1	3	0.007082721	1.003302237
1983	1	3	0.012855708	0.58085919
1984	1	3	0.009958842	0.58085919
1985	1	3	0.00483127	0.739275333
1986	1	3	0.007827743	0.792080714
1987	1	3	0.003787855	0.792080714
1988	1	3	0.008125175	1.16171838
1989	1	3	0.008527088	0.844886095
1990	1	3	0.008491133	0.844886095
1991	1	3	0.007241093	0.686469952
1992	1	3	0.005605051	0.950496856
1993	1	3	0.005826603	1.267329142
1994	1	3	0.003572569	0.739275333
1995	1	3	0.001900544	0.686469952
1996	1	3	0.002393212	0.686469952
1997	1	3	0.002533181	1.214523761
1998	1	3	0.002349113	1.16171838
1999	1	3	8.97E-05	1.372939904
2000	1	3	0.000148018	2.059409856
1970	1	4	12.5	2.285371046
1971	1	4	19.35483871	2.73011929
1972	1	4	28.125	3.106940109
1973	1	4	30	3.166703009
1974	1	4	8.771929825	1.9548323
1975	1	4	27.11864407	3.072132161
1976	1	4	3.636363636	1.29356403
1977	1	4	9.090909091	1.986575168
1978	1	4	1.785714286	0.915147308
1979	1	4	5.063291139	1.515064857
1980	1	4	4.938271605	1.497228298
1981	1	4	2.5	1.078872194
1982	1	4	1.234567901	0.763058197
1983	1	4	1.25	0.767752511
1984	1	4	2.43902439	1.065967165
1985	1	4	0.1	1.52026875
1986	1	4	6.097560976	1.653538081
1987	1	4	1.25	0.767752511
1988	1	4	3.75	1.312845714
1989	1	4	0.1	1.52026875

```
1990      1         4         1.25                0.767752511
1991      1         4         0.1                 1.52026875
1992      1         4         0.1                 1.52026875
1993      1         4         0.892857143         0.650041607
1994      1         4         2                   0.96744375
1995      1         4         0.1                 1.52026875
1996      1         4         1.25                0.767752511
1997      1         4         0.1                 1.52026875
1998      1         4         0.1                 1.52026875
1999      1         4         3.03030303          1.184564567
2000      1         4         10.84337349         2.148605632
2001      1         4         5.952380952         1.634996959
2002      1         4         3.296703297         1.233838337
2003      1         4         5.128205128         1.521949855
2004      1         4         1.282051282         0.77624685
2002      1         5         940                 0.25


1
0

0
-1
0.0001

46 # len bins followed by begin of bin
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 100

26        #N_observations


#Year     Seas      Fleet     sexes     Mkt       Nsamp     begin     data:     females   then      males



1975      1         1         0         0         76        0         0         0         0         0         0.003436426
          0         0         0         0         0.013745704         0.024054983         0.020618557         0.04467354
          0.051546392         0.06185567          0.065292096         0.089347079         0.065292096         0.068728522
          0.065292096         0.099656357         0.072164948         0.06185567          0.030927835         0.017182131
          0.013745704         0.020618557         0.024054983         0.010309278         0.020618557         0.020618557
          0.010309278         0.003436426         0         0.003436426         0.003436426         0         0.003436426
          0.003436426         0.003436426         0.003436426         0         0         0         0
1976      1         1         0         0         120       0         0         0         0         0         0
          0.002754821         0.002754821         0.005509642         0.002754821         0.022038567         0.019283747
          0.035812672         0.03030303          0.046831956         0.052341598         0.068870523         0.05785124
          0.046831956         0.05785124          0.049586777         0.052341598         0.044077135         0.052341598
          0.046831956         0.027548209         0.027548209         0.035812672         0.046831956         0.027548209
          0.019283747         0.03030303          0.016528926         0.016528926         0.022038567         0.019283747
          0.005509642         0         0         0.002754821         0.002754821         0         0.002754821         0
          0         0
1977      1         1         0         0         73        0         0         0         0         0         0         0
          0         0         0.002207506         0.008830022         0.013245033         0.039735099         0.04415011
          0.048565121         0.030905077         0.068432671         0.119205298         0.103752759         0.136865342
          0.099337748         0.057395143         0.035320088         0.037527594         0.030905077         0.015452539
          0.013245033         0.006622517         0.013245033         0.006622517         0.004415011         0.015452539
          0.011037528         0.008830022         0.008830022         0.008830022         0.004415011         0.002207506
          0.002207506         0         0.002207506         0         0         0         0         0
1978      1         1         0         0         66        0         0         0         0         0         0         0
          0.002824859         0         0         0.002824859         0.002824859         0         0.019774011
          0.031073446         0.033898305         0.033898305         0.033898305         0.02259887          0.011299435
          0.031073446         0.02259887          0.04519774          0.042372881         0.053672316         0.036723164
          0.053672316         0.056497175         0.042372881         0.050847458         0.042372881         0.076271186
          0.062146893         0.036723164         0.031073446         0.036723164         0.005649718         0.028248588
          0.016949153         0.016949153         0.008474576         0.008474576         0         0         0         0
1980      1         1         0         0         10        0         0         0         0         0         0         0
          0         0         0         0         0         0         0.022222222         0.044444444         0.066666667
          0.088888889         0.022222222         0.044444444         0.022222222         0.044444444         0.044444444
          0.022222222         0.022222222         0.044444444         0.044444444         0.022222222         0.133333333
          0.022222222         0.044444444         0.044444444         0.022222222         0.022222222         0.022222222
```

```
	0.044444444	0.044444444	0.044444444	0	0	0	0	0	0
	0	0	0
1981	1	1	0	0	12	0	0	0	0	0	0	0
	0	0	0	0	0.033333333	0.033333333	0.1	0.033333333
	0	0.033333333	0	0.066666667	0.133333333	0.066666667	0.033333333
	0.033333333	0	0.066666667	0.133333333	0.1	0.033333333	0.033333333
	0	0.033333333	0	0	0	0	0.033333333	0	0	0
	0	0	0	0	0	0
1982	1	1	0	0	10	0	0	0	0	0	0	0
	0	0.041666667	0	0	0	0	0.041666667	0.083333333	0
	0	0	0.083333333	0.083333333	0.041666667	0	0.041666667
	0.041666667	0.083333333	0.125	0	0.083333333	0.041666667	0.083333333
	0.041666667	0.041666667	0	0	0	0	0	0	0.041666667
	0	0	0	0	0	0	0
1983	1	1	0	0	6	0	0	0	0	0	0	0
	0	0	0	0.047619048	0.047619048	0	0.047619048	0.095238095
	0	0.047619048	0	0	0.047619048	0	0.047619048	0.047619048
	0	0	0.047619048	0.095238095	0.047619048	0.095238095	0.047619048
	0	0.095238095	0	0.047619048	0.047619048	0	0	0	0
	0	0	0	0	0	0	0.047619048
1984	1	1	0	0	10	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0.052631579	0	0
	0.052631579	0.105263158	0	0	0	0	0.052631579	0
	0.052631579	0.105263158	0.052631579	0	0.105263158	0.052631579
	0.105263158	0	0	0.157894737	0	0.052631579	0.052631579	0
	0	0	0	0	0	0	0
1985	1	1	0	0	9	0	0	0	0	0	0	0
	0	0	0	0	0	0.038461538	0	0	0	0	0
	0.038461538	0.038461538	0	0	0.076923077	0	0.038461538
	0.038461538	0.076923077	0	0.115384615	0.076923077	0.115384615
	0.076923077	0.153846154	0	0.038461538	0	0.038461538	0	0
	0.038461538	0	0	0	0	0	0
1986	1	1	0	0	75	0	0	0	0	0	0	0
	0	0	0	0	0	0	0.003726109	0.002745554	0.005491107
	0.023975823	0.025107231	0.039423332	0.050013325	0.059673047	0.038789742
	0.022950011	0.051386102	0.055358606	0.03368583	0.056092765	0.048836659
	0.075065245	0.051728039	0.026967772	0.084327719	0.038392493	0.034907754
	0.050400521	0.040253034	0.031573867	0.023337206	0.005687218	0.002549443
	0.01122861	0.006325836	0	0	0	0
1987	1	1	0	0	54	0	0	0	0	0	0	0
	0.009169147	0	0.004584573	0	0.025235778	0.009169147	0.010376207
	0.004828239	0.015721757	0.007343567	0.00596407	0.002414119	0.009514021
	0.014169823	0.018581959	0.013967406	0.090315795	0.045886983	0.027203815
	0.106483635	0.041201201	0.068487511	0.0960362 0.011826932	0.039416869
	0.073458207	0.074837704	0.054835	0.030723785	0.033625236	0.045452168
	0.009169147	0	0	0	0	0	0	0
1988	1	1	0	0	38	0	0	0	0	0	0	0
	0	0	0	0	0.004063211	0.008126422	0.008126422	0	0
	0.008126422	0.008126422	0.004063211	0.008126422	0.010961167	0.008126422
	0	0.02620965	0	0.045964274	0.031259038	0.006897955	0.064431762
	0.115303454	0.024981183	0.045964274	0.13004389	0.107696812	0.168820984
	0.052442768	0.031613381	0.022146439	0.058378013	0	0	0	0
	0	0	0
1989	1	1	0	0	26	0	0	0	0	0	0	0
	0	0	0.012	0.006	0.006	0.018	0.006	0	0.024	0.024	0.006	0.012
	0	0	0	0.025101604	0.012	0.012	0.031101604	0.053644385
	0.066745989	0.058406417	0.038203209	0.046542781	0.159778075	0.121491979
	0.086949198	0.08928877	0.031101604	0.041644385	0	0.006	0	0
	0	0	0	0.006	0
1992	1	1	0	0	20	0	0	0	0	0	0	0
	0	0.011688095	0.011688095	0	0.011688095	0.02337619	0.058440474
	0.095842378	0.02337619	0	0.051427617	0.260310569	0	0.051427617
	0	0.025713809	0	0.025713809	0.051427617	0	0	0.025713809
	0.025713809	0.051427617	0.051427617	0.105860745	0.025713809	0.001502755
	0	0.004508265	0	0.00300551	0.001502755	0.001502755	0	0
	0	0	0
1993	1	1	0	0	3	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0.090909091	0	0
	0	0.090909091	0	0	0	0	0.090909091	0	0
```

```
        0.181818182     0.363636364     0.181818182     0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0
1994    1       1       0       0       6       0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0       0       0
        0.076923077     0.076923077     0.076923077     0.153846154     0       0       0       0
        0.076923077     0       0.076923077     0.076923077     0.230769231     0.076923077
        0.076923077     0       0       0       0       0       0       0       0       0       0
        0       0
1995    1       1       0       0       6       0       0       0       0       0       0       0
        0       0       0       0       0       0       0.177231565     0.015523933     0       0
        0.089262613     0.028460543     0       0       0       0.012936611     0.086675291
        0.147477361     0       0       0.07373868      0       0       0.07373868      0.147477361
        0.07373868      0.07373868      0       0       0       0       0       0       0       0
        0       0       0       0
1996    1       1       0       0       7       0       0       0       0       0       0       0
        0       0       0       0       0.142857143     0.142857143     0       0       0.142857143
        0       0.142857143     0       0       0       0       0       0       0.142857143     0
        0       0       0       0.142857143     0       0       0       0       0.142857143     0
        0       0       0       0       0       0       0       0       0       0
1997    1       1       0       0       10      0       0       0       0       0       0       0
        0       0       0.333333333     0       0       0       0       0       0       0       0
        0       0       0       0.333333333     0       0       0       0       0       0       0
        0.333333333     0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0       0
1998    1       1       0       0       5       0       0       0       0       0       0       0
        0       0       0.2     0       0       0       0       0       0       0.2     0       0.2
        0       0       0.2     0       0       0       0       0       0       0       0.2     0
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0
1999    1       1       0       0       7       0       0       0       0       0       0       0
        0.052631579     0       0       0       0.052631579     0.105263158     0       0
        0.052631579     0       0       0       0       0.052631579     0.052631579     0
        0.052631579     0.210526316     0.052631579     0.052631579     0.105263158     0.157894737
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0
2000    1       1       0       0       3       0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0       0       0.166666667     0.166666667     0       0
        0.333333333     0       0       0       0.333333333     0       0       0       0       0
        0       0       0       0       0       0       0
2001    1       1       0       0       2       0       0       0       0       0       0       0
        0       0       0       0.333333333     0.333333333     0       0       0       0       0
        0       0       0       0       0       0       0.333333333     0       0       0       0
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0       0
2002    1       1       0       0       3       0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0.333333333     0       0       0       0       0       0       0.333333333
        0       0       0.333333333     0       0       0       0       0       0       0       0
        0       0       0       0       0       0
1973    1       4       0       0       98      0.50310559      0.086956522     0.062111801
        0.093167702     0.062111801     0.055900621     0.043478261     0.037267081     0.037267081
        0.01242236      0       0       0       0.00621118      0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0       0       0
        0       0       0

36      #_N_age'_bins
        #_lower_age_of_age'_bins

1       2       3       4       5       6       7       8       9       10      11      12      13
        14      15      20      21      22      23      24      25      26      27      28      29
        30      35      40      45      50 55 60 65 70 75 80
0       #_number_of_ageerr_types
#_vector_with_stddev_of         ageing_precision_for_each_AGE_and_type
0       #_N_age_observations

#Year   Season  Fleet   Gender  Mkt     ageerr  Lbin_lo Lbin_hi Nsamp
0       #_N_size@age_observations;_values_on_row1;_N_on_row2
```

```
#Year     Season    Fleet     Gender    Mkt       ageerr    Nsamp
#_environmental_data

0         #         N_variables
0         #         N_observations
#_Year    Variable  Value
999       #end      of        file
```

