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Summary

The shortbelly rockfish, *Sebastes jordani*, is one of the most abundant rockfish species in the California Current, and is a key forage species for many piscivorous fish, birds, and marine mammals. This species has not been the target of commercial fisheries, and consequently catch data are limited. Nevertheless, available evidence suggests that the population has undergone significant fluctuations in abundance over the last several decades. The most robust result was a substantial decline in relative abundance between the late 1980s through the 1990s and into the present (~2006). We present a population model, using standard assessment methods and a variety of survey and food habits data, to investigate population changes for this ecologically important species. The results from this analysis provide an opportunity to consider the dynamic nature of an unexploited rockfish population, and should ultimately provide insight into the potential causes and consequences of natural population variability on both exploited and non-exploited populations throughout the California Current. This model and documentation were evaluated and revised during a three day review panel in June 2006 attended by Dr. Chris Francis, Dr. William Lenarz, Dr. George Watters and Mr. Tom Ghio; reports from Dr. Francis and Dr. Lenarz are included as appendices to this memorandum. This documentation also supplements the manuscript on shortbelly rockfish population dynamics published as Field et al. (in press).

Introduction

The shortbelly rockfish (*Sebastes jordani*) range from Punta Baja in Baja California (Klingbeil 1975) as far north as La Perouse Bank off of British Columbia, and as far west as the Cobb seamount off the southern Washington coast (Pearson et al. 1993). However, they are most abundant along the continental shelf break between the northern end of Monterey Bay and Point Reyes, California (particularly in the regions of Ascension Canyon and the Farallon Islands), and around the Channel Islands in the Southern California Bight (Phillips 1964, Pearson et al. 1991, Moser et al. 2000, Love et al. 2002). Although stock structure is poorly understood, genetic analysis of fish collected between San Diego and Cape Mendocino (California) suggest a single, coastwide stock, with slight differences in allele frequencies across Point Conception (Constable 2006). This report considers only the shortbelly rockfish population in this region, which is shown in Figure 1 along with the approximate spatial coverage and duration of the principal data time series used in the model.

Shortbelly rockfish feed primarily on juvenile and adult euphausiids, and are an important prey item to a wide range of piscivorous fishes, seabirds and marine mammals (Chess 1988, Lowry and Carretta 1999, Sydeman et al. 2001). Merkel (1957) reported that juvenile shortbelly rockfish were important prey of Chinook salmon along the central California coast in late spring and summer, accounting for more than 60% of those identified to species. For many breeding California seabirds, as much as 90% of their diet is comprised of pelagic stages of juvenile (age 0) rockfish during the late spring and early summer breeding seasons, and unexploited species (such as shortbelly) generally account for more than two-thirds of the juvenile rockfish identified (Ainley et al. 1993; Sydeman et al. 2001; Miller and Sydeman 2004). However there is considerable interannual and interdecadal variability in the

frequency of rockfish in seabird diets. Throughout the 1990s, foraging rates on juvenile rockfish by central California seabirds declined for both exploited and unexploited rockfish species primarily in response to changes in ocean conditions associated with poor recruitment for rockfish (Sydeman et al. 2001; Miller and Sydeman 2004; Mills et al. in press). Although rockfish have rarely been identified to the species level in the diets of many California Current marine mammals (Morejohn et al. 1978; Antonelis and Fiscus 1980; Stroud et al. 1981; Perez and Bigg 1986), *S. jordani* were among the five most significant prey items for California sea lion (*Zalophus californianus*) in the Channel Islands (Lowry and Carretta 1999) and are frequently encountered in sea lion food habits samples off of Central California (M. Weise, pers. com., see also Weise and Harvey 2006). Shortbelly rockfish are also described as important prey to thresher sharks (Preti 2004), longnose skate (Robinson et al. in press), and jumbo squid (Field et al. in review), among others. Consequently, shortbelly rockfish are an important forage species to a wide range of predators throughout the California Current ecosystem, and generally have a trophic position and life history traits more similar to forage fishes than most other *Sebastes*.

Management History

The expectation of eventual development of a domestic commercial fishery (Kato 1981) led to past efforts to estimate stock abundance and productivity (Lenarz 1980, Pearson et al. 1989, Pearson et al. 1991) as well as evaluations of commercial potential. The first Acceptable Biological Catch (ABC) for shortbelly rockfish was set by the Pacific Fishery Management Council at 10,000 mt for 1983 through 1989. A stock assessment by Pearson et al. (1989, 1991) estimated that allowable catches for shortbelly might range from 13,900 to 47,000 tons per year, based on life history data and hydroacoustic survey estimates of abundance. Subsequently, the Pacific Fishery Management Council established ABC of 23,500 tons, which was reduced to 13,900 tons in 2001 based on observations of poor recruitment throughout the 1990s and the continued lack of a targeted fishery. Yet despite several attempts to develop a commercial fishery for shortbelly, domestic fishery landings have never exceeded 80 tons per year along the West Coast.

Landings and Bycatch

Love et al. (2002) reported that shortbelly rockfish were commonly caught incidentally with trawl gear in the San Francisco-Monterey region during the development of the trawl fishery in the 1930s and 1940s when they were often referred to as steamer rockcod, as they tended to be common in the steamer lanes south of San Francisco. However, as a result of the small size and poor marketability, only modest domestic landings (1 to 65 tons per year) have been reported in the last 25 years. Historical landings were almost certainly less. Phillips (1939) reported that *S. jordani* accounted for 1 lb out of 332,630 lbs examined in Monterey wholesale fish markets between 1937 and 1938. Nitsos (1965) reported trace amounts (approximately 1000 lbs out of 1,920,000 lbs landed) of *S. jordani* landed in Monterey ports from trawlers in 1962-1963, but none were reported from ports other than Monterey. There was historically a short period in which large numbers of shortbelly were caught during the foreign fisheries of the 1960s and 1970s (Rogers 2003). These landings

(nearly 15,000 tons through 1976, over half of which was taken in 1966) were presumably incidental to the targeting of other rockfish and Pacific hake (*Merluccius productus*). Only in the early days of the foreign fisheries (the mid 1960s) were Pacific hake pursued in large numbers south of Cape Mendocino, which is when the bulk of documented historical landings of shortbelly occurred. Since the early 1970s the Pacific hake fishery has been prosecuted primarily off of Oregon and Washington, and to a lesser extent off of Northern California (generally north of Cape Mendocino).

The available data for bycatch rates of shortbelly rockfish are extremely sparse. Shortbelly can be caught incidentally, at times in large numbers, by trawlers targeting other semi-pelagic rockfish (usually chilipepper and widow rockfish). As large hauls of shortbelly are not marketable but occasionally foul the mesh of typical groundfish trawls, more experienced fishermen generally recognize shortbelly sign (as well as habitat preferences) on their acoustics, and work to actively avoid schools (T. Ghio, Groundfish Advisory subPanel, Pacific Fishery Management Council, pers. com). Bycatch monitoring programs conducted north of Cape Mendocino in the mid-1980s suggested very negligible levels of bycatch, such that shortbelly were less than 0.25% of total catches in all fishing strategies (which included nearshore flatfish, bottom rockfish, midwater rockfish and whiting, shrimp and the deepwater complex), including less than 0.05% for midwater trawl whiting and rockfish (Pikitch 1988). Very little contemporary information is available for the region south of Mendocino. However all of these data were collected far north of the usual range of shortbelly, and are of little utility. Data processed from the West Coast Groundfish Observer Program suggests that approximately one ton of shortbelly rockfish were caught and discarded in trawl fisheries south of Mendocino in 2005 (Hastie and Bellman 2006). As regulatory measures have closed the vast majority of habitat optimal to adult shortbelly, such trace landings are to be expected in recent years, and comparable data prior to these closures does not exist.

Some early quantitative data are available from Heimann (1963) who recorded catch composition, weights and discards from commercial trawlers operating between Pigeon Point and Point Sur, CA in 1960. Heimann segregated data from the observed tows into three general categories; shallow-water tows (targeting primarily flatfish), intermediate-depth tows (targeting primarily shelf rockfish) and deepwater tows (targeting primarily slope rockfish and mixed flatfish). Only the intermediate depth tows encountered significant numbers of shortbelly rockfish, which represented 3,412 lbs out of a total rockfish catch of 43,589 lbs (primarily chilipepper and bocaccio rockfish), with total catch of all species of 48,629 lbs. Of the 19 tows observed in this strata, 16 encountered shortbelly rockfish, and an estimated 3410 of the 3412 lbs of shortbelly encountered were discarded. Shortbelly were not noted in any of the nearshore tows, and only very minor numbers of shortbelly (21 lbs out of 5273 lbs of rockfish, 9034 lbs of all species) were encountered in the four deep-water tows observed. In a similar study, Heimann and Miller (1960) evaluated trawl and party boat fisheries in Morro Bay, and described shortbelly as present in 37 out of 64 hauls evaluated, comprising 0.33% of the catch by weight (364 out of 110,805 lbs) of rockfish species. No shortbelly were reported landed in commercial passenger fishing vessels from that study.

One reasonable means of bracketing potential bycatch might then be 7.8% of the shelf rockfish landings (from trawl gear) in the region of high shortbelly abundance (Monterey and San Francisco area ports) as well as the entire area being modeled (all ports south of Cape Mendocino) over the time period being modeled. As the latter is likely to be an overestimate (given that the rate is based on the bycatch rate in a region thought to reflect peak density), we might assume that this estimate would encompass any fixed gear (hook and line, setnet) or recreational catches, both of which would presumably be extremely modest. The former estimate may or may not be an underestimate, but provides a reasonable alternative to extrapolating the bycatch rate to the entire coast and represents approximately 50% of the latter estimate. Both potential catch time series were explored, as well as a time series of reported landings only (typically less than 10 mt/year, with a peak of 65 mt in 1997). The estimated catch by foreign fisheries was also included (Figure 2).

Model and Data

The population was modeled using an age and size structured statistical model, Stock Synthesis II (SS2), a modeling framework used for most recent California Current groundfish assessments. This modeling framework was developed with the intent of allowing the complexity of the model to be consistent with the quantity and quality of the data commonly available for West Coast groundfish. The model treats a cohort as a collection of fish whose size-at-age is characterized by a mean and a variance, such that the numbers at age are distributed across defined length bins- similar to a length-age transition matrix, although with the potential to account for the effects of size-specific survivorship. The model also allows for growth, mortality, selectivity and other functions to be time varying, although such features have not been utilized here. In our application, parameters for growth, fecundity and maturity were estimated externally from the model and input as fixed values. A full description of the population dynamics, selectivity and catch equations, and associated likelihood functions are given in Methot (2005a), while a more practical guide to using this modeling framework is provided in Methot (2005b). The base model developed here is based on equal emphasis factors (lambdas=1.0) for each likelihood component.

Life History

The shortbelly rockfish is best characterized by a fusiform body pattern small size, rapid growth and maturity (approximately 50% of females are mature by age 2, 99% by age 3), and high natural mortality rate (Pearson et al. 1991; Love et al. 2002). Off of Central California, pelagic juveniles tend to recruit to kelp beds and nearshore areas in summer months (June to August), and may recruit to deeper waters as well (Love et al. 2002). Shortbelly are a semipelagic species, which often school in midwater but may also aggregate in large schools over soft-bottom habitat along submarine canyons or steep shelf and slope contours. Schools tend to form in thick aggregations near the bottom during the day, and disperse throughout the water column at night. In this application, growth, fecundity and maturity were estimated externally from the model, based on data obtained from over 8500 aged fish (most of which has been previously published in Pearson et al. 1989; Pearson et al. 1991; and Ralston et al. 2003), and resulting parameter estimates were input as fixed values.

The growth and maturity parameter values are shown in Table 1 and described in the following sections.

Pearson et al. (1989; 1991) estimated natural mortality for shortbelly to be in a range of 0.2 to 0.35 using a variety of methods. Shortbelly rockfish have now been aged to at least 30 years, however this represented one of the 8500 individuals available for this assessment, and the next oldest individual was aged to 24 years. Altogether, very few individuals have been described as greater than 20 years of age. In our data, 95% of all aged shortbelly available to us (n ~8500) were 12 years of age or less, and 99% of the shortbelly available to us were less than 17 years of age or less. This is consistent with estimates of natural mortality of 0.25 to 0.27 based on the Hoenig (1983) rule of thumb approach (such that M is equal to $-$ ln(P)/t_{max}, where P is the proportion of animals surviving to t_{max}). We also evaluated plausible natural mortality rates based on Pauly's method (Pauly 1980), which provided estimates on the order of ~0.35 to 0.43, and Jensen's method (Jensen 1996), which suggests natural mortality rates on the order of 0.24 to 0.37. Ralston et al. (2003) estimated natural mortality with a catch curve to be 0.26, which was consistent with the range of results we evaluated looking at additional catch curves from a wider range of survey sources. Consequently, we used a fixed natural mortality estimate of 0.26, consistent with the range estimated by Pearson et al. (1991), the estimates based on the Hoenig approach, and the point estimate developed by Ralston et al. (2003).

Although maturity could vary both as a function of length and age, for the purposes of parameterizing SS2 the logistic regression model was fit as a function of length. The fraction mature in each 1 cm size class was estimated with a logistic regression, using data collected from 1139 fishes ranging in size from 8 to 32 cm, based on the relationship

$$\varphi_\ell = \frac{1}{1 + e^{(\alpha*(\ell-\beta))}}$$

Where φ is the predicted fraction mature at length ℓ, with a slope α and length at 50% maturity of β. In these samples, less than 5% of fish size 12 cm and smaller were mature, while 95% of fish between 16 and 18 cm, and all fish greater than 19 cm, were determined to be mature. The observed and estimated proportions mature by length are shown in Figure 3, and the resulting parameter estimates are reported in Table 1.

Individual growth is modeled independently for each sex using the Schnute (1981) parameterization of the von Bertalanffy growth equation, based on 5059 aged individuals, where:

$$L_a = L_\infty + (L_{min} - L_\infty)e^{-K(a-a_{min})}$$

and

$$L_\infty = L_{min} + \frac{(L_{max} - L_{min})}{(1 - \exp^{(-K*(a_{max} - a_{min}))}}$$

where L_a is the mean length at age a, L_∞ is the mean asymptotic size, a_{min} is the reference age for young fish, L_{min} and L_{max} are the corresponding mean sizes of fish at a_{min} and a_{max}, and K is the growth coefficient. The observed and predicted length at age relationship is presented in Figure 4, with parameter values by sex reported in Table 1. The standard deviation in size at age was estimated at 2 cm. Although there are modest differences in size at age suggested in time, and latitudinal gradients in size-at-age have been demonstrated for both widow and yellowtail rockfish (Pearson and Hightower 1991, Tagart 1991), most of the data available for this study were from a relatively time periods and region. Consequently, we made no effort to search for potential differences in growth over space or time. The weight-length relationship was modeled as

$$W = aL^b$$

based on weight and length data collected from 641 fish, these parameters are reported in Table 1. Although Ralston et al. (2003) estimated that relative egg production may be slightly greater in larger females, fecundity has been assumed to be directly related to spawning biomass in this model.

Biomass Point Estimates

Pearson et al. (1989; 1991) used hydroacoustic survey estimates of abundance in the region between Monterey Bay and Point Reyes, CA, to arrive at an estimate of optimal yield for the shortbelly rockfish stock. Hydroacoustic estimates were 295,000 and 153,000 tons in 1977 and 1980 respectively, however as there is no estimate of target strength for shortbelly rockfish, the hydroacoustic estimates assumed a target strength equivalent to hake, and are highly uncertain. No effort has been made since this time to either develop a target strength estimate or to estimate the biomass of shortbelly rockfish in subsequent acoustic surveys (Chris Wilson, AFSC, pers. com). In midwater and bottom trawls done to validate the species composition of acoustic surveys, shortbelly rockfish have typically been among the most abundant species after Pacific hake, particularly in trawls done in the region between Monterey and Point Reyes (Nelson and Dark 1985; Wilson and Guttormsen 1995), yet only modest numbers of shortbelly were caught during the 2001 and 2003 surveys (Guttormsen et al. 2003; Fleischer et al. 2005). However, given the non-random nature of such tows, there is little information to be gained in evaluating these data further.

Ralston et al. (2003) used an estimate of larval production (essentially daily larval production and population weight-specific fecundity), and estimated that the spawning biomass in the Monterey to San Francisco area was 67,400 tons in 1991, considerably less than the earlier hydroacoustic survey estimates (Figure 5). MacGregor (1986) had earlier reported on the relative distribution of shortbelly larvae throughout the California Current, such that 53% of shortbelly larvae occurred in the Monterey area, 35% occurred in the Channel Islands area, with the remaining ~12% occurring near the central coast (Morro Bay

and Big Sur regions). This suggests that assuming a fixed catchability of 0.53 for the Ralston et al. (2003) biomass point estimate for 1991 would be reasonable. Although we did not use area-swept biomass estimates from the triennial survey (these data are discussed later), we note that these estimates provided a peak estimate of over 30,000 tons in 1977, with an average of 14,500 tons throughout the survey time series. The meta-analysis of catchability estimates for West Coast *Sebastes* suggested a mean on the order of 0.2 (Millar and Methot 2002), with outliers including widow rockfish (another semi-pelagic species) which was likely to be considerably lower. This catchability coefficient would suggest that the 1977 Triennial Survey biomass estimate would be on the order of 150,000 tons, and the average biomass would be roughly 72,500 tons, excluding the biomass south of Point Conception. Consequently, the biomass estimate based on the Ralston et al. (2003) point estimate represents a reasonable bounds for the total biomass of shortbelly rockfish in the U.S. waters of the California Current.

CalCOFI larval abundance data

Egg or larval abundance data from the California Cooperative Oceanic and Fisheries Investigations (CalCOFI) surveys have been used in stock assessments for a number of commercially important west coast species, including northern anchovy (Jacobson and Lo 1994), Pacific sardine (Conser et al. 2002), bocaccio rockfish (MacCall 2003) and sheephead (Alonzo et al. 2004). Although a larval abundance index was developed in the first stock assessment for cowcod (*S. levis*, Butler et al. 1999), this index was not included in the most recent assessment (Piner et al. 2006) out of concerns for the rarity of cowcod in sampled tows. Cowcod larvae are among the rarest of those larvae identifiable to species identified to species in CalCOFI ichthyoplankton dataset, with a total of 550 larvae counted in 117 positive tows in the standard survey area between 1951 and 1998 (Moser et al. 2000). By contrast, shortbelly rockfish larvae are the most frequently occurring of the rockfish larvae identifiable to species, accounting for approximately 15% of the total rockfish larvae in the survey and occurring in nearly half of the stations in the standard CalCOFI grid (Moser et al. 2000). Although a number of changes in the CalCOFI sampling protocols have occurred over time, including changes in the size and material used in plankton nets, such changes have been accounted for in the calculation of larval abundance (Stevens et al. 1990).

We used tow-specific information and a Delta-GLM approach, which combines a binomial model for presence/absence information with a model of catch per unit effort for positive tows (Stefansson 1996, Maunder and Punt 2004), to generate a relative index of spawning biomass. The data used in this analysis were comprised of 7,563 observations between 1951 and 2005, which include the regularly sampled survey grid observations as well as the extended survey of northern areas (up to 38.5° N latitude); note that from 1967-1984 the CalCOFI survey was limited to a triennial survey. *S. jordani* were identified for the northern areas only for the periods between 1972-1984, 1997-1998, and 2003-2005. Presence/absence (π) was modeled with binomial GLM using a logit link, where:

$$\log\left(\frac{\pi_i}{1-\pi_i}\right) = \mathbf{x}_i^T \boldsymbol{\beta}$$

and the mean (μ) of positive tows was modeled with a normal linear model for the log-transformed data.

$$\mu_i = \log(y_i) - \varepsilon_i = \mathbf{x}_i^T \boldsymbol{\beta}, \qquad \varepsilon \sim \mathrm{N}(0, \sigma^2)$$

As there was no evidence of diel effects (night, day, dawn, dusk), both models included year, latitude, period (bins of 10 julian days), and distance from shore effects. The final index of abundance was the product of the year effects of the two models ($\pi\mu$). However, due to observed interactions between year and latitude effects in the coastwide model, delta-GLM indices were also estimated for the 'southern' (31.5° N – 35.5° N) and 'northern' (35.5° N – 38.5° N) regions (Figure 6). The northern model was limited to 344 observations, and is therefore unlikely to be a reliable index of relative abundance, while the southern model closely mimics the results of the coastwide model (Figure 7). Consequently, the coastwide model and the associated standard errors estimated from a jackknife routine were used as an index of relative abundance for the spawning stock, with selectivity set equal to the maturity curve. In general, high levels of abundance were observed throughout most of the 1950s, and the period from the late 1980s through the early 1990s, while very low abundance levels occurred during the 1958-1959 El Niño, from the mid-1970s through the early 1980s, and through the late 1990s. Figure 8 shows the resulting latitude, distance from shore and julian day effects for the resulting model. Throughout the time series, there is apparently considerable high frequency year-to-year variability in larval distribution and abundance for *S. jordani* as well as other *Sebastes* species, that may be related to oceanographic features and variable reproductive output rather than reflecting actual high frequency changes in abundance (MacGregor 1986; Moser et al. 2000; Lenarz and Wyllie Echeverria 1986; Lenarz et al. 1995).

Triennial Trawl Survey

A primary source of fishery independent information for most managed and assessed groundfish species in the California Current is the West Coast triennial trawl survey conducted between 1977 and 2004. For many species, particularly semi-pelagic species, the patchiness of catches in the survey is particularly problematic and area-swept methods of estimating abundance are highly uncertain. For example, out of nearly 1500 tows made south of Cape Mendocino between 1977 and 2004, over half the total catch of shortbelly rockfish was made in only six tows, and over 95% of the catch was made in only fifty tows. We obtained haul-specific survey data from 1977 to 2004 (M. Wilkins, AFSC, pers. com; B. Horness, NWFSC, pers. com), and excluded bad performance tows, including "waterhauls," based on Zimmermann et al. (2001). We included all remaining tows south of Cape Mendocino (40° N) that occurred between depths of 55 to 366 meters for all years, with the exception of a small number of tows made south of 34° 30" in 1977 (as the survey did not sample this region in subsequent years). Catch per unit effort (CPUE) was estimated for each tow as in Weinberg et al. (2002), and are shown graphically in Figure 9. Figure 10 shows the traditional area swept biomass estimates, developed by expanding average catch rates by depth and latitude strata as in Weinberg et al. (2002), as well as the frequency of occurrence

of large and small catches. However, we developed an alternative index of relative abundance using a delta-GLM that had year, latitude (in 2˚ bins), and depth (in 50 meter bins) factors. The resulting index, with standard error is shown as Figure 11, and Figure 12 shows the corresponding latitude and depth effects. This is comparable to the approach used by Helser et al. (2005) for generating indices of abundance for slope groundfish for the 2005 assessment cycle, and He et al. (2006) for another semipelagic species, widow rockfish (*S. entomelas*).

Length frequency data were also generated for each survey year, in one centimeter length bins between 5 and 32 cm, and were expanded to account for the catch weight in each haul. The resulting length frequencies by sex and year are presented as Figure 13. Due to differences in the depth strata sampled in 1977 (a year in which the survey sampled depths of 90 m and greater, as opposed to 50 m and greater in subsequent years), and low sample sizes (only two hauls had length samples taken for shortbelly rockfish) in 1980, only length data from 1983-2004 were used in the base model. Length data also clearly demonstrate a movement to deeper water with size, as shown earlier by Lenarz (1980), and there is some indication that fish in the south tend to average smaller sizes than fish in the north (Figure 14). Sample sizes for the model were based on the number of hauls in which shortbelly were caught (and length data collected), rather than the number of individual fish measures.

Juvenile Trawl Survey

The Fishery Ecology Division of the Southwest Fishery Science Center has conducted a standardized midwater trawl survey during May-June aboard the NOAA R/V David Starr Jordan every year since 1983. The primary purpose of the survey is to estimate the abundance of pelagic juvenile rockfishes (*Sebastes spp.*) and to develop indices of year-class strength for use in groundfish stock assessments on the U. S. west coast. This is possible because the survey samples young-of-the-year rockfish when they are ~100 days old, an ontogenetic stage that presumably occurs after year-class strength is established, but before cohorts recruit to commercial and recreational fisheries. Historically, the survey was conducted between 36°30' to 38°20' north latitude, (approximately Carmel to just north of Point Reyes, CA), but in 2004 the spatial coverage was expanded from Cape Mendocino in the north to the U.S./Mexico border. Shortbelly rockfish are by far the most abundant rockfish species in the juvenile survey data, accounting for just over 85% of the rockfish identified to species since 1983.