Control File

```
# no length information
# visual survey treated as a relative index with prior
1         # num growth morphs
1         #assign sex to morph
1         #numb areas
1         1         1         1         1 #area for each fleet survey
0         #do migration
0         # numb blocks
# mortality and growth parms
1         #last age for nat mortality young
2         #first age for nat mortality old
1         #age lmin
75        #age lmax
-4        #MG parm dev phase
#mortality and growth
#         lo        hi        init      prior     pr_type   sd        phase env-var       use_dev   dvmnyr    dvmxyr    dvsddv
          block     blktype
          0.01      0.1       0.055     0.055     0         0.8       -3        0         0         0         0         0.5
          0         0         #M young
          0         0         0         0         0         0.8       -3        0         0         0         0         0.5
          0         0         #M old  as exp offset
          3         10        5         5         0         10        -3        0         0         0         0         0.5
          0         0         #Lmin
          80        99        90        90        0         0.8       -3        0         0         0         0         0.5
          0         0         #Lmax
          0.01      0.25      0.056     0.056     0         0.8       -3        0         0         0         0         0.5
          0         0         #vbk
          0.01      0.25      0.05      0.05      0         99        -4        0         0         0         0         0.5
          0         0         #cv lmin
          0         0.1       0         0         0         0.8       -3        0         0         0         0         0.5
          0         0         #cv old as offset
#len-wt and maturity
          -3        3         1.01E-05 1.01E-05 0  0.8      -3        0         0         0         0         0.5       0
          0         #wt len
          -3        3         3.093     3.093     0         0.8       -3        0         0         0         0         0.5
          0         0         # wt len2
          -3        3         43        43        0         0.8       -3        0         0         0         0         0.5
          0         0         #Maturity1
          -3        3         -.64      -.64      0         0.8       -3        0         0         0         0         0.5
          0         0         #Maturity 2
          0         1         1         1         0         0.8       -3        0         0         0         0         0.5
          0         0         #egg/gram
          0         1         0         0         0         0.8       -3        0         0         0         0         0.5
          0         0         #egg.gram slope
#pop*growth morph for the prop of each morph in each area
          0         1         1         1         0         0.8       -3        0         0         0         0         0.5
          0         0         # fraction morph 1 to area 1
#pop lines for the prop assigned to each area
          0         1         1         1         0         0.8       -3        0         0         0         0         0.5
          0         0         # fraction to area 1
# cust env read
0
#custom block read
0
# lo      hi         init     prior     prtype    sd        phase
#SR section
1         #1=beverton holt
#         lo        hi        init      prior     prtype    sd        phase
          1         31        3.8       3.8       0         1000      1         # Ln(R0)
          0.2       1         0.50      0.55      0         1000      -3        #Steepness
```

```
          0         2         0.4       0.9       0         1000      -3        #sd recruitments
          -5        5         0         0         0         1         -3        #env link
          -5        5         0         0         0         1         -3        #init_eq

0 #index of environ variable to be used
#         start_rec end_rec Lower       upper     phase
          2006      2005      -15       15        -3
#init_F
#         Lo        Hi        init      prior     prtype    sd        phase
          0         .2        0.0001 0.0001       0         1000      1
#Qsetup
#add param row for each positive entry below
#float    dopowe    doenv     dodev     envvar    numbio (1=biomass, 0=num)
0         0         0         0         0         1
1         0         0         0         0         0
1         0         0         0         0         0
1         0         0         0         0         1
1         0         0         0         0         1
#lo       hi        init      prior     prtype    sd        phase
-50       50        -5        -5        0         1000      1 # float est for calcofi
-50       50        -5        -5        0         1000      1 # float est for cpue
-50       50        -5        -5        0         1000      1 # float est for outfall
-50       50        -.274     -.274     0         0.5       1 # float est for visual
#selex and retention
#selextype doretention          do male             mirror
4         0         0         0         #fleet1
4         0         0         0         #survey1
4         0         0         0         #survey2
0         0         0         0         #survey3
0         0         0         0         #survey4
#age selex
10        0         0         0         #fleet 1
10        0         0         0         #survey2
10        0         0         0         #survey2
11        0         0         0         #survey4
10        0         0         0         #survey3
#LO       HI        INIT      PRIOR     PR_type   SD        PHASE     env-variable        use_dev   dev_minyr dev_maxyr
          dev_stddev          Block_Pattern
#40       95        90        90        0         1000      -3        0         0         0         0         0.5       0
          0         #peak
#0.0001   0.2       0.001     .001      0         1000      -2        0         0         0         0         0.5       0
          0         #init
#-10    5 1.1       1.1       0         1000      2         0         0         0         0         0.5       0         0
          #infl
#0.001     5        .1        .1        0         1000      3         0         0         0         0         0.5       0
          0         #slope
#-5       10        5         5         0         1000      -3        0         0         0         0         0.5       0
          0         #final
#-10.      5        4         4         0         1000      -4        0         0         0         0         0.5       0
          0         #infl2
#.001      5        0.09      0.09      0         1000      -5        0         0         0         0         0.5       0
          0         #slope2
#0.1      20        12        12        0         1000      -4        0         0         0         0         0.5       0
          0         #width of top
#1     14    1     1     0     25    -99   0     0     0     0     0.5   0     0     # fleet 2 start mirror low
#45    46    46    46    0     25    -99   0     0     0     0     0.5   0     0     #fleet 2 upper mirror
1         40        3         3         0         1000      -1        0         0         0         0         0.5       0
          0         #minage
1         40        3         3         0         1000      -1        0         0         0         0         0.5       0
          0         #maxage
# custom env read
0
#custom block read
0
-4        # phase for selex parms dev
1 #max lambda phases
0 # include (1) or not (0) the constant offset for Logs(s) in the Log(like) calculation
# survey lambdas
1         0.0001    1         0.0001    1
# discard lambdas
```

```
0       0       0       0       0
# mean body wt
0
#lenfreq lambda
0       0       0       0       0
#age freq lambda
0       0       0       0       0
# size at age
0       0       0       0       0
#init equlib catch
1
#rec lambda
1
#parm prior lambda
1
#prior dev timeseries lambda
0
#crashpen lambda
100
#max F
.9999
999
```

Appendix IV. Expansion using CPFV

An expansion factor for the abundance of cowcod (*Sebastes levis*) in the Cowcod Conservation Areas, based on estimates of habitat availability and recreational catch rates.

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April 2005

Introduction

We develop an expansion factor for an estimate of cowcod abundance (Yoklavich et al., in press) in the Cowcod Conservation Areas (CCA), for use in the estimation of stock abundance in the Southern California Bight (U.S. waters south of Point Conception). The approach described in this document incorporates two primary sources of data: 1) logbook data from commercial passenger fishing vessels (CPFVs) and 2) area estimates of benthic habitat for cowcod in the region.

Several sources of uncertainty exist for these data, some of which are unknown or can only be approximated. In addition, cowcod are relatively rare in the logbook data, with the vast majority of trips reporting no catch for this species. To obtain estimates of relative abundance inside and outside the CCA, we estimate the spatial distribution of catch rates (densities) using generalized linear models (GLMs), and then multiply density by the area of available cowcod habitat, which is calculated using Geographic Information System (GIS) software and maps of substrate types.

Data and Methods

Recreational (CPFV) Logbook Data

The California Department of Fish and Game (CDFG) provided us with logbook data for the recreational fishery from 1980-2000. Data from previous years were not included since trip-specific information is unavailable, and the expansion factor should be derived from the state of the stock in recent years. Data from recent years were excluded due to the establishment of the CCA in 2001, which makes comparison of catch rates inside and outside the conservation area inappropriate. In 2000, a bag limit of 1 cowcod and 10 rockfish per landing took effect for recreational anglers in California, whereas in previous years cowcod were included in a 15-rockfish bag limit. To examine the effect of this bag limit on catch rates, we used data from RecFIN (http://www.psmfc.org/recfin/forms/bfreq.html) on the number of cowcod per angler bag over the time period 1980-2000.

As in the previous assessment (Butler et al., 2002), only data from CDFG fishing blocks south of Point Conception and inside U.S. waters were retained (blocks 651-897), excluding blocks 600, 699, 700, 799, and 800, which represent data of uncertain location. To standardize the trips considered in our analysis, trips lasting less than 1 hour (0.02% of records) or greater than 12 hours (‘multi-day’ trips; <1% of total) were removed. Records with zero anglers or more than 60 anglers on a trip were also removed, which accounted for less than 5% of the total records.

The logbook data contained individual records for each species caught, from which we defined trip-specific records as unique combinations of boat, day, month and year. The use of trip-specific records allowed us to examine the composition of catch on a given trip, which in turn provides information on whether a given trip should be considered fishing effort for cowcod. For each trip, we retained information on the catch of 30 species in addition to cowcod. These species were selected because they were relatively common in the historical CPFV database for southern California, or because they indicate trips that should be excluded from the analysis (e.g. benthic invertebrates suggest a dive trip). The presence or absence of each species in a given trip was then used as a binary predictor (‘dummy’ variable) in a multiple logistic regression model, with presence or absence of cowcod catch as the response variable (Stephens and MacCall, 2004). This model estimates, for each trip, the probability of catching a cowcod given the other species that were caught. Trips with low probabilities are those that target species that do not co-occur with cowcod (e.g. tuna trips), and trips with high probabilities are actual fishing effort for cowcod. The decision on which trips to include (a ‘cut-off’ probability) is based on the premise that including all trips increases the variance of the estimates by introducing ‘noise’ (trips targeting other species) into the data, while excluding too many trips increases the variance by reducing sample size. We selected a cut-off point by conducting a sensitivity analysis of the mean CV for block effects in the delta-GLM index of abundance (described below), selecting the cut-off probability that minimized the average CV.

To examine the spatial distribution of catch rates (CPUE) in the SCB, we used a delta-GLM model of relative abundance (Stefansson, 1996). This method is useful for modeling catch rates when there are a large number of records with zero catch. The quantity of interest for this analysis is CPUE per CDFG block. The probability, π_i, of catching a cowcod in block *i* was estimated using a binomial GLM with a probit link function

$$\Phi^{-1}(\pi_i) = \mathbf{x}_i^T \boldsymbol{\beta}$$

where Φ^{-1} is the inverse of the cumulative standard normal distribution function. The probit link was selected over a logit link based on the Bayesian Information Criterion (see Results, Table 3a). The mean CPUE for block *i*, given that a trip caught a cowcod, was modeled as

$$\log(CPUE_i) = \mathbf{x}_i^T \boldsymbol{\beta} + \varepsilon_i$$

where $\varepsilon_i \sim N(0, \sigma^2)$ and β is a vector of regression coefficients. The mean CPUE (μ_i) for block *i*, given that a cowcod was caught, was calculated by exponentiation with a bias correction term ($\sigma^2/2$). The delta-GLM index of relative abundance is the product of the back-transformed block effects from the two models.

Model selection was based on residual analyses and the Bayesian Information Criterion (BIC). Due to computational limitations, years were combined into 4 ‘group.year’ categories to permit investigation of interactions terms.

Standard errors for block effects were estimated using a jackknife routine. If we symbolize the delta-GLM function by $\hat{\theta} = \hat{\theta}(X_1, \cdots, X_n)$, for n observations, and let

$$\hat{\theta}_{(i)} = \hat{\theta}(X_1, \cdots, X_{i-1}, X_{i+1}, \cdots, X_n),$$

then the 'jackknife mean' is simply $\hat{\theta}_{(\bullet)} = \sum_{i=1}^{n} \frac{\hat{\theta}_{(i)}}{n}$

and the jackknife estimate of standard error is defined as

$$\hat{\sigma}_J = \left[\frac{n-1}{n} \sum_{i=1}^{n} (\hat{\theta}_{(i)} - \hat{\theta}_{(\bullet)})^2 \right]^{1/2}.$$

Habitat Data

Area estimates of suitable habitat for cowcod were calculated using GIS software (ArcView 3.2a). Digital maps ('shapefiles') of benthic habitat types were obtained from the Pacific Coast Groundfish Essential Fish Habitat Project (TerraLogic GIS, NMFS and PSMFC), which also included bathymetry data. CDFG provided spatial data for blocks and the perimeters of the CCA. Mary Yoklavich provided shapefiles of the submersible survey area as illustrated in Yoklavich et al. (in press).

Habitat types in the Pacific Coast Groundfish Essential Fish Habitat (EFH) data are a generalized version of the data used to define the submersible survey area (Gary Greene, pers. comm.), but this was the only available habitat data that covered the entire SCB. We defined cowcod habitat as those habitat types in the EFH data that intersected the Yoklavich et al. survey area and fell within the approximate depths of the survey (75-300 m). Bathymetry data that were readily available and in the necessary format (polygon shapefiles) were in 10-meter increments. Therefore this analysis is based on cowcod habitat defined as suitable substrate types within the 70-300 meter depth contours.

The habitat types in the EFH data which intersected the survey area maps from Yoklavich et al. are "rocky ridge," "rocky shelf," "rocky slope," "sedimentary ridge," "sedimentary shelf" and "sedimentary slope." Since the relative densities of cowcod for these habitat classifications are unknown, we estimated the area of cowcod habitat in a given block as the sum of all habitat types. The highest densities of adult cowcod reported in Yoklavich et al. were for "43-fathom Bank" (inside the Eastern CCA). The EFH data classifies this general area as "sedimentary ridge."

Expansion Factor, Catchability Coefficient and Variance Estimator

The expansion factor is defined as the ratio $\frac{\text{cowcod abundance in SCB}}{\text{cowcod abundance in CCA}}$.

Since the unit of spatial resolution for catch rates is CDFG fishing block, it is necessary to classify each block as 'inside' or 'outside' the CCA. A block that crosses the conservation area boundary is classified as 'inside' if the majority of cowcod habitat in that block falls within the CCA (see Results). This assumes that fishing only occurs the in areas defined as cowcod habitat.

Abundances inside and outside the CCA were estimated as

$$N_{Inside} = \sum_{i=1}^{n} (CPUE_i)(H_i) \qquad \text{and} \qquad N_{Outside} = \sum_{j=1}^{m} (CPUE_j)(H_j) \tag{1}$$

where $CPUE$ is the estimated catch rate for a given block, H is the area (km^2) of cowcod habitat in a block, n is the number of blocks classified as inside the CCA, and m is the number of blocks classified as outside the CCA.

The expansion factor is therefore

$$R = \frac{N_{Inside} + N_{Outside}}{N_{Inside}} = 1 + \frac{N_{Outside}}{N_{Inside}} \tag{2}$$

Assuming no error in the area estimates and independence of the block effects in the delta-GLM model, the variance for abundance inside the CCA (and similarly for abundance outside) is

$$Var\{N_{Inside}\} = \sum_{i=1}^{n} Var\{CPUE_i\}(H_i)^2 \tag{3}$$

where $Var\{CPUE_i\}$ is estimated by the jackknife routine for the delta-GLM index.

We used the delta method (Rice, 1995) to approximate the variance of the ratio $N_{Outside}/N_{Inside}$, which equals $Var\{R\}$. Let $X = N_{Inside}$, $Y = N_{Outside}$, and $Z = Y / X$. Then

$$Var\{Z\} \approx \frac{1}{\mu_X^2}\left(\sigma_X^2 \frac{\mu_Y^2}{\mu_X^2} + \sigma_Y^2 - 2\rho\sigma_X\sigma_Y \frac{\mu_Y}{\mu_X} \right) \tag{4}$$

Our estimate of $Var\{R\}$ assumes that $\rho = 0$. Positive or negative correlations in abundance would decrease or increase the variance, respectively. If instead we wish to treat the expansion factor as a catchability coefficient (q), our expansion factor becomes

$$q = \frac{N_{Inside}}{N_{Inside} + N_{Outside}} \tag{5}$$

The variances for inside and outside can again be estimated as in equation 3, and the delta method can approximate the variance of the ratio, as in equation 4.

Results and Discussion

The bag frequency analysis from RecFIN (Table 1) suggests that the bag limit change for cowcod in 2000 should not have a significant effect on catch rates. While this provides an additional year of data, using the expansion factor still assumes no change in relative abundance inside versus outside the CCA between 2000 and 2003, the latter being the year of the submersible survey. The distributions of hours fished and number of anglers from the disaggregated CPFV logbook data (Figures 1 & 2) illustrate that trimming extreme values from the data, as described in the "Data and Methods" section, should isolate trips of interest and improve standardization of catch rates.

Coefficients from the species regression model (Figure 3) illustrate how the presence or absence of species/groups in the reported catch is associated with the probability of catching a cowcod during a CPFV trip. The results are intuitive: species/groups that occupy deeper reefs (rockfish, lingcod, sablefish) have higher probabilities (more positive coefficients) of co-occurrence with cowcod, whereas most highly migratory and nearshore species have lower probabilities (more negative coefficients). Trips that were assigned a probability of greater than 0.12 were retained as 'effective effort' for cowcod, based on the results of the sensitivity analysis (Table 2). An additional 2,046 trips were deleted due to sparse data and the need to stabilize the jackknife routine in the delta-GLM model. These procedures reduced the number of trips in the database from 340,566 to 23,845 (effective effort for cowcod).

Model selection for the delta-GLM index (binomial and Gaussian GLMs) indicated that a 'main effects' model containing block, 'group.year' and month terms was sufficient for estimating block-specific catch rates (Table 3). Given the large number of records and model parameters, investigation of interaction terms required grouping of years into 4 categories ('group years'). This was based on the year effects from the delta-GLM index (Figure 4), and resulted in 4 groups: 1980-1985, 1986-1991, 1992-1997, and 1998-2000. Months were retained in the Gaussian GLM to allow for estimation of delta-GLM month effects.

The delta-GLM index estimated block effects for 97 out of 221 blocks in the SCB (Figure 5). Blocks were classified as 'inside' or 'outside' the CCA, according to the distribution of habitat inside each block (Figure 5). Habitat types inside the CCA contain a greater proportion of rocky substrate than habitat outside (Table 4). The sum of all habitat area in the SCB divided by the area of habitat in the CCA is 2.72, which can be interpreted as an expansion factor based solely on habitat availability.

The expansion factor, R, (Eq. 2) based on estimates of catch rates from 1980 to 2000 and habitat area is 1.55, with an approximate standard error of 0.0655 (the square root of Eq. 4). Treating this factor as a catchability coefficient, q, (Eq. 5) provides an estimate of 0.645, with an approximate standard error of 0.082.

At the request of the stock assessment review (STAR) panel, the final expansion factor was calculated using data from 1990 to 2000. The model structure was unchanged (i.e. model 2 in Table 3a and model 1 in Table 3b) and this subset of the data allowed for estimation of 62 block effects (Figure 6). The final expansion factor is 1.33 (Eq. 2) with an approximate standard error of 0.064. Expressing the factor as a catchability coefficient, q, (Eq. 5) produces an estimate of 0.751 with a standard error of 0.147.

As mentioned above, this analysis cannot account for several major sources of uncertainty (inaccuracies in logbook data, uncertainty in classification of habitats, etc.). Recognition of the uncertainty in components of the model that are presently treated as being without variability would almost certainly produce higher estimates of the standard errors.

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Tables

Table 1: Bag frequency analysis, 1980-1999 (RecFIN). 2000 results shown for comparison.

	Bag Size							
Year	**0**	**1**	**2**	**3**	**5**	**6**	**7**	**Total Bags**
1980	12	5	1	2	2	1	1	24
1981	4	22	1	1				28
1982	9	11		1				21
1983	9	15	1					25
1984	10	16						26
1985	5	15	2	1				23
1986	5	8						13
1987	1							1
1988		2						2
1989	1							1
1993		3	1					4
1994	1	8						9
1995	1							1
1996	1	1						2
1997		1						1
1998		3						3
1999	6	8	1					15
(2000)*	4	3						7
Total Bags, 80-99	**65**	**118**	**7**	**5**	**2**	**1**	**1**	**199**
Cumulative %	**32.7%**	**92.0%**	**95.5%**	**98.0%**	**99.0%**	**99.5%**	**100.0%**	

*** bag limit of 1 cowcod**

Table 2: Sensitivity analysis for the ‘cut-off probability’ in the species-regression model. The cut-off probability that minimized the mean CV of the delta-GLM block effects was used to determine which records were ‘effective effort’ for cowcod.

cut-off probability	Mean CV of block effects in delta-GLM	number of records
0.10	34.92%	28513
0.11	34.92%	28512
0.12	34.68%	25891
0.13	48.15%	6846
0.14	48.75%	6800
0.15	48.75%	6792

Table 3: Model selection for the delta-GLM index (binomial and Gaussian GLMs).

a)	**Binomial GLM (23,845 records)**	**Link Function**	**Parameters**	**BIC**	**BIC difference***
1	cpue (0/1) = block + group.year + month	logit	111	18846	27
2	cpue (0/1) = block + group.year + month	probit	111	18819	0
3	cpue (0/1) = group.year + month	probit	15	20964	2145
4	cpue (0/1) = block + month	probit	108	19170	351
5	cpue (0/1) = block + group.year	probit	100	18830	11
6	cpue (0/1) = block + group.year + month + block:group.year	probit	399	20472	1653

* "BIC difference" is the BIC value minus the smallest BIC value in the set of candidate models

b)	**Gaussian GLM (3,948 records)**	**Link Function**	**Parameters**	**BIC**	**BIC difference**
1	log$_e$(cpue) = block + group.year + month	identity	111	11556	22
2	log$_e$(cpue) = group.year + month	identity	15	11572	38
3	log$_e$(cpue) = block + month	identity	108	11565	30
4	log$_e$(cpue) = block + group.year	identity	100	11534	0
5	log$_e$(cpue) = block + group.year + month + block:group.year	identity	399	12537	1003

c)	**Probability Distribution for Positive Observations**	**Parameters**	**AIC**	**AIC difference**
1	Lognormal[#]	111	-17956	0
2	Gamma	111	-17107	849

[#] Identical to model 1 in part (b), but fit using a lognormal likelihood function for cpue, rather than a gaussian likelihood for log(cpue)

Table 4: Habitat types inside and outside the CCA.

	Inside CCA		**Outside CCA**	
Habitat Type	**Area (km^2)**	**Proportion of Habitat**	**Area (km^2)**	**Proportion of Habitat**
Rocky Ridge	730.51	0.294	19.42	0.005
Rocky Shelf	25.16	0.010	344.38	0.081
Rocky Slope	15.11	0.006	311.37	0.073
Sedimentary Ridge	704.83	0.284	201.13	0.047
Sedimentary Shelf	422.03	0.170	2526.54	0.591
Sedimentary Slope	588.26	0.237	868.62	0.203

Figure 1: Distribution of hours fished in the disaggregated (1 record per species) CPFV logbook data for Southern California.

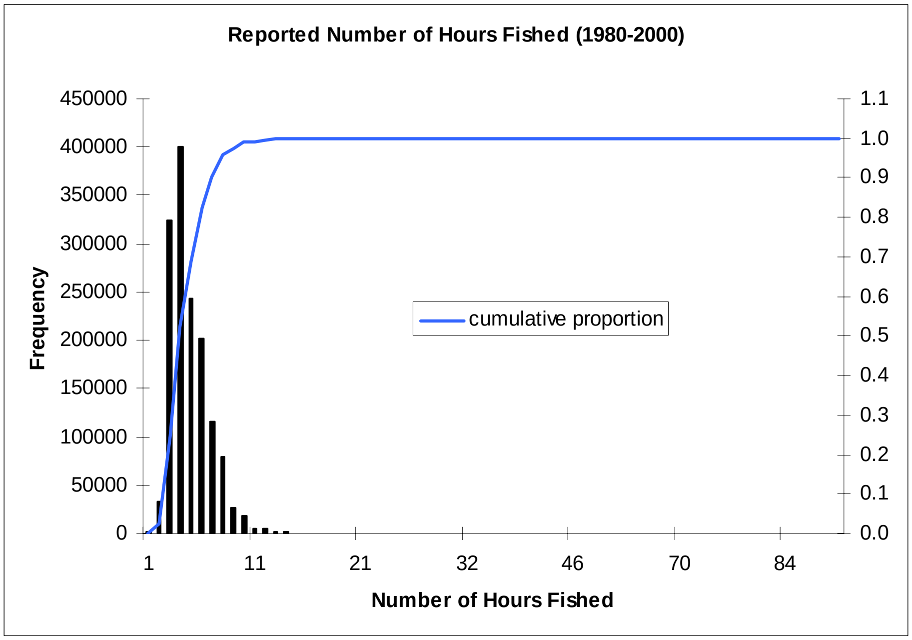


Figure 2: Distribution of the number of anglers in the disaggregated (1 record per species) CPFV logbook data for Southern California.

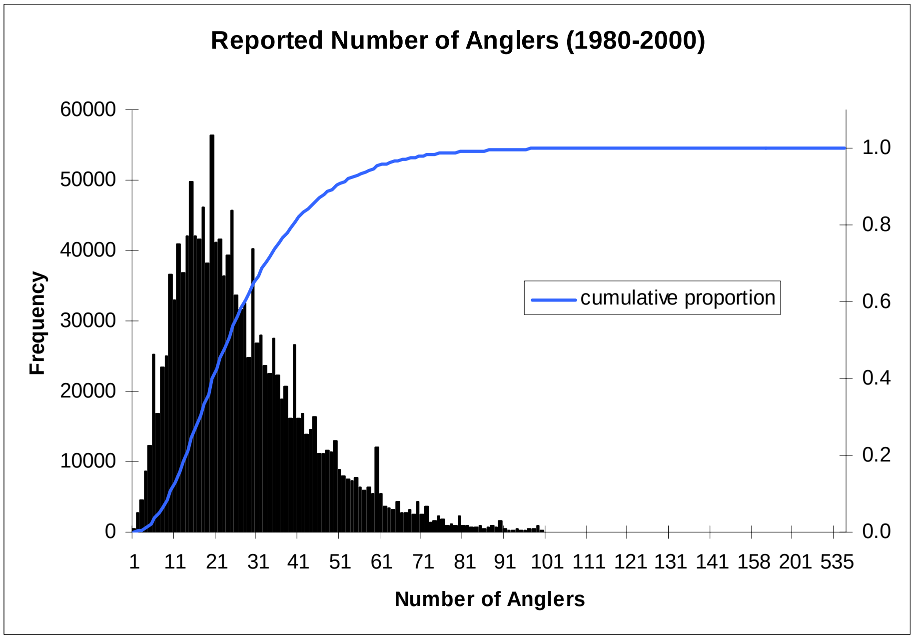


Figure 3: Coefficients from the logistic regression model for the probability of catching cowcod. Positive and negative coefficients represent higher and lower probabilities, respectively, that a species/group co-occurs with cowcod in the CPFV logbook data.