This survey has encountered tremendous interannual variability in the abundance of the ten species that are routinely indexed, as well as high apparent synchrony in abundance among the ten most frequently encountered species. In Figure 15, ten species-specific time series of standardized abundance ($\mu = 0.0$ and $\sigma = 1.0$ on logarithmic scale) are plotted, along with the first two principal component scores for the collective rockfish assemblage. A number of striking patterns are evident, including: (1) substantial high frequency interannual variation (e.g., 1991-1992), (2) obvious low-frequency variability, as evidenced by the protracted period of low abundance from 1994-2000, and (3) a divergence in the relationship between the first and second principal components, which are positively correlated early in the time series but are negatively correlated late. The first of these conclusions is consistent

with very poor reproductive success for these winter-spawning species during El Niño years, including the 1983, 1992, and 1998 events. The second observation is potentially related to "regime" scale variability. Finally, the third relationship is apparently due to a shift in the species composition of survey catches towards a more northern assemblage, particularly during the last 4 years, as evidenced by relatively higher catches of blue, black, widow, and canary rockfish in relation to catches of shortbelly, bocaccio, chilipepper, and squarespot rockfish.

Indices of year-class strength derived from this have been used in forecasting year class strength for a number of groundfish species, including widow rockfish (He et al. 2005), Pacific hake (Helser et al. 2005) and chilipepper rockfish (Ralston et al. 1998). The survey index is calculated after the raw catch data are adjusted to a common age of 100 days to account for interannual differences in age structure. Similar to other surveys, we used a delta-GLM to remove spatial and seasonal effects, with a jackknife routine to estimate the standard error and CV (Figure 16). Past assessments have at times used a power coefficient to transform this index, based on the assumption of a compensatory relationship between pelagic juvenile abundance and subsequent recruitment to the adult population following settlement (Adams and Howard 1996). Although this transformation was explored during the development and review of the model, there was consensus that such a transformation could be misleading for this stock due to the lack of age data to validate relative year class strength in the model.

Several observations from 2005 and the most recently completed cruise (2006) are relevant. During 2005, pelagic juvenile rockfish catches (including shortbelly) in the core part of the survey area were at an all time low when considered in relation to the 23 years the survey has been conducted. More recently, 2006 juvenile abundance levels (which were not available when this assessment was first developed and reviewed), show equally poor recruitment. Furthermore, with data available from the expanded survey coverage in 2005, including several years of northern data from a comparable survey conducted by the Pacific Whiting Conservation Cooperative and the Northwest Fisheries Science Center, two types of shifts in distribution were revealed. Specifically, species characterized by a more southerly geographic range (e.g., bocaccio, shortbelly, and squarespot rockfish) were caught in relatively large numbers south of Point Conception, particularly in 2005 and 2006, while species with more northerly distributions (widow, canary, and yellowtail rockfish) were caught in moderate numbers north of Cape Mendocino. Apparently the near absence of fish in the core survey area then, was associated with a redistribution of fish both to the north and the south of the core survey area, which also happens to be the core of the distribution for this species.

Seabird food habits data

Marine birds have often been described as potential ecosystem indicators, and a modest but growing literature suggests that seabird food habits data could play a useful role in the assessment of stock status and/or recruitment for some species (Sunada et al. 1981, Montevecchi and Myers 1995). However behavioral complications can undermine the utility

of such data in quantitative population assessments, as seabirds (and marine mammals) food habits tend to reflect prey availability rather than abundance, and predators tend to concentrate their effort where prey are most available. As Cairns (1992) and Walters (2003) point out, these are complications that similarly undermine the integrity of many fisheries-dependent time series.

The abundance, biology and food habits of several species of seabirds in the California Current have been monitored by the Point Reyes Bird Observatory (PRBO) on the Southeast Farallon Islands (west of San Francisco, CA) since the early 1970s, providing thirty year time series of food habits for some species (Ainley et al. 1996, Miller and Sydeman 2004). Although prey information is collected for several species, one of the most important is the Common Murre (*Uria aalge*), which is one of the most abundant piscivorous seabirds in the California Current (Wiens and Scott 1975, Hunt et al. 2000). Common murre have numbered between 30,000 and 110,000 breeding birds on the islands since the early 1970s, and juvenile rockfish dominated the diets of murres (and many other seabird species, particularly the rhinoceros auklet, *Cerorhinca monocerata*) throughout most of the 1970s and 1980s. However the proportion of rockfish in seabird diets declined severely through most of the 1990s, likely related to ocean conditions (Sydeman et al. 2001, Miller and Sydeman 2004). Figure 17 shows the decline in rockfish observed in Common Murre and Rhinoceros Auklet diets from these data, associated sample sizes are reported in Table 2.

Several factors make the utility of this dataset as an indicator of year class strength appealing. First, shortbelly are generally quite easy to distinguish in the sampling regime, and are the overwhelmingly dominant rockfish species found in murre diets (Ainley et al. 1996). Second, research has shown that common murres prefer to forage locally for juvenile rockfish during their breeding season (May-June, when juvenile rockfish are most abundant), because the close proximity to the breeding grounds reduces foraging trip duration. In years when juvenile rockfish are less abundant, murres forage in coastal waters for northern anchovy (*Engraulis mordax*) and other forage fishes (Ainley and Boekelheide 1990, Miller and Sydeman 2004). Third, the species composition of common murre prey has been at least partially validated by comparisons with rhinoceros auklet food habits from 1987-2004. Although samples of murre diets are observed from a distance of 10 meters, usually with binoculars or unaided vision for which some identification error is unavoidable, rhinoceros auklet prey are physically taken from the sampled birds and identified to species in a controlled setting (Sydeman et al. 2001). Finally, Mills et al. (in press) described the proportion of juvenile rockfish in murre diets as being highly correlated (R^2=0.81) to the NMFS midwater trawl estimates of juvenile abundance, which indexes juvenile rockfish abundance over a larger spatial extent (see also Ainley et al. 1993). Similarly, the proportion of rockfish in the diets of Pigeon Guillemots (*Cepphus columba*), Rhinoceros Auklets, and Chinook salmon have been shown to be correlated with each other, as well as the NMFS juvenile survey (Mills et al., in press).

Individual prey observations were treated with a binomial GLM (logit link) to obtain annual indices and remove calendar date effects. Annual indices were arcsine transformed, as is appropriate for indices of proportionality (Zar 1996). The resulting index (which deviated

little from the raw frequency of occurrence results) was included in the model as an index of age 0 abundance for the period from 1975 to 2004. As this survey can best be thought of as an index of juvenile rockfish over a smaller spatial scale to the juvenile cruise index, the coefficients of variation (CVs) input to the model were set to a maximum of the mean CV from the juvenile survey index, or the estimated CV from the GLM model. Neither the Rhinoceros auklet, nor the Pigeon Guillemot data were used as indices in the model, due to the more limited foraging ranges of these two species relative to the Common Murre (Figure 18), as well as some questions regarding the "independence" of observations for Rhinoceros auklets (while Murres deliver a single prey to their chicks, with multiple trips per day, Rhinoceros auklets deliver a "bill-load" of fish to their chicks in the evening, thus one might not expect every given prey item to be "independent" of the next). However, the Rhinoceros auklet data generally confirm the shortbelly trend observed in the Murre data; the R^2 between the resulting index and a comparable index generated for Rhinoceros Auklets is 0.70.

Although not used in the model, salmon food habit studies conducted throughout this same period are also consistent with the pattern of juvenile rockfish (including shortbelly) variability inferred by both the trawl survey and the seabird food habit studies. Although this sampling was not have been conducted optimally for a cpue time series (as stomachs were collected from salmon charter vessels when individual captains reported large numbers of juveniles to biologists), the data generally support the trends indicated by the juvenile trawl survey and seabird food habits indices (Figure 19; see Mills et al., in press).

Sea lion food habits data

Another source of food habits data were also available for this model, based on ongoing monitoring of California sea lion (*Zalophus californianus*) food habits in the Channel Islands (Lowry et al. 1990, 1991; Lowry and Carretta 1999). Scat samples have been collected at regular (monthly to quarterly) intervals from 1981 to the present, from San Nicolas, San Clemente, and Santa Barbara Islands. Prey species have been identified to the lowest possible taxon based on recovered hard parts (otoliths, cephalopod beaks, shark teeth, and invertebrate exoskeletal fragments). For the period between 1981 and 2002, over 9300 samples with identifiable prey remains were collected and enumerated. Shortbelly rockfish were among the most frequently occurring prey, generally present in 10 to 30% of samples. Other important prey species include northern anchovy (*Engraulis mordax*), market squid (*Loligo opalescens*), Pacific hake (*Merluccius productus*), and jack mackerel (*Trachurus symmetricus*). Halfbanded rockfish (*S. semicinctus*) was the next most abundant rockfish identified to species, other *Sebastes* species were relatively infrequent. Although the relative importance of all prey items varied over time, Lowry and Carretta (1999) showed that the frequency of occurrence of market squid was closely correlated to market squid landings from commercial fisheries in southern California, which are commonly though to reflect the relative abundance of this highly variable resource.

The presence or absence of shortbelly in sample data were treated with a binomial GLM (logit link) with year, island and seasonal effects, and the arcsine transformed year effects were used as an index of relative abundance. Length frequency information was also

available to assess the vulnerable portion of the shortbelly stock being predated upon, with lengths reconstructed from otolith lengths in specimens that were not eroded by digestion, based on the otolith to fish length regression reported in Wyllie Echieverra (1987). A total of just over 3900 reconstructed lengths are available from 1981 through 2003, most of which are between 5 and 20 cm. This suggests that sea lions are primarily foraging on younger, more shallowly distributed shortbelly rockfish, which may become less vulnerable as they move into deeper water with age and size. California sea lions are known to forage in waters between 0 and 500 meters, yet most foraging seems to take place between depths of 20 to 280 meters (Melin 2002), overlapping most of the range of shortbelly rockfish. In the length composition data itself, strong cohorts are clearly visible over time (Figure 20), these cohorts are even more visible when data are plotted on seasonal time scales (Figure 21). The cohorts are also cohesive across space, with length compositions from different islands suggesting similar strong year classes. Length compositions were pooled into annual averages, with an assumed 1:1 sex ratio by length. Table 3 shows the number of samples collected by year and island, including the number of reconstructed lengths by year.

Although the lack of age data or other juvenile indices for this region may make validating the signal from this dataset difficult, it is worth noting that the information content of these data have been at least partially validated with respect to sea lion predation on Pacific hake (*Merluccius productus*). Pacific hake are one of the most frequently encountered prey items by sea lions in this region, and are also the largest fishery by volume in the California Current, and one of the largest by value. Pacific hake are also among the most dynamic groundfish populations in the ecosystem, with extremely high recruitment and population variability (Helser et al. 2006). To evaluate the potential for the sea lion data to be informative with respect to impending year class strength, a model was developed that accounted for fisheries landings (smoothed with a 3-year running mean and without including length data for the post-1978 period), had a growth curve fit to age 0-3 fish (to better capture the size composition at young ages), and used frequency of occurrence information as relative abundance data, with reconstructed "length composition" data from the otolith length-fish length regressions (~9000 observations). The resulting recruitments from the model compared favorably with those from the most recent (2006) hake stock assessment, particularly with respect to capturing the magnitude of the tremendously strong 1980, 1984, and 1999 year classes. The R^2 between the food habits model and the fisheries model was 0.51, when both time series were log-transformed the R^2 was 0.57.

Model selection and evaluation

We explored a wide range of model structures and trade-offs between model complexity and the informative limits of the data. Through the process of evaluating alternative model configurations, we developed a base model that had growth and the natural mortality rate estimated externally, and sigma-R (the standard deviation of the log-normally distributed recruitment deviations) fixed at 1. The model uses a Mace-Doonan (Mace and Doonan 1988) stock recruitment relationship, where R_0, or equilibrium recruitment, represents the number of recruits that would be expected on average for an unfished stock and steepness (h) refers to the amount of compensation in the spawner-recruit relationship. We estimated

equilibrium recruitment (R_0), but found that the data were inadequate to provide a meaningful estimate of steepness. As steepness values close to 1 represent high compensation and those close to 0.2 represent little or no compensation, we fixed steepness at 0.65, consistent with Dorn (2002). Similar approaches are taken for most West Coast groundfish assessments of commercially exploited species. An additional parameter estimated in this model was a scaling factor for the initial biomass, which allows the starting biomass value to deviate from the model estimated equilibrium biomass. As marine populations are typically not stationary, the equilibrium biomass is best described as the theoretical average level of biomass (or spawning biomass) around which the population would fluctuate in the absence of fishing. Allowing the starting biomass to be higher or lower than this value is typically not done in assessments for commercially exploited species, where historical catches are believed to have a greater impact on population trajectories than recruitment variability, but is a logical approach for this model given the lack of exploitation history.

We also estimated recruitment deviations from 1960 to 2005 (which reflect relatively stronger or weaker year classes than would be expected from the spawner-recruit relationship), logistic selectivity curve parameters for fisheries catches (based on measurements of landed fish), the Triennial Survey length data, and the sea lion prey length composition data. Selectivity curves for the CalCOFI data and the larval production point estimate were fixed at the maturity function. Selectivity for the pelagic juvenile (age-0) indices (the juvenile survey and the seabird data) were age-based and were fixed for both of these indices, such that fish were assumed to be fully vulnerable at age 0, and fully invulnerable at all ages thereafter. The total number of freely estimated parameters in the model was 54, most were recruitment deviations (46) or selectivity parameters (6), with the remaining two the estimated equilibrium recruitment (R_0) and the initial biomass scalar. Table 4 presents the point estimate for these parameters.

Based on discussions of the benefits and pitfalls of model tuning that took place at the June 2006 review panel, including comparisons of tuned versus untuned model output, the only tuning done in arriving at a base model was tuning of the effective sample sizes for the length-frequency compositions in the sea lion data. The rationale for this was that the effective sample sizes based on the raw number of observations was considered likely to overemphasize the importance of this data, while the number of island/season combinations (roughly analogous to the number of tows sampled from a survey for traditional length composition data) was considered to be too low, and underemphasized the data. Consequently, a single iteration was evaluated in which the starting sample sizes were the number of measurements, and this was reduced by a scalar based on the regression (through the origin) of the effective sample sizes against the observed sample sizes from the model, which effectively scaled these sample sizes to ~20% of their starting value.

Base Model Results

A compilation of the primary trend indices used in the coastwide model is included as Figure 22, and the results of the "lightly tuned" base model are presented graphically in Figure 23, which shows the estimated total biomass, spawning biomass and depletion over the

time period from 1950 to 2005. The corresponding values for total biomass, spawning biomass, recruitment, depletion, estimated catch and estimated harvest rates are provided in Table 5. The model estimated a mean unfished total biomass of 98,400 tons and a mean unfished spawning biomass of 49,500 tons. As the starting biomass was allowed to float, the total estimated biomass in 1950 was 381,000 tons with a spawning biomass of 195,000 tons, and the 2005 ending biomass was 64,000 tons with a spawning biomass of 33,000 tons. The depletion level in 2005 relative to the mean spawning biomass was 67%, however the 2005 spawning biomass was only 17% of the 1950 spawning biomass and was only 43% of the estimated 1993 spawning biomass. The consequence of fisheries, including high and low estimates of plausible discards, were estimated to be negligible (<0.01) in all years with the exception of the foreign fisheries of the mid-1960s, in which fishing mortality may have been as high as 0.08. The use of either the "high" or the "low" bycatch streams did not result in meaningful deviations from the base model results; and the "low" catch stream was used in the base model. This suggests that it is unlikely that fishing mortality has had any substantive impact on this stock since the days of the foreign fisheries.

Although recruitment deviations are estimated from 1960 onward, greater confidence can be had in the year class strength variability observed from 1975 onward, as prior to 1975 recruitment deviations are fitting only to long term trends inferred by CalCOFI data. Figure 24 shows the estimated recruitment and recruitment deviation time series, and Figure 25 shows the observed recruitments between 1975 and 2005 plotted around the fixed spawner-recruit relationship. The model clearly suggests a long period of poor recruitment through most of the 1990s, associated with a significant decline in biomass, a trend that is reflected in all of the recruitment and biomass indices used in the model.

Figure 26 shows both the fixed (CalCOFI and larval production, fixed to the maturity function) and fitted (fishery, triennial survey, and sea lion data) selectivity curves, and Figure 27 shows the model fits to the CalCOFI time series data, the triennial survey index, and the sea lion frequency of occurrence index. For the fit to the CalCOFI data in particular, note that the recruitment deviations for the period between 1950 and 1960 were fixed at the equilibrium recruitment, in order to phase in a mean recruitment level for the early part of the time series. Model behavior, and subsequent depletion levels, were highly sensitive to the time in which recruitment deviations were free, particularly given the very rapid decline in the CalCOFI index associated with the 1958-1959 El Niño event. Tuning to an equilibrium recruitment that captured both the high and the low index values throughout the early part of the time series is a reasonable balancing of model freedom and the limitations of the data, however alternative approaches are plausible. Furthermore, throughout the CalCOFI time series, there is considerable high frequency year-to-year variability in larval distribution and abundance for shortbelly rockfish (as well as other *Sebastes* species), that may be not reflect interannual changes in abundance.

The fit to the Triennial Survey index shown in Figure 27 is not remarkable, which is not surprising given that indices of many rockfish, particularly semi-pelagic species, are highly variable in this survey. Although the model does capture the declining trend from the late 1980s through 2001, the early years of the Triennial Survey (1977-1983) suggest a

decline, while the model (by virtue of other indices) predicts an increase in abundance. Similarly, the Triennial Survey index predicts a sharp increase in abundance in 2004. Although there is an increase in recruitment suggested by the juvenile survey data and the seabird data (Figure 28), and the CalCOFI data in the post-1998 period, the increase is of a considerably lesser magnitude than predicted by the 2004 Triennial Survey index. The relative abundance index generated from the sea lion food habits data seems to be uninformative, however the fit to both the seabird food habits data and the juvenile cruise survey data are quite reasonable. These fits also illustrate some of the primary sources of tension in the model, between the strong year classes observed in the sea lion length composition data in the south (which suggest strong 1991, 1995-96, and 1999 year classes) and the seabird and juvenile cruise data in the north (which have very low recruitment throughout the entire 1990s).

The observed, expected, and residual bubble plots of the triennial survey length frequency data are shown as Figure 29, and the same information from the sea lion length composition data is included as Figure 30. For the sea lion data, the poor fit to the smallest size classes of the length frequency data reflects the mismatch between the actual size of pelagic (age 3 to 6 month) juveniles and the growth model predictions of size at age 0.5 years (which are somewhat larger). Although greater seasonal resolution could address some of this mismatch, the consensus of the review panel was that such residuals were essentially unimportant, as they did not affect model behavior. The model results demonstrate that although the relative abundance index generated from the sea lion food habits data is somewhat uninformative, the length composition data associated with this index (discussed below) have a substantial influence on the model as they clearly show patterns of strong and weak year classes. The observed and predicted fits to the age composition data associated with the 1991 larval production point estimate of standing biomass are shown as Figure 31; these were the only age data directly included in the model. Although these data were consistent with the other sources of information with respect to strong and weak year classes, they generally had very little influence on the model behavior.

Model Review and Sensitivity

During the review panel of June 2006 several important changes were made to the review draft with respect to the structure of the model and the parameters that were estimated. These included iterating the sample sizes of the sea lion "length" data (as these data are very informative, but were not informing the model by virtue of assuming very low sample sizes), abandoning the use of a "power transformation" function with the juvenile indices, fixing steepness in the model (which was poorly informed by the data, and is typical of most west coast rockfish assessments), and estimating an initial equilibrium parameter that allowed the model starting biomass to diverge from B_0, which in turn is described as the average long term biomass and recruitment. Several of these changes had strong interactions, for example when the model was run with appropriately weighted length composition data from the sea lion samples (essentially, the only source of relative year class strength beyond the juvenile and seabird surveys), these power parameters were estimated very close to the default value of 1, suggesting that a transformation might not be appropriate in this model. Instead, freeing

this parameter in the model (particularly in the absence of informative length or age data) appears to result in a general "smoothing" of the juvenile index, reducing the overall variance in the model and tending the estimated recruitments towards the mean. This was not unexpected, as the paucity of length and age data prevents an effective tuning to the observed variability in numbers at age, which is the intended purpose of the parameter.

The sensitivity of the model to a wide range of different parameter values was also evaluated, including freeing up parameters such as natural mortality, the duration over which recruitment deviations were freed (e.g., to 1950, or beginning in 1975), the standard deviation of lognormal recruitment (sigma-R), selectivity curve parameterization, and other factors. For brevity, only a summary of model sensitivities is provided here. In general, the model estimated a higher natural mortality rate (~0.35) and greater recruitment deviation (sigma-R, ~1.6) when these parameters were freely estimated. This was largely due to the improvement in model fit to the variability in the CalCOFI data, particularly the spike in the mid-1960s suggested by the larval abundance data. Fits to other data with higher sigma-R and/or natural mortality were generally the same or eroded. Although it is possible that a higher natural mortality rate, or possibly a time or age-varying rate, could be reasonable for this species (particularly given changes in the abundance and distribution of key predators, such as marine mammals), we currently have inadequate information to justify such changes.

There was general agreement that the hydroacoustic survey estimates from earlier work were likely to be unreliable, due to the lack of a target strength, the substantial changes in technology since the 1977 and 1980 surveys, and the very minor influence that survey had on the model. Logically then, age and length data associated with these surveys were not used in the final model, although both the index and length and age data are present in the .dat and .ctl files. Another sensitivity exercise was to sequentially considered the consequences of removing datasets sequentially on the model trend and behavior. Although dramatically different results were obtained when the CalCOFI index was excluded, due to the fact that no other indices extend farther back in time than 1975, the trends from the late 1970s through 2005 were very similar even without these data, and tended to vary very little when other data time series were removed. The decline in either recruitment or relative abundance in the 1990s was seen in all time series (with the exception of the relatively flat sea lion frequency of occurrence data), and was generally the most robust result in the model. As the seabird and trawl survey data were strongly consistent with each other, removal of one or the other of these time series had little effect on estimates of recruitment variability. However, the estimated recruitments changed significantly when the sea lion length composition data were removed, as these data tended to be more informative than either the juvenile survey or seabird data.

These perceived differences in recruitment from areas north and south of Point Conception spoke to a key issue that arose often during the model development and review. Specifically, the data show fairly substantial differences in recruitment between these two regions, suggesting that individual models for these two regions may be appropriate. Consequently, two alternative models, based on excluding northern and southern data accordingly, are included here in addition to the coastwide model. In the southern model,

only the CalCOFI larval abundance and the sea lion data were used to estimate trends, although the point estimate based on larval production in 1991 was used to anchor the model (scaled to the relative proportion of shortbelly larvae described by MacGregor 1986 as occurring in the southern region). For catches in the south, foreign fishery catches were excluded, and domestic (incidental bycatch) scaled to 25% of that in the base model (there was no substantive difference when higher or lower catches were assumed). Results of this run are shown in Figure 32, and the likelihood values for this run as well as the coastwide model and the northern model run are shown as Table 6. These results are fairly consistent with the results of the coastwide model, the primary exception is that the decline in the 1990s is not as severe as was observed in the coastwide model. The primary reason for this is the flatness of the sea lion diet frequency of occurrence data, when these data are downweighted, the relative decline in spawning biomass in the southern model is comparable, if not greater, than that observed in the coastwide model.

For the northern model, the CalCOFI and sea lion data were excluded, the catchability of the larval production survey was set to 1, and recruitment deviations were only estimated from 1975 onward. For consistency, and to include the potential impact of the foreign fishery, the modeled time period was the same. The results suggest a slight dip in the mid-1960s as a result of the foreign fisheries, an increase in biomass throughout the 1970s and 80s, and a decline from the mid-1990s to the present. The two models exhibited somewhat different trends in both abundance and recruitment, and clearly for both models (as well as the coastwide model) the lack of a consistent time series of age data with which to better validate the recruitment variability are substantial. Despite these apparent differences regionally, substantial data limitations make it difficult to make the case for separate regional models in this (as in most) assessments. Additional discussion of this issue, as well as basic model sensitivities and potential shortcomings with data and modeling approaches are provided in the reports delivered by Dr. Chris Francis from the Center for Independent Experts (Appendix B) and Dr. William Lenarz, National Marine Fisheries Service, retired (Appendix C).

Discussion

Although there is considerable uncertainty surrounding the model results, and the lack of fishery-dependent data has led us to rely primarily on less traditional sources of information, the results of the model are consistent with both what is known about shortbelly life history and the available data regarding juvenile and adult abundance. Even without having a clear sense of the causes of such fluctuations, the most important result is the insight that substantive population variability has occurred for an (effectively) unexploited species in the California Current. While fishery-independent drivers of population variability have been described for many other California Current species (Baumgartner et al. 1992; MacCall 1996), comparable changes are less evident for groundfish, for which management tends to rely on equilibrium-based assessment methods and biological reference points. Such reference points have proven critical to implementing sustainable management measures, by portraying the consequences of exceeding biological limits to decision makers in terms of the risk to the resource (Mace 2001). Yet such reference points are unavoidably based on the assumption of stationarity, such that the biomass at the beginning of the exploitation history is

assumed to represent a steady-state unfished equilibrium. However, it should be acknowledged that the life history traits of shortbelly rockfish, which is more similar to a forage fish than most longer-lived, slower growing and larger Sebastes, may impede the utility of considering this species as a "control" for commercially important stocks with different life history types.

As Hollowed et al. (2000) suggest, the role of all fisheries models, whether single or multispecies, is to understand and inform decision-makers of the consequences of fishing or other activities on living resources and the ecosystem in which they exist. They described three fundamental processes that structure populations; competition, predation (including fishing), and environmental variability. Any of these factors could plausibly account for the observed changes in the abundance shortbelly rockfish in the California Current. For example, California sea lions, important predators of shortbelly rockfish, were severely depleted throughout the early part of the 20th century as a result of hunting and culling (Cass 1985). Following increasing levels of protection from such impacts from the 1950s through 1970s, rapid population increases have been observed. Currently population growth rates regularly approach 9% per year, such that the population is thought to be well over 200,000 animals (Carretta et al. 2002). Models that account for changing natural mortality rates, by incorporating relative changes in the abundance of key predators have been shown to be plausible for some species (Livingston and Methot 1998), and are worth exploring here. Environmental variability is also likely to be a factor. Large-scale changes in both physical and biological conditions throughout the California Current, including monotonic changes, have been well documented (McGowan et al. 1998; Francis et al. 1998; Mendelssohn et al. 2003), and climate information has the potential to inform population models under some circumstances (Maunder and Watters 2003; Schirripa and Colbert 2005). It has also been suggested that the observed long-term dynamics of many marine populations in the Northeast Pacific may not be a direct function of low frequency climate variation, but rather are responses to nonlinear amplification of physical forcing by ecological processes (Hsieh et al. 2005). Regardless of the mechanism, shortbelly rockfish have a potentially important role as a species from which further exploration can be made of the linkages between population variability and environmental factors.

Future Research Priorities

As with most stock assessments, a number of potential research efforts that could improve on future work to model shortbelly abundance and productivity exist. Collection and analysis of age composition data, particularly from the now annual NWFSC combined trawl survey, would provide the opportunity to evaluate whether a time series of an annual bottom trawl survey is capable of generating a trend index and internally consistent length or age composition data for an abundant, yet patchy and semipelagic, species. If so, the survey data should allow us to assess whether the age structure and recruitment variability inferred from both the seabird, sea lion, and juvenile trawl survey are consistent with that seen in the adult population as indexed by the trawl survey. Closely related to this, one reviewer suggested that bootstrapping the triennial length frequency data might be one appropriate means of

evaluating how well they are determined, such an approach may make particular sense with new length frequency data in the future from the annual trawl survey.

While there is considerable uncertainty surrounding the use of food habits data, particularly the frequency of occurrence data as indicators of relative abundance, the ability to utilize food habits data as supplementary sources of information was particularly valuable in constructing this model given the absence of traditional fishery information. However the sensitivity of such indices to saturation is a significant challenge, even with arcsin (or other) transformations typically used for proportional data. One suggestion made with respect to the length frequency data derived from the sea lion index was that a probability distribution could be a more appropriate means of relating otolith lengths to fish lengths than a one-to-one mapping based on point estimates. This could explain why the observed sea lion length frequencies appeared "more peaked" than the predicted length frequencies (although time-varying growth could possibly be another factor).

The real or potential differences in abundance, abundance trends, and recruitment by area clearly needs additional exploration. The current "expansion" factor for the biomass point estimate based on the larval production method is clearly inadequate, and a careful and deliberate analysis of relative larval abundance by area and time will be required to develop a robust expansion factor in the future. Given that the new trawl survey also samples off of the Southern California Bight region, the potential to evaluate possible differences in recruitment, biomass trend, growth, maturity, and natural mortality among these two areas should also increase with time.

There are a number of issues associated with the CalCOFI larval abundance index that warrant greater evaluation. The patchiness of larvae in space and time is a major factor associated with this index, and may preclude any meaningful contribution of the northern data, for which only one station is reasonably close to areas of known (adult) shortbelly aggregations. It was also noted at the review that the monthly effects associated with the glm used for this index in the south are not fully consistent with those suggested by the larval production biomass estimate in the north. More careful evaluation of station location and date effects were strongly encouraged in the review.

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Table 1: Growth and maturity parameters fixed in the assessment model

Growth Parameters

	females	males
Agemin	2	2
Agemax	10	10
Lmin	154	153
Lmax	258	243
K	0.198	0.200
Linf	285	266
alpha	0.00000993	0.00000997
beta	3.08	3.05

Maturity Parameters		
Maturity-inflection	14.1	
maturity-slope	-1.44	

Table 2: Sample sizes of prey identified for Common Murre and Rhinoceros Auklet food habits studies by the Point Reyes Bird Observatory.

	Common Murre	Rhinoceros auklet
1975	4217	
1976	2844	
1977	3796	
1978	1357	
1979	926	
1980	1689	
1981	1289	
1982	268	
1983	451	
1984	1022	
1985	1069	
1986	1504	
1987	2479	155
1988	2573	166
1989	1609	77
1990	1849	120
1991	1746	213
1992	98	231
1993	1957	377
1994	1804	124
1995	2036	152
1996	913	122
1997	1309	105
1998	192	172
1999	1190	192
2000	444	71
2001	2116	451
2002	3815	232
2003	1877	135
2004	2476	171

Table 3: Number of length measurements by year and island, for the sea lion food habits frequency of occurrence data and reconstructed length compositions

	Samples per island			number of length
	Santa Barbara	San Nicolas	San Clemente	measurements
1981	26	42	42	6
1982	53	101	311	59
1983	99	260	331	120
1984	45	280	351	294
1985	39	235	102	63
1986	48	251	121	81
1987	48	31	118	20
1988	67	92	154	184
1989	54	88	183	99
1990	52	48	164	73
1991	51	287	200	539
1992	44	399	177	571
1993	51	410	181	437
1994	48	167	82	63
1995	43	406	120	155
1996	20	396	180	213
1997		381	175	138
1998		361	182	185
1999		417	174	255
2000		268	187	144
2001		75		127
2002		72		35

Table 4. Parameter estimates for base model

parameter	value	parameter	value
R0	309248	1979 rec_dev	1.17
init equil.	4.2	1980 rec_dev	1.23
selparm_L50_fishery	16	1981 rec_dev	0.98
selparm_L50-L95 triennial	5	1982 rec_dev	-0.05
selparm_L50_triennial	14	1983 rec_dev	-1.19
selparm_L50-L95 triennial	7	1984 rec_dev	1.15
selparm_L50 sea lion	5	1985 rec_dev	1.03
selparm_L50-L95 sea lion	-14	1986 rec_dev	0.05
1960 rec_dev	-0.45	1987 rec_dev	1.43
1961 rec_dev	-0.39	1988 rec_dev	1.46
1962 rec_dev	-0.36	1989 rec_dev	0.42
1963 rec_dev	-0.20	1990 rec_dev	-0.70
1964 rec_dev	0.18	1991 rec_dev	1.90
1965 rec_dev	2.68	1992 rec_dev	-0.99
1966 rec_dev	0.01	1993 rec_dev	-0.12
1967 rec_dev	-0.15	1994 rec_dev	-1.28
1968 rec_dev	-0.29	1995 rec_dev	0.29
1969 rec_dev	-0.37	1996 rec_dev	0.47
1970 rec_dev	-0.38	1997 rec_dev	-1.03
1971 rec_dev	-0.35	1998 rec_dev	-3.00
1972 rec_dev	-0.33	1999 rec_dev	0.27
1973 rec_dev	-0.39	2000 rec_dev	-1.26
1974 rec_dev	-0.46	2001 rec_dev	-0.35
1975 rec_dev	1.53	2002 rec_dev	-0.36
1976 rec_dev	0.06	2003 rec_dev	1.21
1977 rec_dev	1.18	2004 rec_dev	-0.67
1978 rec_dev	-0.60	2005 rec_dev	-3.00

Table 5: Key outputs from base model, biomass and spawning biomass in 1000s of tons, recruits in 1000s of fish, catch in tons.

Year	Total B	SSB	Recruits	Depletion	catch	harvest rate
1950	381	195	309	3.97	127	0.0004
1951	365	194	309	3.95	125	0.0004
1952	341	184	309	3.75	137	0.0005
1953	313	170	309	3.46	143	0.0005
1954	283	154	309	3.13	161	0.0007
1955	254	138	309	2.80	172	0.0008
1956	227	123	309	2.50	174	0.0009
1957	204	109	309	2.23	154	0.0009
1958	183	98	309	1.99	150	0.0010
1959	166	88	309	1.80	122	0.0009
1960	150	80	120	1.63	119	0.0009
1961	135	73	127	1.49	140	0.0012
1962	121	66	131	1.34	96	0.0009
1963	108	59	153	1.19	120	0.0013
1964	98	52	224	1.06	166	0.0020
1965	114	47	1500	0.95	261	0.0033
1966	131	50	189	1.01	1690	0.0193
1967	143	68	162	1.38	8491	0.0783
1968	141	73	140	1.49	1805	0.0153
1969	139	74	130	1.51	247	0.0020
1970	133	72	128	1.46	119	0.0010
1971	124	67	132	1.36	95	0.0009
1972	113	61	135	1.25	201	0.0020
1973	103	55	127	1.13	1228	0.0138
1974	91	49	118	1.00	369	0.0047
1975	89	44	853	0.89	973	0.0137
1976	87	41	194	0.83	927	0.0137
1977	91	43	600	0.88	142	0.0020
1978	93	45	101	0.92	102	0.0014
1979	98	48	603	0.98	222	0.0028
1980	105	49	644	1.00	287	0.0035
1981	113	53	502	1.07	178	0.0020
1982	117	58	179	1.17	204	0.0022
1983	117	61	57	1.24	161	0.0016
1984	117	61	594	1.23	215	0.0022
1985	119	58	525	1.18	114	0.0012
1986	118	59	197	1.20	93	0.0010
1987	122	60	785	1.22	89	0.0009
1988	130	61	805	1.23	77	0.0008
1989	135	65	287	1.32	98	0.0009
1990	136	70	93	1.42	122	0.0011
1991	144	71	1260	1.44	96	0.0008
1992	147	71	70	1.44	57	0.0005
1993	146	76	166	1.54	63	0.0005
1994	140	75	52	1.53	46	0.0004
1995	132	71	250	1.44	66	0.0006
1996	123	65	301	1.33	81	0.0008
1997	114	60	67	1.22	65	0.0007
1998	103	56	9	1.14	46	0.0005
1999	93	51	245	1.03	26	0.0003
2000	84	45	52	0.91	13	0.0002
2001	75	41	128	0.83	10	0.0002
2002	68	36	125	0.74	6	0.0001
2003	67	33	591	0.67	0	0.0000
2004	66	31	89	0.64	2	0.0000
2005	64	33	9	0.67	0	0.0000

Table 6: Estimated base, northern, and southern model likelihoods.