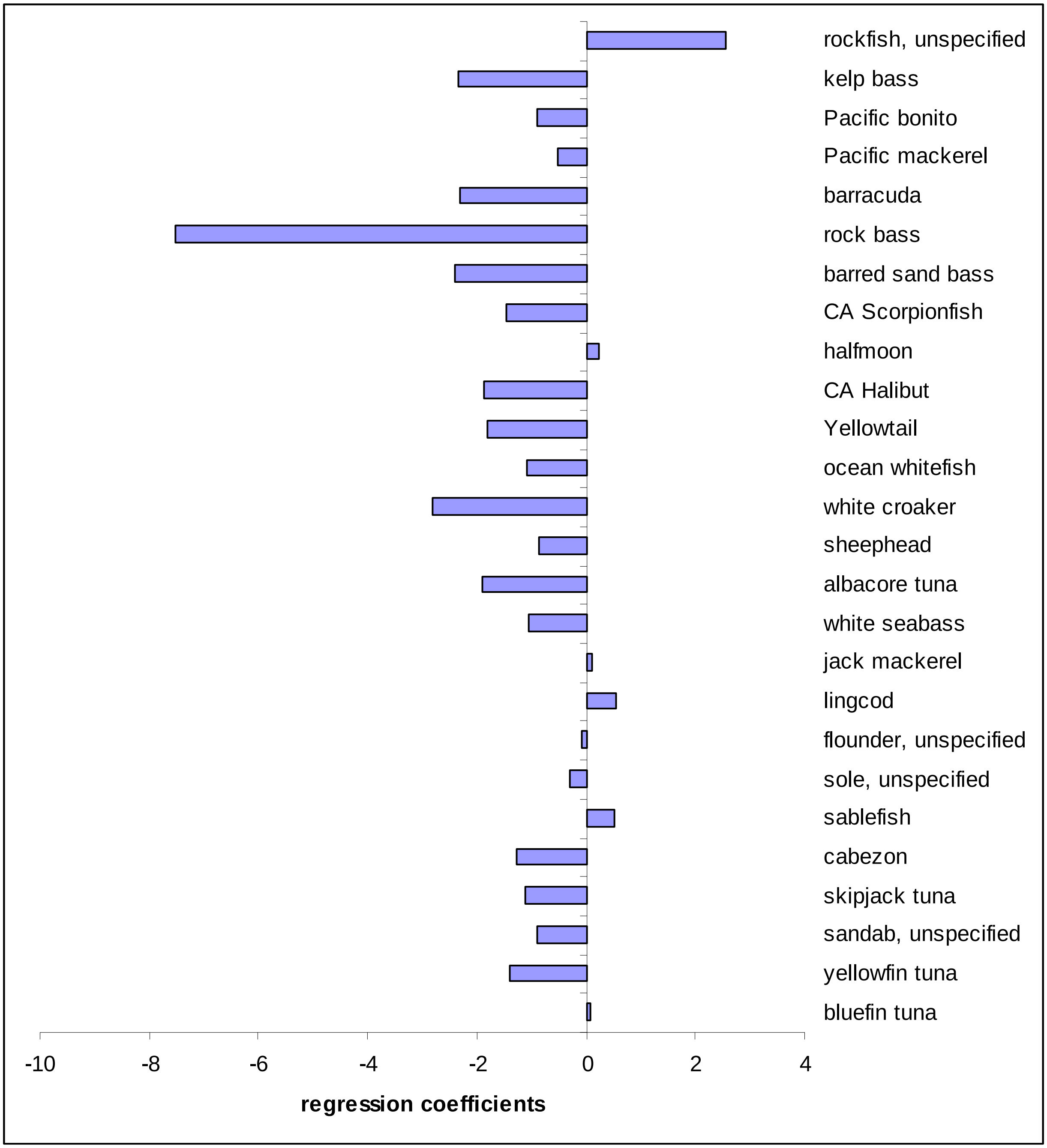


Figure 4: Estimated year effects from the binomial GLM (upper panel), Gaussian GLM (middle panel), and delta-GLM index (lower panel). Vertical lines in the lower panel separate groups of years in the final model.

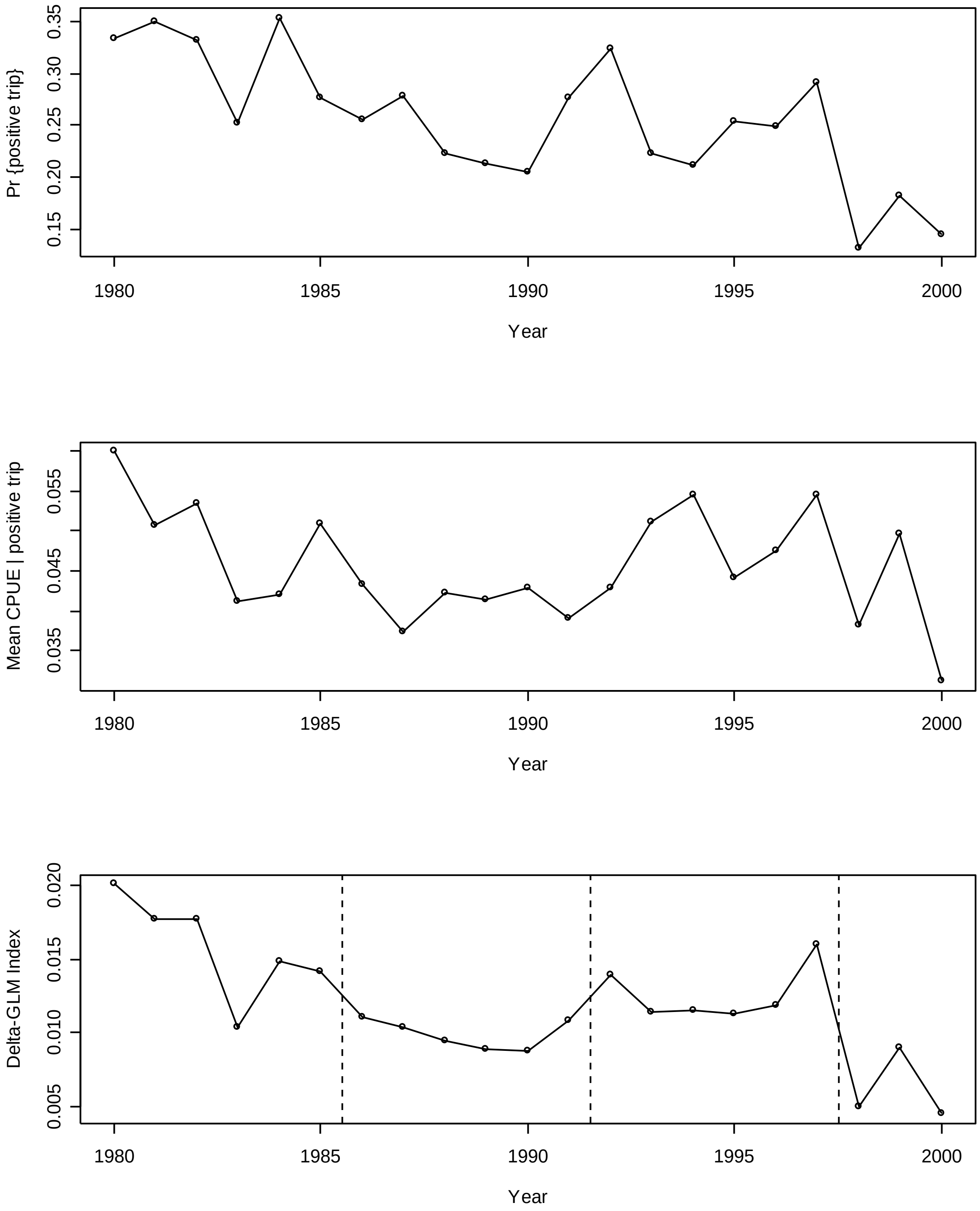


Figure 5: Distribution of cowcod habitat and catch rates (1980-2000) by CDFG fishing block in the Southern California Bight.
Block effects are categorized by quartiles.

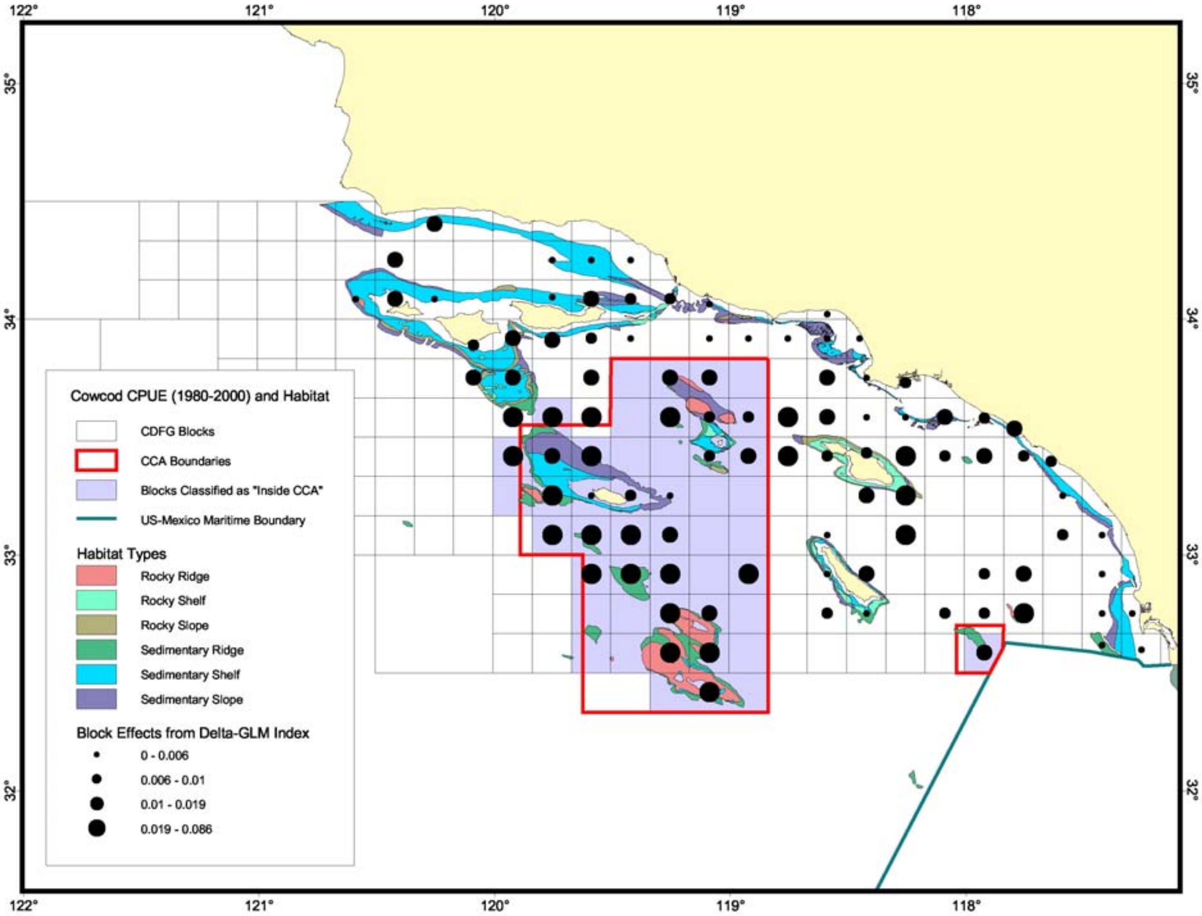
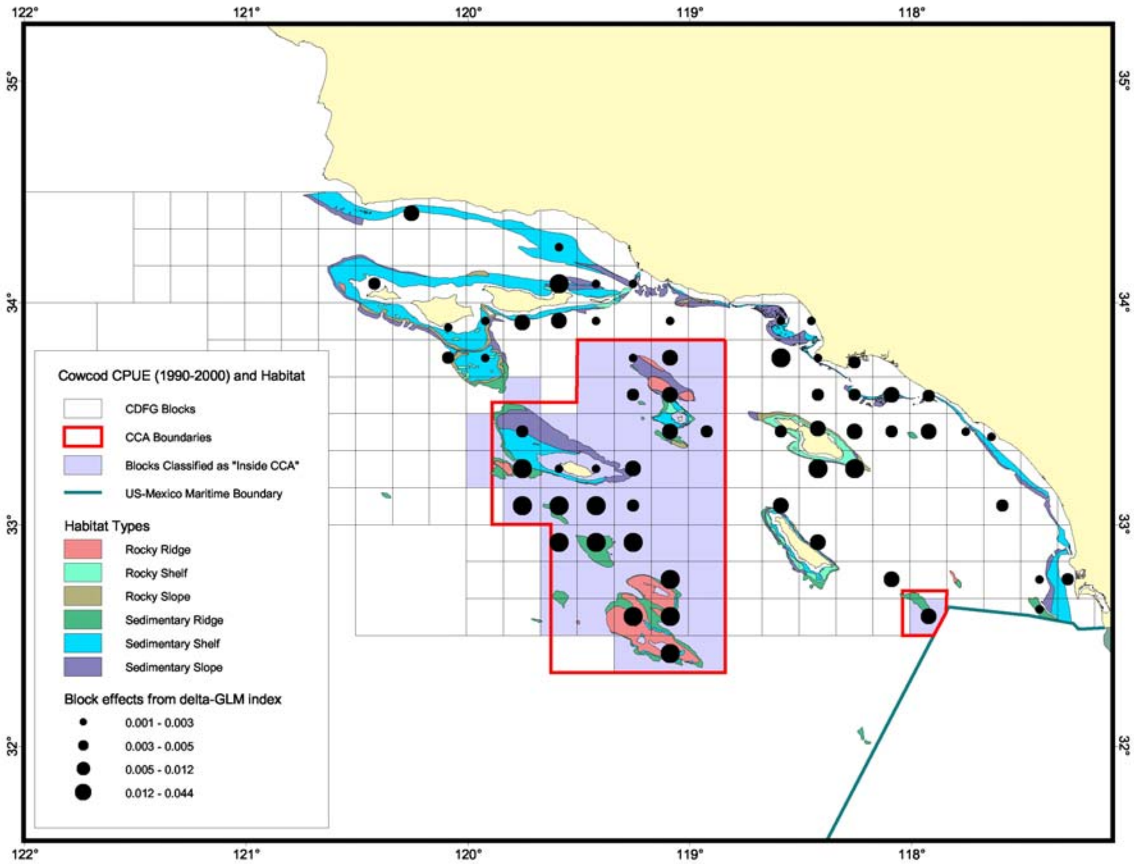