	Coastwide	North	South
Total likelihood	2061.17	266.77	1584.87
Abundance indices			
CalCOFI	113.49		130.66
Triennial	5.36	6.98	
Murre	93.21	37.86	
Juvenile	135.31	26.74	
Larval Production	0.0002078	0.0003726	0.0000046
Sea Lion	56.54		16.47
Length and age			
Fishery	2.30	1.96	
Triennial	154.03	159.09	
Sea Lion	1455.85		1401.84
Larval Production (Age)	4.56	4.75	
penalties			
Recruitment	38.85	29.28	34.64
Parm_priors	1.67	0.11	1.26
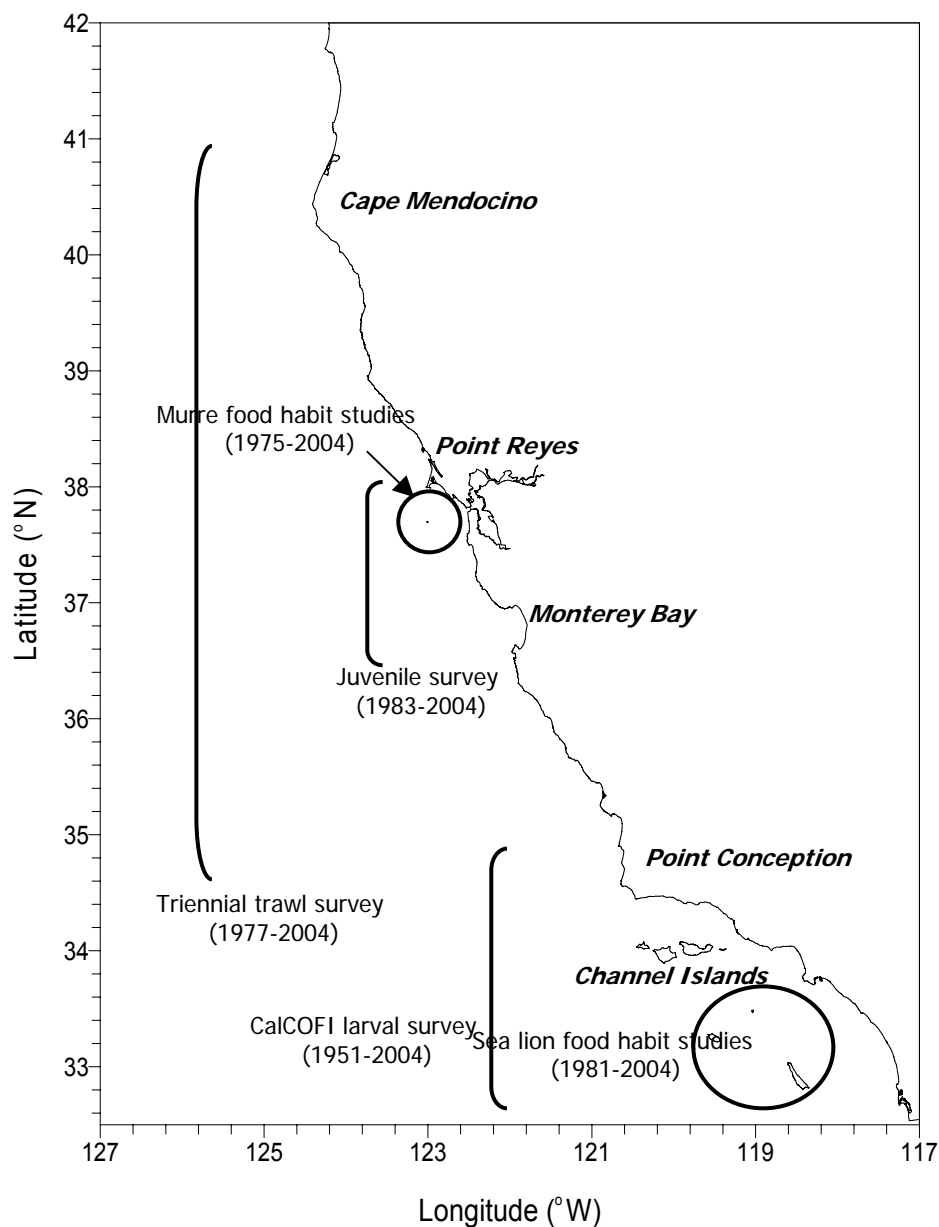
Figure 1: Approximate spatial coverage of major data sources used in this study. Note that actual coverage varied among years for many surveys, areas shown approximate the core areas sampled with consistency throughout the duration of the time series.
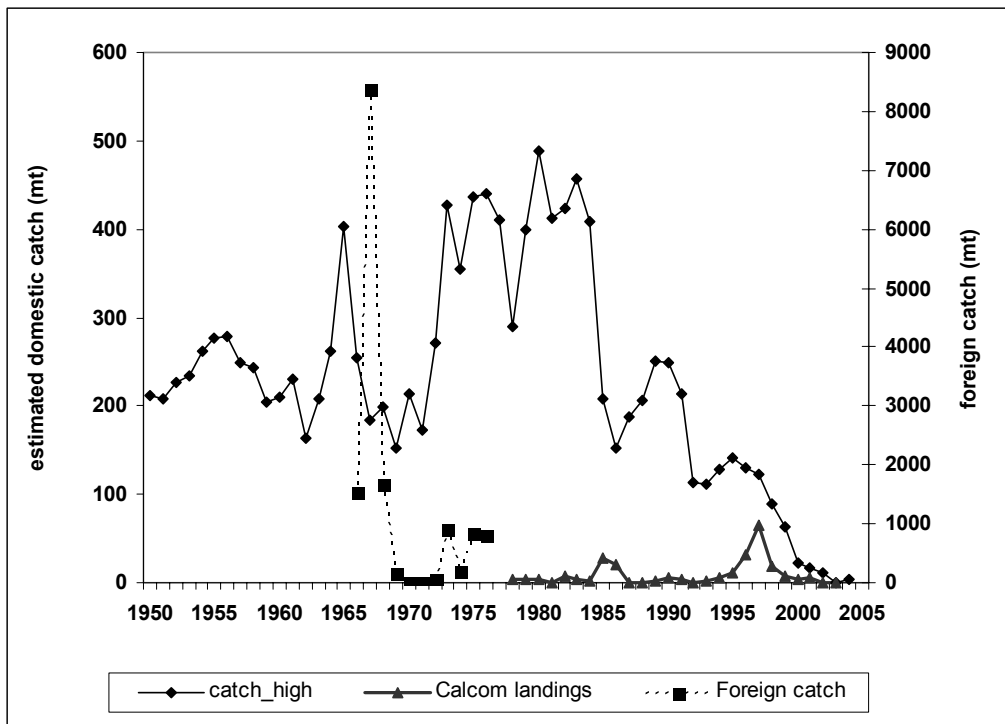
Figure 2: Reported (CalCOM) landings, estimates of foreign catches, and the estimates of the "low" bycatch estimate for shortbelly rockfish as described in text. Note that foreign landings are on the second y-axis.
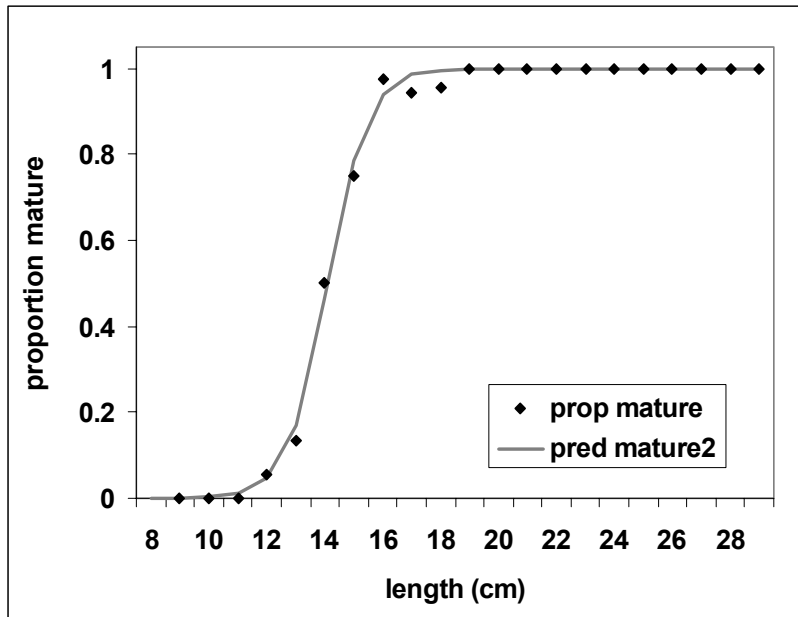
Figure 3: Length-based maturity curve and observed data on the proportion of mature individuals
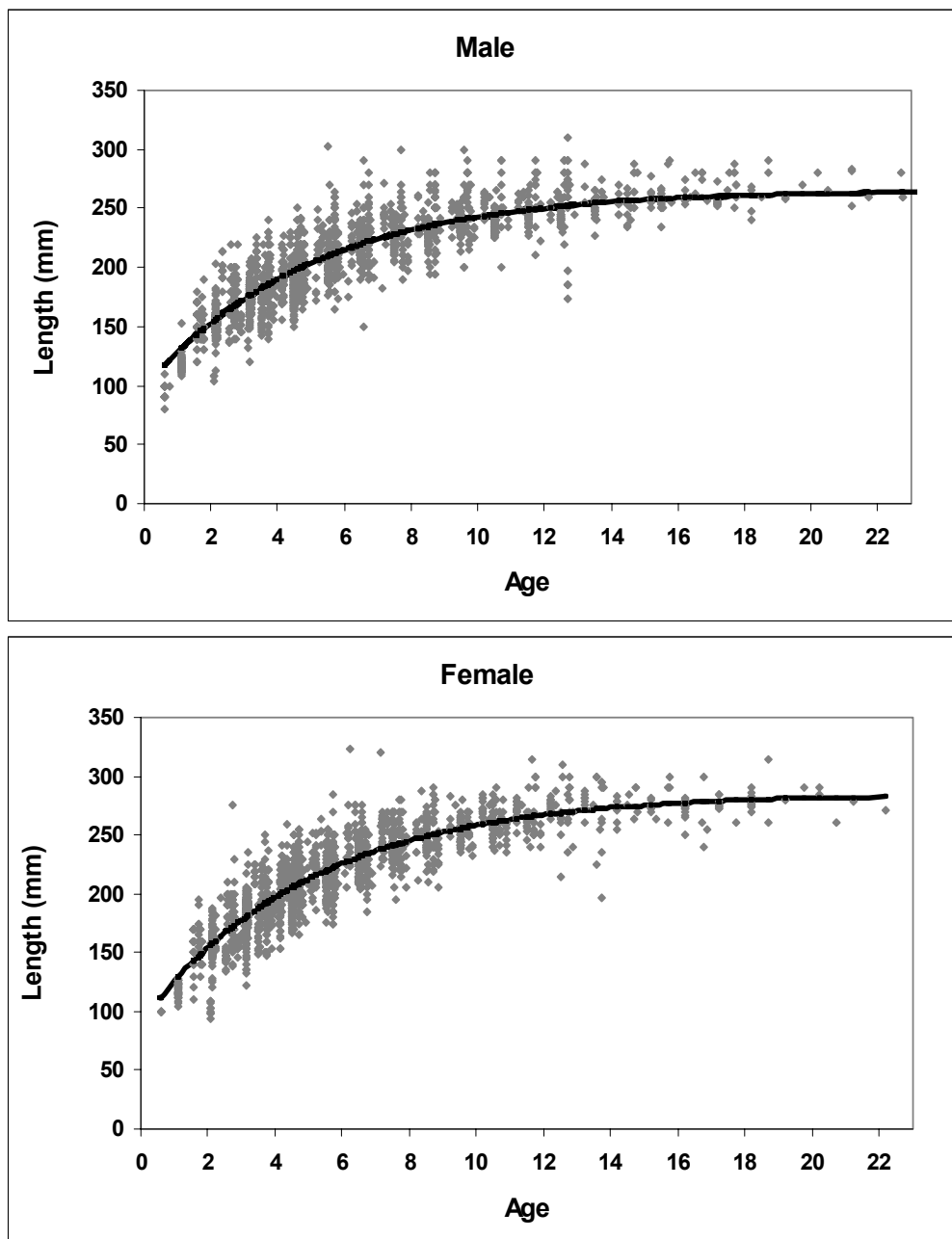
Figure 4: Male (top) and female (bottom) growth curves, using the Schnute (1981) parameterization of the von Bertalanffy growth equation
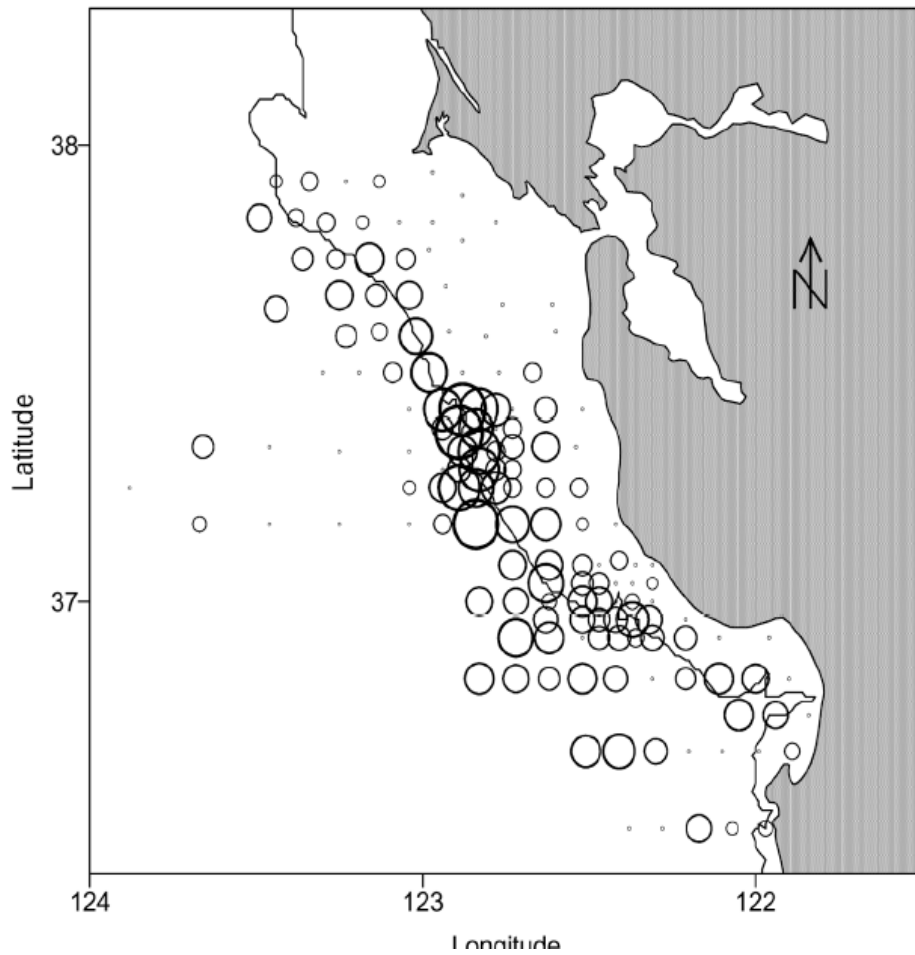
Figure 5: Map showing the spatial distribution of 0 to 2 day old shortbelly rockfish larvae sampled during February of 1991, in order to develop the biomass point estimate in Ralston et al. (2003).
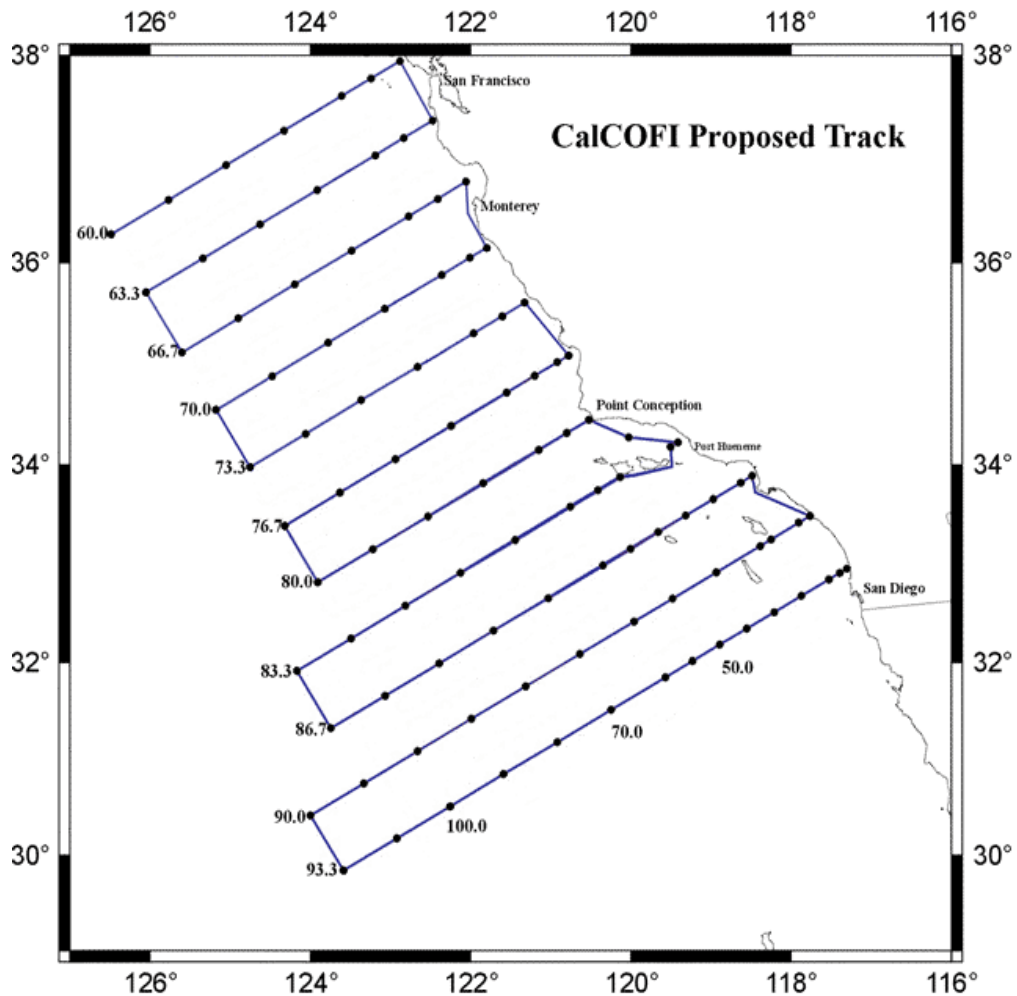
Figure 6: Current (extended) CalCOFI station plan for winter and spring surveys, core (southern) area sampled continously since 1951includes lines 76 south to line 93.
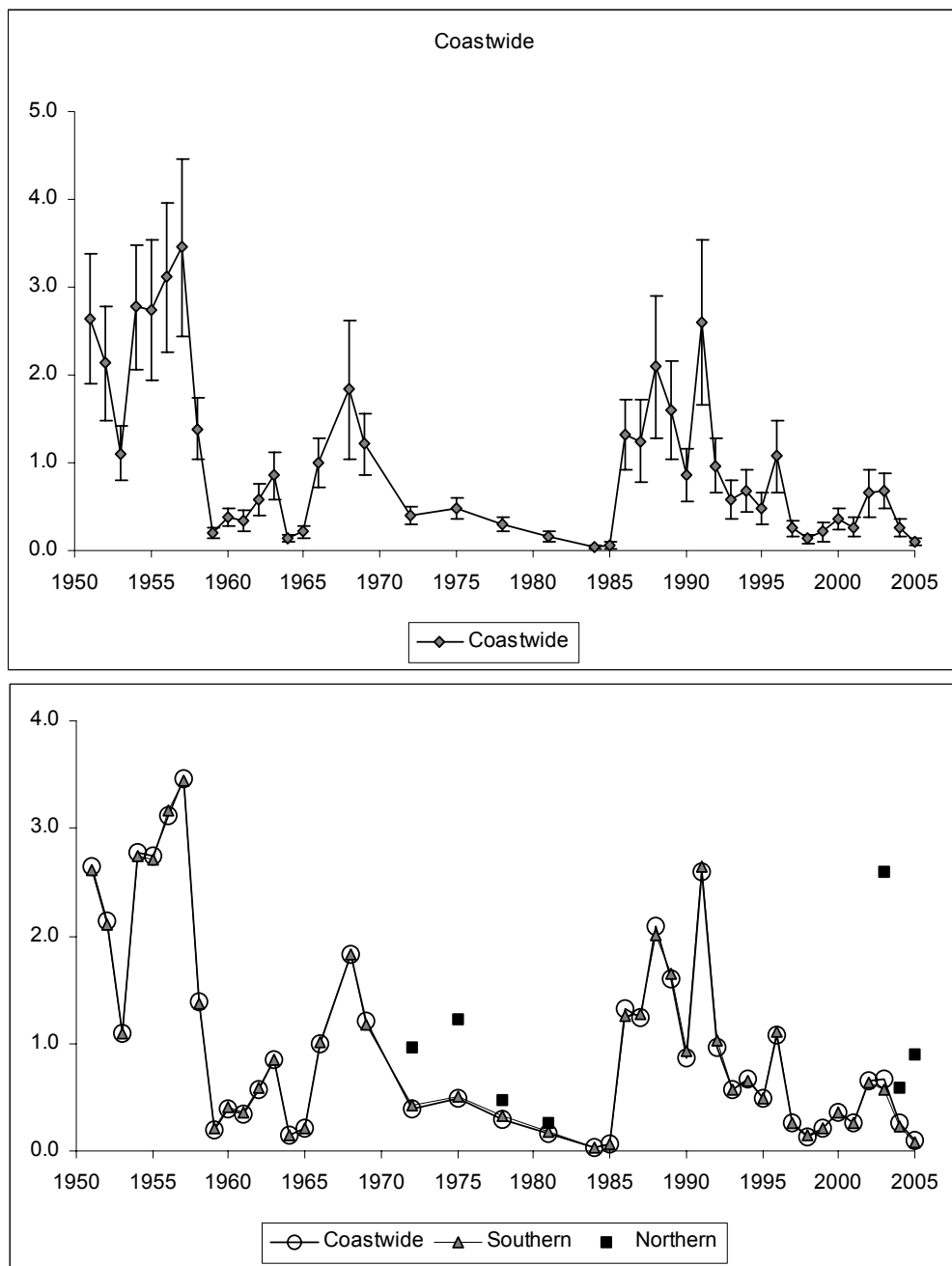
Figure 7: Top: CalCOFI larval abundance index year effects for the coastwide model, with standard errors estimated from a jackknife routine, bottom: point estimates for year effects using separate southern and northern models, relative to the coastwide model.
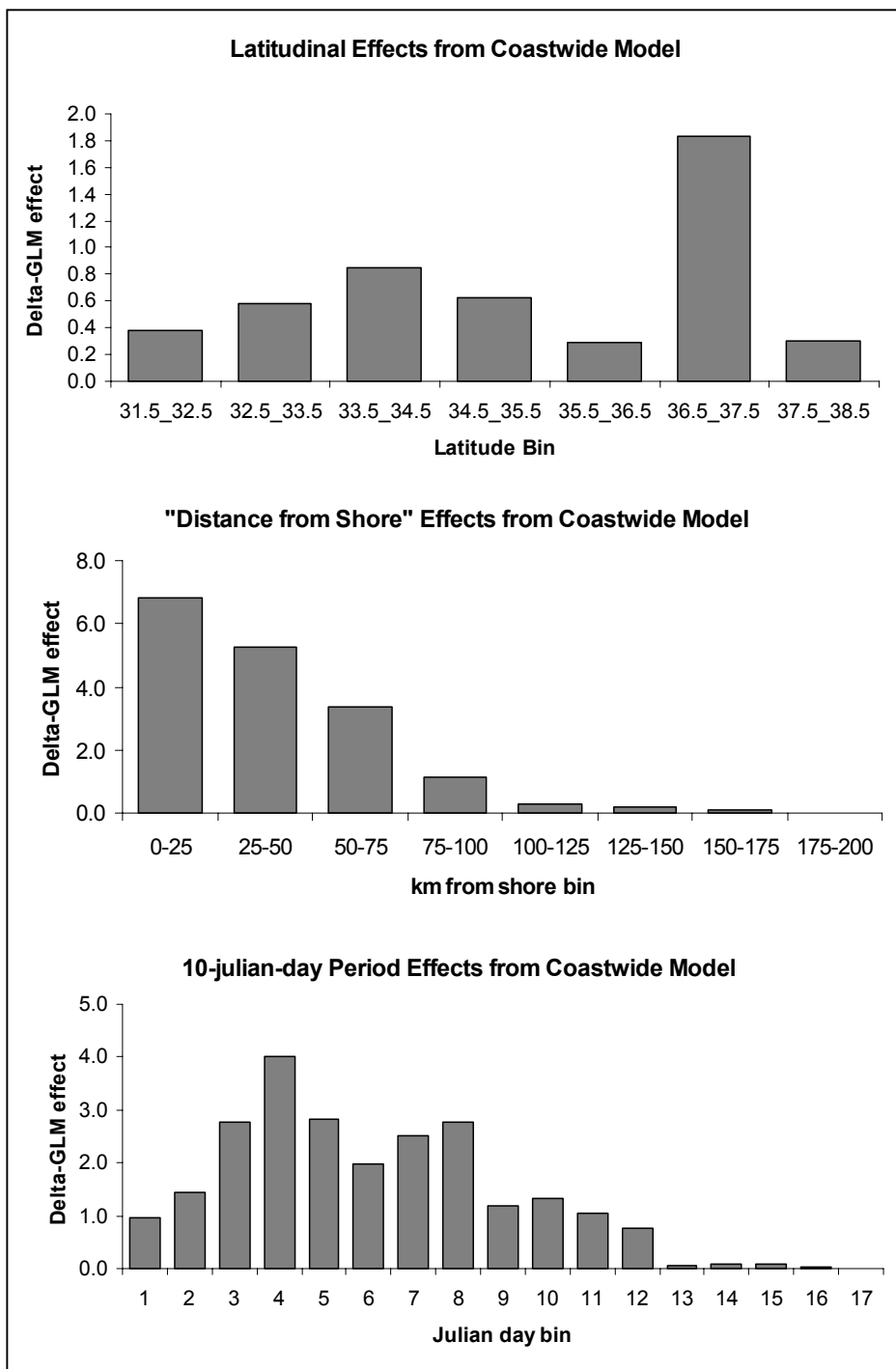
Figure 8: Latitudinal (top), distance from shore (center), and julian day (bottom) main effects estimated from the CalCOFI larval abundance survey Delta-GLM.
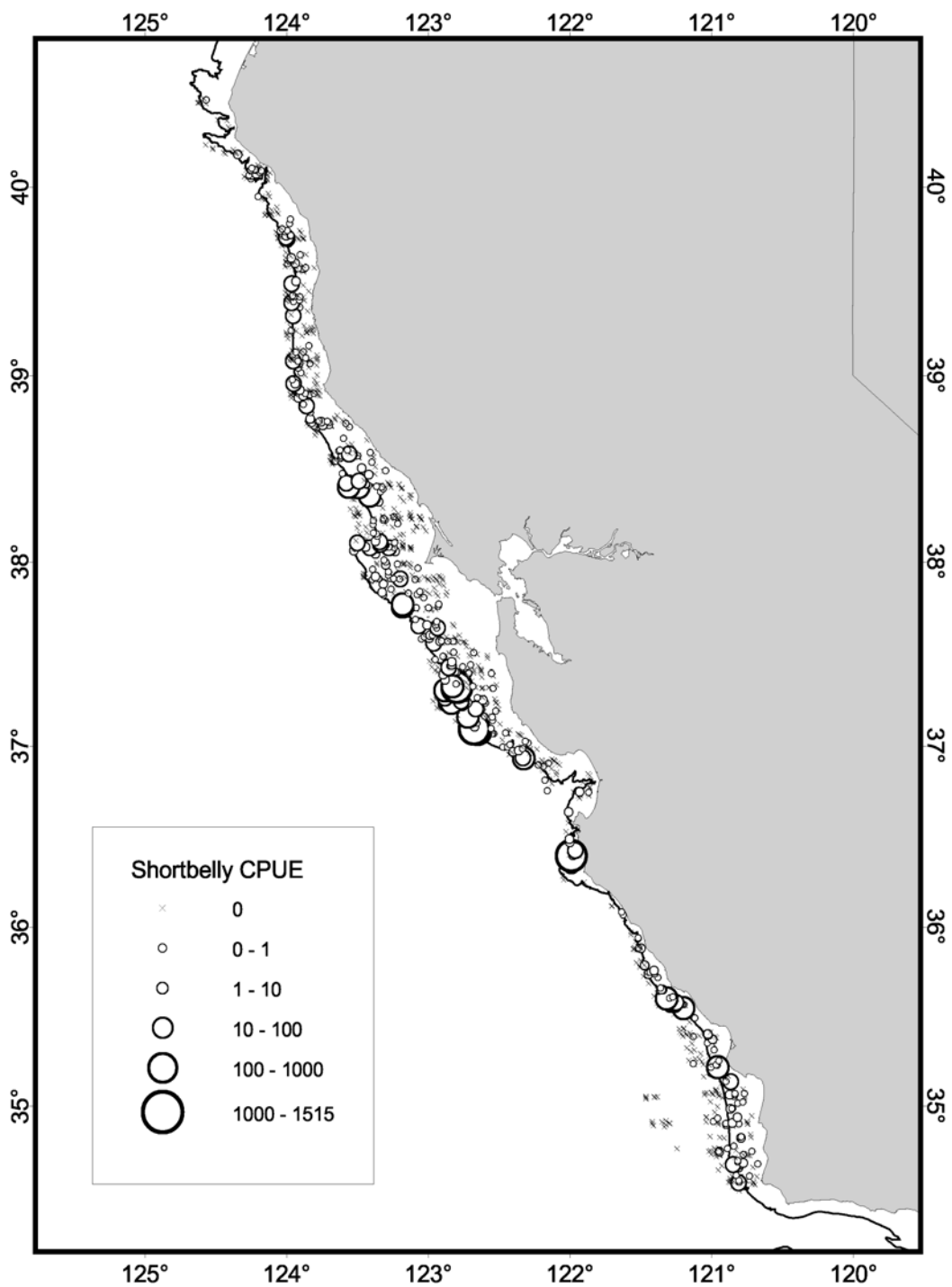
Figure 9: Tow locations and resulting CPUE for shortbelly rockfish from triennial trawl survey tows between 1977 and 2004.
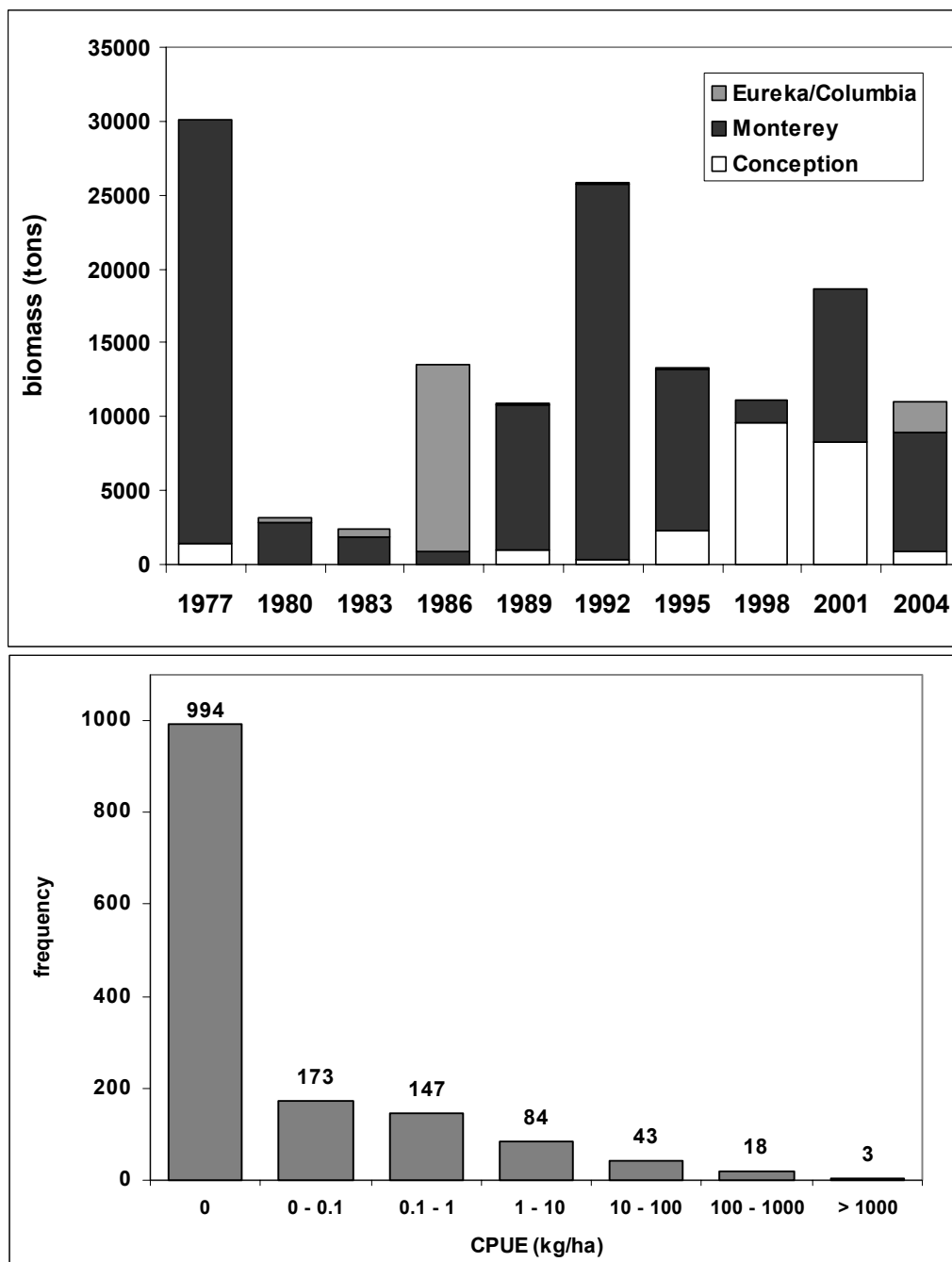
Figure 10: Traditional area-swept biomass point estimates from the Triennial survey (top) and the frequency of occurence of *S. jordani* in triennial survey hauls between 1977-2004, (south of Cape Blanco, 50 to 366 meters only).
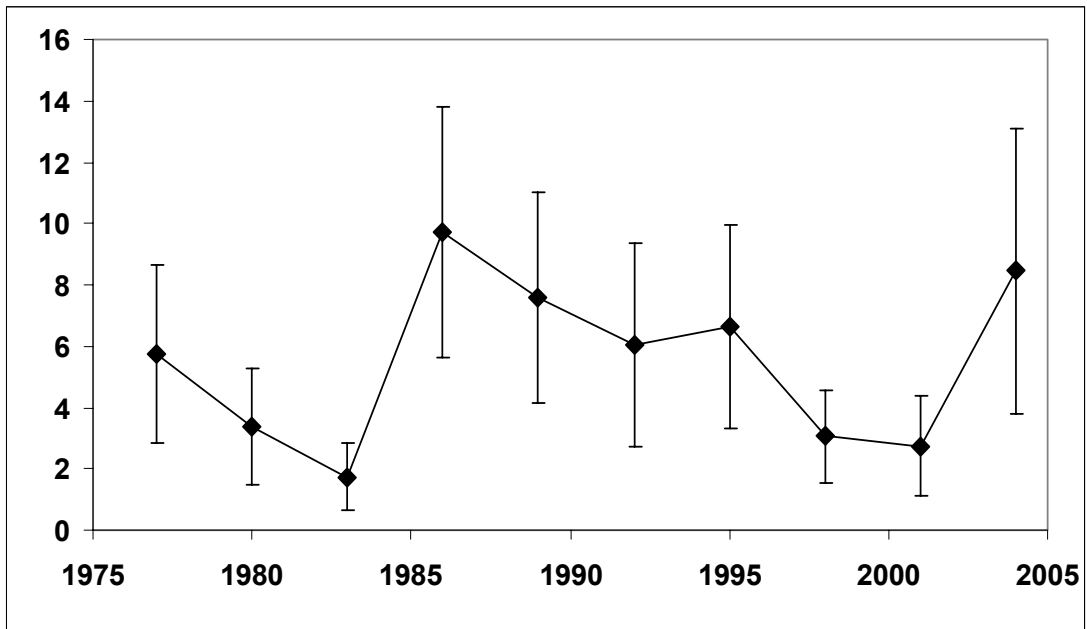
Figure 11: Delta-GLM year effects for the triennial trawl survey CPUE data south of Cape Mendocin, with standard errors estimated from a jackknife routine.
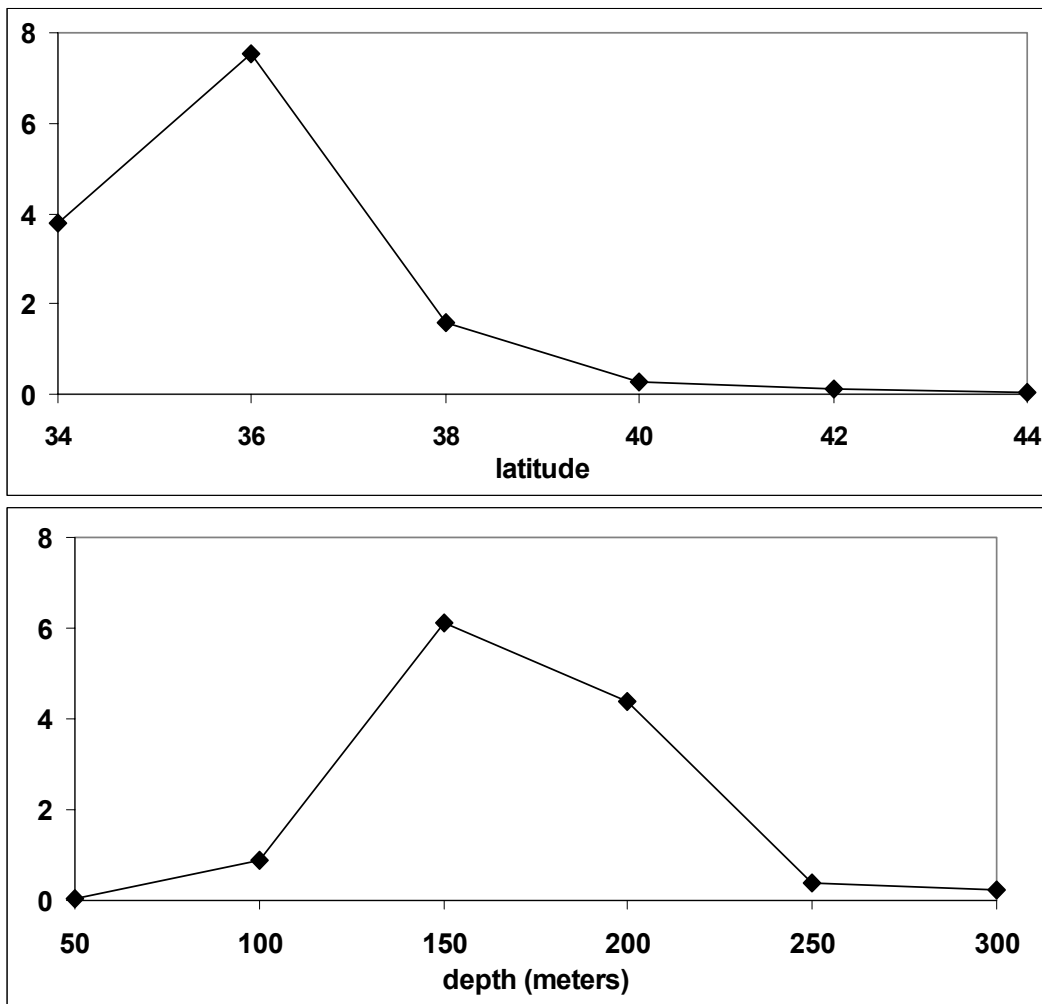
Figure 12: Delta-GLM latitude and depth effects for the triennial trawl survey CPUE data. These data include results from north of Cape Mendocino simply to demonstrate the decline in relative abundance with latitude; the final index only used data from south of Mendocino.
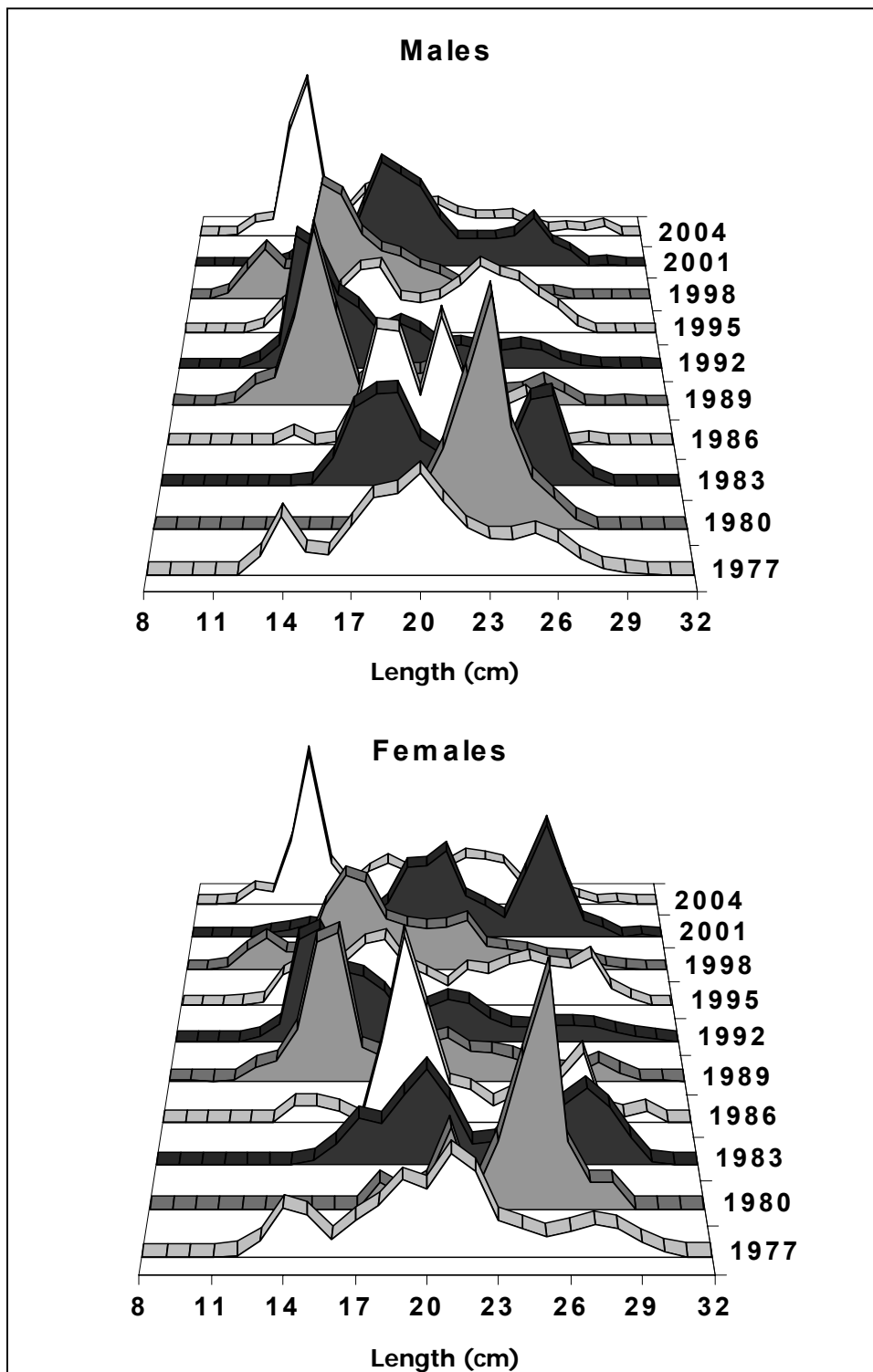
Figure 13: Male (top) and female (bottom) length compositions by year from triennial trawl surveys (1977-2004)
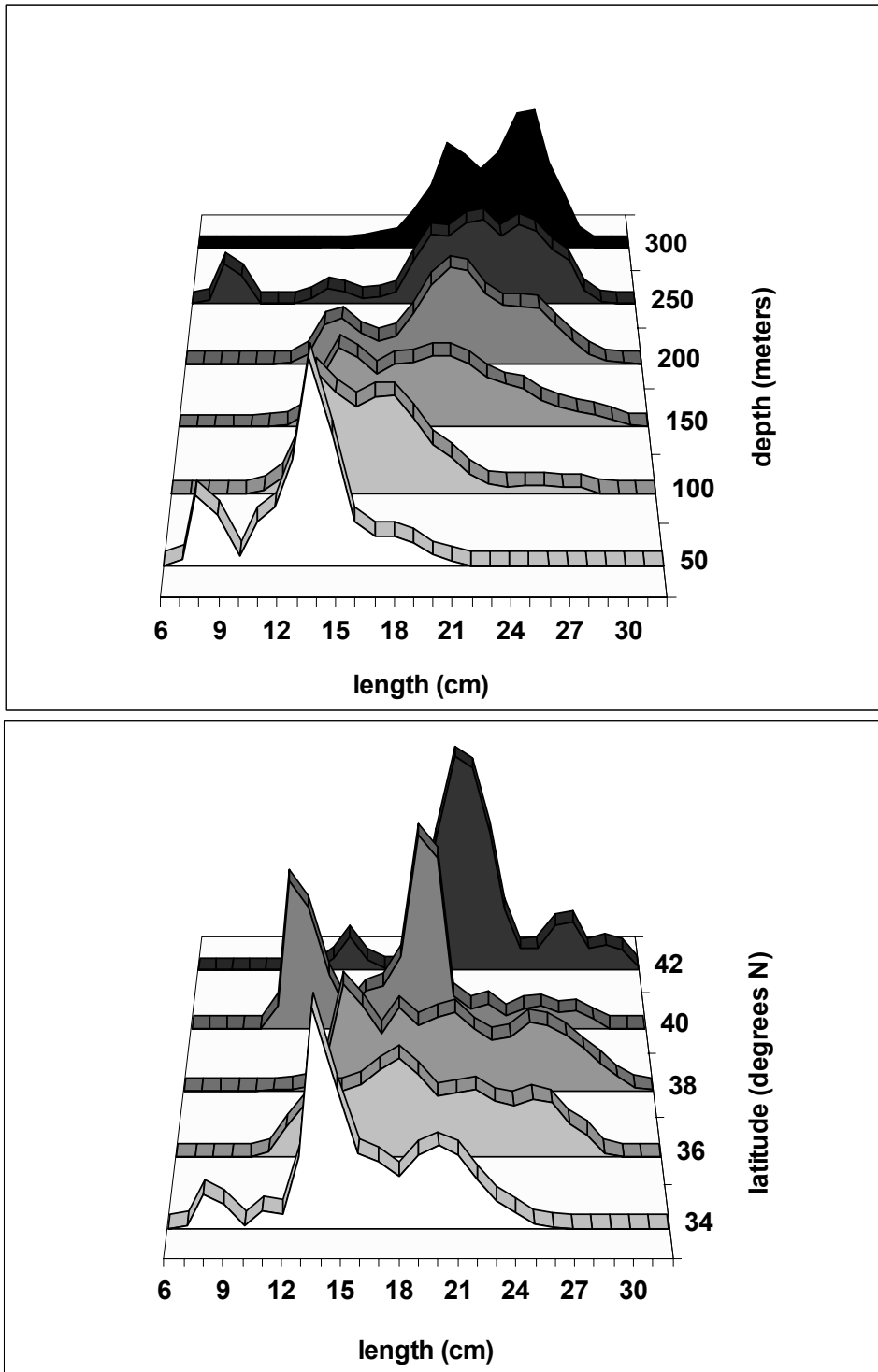
Figure 14: Top panel: length composition of shortbelly rockfish across 50 meter depth bins. Bottom panel: length composition across 2 degree latitude bins. Data are from triennial survey data (all years, 1977-2004).
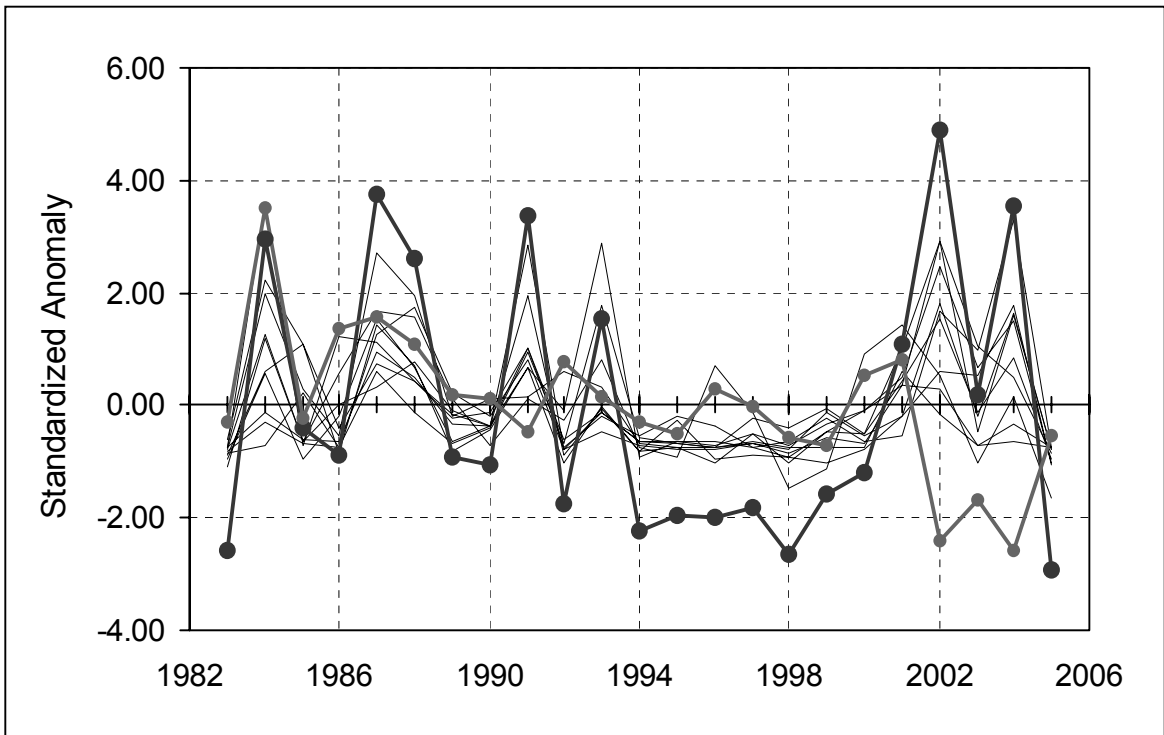
Figure 15: Longterm trends in reproductive success of 10 species of rockfish (genus *Sebastes*) shown on log-scale (individual species patterns are shown as thin black lines). The bold lines represent the first (black) and second (grey) principal components scores, respectively, which together account for 75% of the total variance.
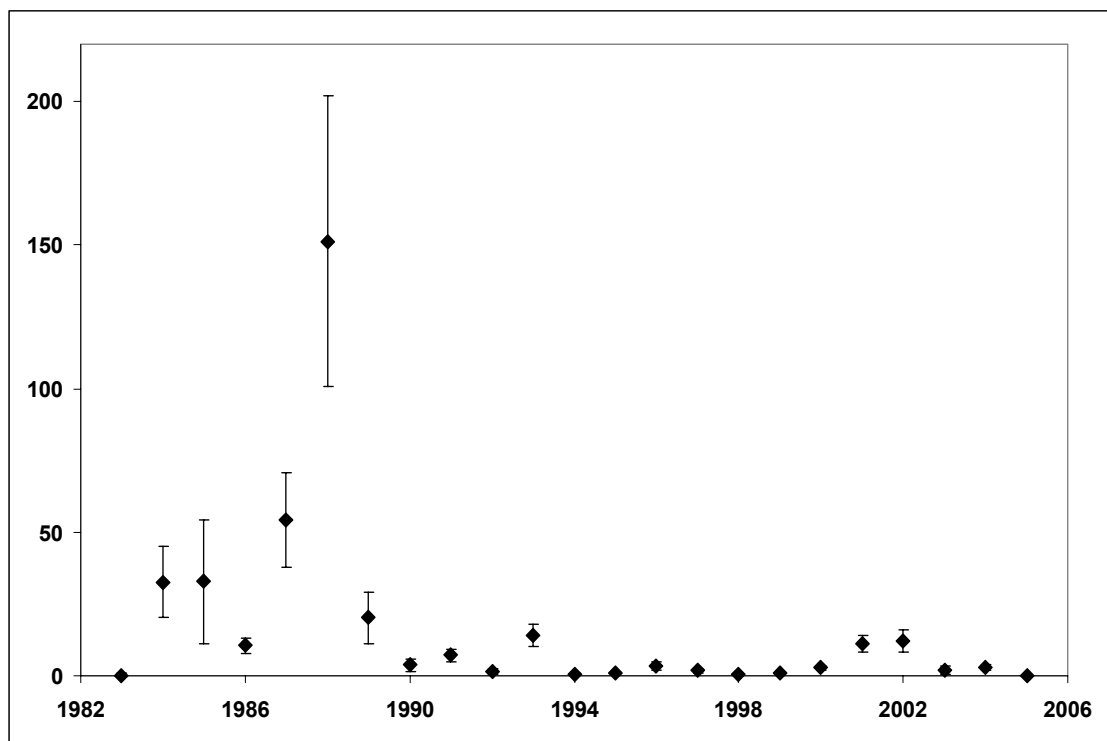
Figure 16: Delta-GLM model results for the juvenile shortbelly index from the of
Juvenile Trawl Survey (1983-2004), with standard errors as estimated with a jackknife
routine.
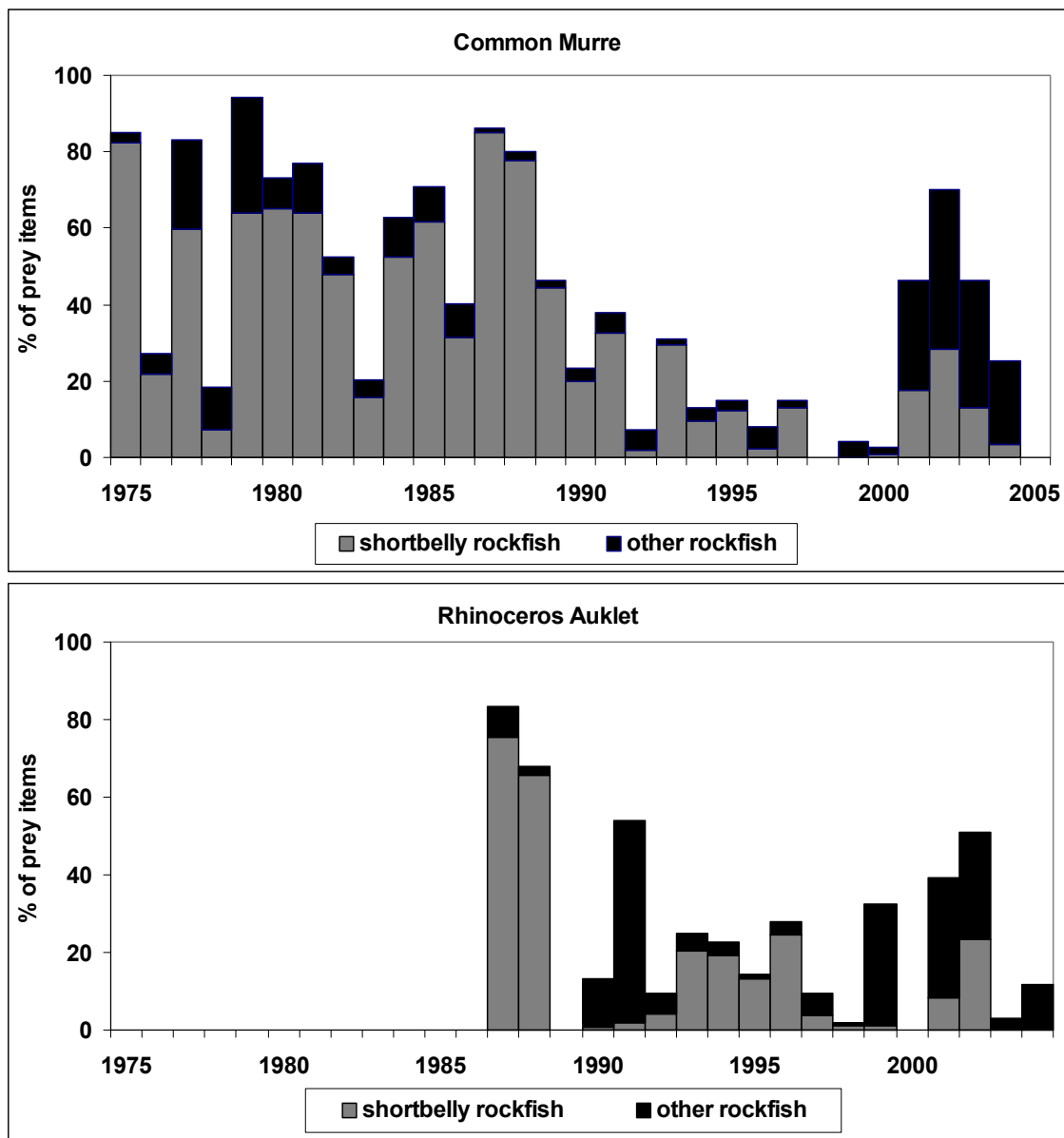
Figure 17: Proportion of juvenile shortbelly rockfish in the diets of Common Murres (1975-2004) and Rhinoceros Auklets (1987-2004) on the Southeast Farrallon Islands, data courtesy of Point Reyes Bird Observatory. The R^2 for the proportion of shortbelly rockfish (following treatment by binomial GLM) among the two time series is 0.70.
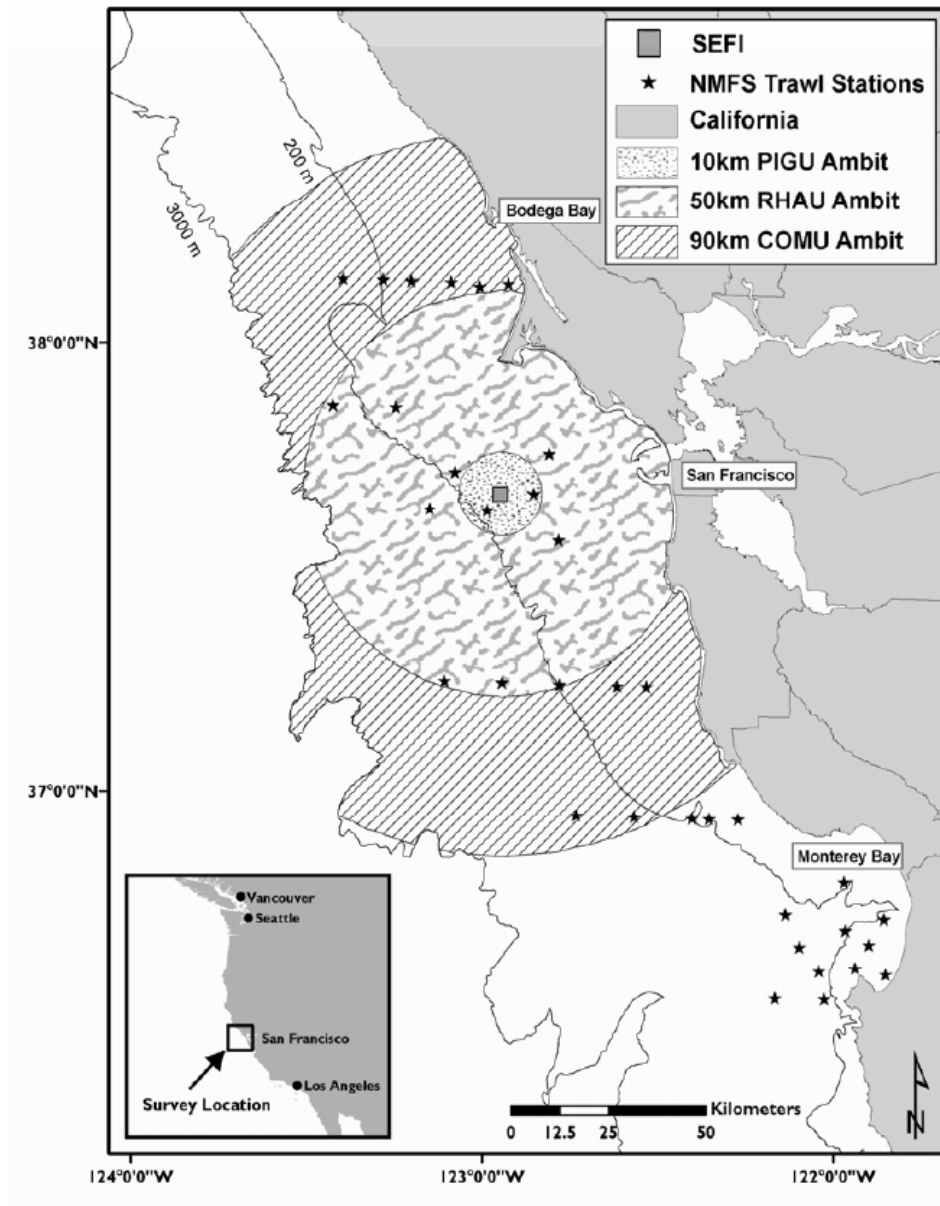
Figure 18: Approximate foraging ranges for Common Murres, Rhinoceros Auklets, and Pigeon Guillimots around the Southeast Farrallon Islands, figure from Mills et al. (in press).
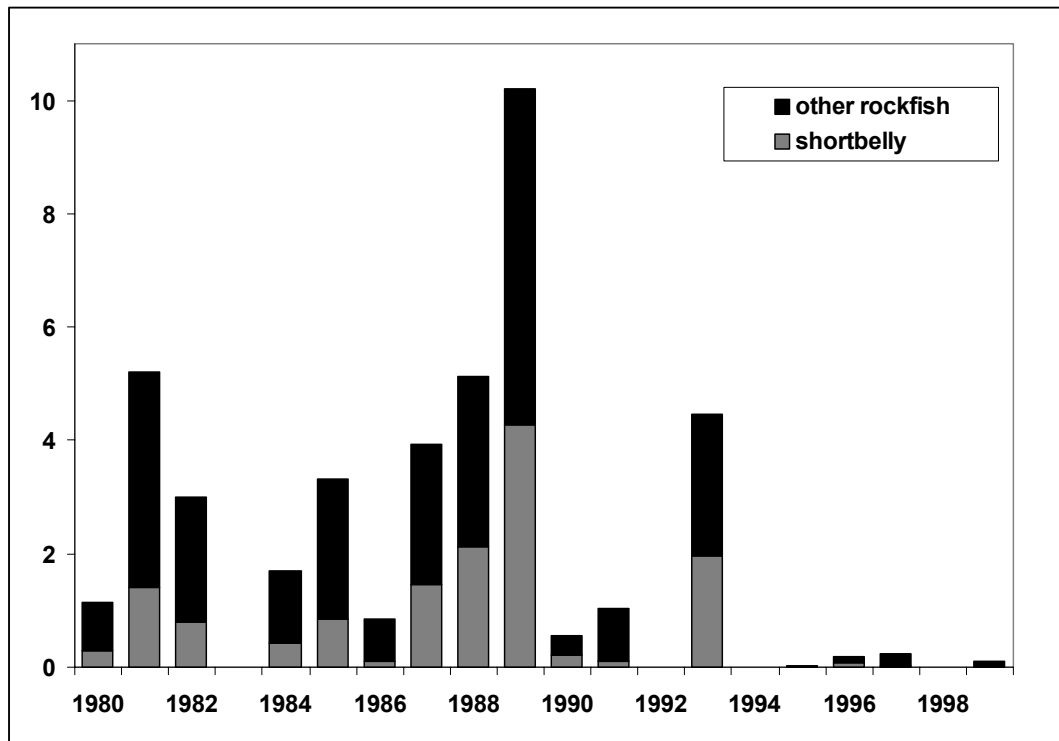
Figure 19: Average number of shortbelly rockfish and other rockfish per salmon stomach in 6484 stomachs collected from recreational charter vessels in the San Francisco Bay region, by the NMFS Tiburon Lab between 1980 and 1999 (T. Laidig, pers. com). Note that no salmon stomachs were collected in 1983, 1992, 1994 and 1998, as charter captains did not report salmon predation on juvenile rockfish during these years.
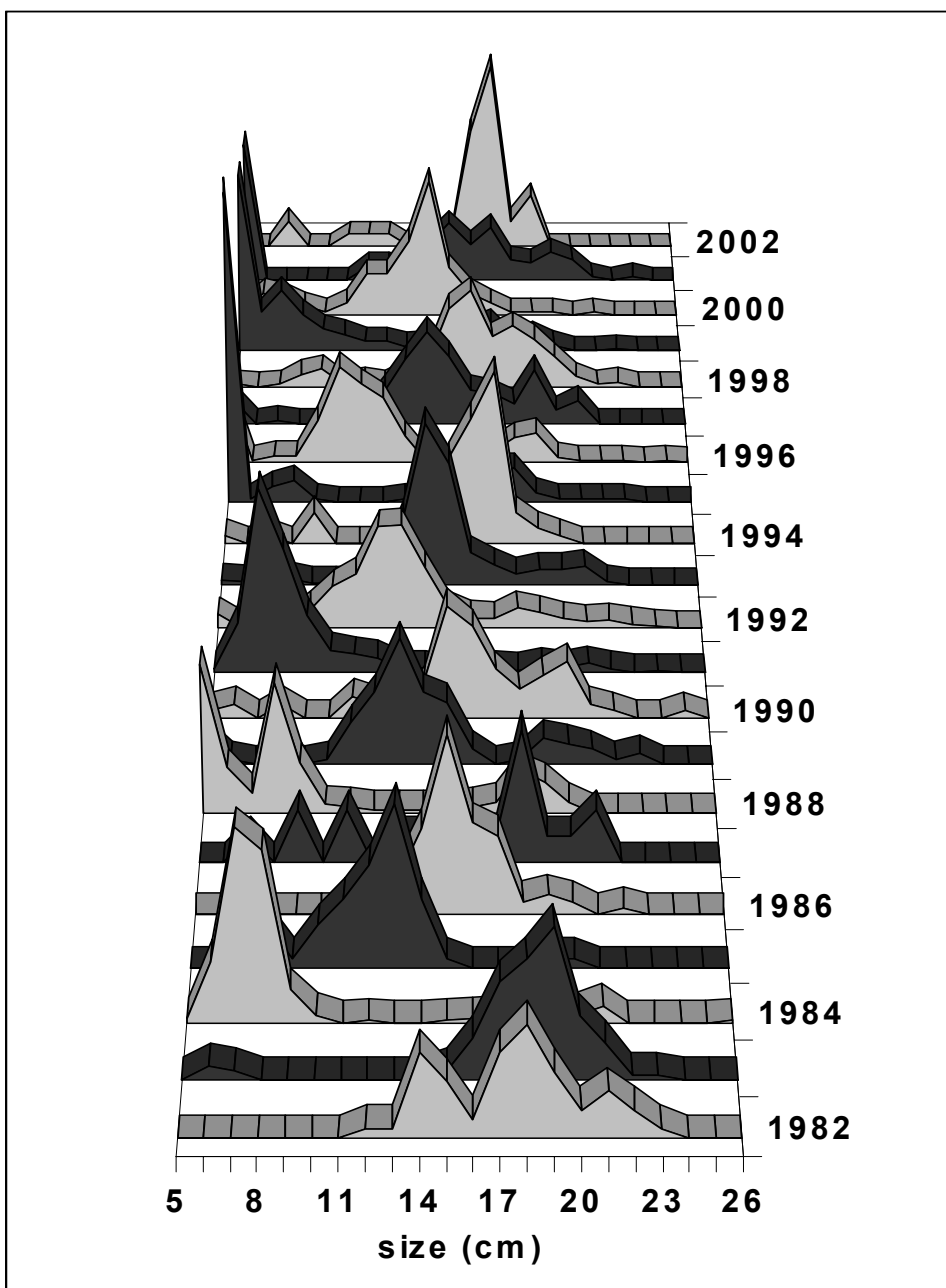
Figure 20: Length frequency composition derived from otoliths collected in sea lion scat samples, based on otolith length/fish length regressions.
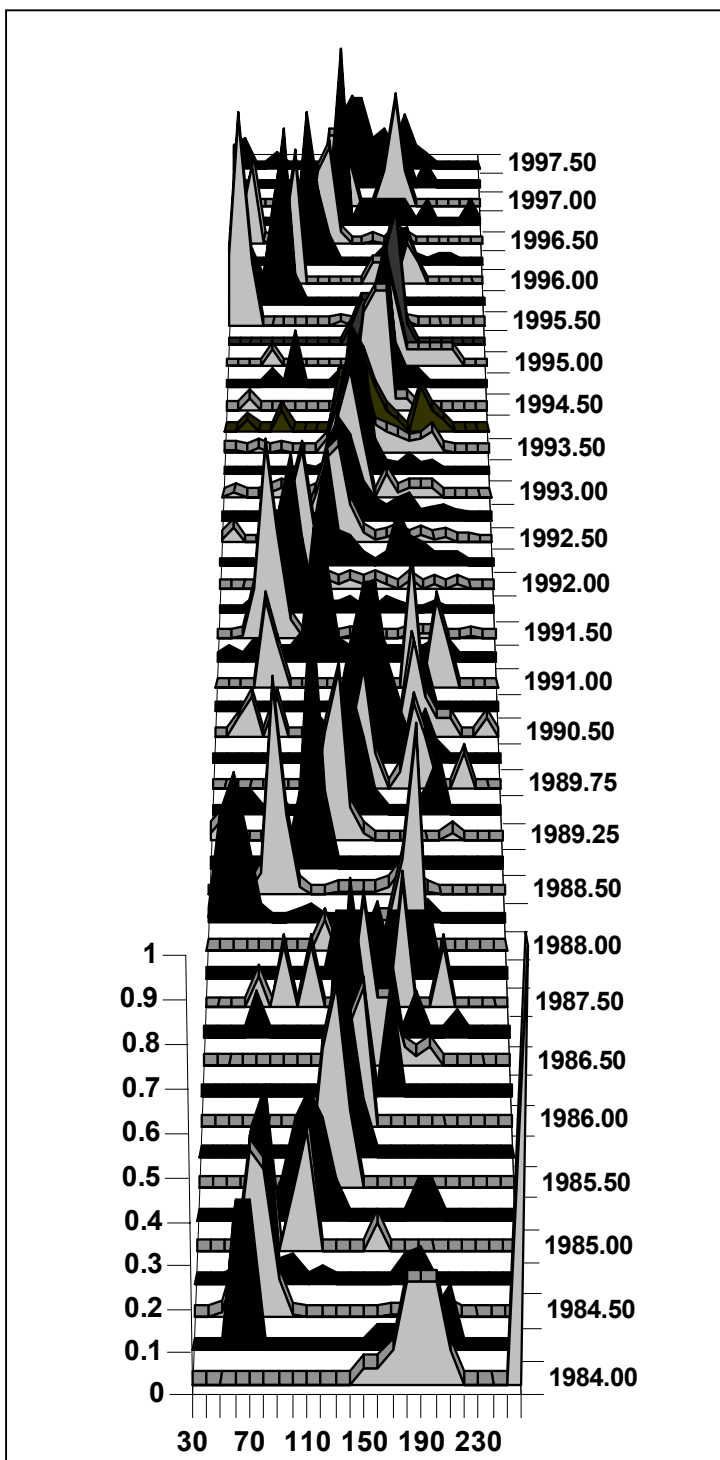
Figure 21: Length frequency composition derived from otoliths collected in sea lion scat samples, based on otolith length/fish length regressions, plotted seasonally rather than annually, in which the clear progression of a cohort can be followed.
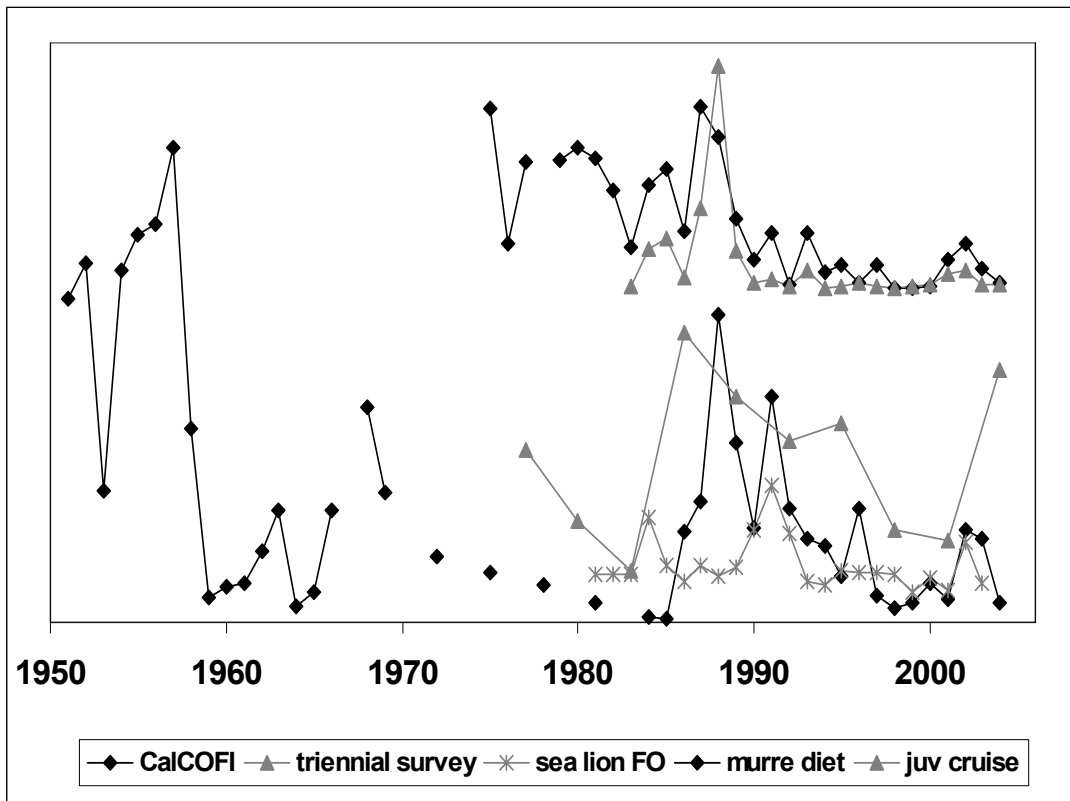
Figure 22: The five primary indices of relative abundance trends used in the model.
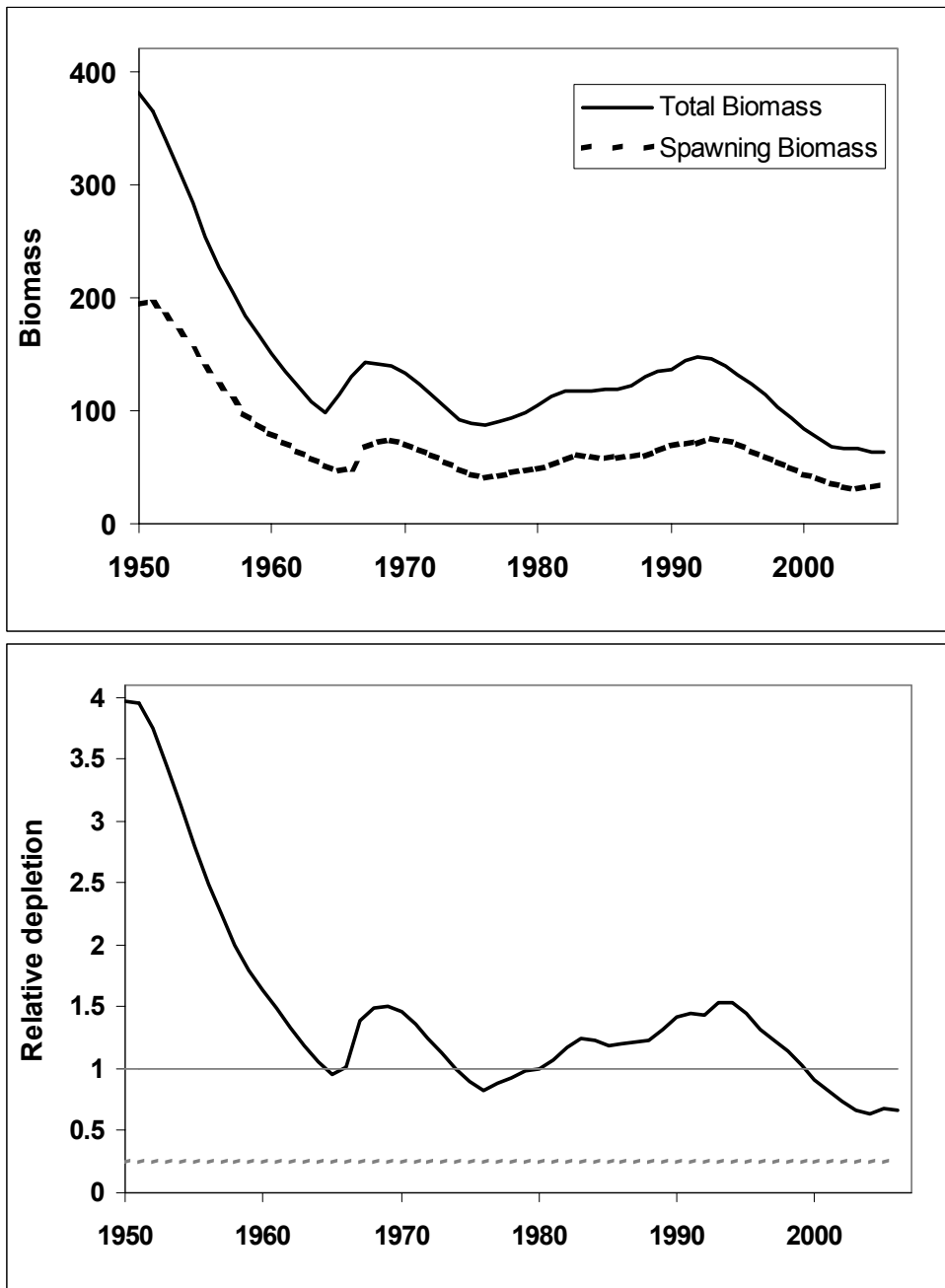
Figure 23: Results of the shortbelly rockfish base model. Total biomass and spawning stock biomass (SSB) estimates (top figure) and estimated depletion based on the long-term estimate of the unfished biomass (bottom figure, with the static unfished spawning biomass and 25% of the unfished spawning biomass shown for reference).
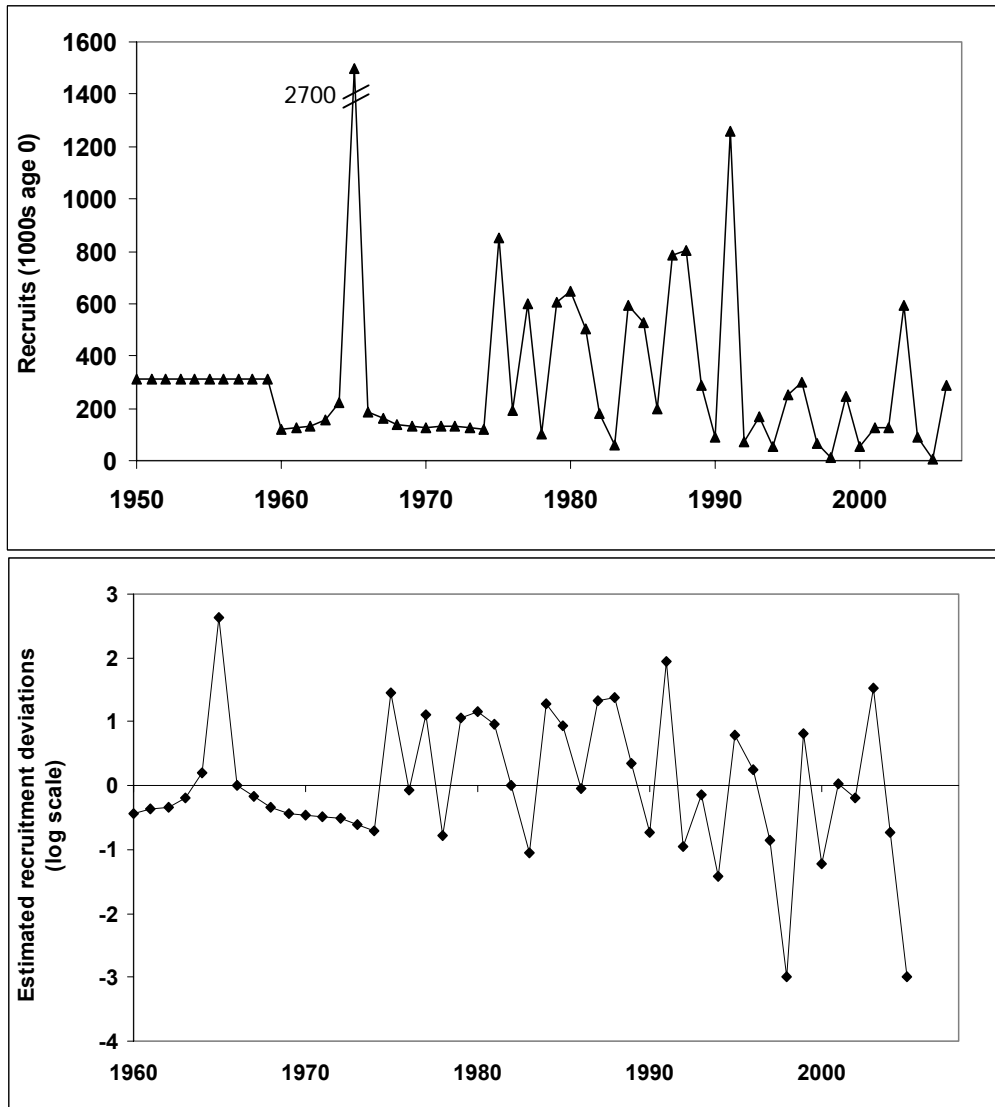
Figure 24: Top: model estimated recruitment, bottom: estimated recruitment deviation values (log-scale).
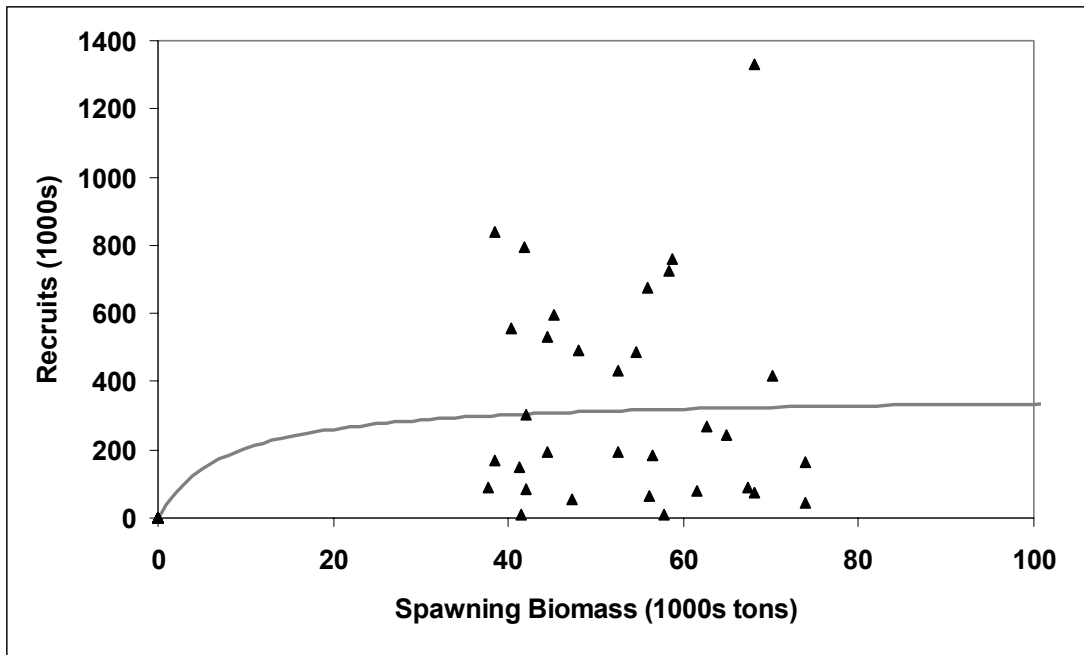
Figure 25: Spawner-recruit data for 1975-2005 period, with the assumed spawner recruit relationship where steepness is fixed at 0.65.
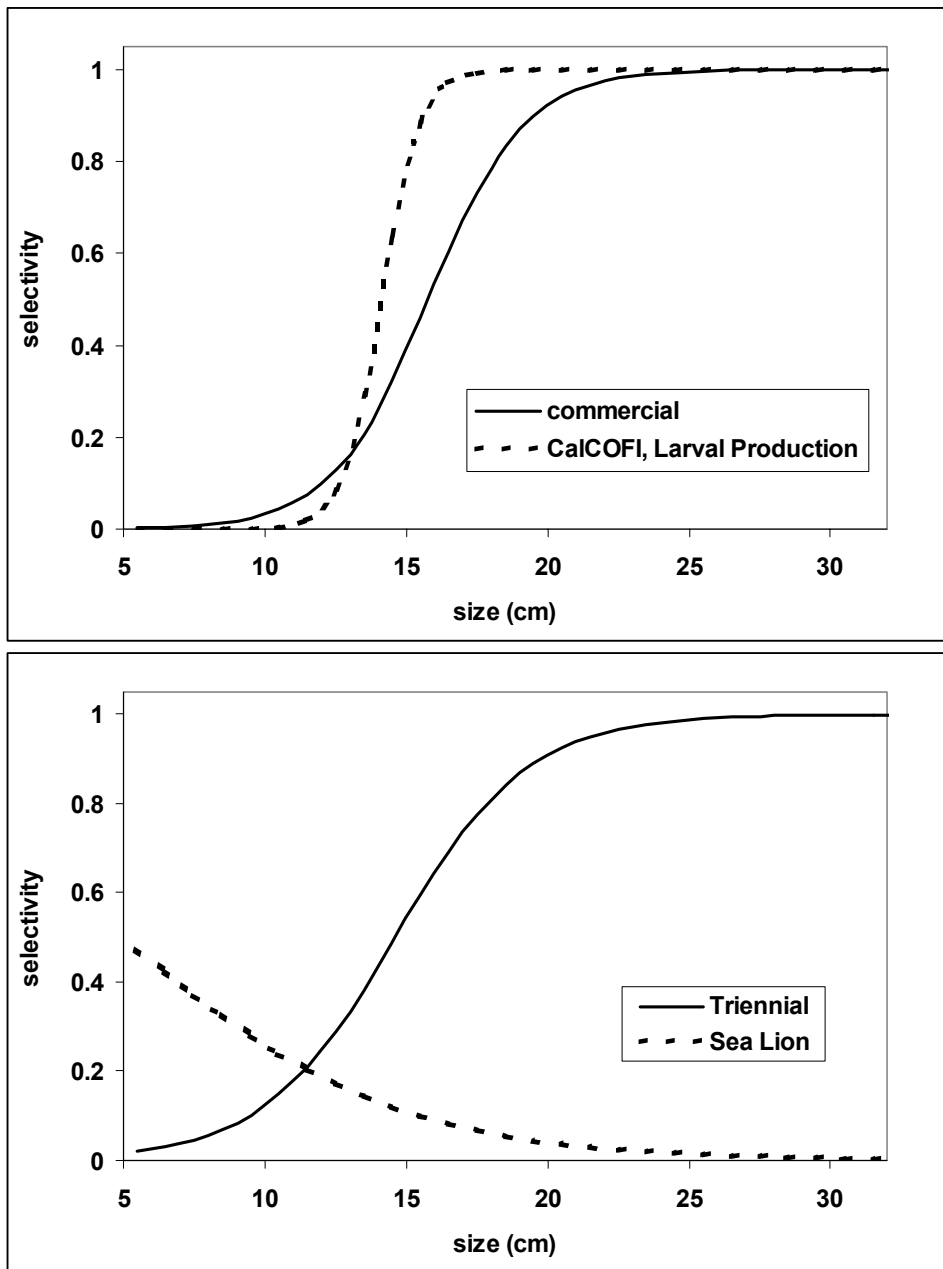
Figure 26: Selectivity functions for all fisheries.
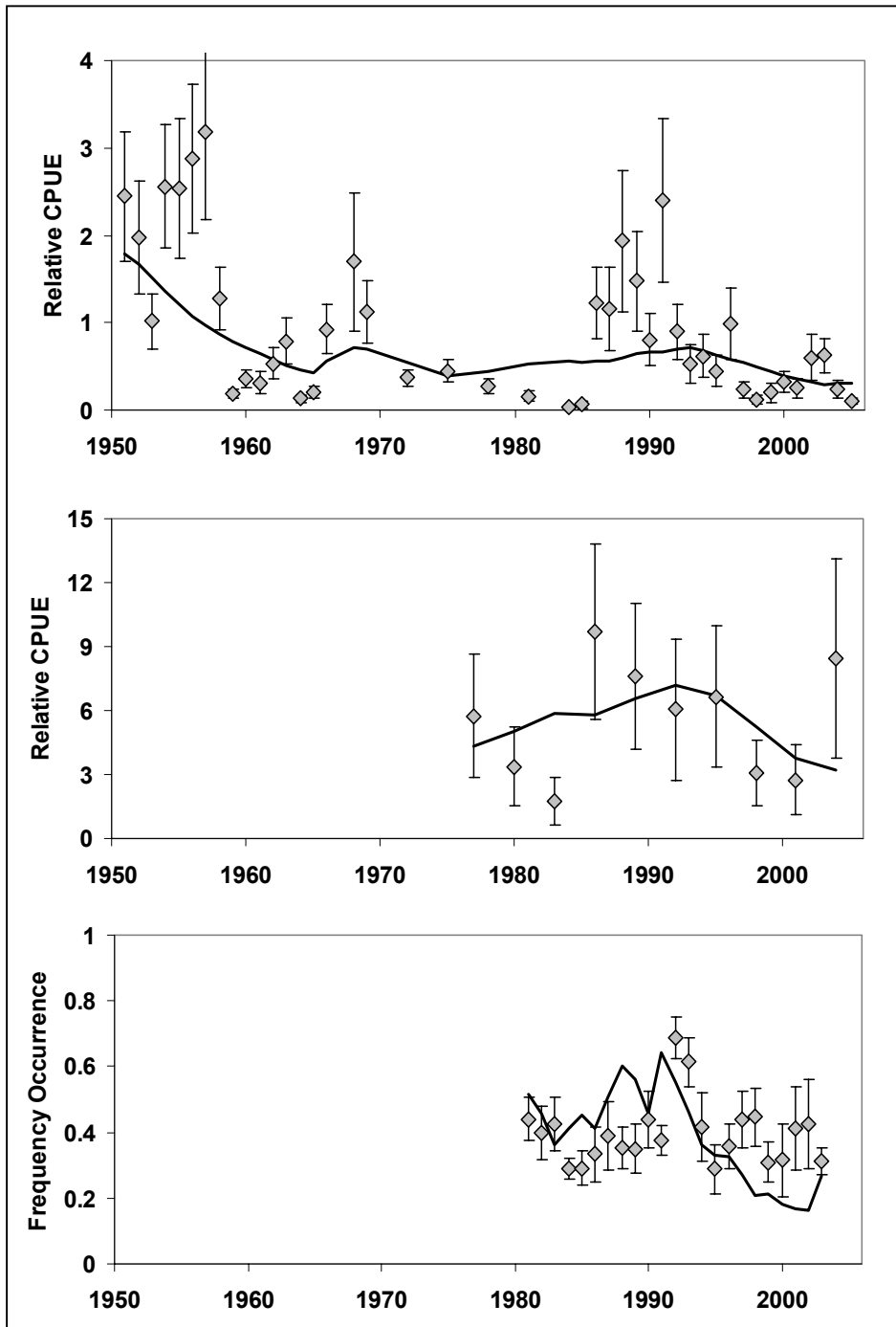
Figure 27: Model fits to relative abundance data, CalCOFI larval abundance (top), triennial trawl survey (center) and sea lion frequency of occurrence (bottom). Data are points, model predicted fits are lines. The dotted line in fit to the 1950-1960 CalCOFI data reflects the fact that recruitment deviation parameters were not free until 1960.
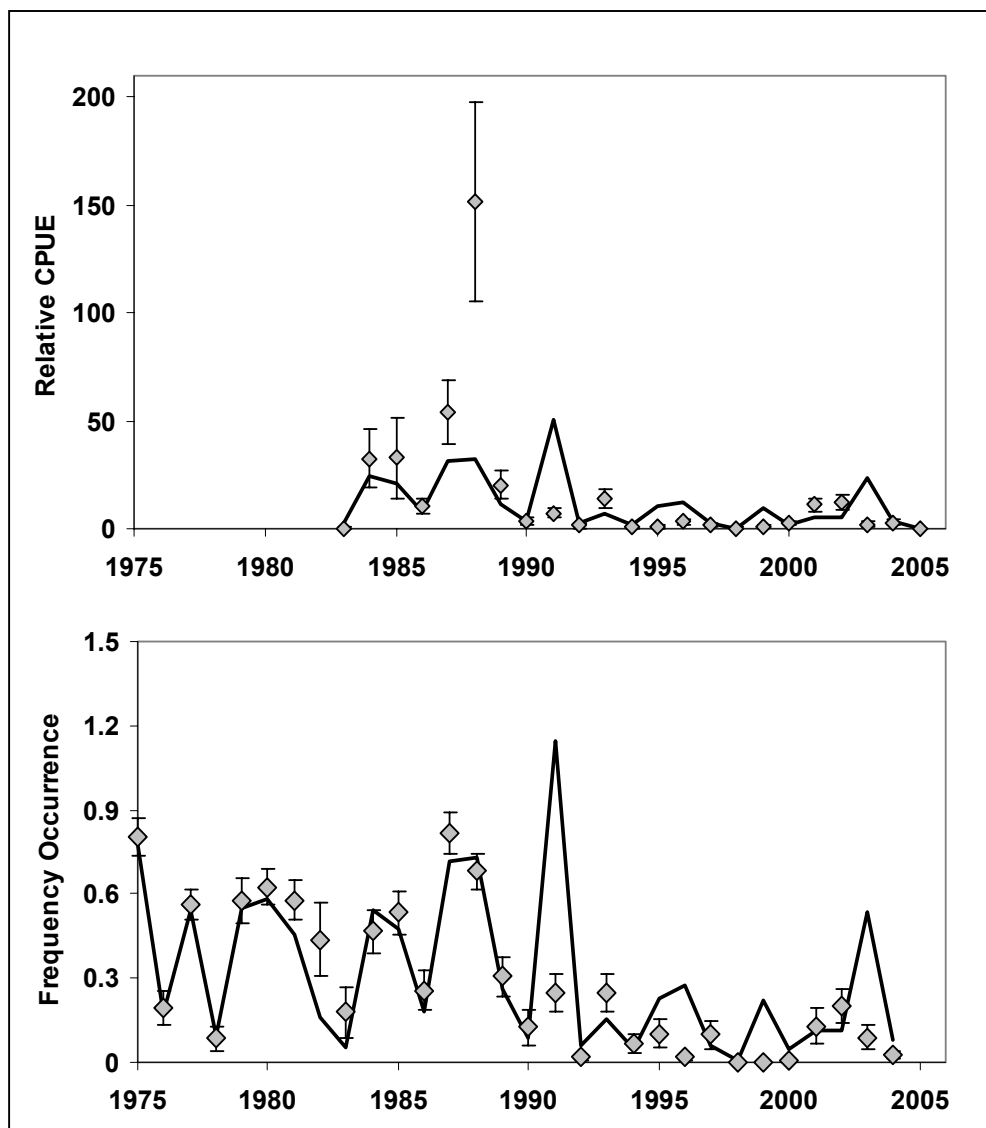
Figure 28: Observed (points) and predicted (lines) juvenile indices from the Central California juvenile survey (top) and murre food habits data (bottom).
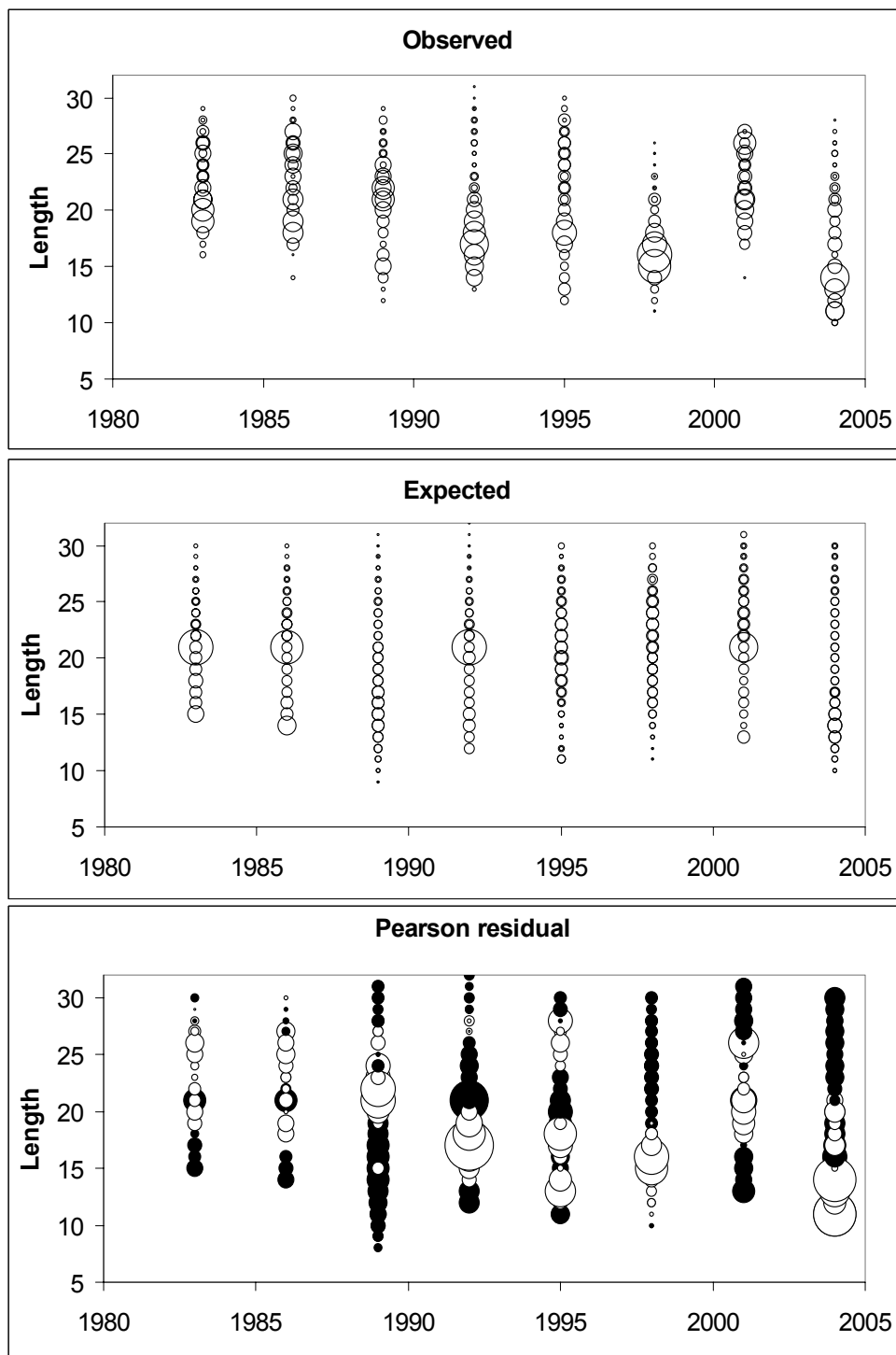
Figure 29: Model observed (top), expected (center), and residual (bottom) bubble plots of fits to length frequency data from the triennial trawl survey. For the residuals, solid circles reflect negative residuals, open circles reflect positive residuals.
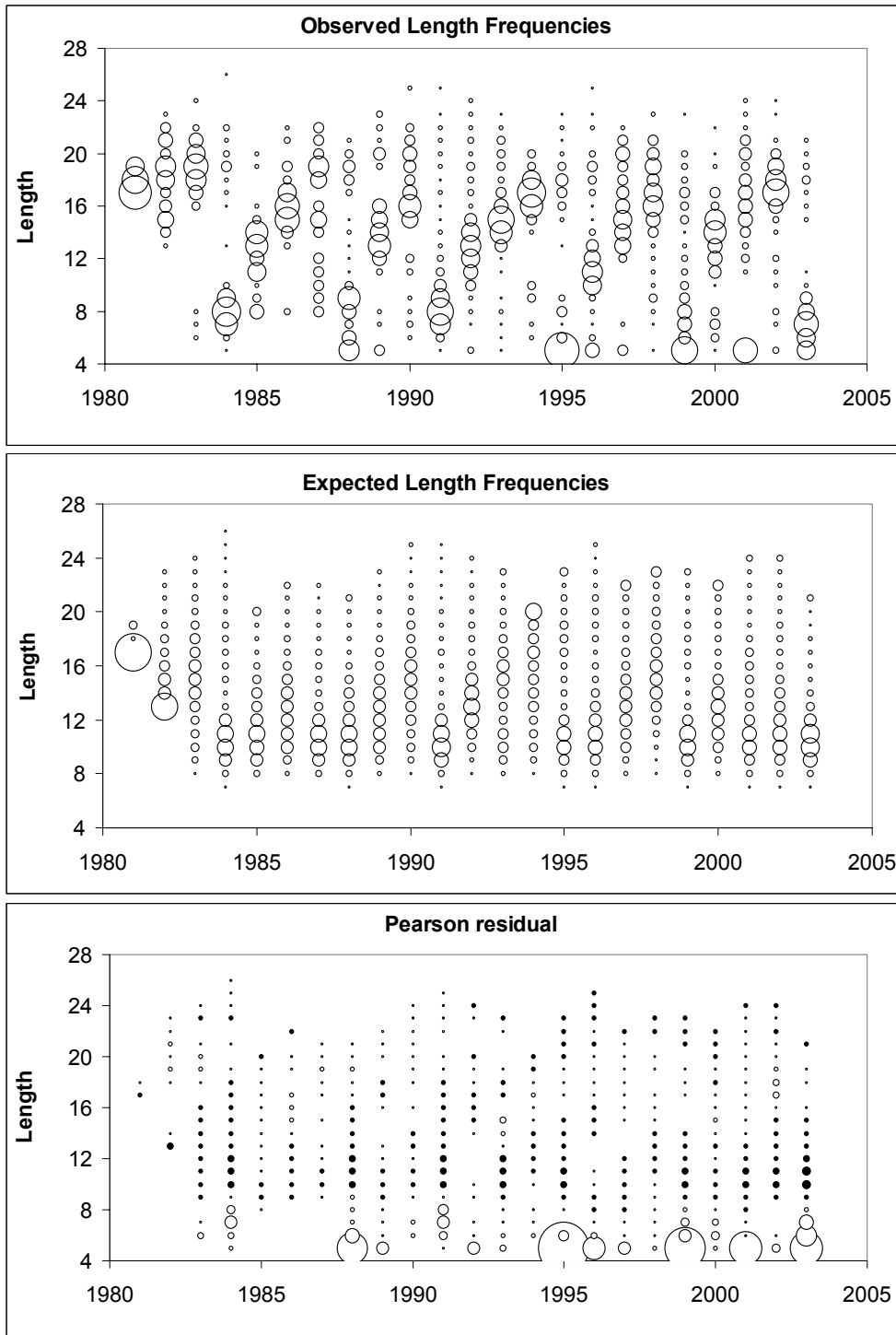
Figure 30: Model observed (top), expected (center), and residual (bottom) bubble plots of fits to length frequency data from the California sea lion food habits study. Solid circles reflect negative residuals, open circles reflect positive residuals. The poor fit to the smallest size classes of the length frequency data reflects the mismatch between the actual size of age 3 to 6 month juveniles and model predictions of size at age 0.5.