Figure 6: Distribution of cowcod habitat and catch rates (1990-2000) by CDFG fishing block in the Southern California Bight.
Block effects are categorized by

quartiles.


122°
121°
120°
119°
118°
35°
34°
33°
32°
Cowcod CPUE (1990-2000) and Habitat
CDFG Blocks
CCA Boundaries
Blocks Classified as "Inside CCA"
US-Mexico Maritime Boundary
Habitat Types
Rocky Ridge
Rocky Shelf
Rocky Slope
Sedimentary Ridge
Sedimentary Shelf
Sedimentary Slope
Block effects from delta-GLM index
0.001 - 0.003
0.003 - 0.005
0.005 - 0.012
0.012 - 0.044

Appendix V.

*The use of CalCOFI larval abundance data to derive an expansion factor for the estimated abundance of cowcod (*Sebastes levis*) inside the Cowcod Conservation Areas*

John Field, Alec MacCall and Edward Dick, April 29 2005

Introduction

The objective of this addendum to the cowcod assessment is to present a potential expansion factor for scaling the cowcod (*Sebastes levis*) biomass estimates generated by Yoklavich et al. (in prep) in order to reflect plausible biomass levels throughout the Southern California Bight. As described by Moser et al. (2000), cowcod larvae are among the few rockfish larvae easily identified to species in California Cooperative Oceanic Fisheries Investigations (CalCOFI) ichthyoplankton dataset. They are also among the rarest of those larvae identifiable to species, with a total of 550 larvae counted in 117 positive tows in the standard survey area between 1951 and 1998 (Moser et al. 2000). The low frequency of positive tows, and small number of larvae overall, suggests that any inference about the abundance, particularly of relative abundance by area, based on such data is tenuous. Nevertheless, a reasonable approach to doing so is attempted here.

General Approach

Our basic approach used generalized linear models to estimate the relative density of cowcod larvae both inside and outside of the Cowcod Conservation Areas (CCAs), expanded the density by the relative area sampled both inside and outside of the CCAs, and used the ratio between the two to derive a possible expansion factor for Yoklavich et al's point estimate of biomass within the CCAs. The first significant assumption is that larval density is linearly proportional to adult abundance (spawning biomass). Although this is a difficult assumption to judge, it is reasonable based on Mangel and Smith's (1990) observation that at low encounter rates, the proportion of positive tows for sardine eggs seemed to be strongly correlated with population biomass levels. Additionally, these data have already been used as abundance indices for cowcod (Butler et al. 1999). Consequently, we feel that this assumption is reasonable.

The second major assumption is that cowcod larvae are caught in reasonably close proximity to the location of parturition, and consequently represent adult densities in the general locality of their capture. MacGregor (1986) presented length frequency compositions of rockfish larvae from CalCOFI samples, and found that 70% of *S. levis* larvae were within one millimeter of the expected size of newly hatched larvae, suggesting that a large proportion of captured larvae were spawned during the month of capture. He interpreted the decrease in numbers of larvae of larger sizes to reflect both high natural mortality rates and increasing net avoidance behavior with time. This would suggest that larvae tend to be caught in reasonable proximity to the area of parturition.

Yet presumably currents, eddies and other physical features are capable of dispersing larvae over substantial distances over short time periods. Consequently, the extent to which larval numbers in tows within and outside of the CCA may actually represent reproductive effort in these respective areas is uncertain.

A third assumption regards the use of the enhanced CalCOFI survey data. The enhanced CalCOFI survey grid includes roughly 75 stations that were sampled in February of 2002 and 2003 (data since 2003 are not yet available). Nearly all of these stations are within the boundaries of the CCAs. The majority of these stations were not sampled prior to 2002, and consequently treating them as the relative equivalent to the usual CalCOFI stations may be questionable. However, this additional data represents a valuable source of information, therefore we have generated expansion factors both with and without the enhanced survey data.

Data and Methods

Moser et al. (2000) found that the highest numbers of cowcod were captured at the cluster of stations in the northern Channel Islands, with 68% of occurrences and 76% of the total numbers in an area bounded by lines 80 and 87 and seaward to station 55. As larvae were rare north of Point Conception and seaward of station 60, only data from CalCOFI lines 80-93, and stations seaward to station 60, were used in this analysis. This is similar to the approach used in the 1999 assessment. Several of the stations within the boundaries of the western CCA include those with the highest frequency of occurrence over time, particularly 87.40, 87.45 and 87.50, which had 24 of the 29 positive tows in the CCA over this time period. The other regular CalCOFI stations in the CCA are stations 90.45, 90.53, and 93.35; the latter is the only station to fall within the boundaries of the eastern CCA. For continuity, stations were assigned as inside or outside of the CCA based on their average coordinates over the time series. As the locations of tows may vary by a kilometer or more, a small number of the tows taken from stations considered inside the CCA may have actually been taken outside the CCA boundaries.

Figure 1 shows the location of the standard CalCOFI stations used in this exercise (grey) and the enhanced cowcod survey stations (black). The size of the circles for the traditional stations reflects the average (Jan-June) CPUE for cowcod, and the number to the left of each station reflects the number of positive tows over the entire time series. For enhanced stations, triangles reflect positive stations (small were positive one year, large were positive both years), crosses reflect stations with no larvae either year. The CCAs and the effective CalCOFI sampling area are also outlined. The effective CalCOFI sampling area was estimated using boundaries connected by the shoreward stations, extending seaward equidistant between the stations included in this analysis and the next-nearest station (note- this could be improved upon by using the landward boundary, although this should not have a notable impact on the result). Using this approach, the total area of the CalCOFI region was determined to be 75,600 km^2, and the area of the CCAs (inside) estimated at 13,700 km^2, leaving 61,900 km^2 as the area sampled outside the CCAs. Figure 2 reflects the paucity of data with which to consider current differences in the relative density of cowcod inside and outside of the CCAs, as it shows the same larval catch information as Figure 1 for the years 1996-2003 only.

In addition to inferred patchiness, larvae are typically most abundant during winter months, with 45% of spawning apparently occurring in January and another 39% in February and March (MacGregor 1986), such that only 4 tows produced larvae between July and December. Consequently only tows taken from January-June were used here, again consistent with the 1999 assessment. Rather than use months as independent factors, we used three-month periods (January-March, April-June) to reflect the quarterly nature of the majority of CalCOFI survey effort over time. Additionally, as the time series is generally considered to be noisy, with high frequency variability that is not likely to reflect actual changes in adult spawning biomass, the years of data collection were binned into five year periods to decrease the number of coefficients used in the models. Table 1 shows the estimated proportions of positive tows and of CPUE inside and outside of the CCA in five year intervals, and figure 3 shows the information in Table 1 graphically.

To evaluate the potential differences in both presence/absence and abundance of cowcod larvae among stations inside and outside of the CCAs, we ran both binomial generalized linear models (GLMs) using presence/absence data, and a Delta-GLM (which combines a binomial model with a model of catch per unit effort for positive tows) to estimate the relative differences in larval densities inside and outside of the CCAs. The coefficients evaluated were inside or outside the CCAs, five-year intervals of time, and seasons (Jan-March, April-June). The GLM analyses was executed in R programming language using a procedure developed by E.J. Dick, which allows for evaluation of alternative distributions and a variety of diagnostics, and includes a jackknife estimation of precision. The appropriate probability distributions were diagnosed using Akaike Information Criteria (AIC), as in Dick (2004). Based on the results of the diagnostics, a logit link was used for the binomial model, and (where relevant) a lognormal distribution was used for the positive (Delta-GLM) model. The binomial component of the model generally explained a reasonable fraction of the variance as determined by AIC criteria. The positive component of the model improved the fit, but AIC shows the improvement to be insufficient. In general, the effects of including the factors of inside or outside the CCA, season, and five year intervals in the models improved the model performance, although the amount of variability explained was never substantial.

To develop the expansion factor, we scaled the relative abundance of cowcod larvae by the respective area inside and outside of the CCA in the southern California Bight. The expansion factor was thus estimated as the ratio of the sum total of larvae (relative abundance, as indicated by percentage of positive tows) inside and outside the CCAs over the total number inside the CCAs, which simplifies to:

Eq. 1: $E = 1 + \frac{A_o D_o}{A_i D_i}$

Where E is the expansion factor, A_o is the area outside the CCAs, A_i is the area inside the CCAs, D_o is the density (relative abundance) of cowcod larvae outside the CCAs and D_i is the density (relative abundance) of cowcod larvae inside the CCAs. The jackknife routine in the model generates a standard error for D_i and D_o, consequently the variance of the expansion factor can be estimated using the delta method for approximating the standard error of a transformation (Seber 1973). In doing so we assume independence among coefficients (positive or negative correlations in abundance would decrease or increase the variance, respectively), and estimate the variance of E as:

Eq. 2: $$Var(E) = se^2(D_i)\left(\frac{\partial E}{\partial D_i}\right)^2 + se^2(D_o)\left(\frac{\partial E}{\partial D_o}\right)^2$$

Providing us a variance for the expansion factor that can be treated as normally distributed about the mean. Alternatively, we can estimate our expansion factor as a catchability coefficient, q,

Eq. 3: $$q = \frac{A_i D_i}{A_i D_i + A_o D_o}$$

and we would again use the delta method to approximate the variance of the ratio, as in equation 2.

Results

Table 3a shows the AIC scores and the deviance explained by these coefficients for the binomial model run over the entire time series, both with and without the inclusion of the enhanced CalCOFI data. Table 3b shows the same information for the delta-glm model. These results are derived from the step function in R, in which coefficients are removed from the fitted model sequentially. The first line gives the residual deviance and AIC score from the fitted model, and sequential lines give the residual deviance and AIC scores with various coefficients excluded from the model. In both the binomial and the binomial component of the delta-glm models, there is a substantial improvement in the AIC score with the inclusion of each of these coefficients for the models that include the enhanced data, suggesting that the most appropriate model would include all of these factors (time period, season, and CCA). By contrast, in the positive portion of the Delta-GLM model, the only real improvement in AIC is with the inclusion of grouped years as coefficients. In general, there is little difference between these two models. Similar results were obtained when individual years and individual months (rather than grouped years or seasons) were used as coefficients.

When smaller subsets of the data were used, the relative improvement to the model fit declines as the small number of positive tows constrains the ability to fit the model. Table 4 shows the AIC scores and deviance explained by the same set of coefficients, using only the years between 1996 and 2003 (e.g., only two group-year coefficients), with and without the inclusion of the enhanced CalCOFI data. Although the model that included the enhanced data and all three factors did improve the model performance, this improvement was extremely modest. In contrast, for the model that did not include the enhanced CalCOFI data, the inclusion of all three factors actually degraded model performance. If the groupyear and seasonal coefficients are excluded from the model however, the model that includes the enhanced data suggests a much better fit (AIC score from 227 to 211, deviance from 225 to 207, when CCA is the only factor), although there is little change in the model performance for the model that does not include the enhanced data. Yet excluding factors that are known (by virtue of the model utilizing the entire time series) to be important in explaining temporal patterns in abundance does not seem reasonable in this instance, as the expectation would be for greater uncertainty in response to a smaller dataset.