1991 Larval Production Survey
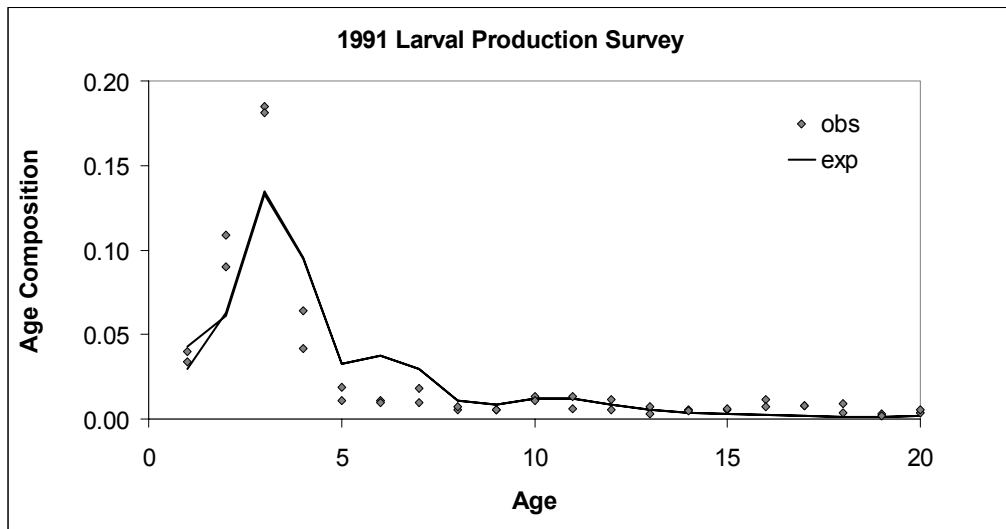
Figure 31: Observed and expected fits to 1991 age composition data from the Larval Production Survey (Ralston 2003).
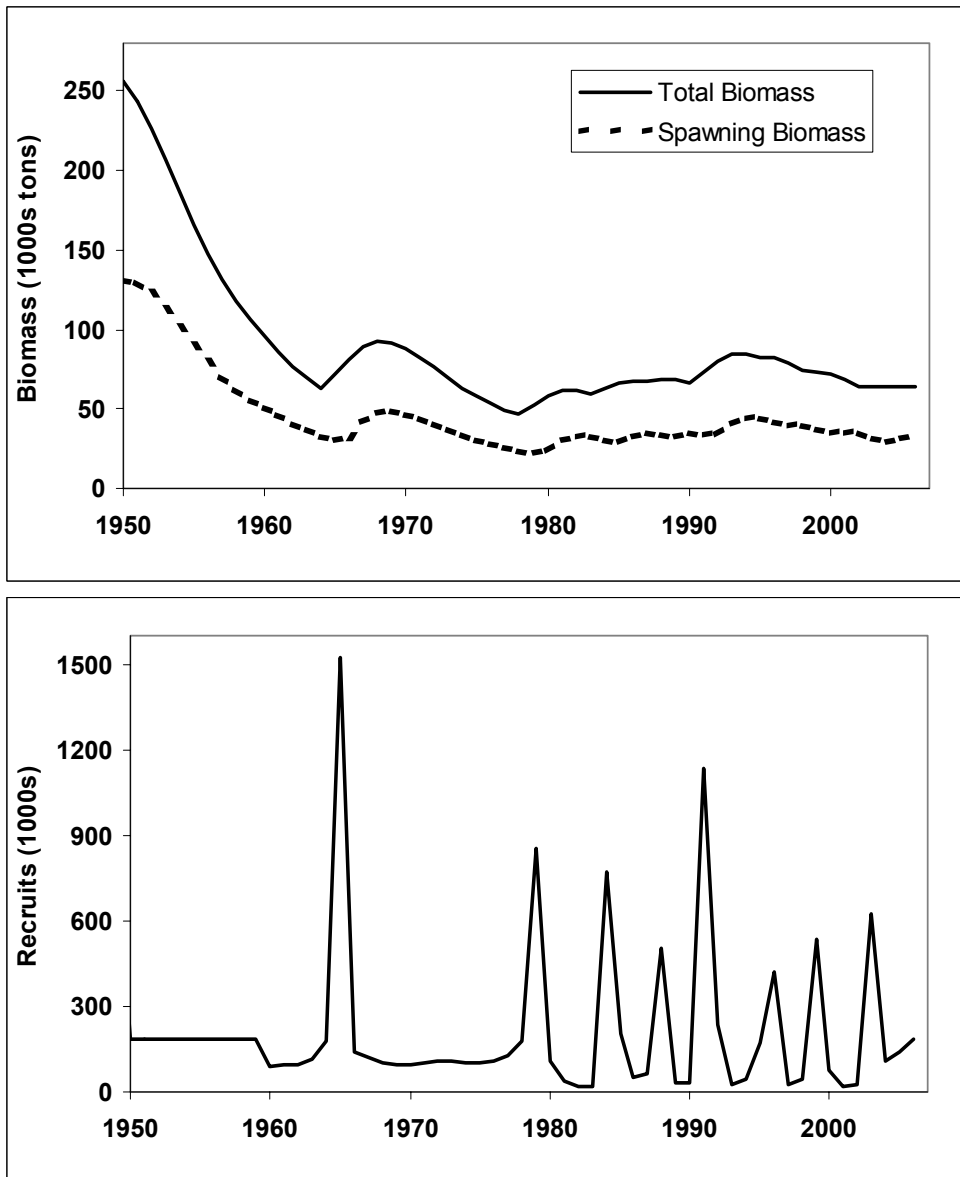
Figure 32: Results of the shortbelly rockfish model using only southern (CalCOFI, sea lion) data, but including a point estimate based on the larval production model to scale the total biomass.
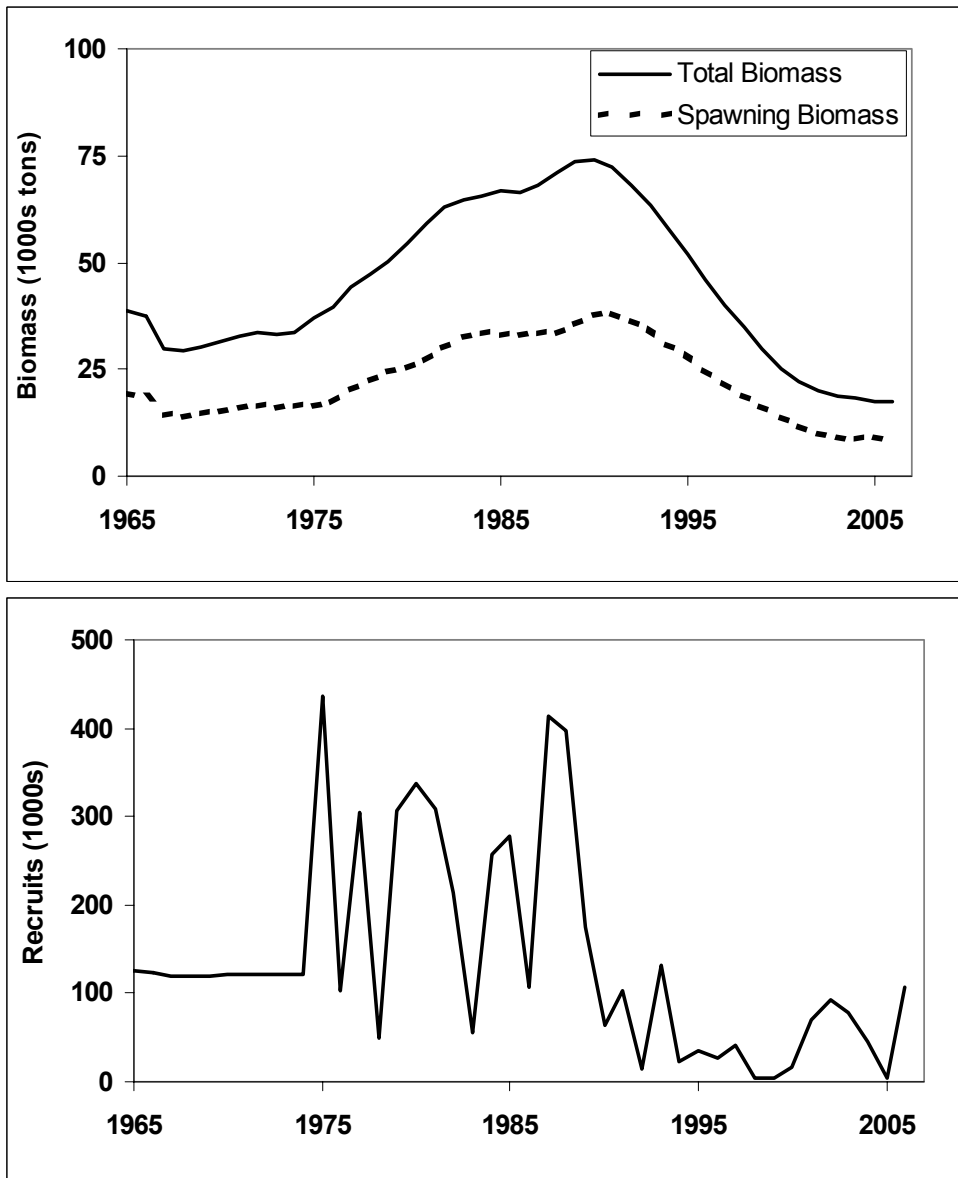
Figure 33: Results of the shortbelly rockfish model using only northern (triennial, seabird, larval production and juvenile survey) data, but including a point estimate based on the larval production model to scale the total biomass.