Table 5 provides the point estimates and standard errors for the larval densities inside and outside the CCAs, in which densities were typically 2 to 3 times higher inside the CCAs than outside. Also given are the expansion factors (*E*) for each model (Eq.1), and the variance and standard deviation of the expansion factor (Eq. 3). Similarly, Table 6 provides the point estimates and standard errors for the catchability coefficients (q) for the five models presented here, as well as their standard errors. Figure 4 shows the results for expansion factors (*E*) graphically, as normally distributed curves around the mean point estimate. These results suggest first of all that very similar results are obtained for all models, which suggest an expansion factor on the order of 2 to 4 times the point estimate for biomass inside the CCAs is the most reasonable based on these data. These results also suggest that the expansion factor should be smaller (catchability larger) when only recent (1996-2003) data are used, which is consistent with the assumption that the relative abundance of cowcod inside the CCAs has declined less than that outside the CCAs, as inferred by spatial patterns of changing catch rates described in the assessment by Butler et al. (1999). Finally, these results may illustrate the value of the enhanced CalCOFI data, assuming that the use of these stations is valid, as there is greater confidence in the estimate of the expansion factor than might be inferred when excluding these data.

Conclusions

There are clearly shortcomings in considering the CalCOFI data as a means to estimate an expansion factor for cowcod throughout the Southern California Bight from the estimated biomass within the Cowcod Conservation Areas. Despite this, the results presented here provide a reasonable means for doing so, based on data that are already included as key elements of the stock assessment. The results seem to account for the spatial patterns of stock declines by suggesting a greater abundance of cowcod inside the CCAs in recent years relative to the entire time series, consequently our recommended expansion factor would be the binomial model for the 1996-2003 period, including the enhanced CalCOFI data.

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Table 1: Number of positive and total tows, and the percentage of positive tows, outside and inside the CCA over the entire CalCOFI time period.

	Outside CCA			Inside CCA		
year	pos	tows	% pos	pos	tows	% pos
1951-1955	19	551	3.4	8	145	5.5
1956-1960	18	613	2.9	6	173	3.5
1961-1965	10	317	3.2	2	63	3.2
1966-1970	20	300	6.7	7	71	9.9
1971-1975	11	243	4.5	3	43	7.0
1976-1980	0	169	0.0	0	27	0.0
1981-1985	0	274	0.0	0	64	0.0
1986-1990	1	256	0.4	0	60	0.0
1991-1995	2	257	0.8	0	60	0.0
1996-2000	3	261	1.1	1	58	1.7
2001-2003	4	151	2.6	2	36	5.6

Table 2: Number of positive and total tows, and the percentage of positive tows, from the enhanced CalCOFI cowcod survey conducted in February of 2002 and 2003.

	Enhanced CalCOFI		
	pos	tows	% pos
inside	17	139	0.109
outside	0	10	0

Table 3a: Deviance explained and AIC scores from the binomial GLM model with and without the inclusion of the enhanced CalCOFI data. The table reports the residual deviance and AIC score for the model with all three components (none) and with each component removed sequentially, as ordered by increasing AIC scores.

Binomial GLM (pos ~ CCA + season + groupyear)				**Binomial GLM** (no enhanced)	
coefficient	Df	Deviance	AIC	Deviance	AIC
<none>		1072.0	1098.0	951.8	971.8
- CCA	1	1077.8	1101.8	954.4	972.4
- season	1	1096.7	1120.7	972.9	990.9
- groupyea	10	1159.5	1165.5	987.8	993.8

Table 3b: Deviance explained and AIC scores from the positive portion of the Delta-GLM model.

Delta-GLM, positive model (cpue ~ CCA + season + groupyear)			
coefficient	Df	Deviance	AIC
- CCA	1	38.3	231.8
- season	1	38.7	233.1
<none>		38.2	233.6
- groupyea	10	55.4	268.9

Table 4: Deviance explained and AIC scores from the binomial GLM using 1996-2003 data only, with and without including data from the enhanced survey

1996-2003 Binomial with enhanced data				**1996-2003 Binomial** without enhanced data			
coefficient	Df	Deviance	AIC	coefficient	Df	Deviance	AIC
<none>		199.0	207.0	- CCA	1	94.7	100.7
- CCA	1	201.4	207.4	- season	1	95.3	101.3
- season	1	203.2	209.2	<none>		94.0	102.0
- groupyear	1	205.1	211.1	- groupyear	1	96.0	102.0
Null	654	225.1	207.0	Null	505	98.3	102.0
Residual	651	199.0	211.1	Residual	504	96.1	100.1

Table 5: Model estimates of densities inside (D_i) and outside (D_o) of the CCAs, with and without the enhanced data. Standard errors were estimated by the jackknife routine, the expansion factor as estimated with equation 1, and the variance of the expansion factor as estimated with equation 2.

	Binomial GLM all years enhanced	Binomial GLM all years no enhanced	Delta GLM all years enhanced	Binomial GLM 1996-2003 enhanced	Binomial GLM 1996-2003 no enhanced
Di	0.0379	0.0328	0.2228	0.0430	0.0296
Do	0.0233	0.0230	0.1196	0.0143	0.0160
Se(Di)	0.0073	0.0073	0.0576	0.0186	0.0184
Se(Do)	0.0041	0.0041	0.0264	0.0067	0.0072
Expansion	3.775	4.168	3.426	2.500	3.434
Var(Expansion)	0.524	0.813	0.680	0.920	3.472
St error (Expansion)	0.724	0.902	0.825	0.959	1.863
CV (Expansion)	0.192	0.216	0.241	0.384	0.543

Table 6: Model estimates of catchability (q) as estimated with equation 3, and standard error, as estimated in equation 2.

	Binomial GLM all years enhanced	Binomial GLM all years no enhanced	Delta GLM all years enhanced	Binomial GLM 1996-2003 enhanced	Binomial GLM 1996-2003 no enhanced
catchability	0.265	0.240	0.292	0.400	0.291
Var(catchability)	0.0026	0.0027	0.0049	0.0235	0.0250
St error (catchability)	0.0508	0.0519	0.0703	0.1534	0.1580
CV (catchability)	0.192	0.216	0.241	0.384	0.543

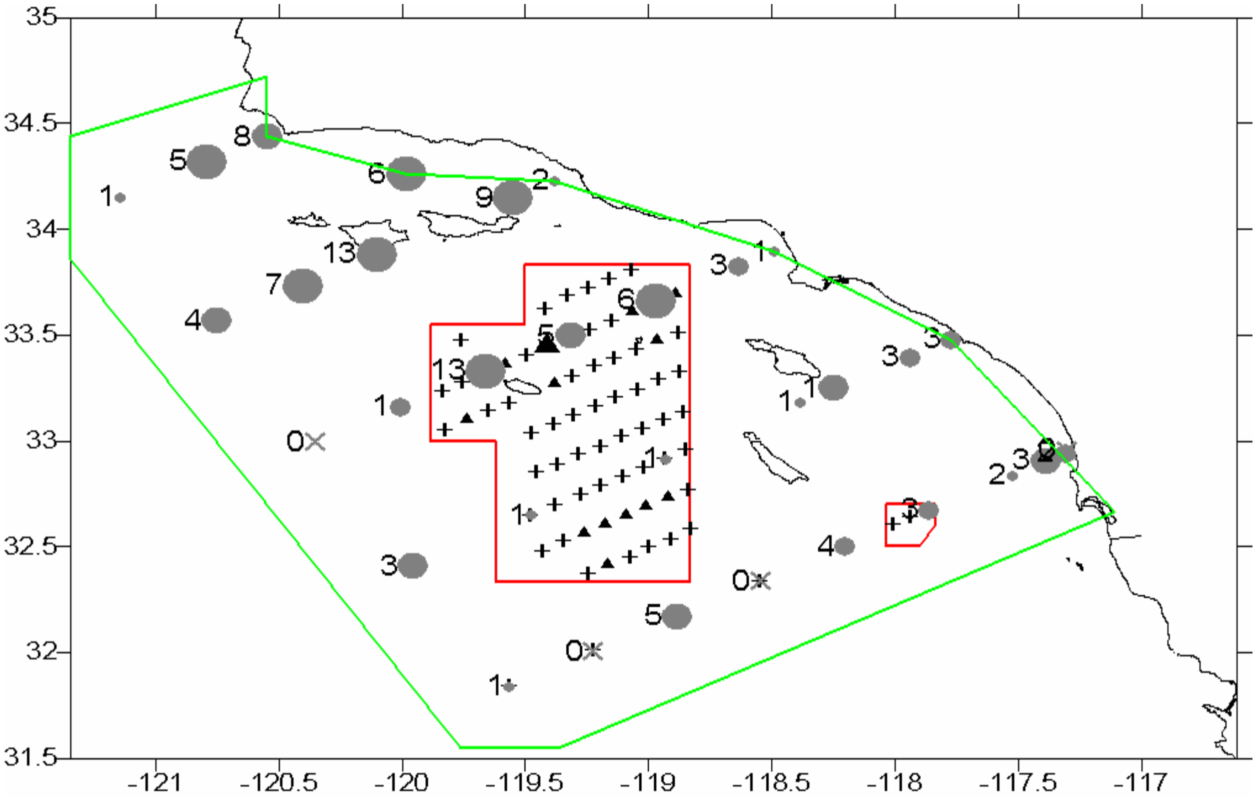

Figure 1: Location of the standard (grey) and enhanced (black) CalCOFI stations used in this exercise. The size of the circles for the standard stations represents the mean CPUE, and the number reports the number of positives for each standard station over the length of the time series. Cowcod Conservation Areas (CCAs) are outlined in red, the effective CalCOFI sampling area is outlined in green.

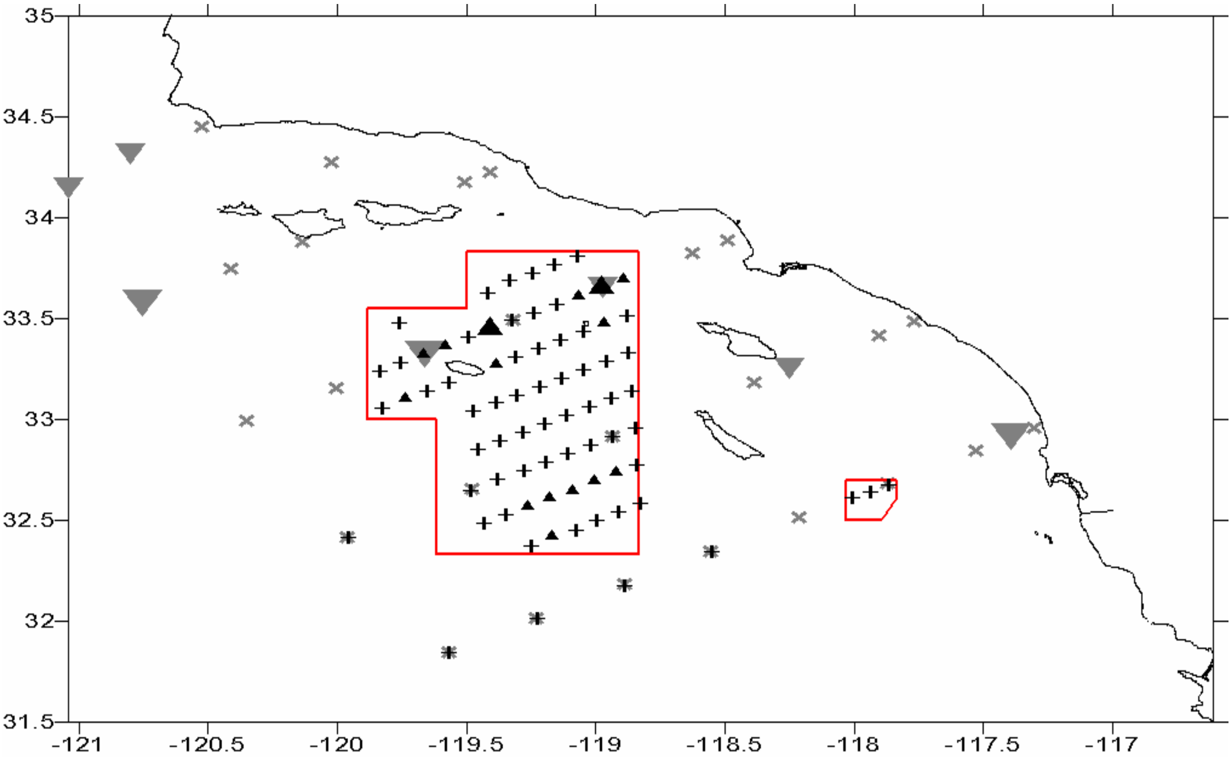

Figure 2: Location of the traditional (grey) and enhanced (black) CalCOFI stations used in this exercise for the years 1996-2003 only, indicating the location of the 10 standard and 17 enhanced station positives during this period. Small triangles indicate one positive tow, large triangles indicate two positive tows, crosses indicate no positive tows.

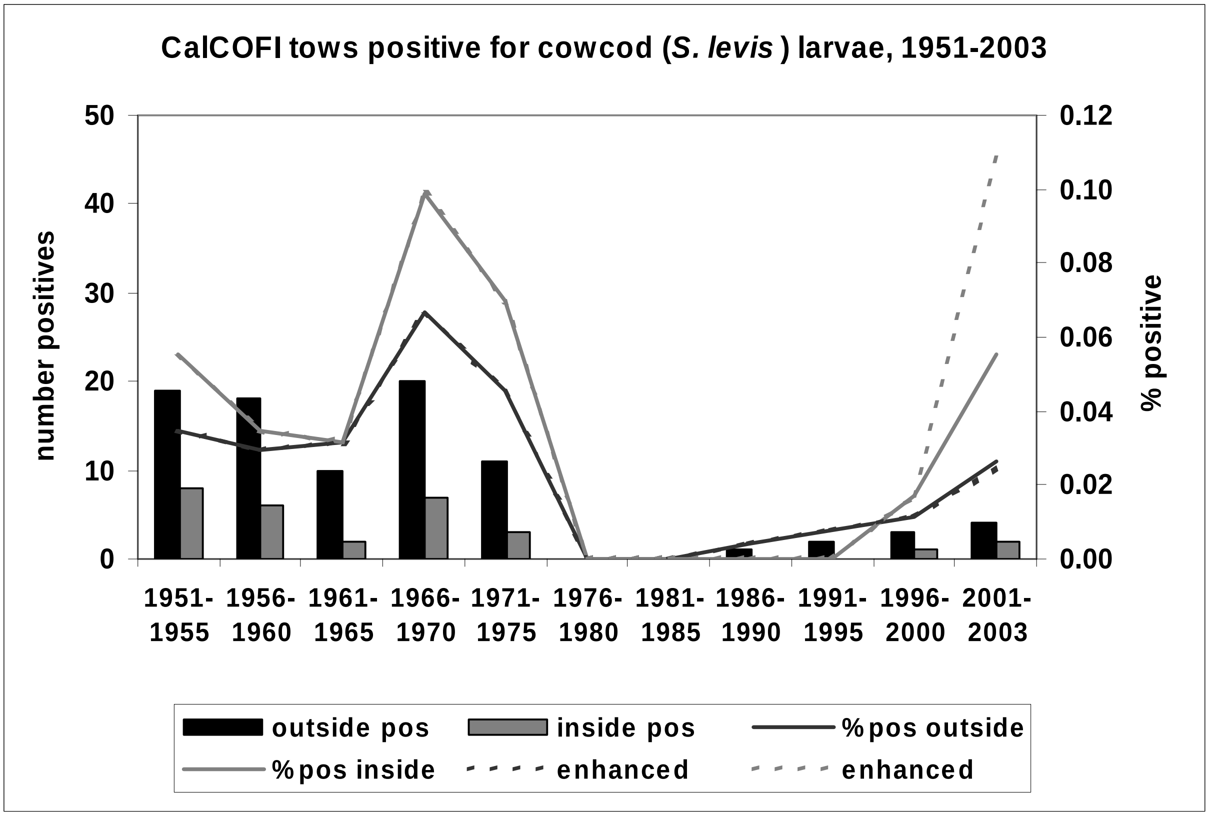

Figure 3: Number and percentage of tows positive for cowcod larvae in five year intervals since 1951, including the percentage of positive tows in the most recent (2001-2003) period when enhanced cowcod data are used.

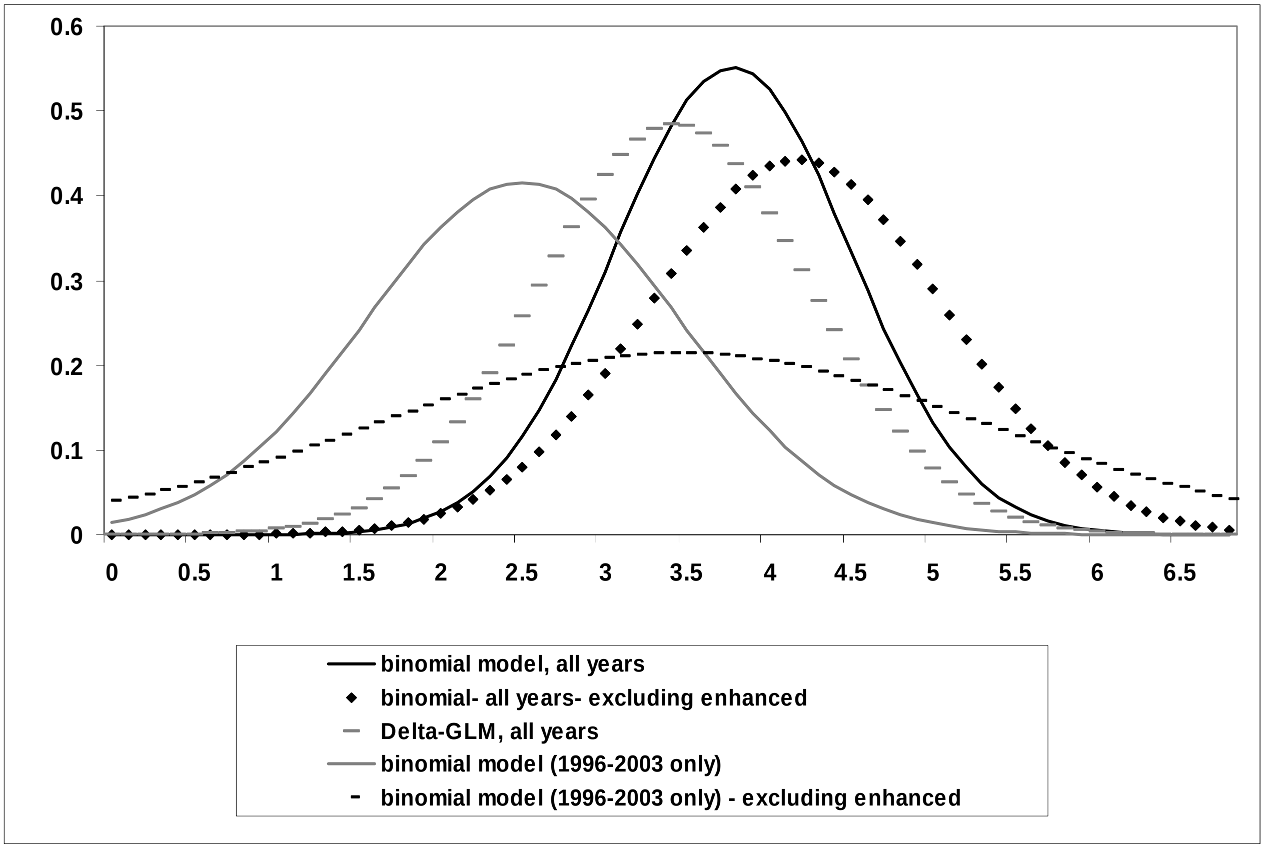

Figure 4**:** The distribution of the point estimates for the expansion factor, based on the variances estimated by the delta method

Appendix VI. Numbers at age for model *h*=0.5. Numbers are given every 10 years except in the most recent period.