Appendix A: Shortbelly rockfish .dat and .ctl files for SS2


```
# ************************************************************
# sbelly.dat
# setup was based on SS2 ver 1.19 User manual (June 2006)
# J Field July 2006
# ************************************************************
1950      # start year- first year of CalCOFI data
2005      # end year
1         # n seasons
12        # months/season
1         # spawning season
1         # fishing fleets
7         # surveys
allfisheries%calcofi%triennial%juvenile%murre%larvprod%hydro%sealion
0.5     0.25    0.5     0.5     0.5     0.5     0.5     0.5     #timing
2         # number of genders
20        # accumulator age
# catch (mtons)
139       # init equil
127       #       1950
125       #       1951
137       #       1952
143       #       1953
161       #       1954
172       #       1955
174       #       1956
154       #       1957
150       #       1958
122       #       1959
119       #       1960
140       #       1961
96        #       1962
120       #       1963
166       #       1964
261       #       1965
1690      #       1966- 1976 include foreign fisheries
8491      #       1967
1805      #       1968
247       #       1969
119       #       1970
95        #       1971
201       #       1972
1228      #       1973
369       #       1974
973       #       1975
927       #       1976
142       #       1977
102       #       1978
222       #       1979
287       #       1980
178       #       1981
204       #       1982
161       #       1983
```