Year age	1914	1920	1930	1940	1950	1960	1970	1975	1980	1985	1990	1995	2000	2001	2002	2003	2004	2005
0	59.5551	59.1434	58.837	58.6666	58.3483	56.0677	52.2639	47.628	39.6995	31.166	17.3169	19.5965	23.4886	24.3218	25.2408	26.0972	26.9011	27.6581
1	56.368	56.0097	55.717	55.5269	55.2715	53.3293	49.7968	46.5461	39.2238	32.4271	16.1381	18.4719	21.4188	22.2316	23.0202	23.8901	24.7007	25.4615
2	53.3515	53.0662	52.7662	52.5578	52.3522	50.7645	47.634	45.0602	38.137	31.3412	17.4866	16.7916	19.287	20.2726	21.0419	21.7883	22.6116	23.3788
3	50.4964	50.275	49.9723	49.7528	49.5945	48.3294	45.7754	43.3911	37.3688	31.395	18.5848	15.7148	17.3755	18.2549	19.1877	19.9158	20.6223	21.4015
4	47.7941	47.6108	47.3354	47.1	46.9979	46.0429	43.8125	41.4489	37.0373	30.3555	21.7166	14.3232	16.2083	16.4457	17.278	18.1609	18.85	19.5187
5	45.2364	45.2364	44.8242	44.5906	44.5536	43.8292	41.6757	39.6982	36.1769	30.1546	23.6728	13.1535	14.885	15.3409	15.5656	16.3533	17.189	17.8413
6	42.8156	42.8156	42.4419	42.2137	42.1907	41.6446	39.5849	37.8243	35.3551	29.7933	24.6307	12.2581	14.0307	14.0884	14.5199	14.7326	15.4782	16.2692
7	40.5243	40.5243	40.189	39.965	39.9298	39.5065	37.6218	36.1814	34.2265	28.9677	23.8059	13.2823	12.7544	13.2799	13.3345	13.7429	13.9442	14.6499
8	38.3556	38.3556	38.0517	37.8415	37.7816	37.4757	35.7578	34.7694	32.9582	28.3835	23.846	14.1162	11.9365	12.0719	12.5692	12.6209	13.0074	13.1979
9	36.303	36.3029	36.0309	35.8406	35.7599	35.5228	33.9889	33.2745	31.4777	28.1226	23.049	16.491	10.8791	11.2975	11.4258	11.8965	11.9455	12.3113
10	34.3603	34.3592	34.1216	33.9453	33.8459	33.6561	32.3359	31.6206	30.1058	27.3963	22.831	17.9401	9.98805	10.2951	10.6927	10.8142	11.2597	11.3061
11	32.5215	32.5161	32.309	32.1426	32.0275	31.8499	30.7062	29.8995	28.5001	26.4564	22.2284	18.4934	9.29686	9.44572	9.74342	10.1198	10.2348	10.6566
12	30.7811	30.7644	30.5996	30.4338	30.2979	30.0901	29.0988	28.107	26.8313	24.9034	20.6893	17.4663	10.0417	8.78066	8.9385	9.22037	9.57668	9.68567
13	29.1339	29.0985	28.9716	28.8114	28.6537	28.3795	27.4779	26.2668	25.1278	22.9826	18.6235	16.8375	10.6025	9.47041	8.30805	8.45765	8.72457	9.06191
14	27.5748	27.5171	27.4125	27.2764	27.0903	26.7329	25.8806	24.4702	23.2448	20.8382	16.2916	15.4484	12.2245	9.98718	8.95968	7.86032	8.00212	8.25489
15	26.0991	26.0203	26.018	25.8115	25.6043	25.16	24.3107	22.7903	21.2253	18.8128	13.6158	14.3733	13.0059	11.5036	9.44773	8.47613	7.4364	7.57081
16	24.7024	24.6063	24.5967	24.4196	24.1929	23.635	22.7806	21.1906	19.2554	16.7823	11.177	13.0914	13.0408	12.2279	10.8813	8.93717	8.01845	7.03514
17	23.3805	23.2705	23.2511	23.1013	22.8588	22.1815	21.3089	19.6907	17.4182	14.9347	9.02721	11.4419	11.996	12.2498	11.5655	10.2926	8.45403	7.58531
18	22.1293	22.0076	21.9771	21.8486	21.603	20.8106	19.9207	18.2598	15.7214	13.2783	7.23749	9.72911	11.306	11.2585	11.5853	10.9389	9.7355	7.99687
19	20.945	20.8129	20.7708	20.6618	20.423	19.5288	18.5933	16.9025	14.1725	11.6879	5.73063	8.06618	10.1662	10.6015	10.6469	10.9569	10.3462	9.20847
20	19.8242	19.6826	19.6283	19.5383	19.3069	18.3243	17.3306	15.6066	12.7782	10.1584	4.51254	6.39352	9.27731	9.52411	10.0248	10.0686	10.3624	9.78546
21	18.7633	18.613	18.5456	18.4718	18.2469	17.1912	16.1278	14.3741	11.4996	8.76701	3.49644	4.97512	8.28793	8.68352	9.00529	9.47955	9.52171	9.80023
22	17.7592	17.6011	17.5193	17.4686	17.2444	16.1267	14.9892	13.2138	10.339	7.53909	2.68882	3.80601	7.10331	7.75048	8.20982	8.51487	8.96405	9.00456
23	16.8088	16.6438	16.5462	16.5165	16.2953	15.1271	13.9164	12.1394	9.2741	6.4648	2.05517	2.88823	5.92156	6.63673	7.32709	7.76216	8.05129	8.47665
24	15.9093	15.7381	15.6247	15.6073	15.3994	14.1868	12.9095	11.1345	8.30261	5.53428	1.5474	2.16341	4.81237	5.52769	6.27368	6.92705	7.33906	7.61305
25	15.0579	14.8814	14.7541	14.7944	14.5464	13.3016	11.967	10.1994	7.41395	4.73715	1.14499	1.61103	3.73868	4.48833	5.22489	5.93072	6.54904	6.93917
26	14.2521	14.071	13.9328	13.9685	13.7376	12.4685	11.0732	9.32905	6.60448	4.04699	0.83754	1.18031	2.85143	3.48393	4.24214	4.93892	5.60672	6.19182
27	13.4894	13.3045	13.1582	13.1875	12.9732	11.688	10.2375	8.5235	5.87349	3.45436	0.60789	0.858308	2.13815	2.65488	3.29258	4.00968	4.6688	5.30059
28	12.7675	12.5796	12.4269	12.4492	12.2484	10.9597	9.46282	7.78114	5.22163	2.94245	0.43824	0.620499	1.59061	1.98911	2.50888	3.11194	3.79014	4.41363
29	12.0842	11.894	11.7363	11.7511	11.5633	10.2812	8.75021	7.09934	4.63657	2.5025	0.31424	0.442062	1.16819	1.47853	1.87958	2.37107	2.94138	3.58279
30	11.4375	11.2457	11.084	11.091	10.9161	9.64559	8.09216	6.47475	4.11366	2.12402	0.22451	0.30967	0.85316	1.08503	1.39702	1.77623	2.24099	2.7803
31	10.8255	10.6325	10.4679	10.4664	10.3032	9.04813	7.48417	5.89645	3.64635	1.79961	0.15956	0.214592	0.6132	0.791809	1.02514	1.32012	1.67868	2.11816
32	10.2461	10.0527	9.88597	9.87531	9.72789	8.4887	6.92318	5.36719	3.23053	1.52332	0.11294	0.14767	0.4376	0.568679	0.74805	0.968646	1.24755	1.58659
33	9.69783	9.50445	9.33641	9.31581	9.18322	7.96435	6.40577	4.88633	2.8617	1.2901	0.07954	0.101022	0.31057	0.405531	0.53722	0.706791	0.91535	1.17905
34	9.17885	8.98603	8.81746	8.78685	8.66437	7.47424	5.92783	4.45211	2.53532	1.09229	0.05577	0.068807	0.2173	0.287608	0.38307	0.507556	0.66787	0.865047
35	8.68764	8.49582	8.32744	8.28789	8.20084	7.01258	5.48607	4.05865	2.24697	0.92496	0.03891	0.046745	0.14956	0.201098	0.27166	0.361901	0.47958	0.631135
36	8.22273	8.03232	7.86476	7.81799	7.7318	6.57927	5.07782	3.70185	1.99003	0.783364	0.02703	0.031626	0.10188	0.13832	0.18994	0.256636	0.34194	0.453183
37	7.78269	7.59406	7.42791	7.37546	7.28931	6.17368	4.70186	3.37855	1.76304	0.66385	0.01871	0.021336	0.06894	0.09416	0.13064	0.179422	0.24247	0.323102
38	7.3662	7.17969	7.01547	6.95839	6.87187	5.79295	4.35672	3.0856	1.56349	0.563129	0.01292	0.014339	0.04641	0.063683	0.08892	0.123398	0.16951	0.229102
39	6.972	6.78791	6.62608	6.56512	6.47805	5.43641	4.04023	2.8197	1.3888	0.478318	0.00889	0.009606	0.03111	0.04284	0.06014	0.083993	0.11657	0.160158
40	6.59889	6.41749	6.25845	6.19423	6.10639	5.1027	3.74855	2.5781	1.23531	0.406914	0.00611	0.006413	0.02082	0.028706	0.04045	0.056801	0.07935	0.11014
41	6.24575	6.06728	5.91137	5.84445	5.75551	4.78958	3.47884	2.35853	1.10027	0.346354	0.00418	0.004267	0.01388	0.019197	0.02711	0.038207	0.05366	0.074963
42	5.91151	5.73616	5.58368	5.51458	5.42411	4.49808	3.23019	2.15949	0.98143	0.295263	0.00286	0.002833	0.00923	0.012791	0.01813	0.0256	0.03609	0.050691
43	5.59516	5.42311	5.27431	5.20351	5.11105	4.2245	3.00066	1.97946	0.87676	0.252274	0.00195	0.001879	0.00612	0.008503	0.01208	0.017118	0.02418	0.034094
44	5.29573	5.12713	4.98223	4.91018	4.81563	3.96622	2.7892	1.81671	0.78435	0.216163	0.00133	0.001244	0.00405	0.005634	0.00803	0.011405	0.01617	0.022842
45	5.01233	4.84731	4.70645	4.63359	4.53747	3.73633	2.59299	1.66885	0.70263	0.185705	0.0009	0.000823	0.00267	0.003723	0.00532	0.007581	0.01077	0.015273
46	4.7441	4.58276	4.44607	4.37277	4.27596	3.50669	2.41141	1.53406	0.63029	0.15995	0.00061	0.000544	0.00175	0.002453	0.00351	0.005023	0.00716	0.010175
47	4.49022	4.33264	4.20022	4.12684	4.03008	3.29167	2.24371	1.41144	0.56631	0.138138	0.00041	0.000359	0.00115	0.001612	0.00232	0.003319	0.00474	0.006763
48	4.24993	4.09618	3.96807	3.89494	3.79873	3.09029	2.08836	1.29972	0.5098	0.119626	0.00028	0.000236	0.00075	0.001057	0.00152	0.002186	0.00313	0.004481
49	4.02249	3.87262	3.74887	3.67626	3.58092	2.90162	1.9447	1.19805	0.45984	0.103863	0.00019	0.000156	0.00049	0.000693	0.001	0.001436	0.00206	0.00296
50	3.80723	3.66126	3.54188	3.47004	3.37581	2.72477	1.81184	1.10489	0.41546	0.090404	0.00012	0.000103	0.00032	0.000454	0.00065	0.000942	0.00136	0.00195
51	3.60349	3.46144	3.34641	3.27557	3.18265	2.55889	1.68865	1.01969	0.37588	0.078887	8.3E-05	6.73E-05	0.00021	0.000297	0.00043	0.000618	0.00089	0.001281
52	3.41065	3.27253	3.16181	3.09216	3.00074	2.4032	1.57518	0.94187	0.34062	0.069027	5.5E-05	4.41E-05	0.00014	0.000194	0.00028	0.000404	0.00058	0.00084
53	3.22813	3.09393	2.98748	2.91919	2.82943	2.25702	1.46985	0.87057	0.30913	0.06058	3.6E-05	2.89E-05	9E-05	0.000127	0.00018	0.000265	0.00038	0.000551
54	3.05537	2.92508	2.82284	2.75604	2.66809	2.11986	1.3715	0.80532	0.28102	0.05333	2.3E-05	1.89E-05	5.9E-05	8.28E-05	0.00012	0.000173	0.00025	0.000361
55	2.89187	2.76545	2.66734	2.60215	2.51614	1.99142	1.28443	0.74556	0.25576	0.047073	1.5E-05	1.23E-05	3.8E-05	5.41E-05	7.8E-05	0.000113	0.00016	0.000236
56	2.73711	2.61453	2.52046	2.45698	2.37303	1.87127	1.19875	0.69069	0.23307	0.041649	9.6E-06	8.01E-06	2.5E-05	3.53E-05	5.1E-05	7.38E-05	0.00011	0.000154
57	2.59063	2.47184	2.38174	2.32003	2.23823	1.75887	1.11925	0.64059	0.21271	0.036946	6E-06	5.19E-06	1.6E-05	2.3E-05	3.3E-05	4.82E-05	7E-05	0.000101
58	2.45199	2.33695	2.2507	2.19083	2.11126	1.6536	1.04545	0.59449	0.19436	0.032855	3.7E-06	3.34E-06	1.1E-05	1.5E-05	2.2E-05	3.14E-05	4.5E-05	6.58E-05
59	2.32078	2.20942	2.12692	2.06893	1.99165	1.55494	0.976884	0.55183	0.17784	0.029292	2.2E-06	2.13E-06	6.9E-06	9.72E-06	1.4E-05	2.05E-05	3E-05	4.29E-05
60	2.19658	2.08885	2.00999	1.9539	1.87897	1.46243	0.91313	0.51425	0.16293	0.026169	1.2E-06	1.34E-06	4.5E-06	6.31E-06	9.2E-06	1.33E-05	1.9E-05	2.8E-05
61	2.07903	1.97486	1.89953	1.84536	1.7728	1.37568	0.853794	0.47769	0.14945	0.023429	6.5E-07	8.38E-07	2.9E-06	4.09E-06	6E-06	8.66E-06	1.3E-05	1.83E-05
62	1.96777	1.8671	1.79517	1.74293	1.67276	1.2943	0.798517	0.44402	0.13731	0.021023	3.1E-07	5.13E-07	1.9E-06	2.64E-06	3.9E-06	5.62E-06	8.2E-06	1.19E-05
63	1.86247	1.76521	1.69658	1.64626	1.57849	1.21795	0.746983	0.41299	0.12629	0.018903	1.3E-07	3.08E-07	1.2E-06	1.7E-06	2.5E-06	3.64E-06	5.3E-06	7.72E-06
64	1.7628	1.66889	1.60344	1.55502	1.48965	1.1463	0.698959	0.38435	0.11623	0.017033	3.5E-08	1.79E-07	7.5E-07	1.09E-06	1.6E-06	2.35E-06	3.4E-06	5.01E-06
65	1.66846	1.57783	1.51544	1.4689	1.40592	1.07906	0.654269	0.35789	0.10744	0.015379	2.1E-09	9.94E-08	4.7E-07	6.89E-07	1E-06	1.51E-06	2.2E-06	3.25E-06
66	1.57917	1.49173	1.43229	1.38761	1.32698	1.01593	0.612718	0.33342	0.09904	0.013912	4.5E-12	5.19E-08	2.9E-07	4.33E-07	6.5E-07	9.67E-07	1.4E-06	2.1E-06
67	1.49466	1.41033	1.35373	1.31086	1.25257	0.95665	0.574063	0.31076	0.09139	0.012614	3.6E-12	2.46E-08	1.8E-07	2.68E-07	4.1E-07	6.14E-07	9.1E-07	1.35E-06
68	1.41468	1.33338	1.2795	1.23841	1.18242	0.90098	0.53806	0.28975	0.08441	0.011457	3.1E-12	9.8E-09	1.1E-07	1.64E-07	2.5E-07	3.85E-07	5.8E-07	8.62E-07
69	1.33897	1.26063	1.20935	1.17001	1.11627	0.84869	0.504495	0.27028	0.07804	0.010419	2.6E-12	2.71E-09	6.2E-08	9.76E-08	1.5E-07	2.39E-07	3.6E-07	5.47E-07
70	1.26732	1.19184	1.14307	1.10542	1.05389	0.79955	0.473182	0.25226	0.07222	0.009522	2.3E-12	1.61E-10	3.4E-08	5.64E-08	9.2E-08	1.46E-07	2.3E-07	3.44E-07
71	1.1995	1.12681	1.08044	1.04443	0.99506	0.75338	0.443954	0.23558	0.06688	0.008683	2E-12	3.36E-13	1.8E-08	3.13E-08	5.3E-08	8.69E-08	1.4E-07	2.13E-07
72	1.13531	1.06533	1.02125	0.98684	0.93957	0.70997	0.416663	0.22013	0.06198	0.00793	1.7E-12	2.68E-13	8.4E-09	1.63E-08	3E-08	5.03E-08	8.2E-08	1.3E-07
73	1.07455	1.00721	0.96531	0.93245	0.88723	0.66917	0.391168	0.20581	0.05749	0.007254	1.5E-12	2.26E-13	3.3E-09	7.67E-09	1.5E-08	2.78E-08	4.7E-08	7.75E-08
74	1.01705	0.95226	0.91246	0.88109	0.83785	0.63079	0.367342	0.19252	0.05335	0.006645	1.3E-12	1.92E-13	9.2E-10	3.05E-09	7.2E-09	1.45E-08	2.6E-08	4.48E-08
75	0.962618	0.9003	0.8625	0.83258	0.79126	0.5947	0.345066	0.18016	0.04956	0.006095	1.2E-12	1.65E-13	5.4E-11	8.42E-10	2.9E-09	6.83E-09	1.4E-08	2.48E-08
76	0.911104	0.85118	0.81529	0.78676	0.74731	0.56074	0.324233	0.16867	0.04607	0.005598	1E-12	1.42E-13	1.1E-13	4.97E-11	7.9E-10	2.72E-09	6.4E-09	1.29E-08
77	0.862346	0.80474	0.77067	0.74348	0.70583	0.52879	0.30474	0.15798	0.04286	0.005147	9.1E-13	1.22E-13	9E-14	1.04E-13	4.7E-11	7.5E-10	2.6E-09	6.09E-09
78	0.816198	0.76084	0.7285	0.7026	0.66668	0.49872	0.286494	0.14803	0.03991	0.004738	8.1E-13	1.06E-13	7.6E-14	8.23E-14	9.8E-14	4.42E-11	7.1E-10	2.42E-09
79	0.772519	0.71933	0.68864	0.66399	0.62974	0.47042	0.269409	0.13876	0.03719	0.004366	7.2E-13	9.24E-14	6.4E-14	6.92E-14	7.8E-14	9.22E-14	4.2E-11	6.68E-10
80	13.6631	12.4745	11.9301	11.4766	10.8407	8.01917	4.48708	2.26108	0.58297	0.064047	8.8E-12	9.15E-13	5.1E-13	5.26E-13	5.6E-13	6.04E-13	6.6E-13	4E-11