215	#	1984
114	#	1985
93	#	1986
89	#	1987
77	#	1988
98	#	1989
122	#	1990
96	#	1991
57	#	1992
63	#	1993
46	#	1994
66	#	1995
81	#	1996
65	#	1997
46	#	1998
26	#	1999
13	#	2000
10	#	2001
6	#	2002
0	#	2003
2	#	2004
0	#	2005

Abundance indices

133   # number of observations

year season type value SD
calcofi

year	season	type	value	SD
1951	1	2	2.44535841	0.3020289
1952	1	2	1.9704271	0.3287643
1953	1	2	1.01600638	0.3052193
1954	1	2	2.55894603	0.2744458
1955	1	2	2.53396354	0.3146708
1956	1	2	2.87422011	0.2972331
1957	1	2	3.18895311	0.316188
1958	1	2	1.27842044	0.2760547
1959	1	2	0.18819968	0.3050918
1960	1	2	0.35503673	0.2958913
1961	1	2	0.31113843	0.4038899
1962	1	2	0.53187397	0.3373097
1963	1	2	0.78515074	0.3379396
1964	1	2	0.1310738	0.3416369
1965	1	2	0.20273422	0.3449758
1966	1	2	0.92445324	0.3028957
1968	1	2	1.69512738	0.4649369
1969	1	2	1.12172942	0.3156536
1972	1	2	0.36653831	0.2566047
1975	1	2	0.44697658	0.2772017
1978	1	2	0.27618524	0.3154204
1981	1	2	0.15556451	0.3876955
1984	1	2	0.03228418	0.5502586
1985	1	2	0.05983514	0.6592323
1986	1	2	1.220644	0.3333913
1987	1	2	1.15324882	0.4127458
1988	1	2	1.9364651	0.4176389
1989	1	2	1.47569696	0.3847476
1990	1	2	0.80045731	0.3724263
1991	1	2	2.40379385	0.388775

1992	1	2	0.8952629	0.3552153
1993	1	2	0.53315053	0.4205956
1994	1	2	0.62089598	0.3895749
1995	1	2	0.44987824	0.4018767
1996	1	2	0.99178726	0.413795
1997	1	2	0.23577299	0.3984737
1998	1	2	0.12248688	0.4000461
1999	1	2	0.20126664	0.5474729
2000	1	2	0.3244219	0.3715912
2001	1	2	0.24863275	0.4440022
2002	1	2	0.60341128	0.4486152
2003	1	2	0.62329844	0.3151279
2004	1	2	0.24562498	0.41312
2005	1	2	0.09675862	0.3615625

next is triennial

1977	1	3	5.753	0.501
1980	1	3	3.378	0.554
1983	1	3	1.738	0.638
1986	1	3	9.706	0.423
1989	1	3	7.592	0.45
1992	1	3	6.045	0.545
1995	1	3	6.66	0.498
1998	1	3	3.079	0.492
2001	1	3	2.745	0.597
2004	1	3	8.463	0.551

juvenile survey

1983	1	4	0.22386114	1.1364975
1984	1	4	32.5914477	0.4196748
1985	1	4	32.79414882	0.5742542
1986	1	4	10.44356614	0.3422083
1987	1	4	54.24171251	0.2753726
1988	1	4	151.3029638	0.3055364
1989	1	4	20.25530819	0.3199336
1990	1	4	3.80330476	0.4849181
1991	1	4	7.08974103	0.3163444
1992	1	4	1.44648794	0.7396469
1993	1	4	14.06285427	0.3117054
1994	1	4	0.62310782	0.6389292
1995	1	4	0.87762365	0.6601251
1996	1	4	3.37441245	0.370432
1997	1	4	1.85131715	0.4581122
1998	1	4	0.24326274	0.9489322
1999	1	4	0.93690434	0.4864939
2000	1	4	2.83913226	0.3083893
2001	1	4	11.08416106	0.2577386
2002	1	4	12.2233307	0.2844328
2003	1	4	1.90237358	0.75268
2004	1	4	2.98805096	0.3740108
2005	1	4	0.04324357	0.489380377

murre food habits

1975	1	5	0.804	0.081008269
1976	1	5	0.195	0.312242159
1977	1	5	0.564	0.092866916
1978	1	5	0.085	0.5
1979	1	5	0.576	0.139950685
1980	1	5	0.626	0.104404629

1981	1	5	0.578	0.125196901
1982	1	5	0.437	0.296094818
1983	1	5	0.179	0.5
1984	1	5	0.466	0.162069439
1985	1	5	0.534	0.144386858
1986	1	5	0.255	0.27603038
1987	1	5	0.817	0.086158802
1988	1	5	0.680	0.097689266
1989	1	5	0.307	0.228100156
1990	1	5	0.125	0.5
1991	1	5	0.248	0.274342735
1992	1	5	0.019	0.5
1993	1	5	0.248	0.263940399
1994	1	5	0.067	0.5
1995	1	5	0.102	0.5
1996	1	5	0.020	0.5
1997	1	5	0.100	0.5
1998	1	5	0.001	0.5
1999	1	5	0.001	0.5
2000	1	5	0.008	0.5
2001	1	5	0.130	0.5
2002	1	5	0.202	0.289387969
2003	1	5	0.089	0.5
2004	1	5	0.027	0.5

larval prod point est
1991	1	6	67400	0.2

hydro survey
1977	1	7	295000	0.2
1980	1	7	152700	0.2

sea lion survey
1981	1	8	0.439196421	0.148910122
1982	1	8	0.398566866	0.206378526
1983	1	8	0.424617968	0.193775522
1984	1	8	0.288826223	0.107695048
1985	1	8	0.291121199	0.174941704
1986	1	8	0.33360948	0.251555869
1987	1	8	0.388258003	0.268029808
1988	1	8	0.352873576	0.184978472
1989	1	8	0.35053154	0.216122492
1990	1	8	0.439283551	0.194974866
1991	1	8	0.375670554	0.117852239
1992	1	8	0.688068269	0.091119889
1993	1	8	0.613631714	0.120039534
1994	1	8	0.415498762	0.24924107
1995	1	8	0.287549168	0.256802616
1996	1	8	0.358486986	0.187004503
1997	1	8	0.437779839	0.195347658
1998	1	8	0.447377416	0.196253033
1999	1	8	0.308116134	0.197008934
2000	1	8	0.315492168	0.349429955
2001	1	8	0.411257432	0.307785206
2002	1	8	0.424324515	0.321229887
2003	1	8	0.311472535	0.133161235

Discard section- currently I have no discard data
2   # Discard biomass (1=biomass, 2=fraction)
0   # number of observations

```
# mean body weight (in kg)
0          # number of observations
# length composition
0.00001 # compress tails of composition (negative turns off)
0.0001   # constant added to observed and expected proportions at age
28        # number of length bins
5      6      7      8      9      10     11     12     13     14     15     16
       17     18     19     20     21     22     23     24     25     26     27
       28     29     30     31     32
32        # number of length observations- 80, 83, 86 removed as sampling was irregular, sample size
between 3 and 5..
# length composition
# year  season  type    gender  partition # samples    5      6      7      8      9
        10     11     12     13     14     15     16     17     18     19     20
        21     22     23     24     25     26     27     28     29     30     31
        32
# fishery length comps (based on 1978 CalCom data- very little data!)
1960   1      1      3      0      5      0      0      0      0      0      0
       0      0      0      0      0      0.05   0.1    0      0.05   0.05   0.05
       0.1    0      0      0.05   0.05   0      0      0      0      0      0
       0      0      0      0      0      0      0      0      0      0      0
       0.05   0.1    0      0.05   0.05   0.05   0.1    0      0      0.05   0.05
       0      0      0      0      0      0
# triennial lengths
# 1977 currently off due to differences in depths sampled, 1980 is off as sample size very low (2 hauls!)
#year                                     50     60     70     80     90     100
        110    120    130    140    150    160    170    180    190    200    210
        220    230    240    250    260    270    280    290    300    310    320
        50     60     70     80     90     100    110    120    130    140    150
        160    170    180    190    200    210    220    230    240    250    260
        270    280    290    300    310    320
#1977  1      3      3      0      28     0      0      0.00012 0.00125 0.00084 0
       0      0      0      0      0      0      0      0      0      0      0.083
       0.06767 0.02227 0.0162 0.01088 0.00965 0.01155 0.01203 0.00426 0.00123 0.00021 0.00002
       0      0      0.00012 0.00125 0.00084 0      0      0.00002 0.00384 0.00502 0.00318
       0.00325 0.0265 0.07639 0.07193 0.073  0.06552 0.05145 0.02351 0.01881 0.02053 0.01864
       0.00995 0.00205 0.00016 0      0      0
#1980  1      3      3      0      2      0      0      0      0      0      0
       0      0      0      0      0      0      0      0      0      0      0.03092
       0.00515 0.02577 0.0567 0.08762 0.02577 0.0103 0.0103 0      0      0      0
       0      0      0      0      0      0      0      0      0      0      0
       0      0      0.0103 0.0103 0.03608 0.08247 0.15463 0.23195 0.10309 0.05154 0.03092
       0.0103 0      0      0      0      0
1983   1      3      3      0      5      0      0      0      0      0      0
       0      0      0      0      0      0      0      0      0      0      0.0758
       0.02454 0.02473 0.02137 0.01682 0.03284 0.03224 0.01661 0.00507 0.00008 0      0
       0      0      0      0      0      0      0      0      0      0      0.00044
       0.0077 0.00775 0.03454 0.10425 0.10651 0.07293 0.06338 0.034  0.03194 0.05243 0.04728
       0.01215 0.00618 0      0      0      0
1986   1      3      3      0      4      0      0      0      0      0      0
       0      0      0      0      0      0      0      0      0      0      0.01988
       0.01273 0.00636 0.02066 0.03921 0.03457 0.06027 0.00927 0.00463 0.00927 0      0
       0      0      0      0      0      0      0      0      0      0.00636 0
       0.00212 0.03011 0.08106 0.07894 0.03397 0.08704 0.0467 0.0506 0.06027 0.07417 0.04636
       0      0.00463 0      0      0      0
```

```
1989    1       3       3       0       37      0       0       0       0.00006 0.00016 0.00006
        0.00006 0       0       0       0       0       0       0       0       0       0.05952
        0.05728 0.05465 0.04819 0.01562 0.01048 0.00588 0.01282 0.0043  0.00003 0.00001 0
        0       0       0       0.00012 0.0001  0.00006 0.00042 0.00306 0.0048  0.02319 0.05088
        0.02974 0.00814 0.02277 0.03442 0.05799 0.10554 0.09413 0.0304  0.00859 0.01104 0.01728
        0.00922 0.00036 0       0.00034 0       0
1992    1       3       3       0       43      0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0       0.03403
        0.01765 0.00833 0.00269 0.00355 0.00572 0.00902 0.0086  0.00501 0.00146 0.0011  0.00003
        0       0       0       0       0       0       0       0.00014 0.00533 0.0441  0.05265
        0.06491 0.13095 0.07722 0.06538 0.04418 0.01379 0.00621 0.0104  0.00345 0.00501 0.00673
        0.00457 0.00308 0.0009  0.00003 0.00006 0
1995    1       3       3       0       43      0       0       0       0       0       0
        0.00046 0       0       0       0       0       0       0       0       0       0.01243
        0.02326 0.0149  0.02951 0.02017 0.03325 0.02206 0.03396 0.00784 0.00415 0       0
        0       0       0       0       0       0       0.00039 0.01326 0.03131 0.02145 0.01148
        0.02409 0.05544 0.10036 0.04933 0.03141 0.02756 0.03043 0.02617 0.02968 0.02812 0.02643
        0.0113  0.00462 0.00056 0       0       0
1998    1       3       3       0       5       0       0       0       0       0       0.0001
        0.00066 0       0       0       0       0       0       0       0       0       0.02054
        0.00261 0.00429 0.0017  0.00128 0.001   0.00021 0.00016 0.00008 0.00002 0       0
        0       0       0       0       0       0.00014 0.00131 0.0045  0.01081 0.02302 0.12228
        0.14448 0.06704 0.03917 0.02036 0.0106  0.00527 0.0007  0.00112 0.00113 0.00084 0.0001
        0.00007 0.00001 0       0       0       0
2001    1       3       3       0       32      0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0       0.06772
        0.03059 0.02442 0.02717 0.06331 0.10097 0.04617 0.00016 0.00009 0       0.00001 0
        0       0       0       0       0       0       0       0       0.00026 0.0008  0.0003
        0.00033 0.02178 0.0504  0.06034 0.08003 0.08533 0.04956 0.04532 0.03142 0.0314  0.02291
        0.00412 0.00021 0.00001 0.00003 0       0
2004    1       3       3       0       61      0       0       0       0       0       0.00728
        0.05527 0       0       0       0       0       0       0       0       0       0.02365
        0.01646 0.01031 0.00525 0.00642 0.00274 0.00474 0.00207 0.00002 0.00006 0       0
        0       0       0       0       0       0.0072  0.05674 0.03434 0.07231 0.13266 0.03615
        0.00719 0.03339 0.02378 0.02029 0.03051 0.01274 0.00886 0.00382 0.0052  0.00757 0.00333
        0.00043 0.00019 0.00015 0.00025 0       0
#hydrosurvey length comps
#1977   1       7       3       0       9       0       0       0       0       0       0
        0       0       0       0       0       0       0.00183 0.03482 0.06598 0.10264 0.15385
        0.24539 0.13358 0.10889 0.03935 0.03115 0.03665 0.03849 0.00549 0.00183 0       0
        0       0       0       0       0       0       0       0       0       0       0
        0       0.05141 0.08568 0.12802 0.12802 0.11088 0.12802 0.12802 0.08568 0.06854 0.05141
        0.01713 0       0.01713 0       0       0
#1980   1       7       3       0       5       0       0       0       0       0       0
        0       0       0       0       0       0       0       0       0       0.05098 0.10588
        0.0549  0.02352 0.11764 0.22745 0.21568 0.08627 0.07843 0.03529 0.00392 0       0
        0       0       0       0       0       0       0       0       0       0       0
        0       0       0.03846 0.03846 0.07692 0.07692 0.11538 0.11538 0.11538 0.11538 0.11538
        0.07692 0.07692 0.03846 0       0       0
# below are sea lion diet length frequencies (based on otolith/fish length regressions)- tuned
# year  season  type    gender  partition # samples     5       6       7       8       9
        10      11      12      13      14      15      16      17      18      19      20
        21      22      23      24      25      26      27      28      29      30      31
        32      5       6       7       8       9       10      11      12      13      14
        15      16      17      18      19      20      21      22      23      24      25
        26      27      28      29      30      31      32
```

1981	1	8	0	0	1.0992	0	0	0	0	0	0
	0	0	0	0	0	0	0.25	0.167	0.083	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0.25	0.166665		0.08333	0	0	0	0	0	0
	0	0	0	0	0	0	0				
1982	1	8	0	0	10.8088	0	0	0	0	0	0
	0	0	0.008	0.034	0.068	0.042	0.034	0.093	0.102	0.025	0.051
	0.034	0.008	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0.00847	0.033895	
	0.067795		0.04237	0.033895		0.09322	0.10169	0.02542	0.050845		
	0.033895		0.00847	0	0	0	0	0	0	0	0
	0										
1983	1	8	0	0	21.984	0	0.008	0.004	0.008	0	0
	0	0	0	0	0	0.021	0.05	0.1	0.154	0.083	0.054
	0.013	0	0.004	0	0	0	0	0	0	0	0
	0	0.00833	0.004165		0.00833	0	0	0	0	0	0
	0	0.02083	0.05	0.1	0.154165		0.08333	0.054165		0.0125	0
	0.004165	0	0	0	0	0	0	0	0		
1984	1	8	0	0	54.044	0.002	0.01	0.121	0.196	0.087	0.015
	0	0	0.002	0	0	0.002	0.005	0.005	0.026	0.014	0.007
	0.009	0	0	0	0.002	0	0	0	0	0	0
	0.002	0.0102	0.120745		0.195575		0.08673	0.015305		0	0
	0.0017	0	0	0.0017	0.0051	0.0051	0.02551	0.013605		0.0068	0.0085
	0	0	0	0.0017	0	0	0	0	0	0	
1985	1	8	0	0	11.5416	0	0	0	0.048	0.016	0.008
	0.087	0.048	0.135	0.119	0.016	0.008	0	0	0.008	0.008	0
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0.047615		0.01587	0.007935		0.0873	0.047615	
	0.13492	0.119045		0.01587	0.007935		0	0	0.007935		
	0.007935	0	0	0	0	0	0	0	0	0	
	0	0	0								
1986	1	8	0	0	14.8392	0	0	0	0.012	0	0
	0	0	0.012	0.037	0.142	0.142	0.093	0.019	0.025	0	0.012
	0.006	0	0	0	0	0	0	0	0	0	0
	0	0	0	0.012345		0	0	0	0	0.012345	
	0.037035		0.141975		0.141975		0.09259	0.018515		0.02469	0
	0.012345		0.00617	0	0	0	0	0	0	0	0
	0	0									
1987	1	8	0	0	3.664	0	0	0	0.025	0.025	0.025
	0.025	0.025	0	0.025	0.075	0.025	0	0.075	0.1	0.025	0.025
	0.025	0	0	0	0	0	0	0	0	0	0
	0	0	0	0.025	0.025	0.025	0.025	0.025	0	0.025	0.075
	0.025	0	0.075	0.1	0.025	0.025	0.025	0	0	0	0
	0	0	0	0	0	0					
1988	1	8	0	0	41.0368	0.109	0.06	0.022	0.049	0.125	0.022
	0.003	0.003	0.003	0.005	0.003	0	0.011	0.024	0.035	0.019	0.008
	0	0	0	0	0	0	0	0	0	0	0
	0.109	0.05978	0.021735		0.04891	0.125	0.021735		0.002715		
	0.002715		0.002715		0.00543	0.002715		0	0.010865		
	0.024455		0.035325		0.01902	0.00815	0	0	0	0	0
	0	0	0	0	0	0					
1989	1	8	0	0	19.0528	0.025	0	0.005	0.005	0	0
	0.015	0.051	0.121	0.081	0.061	0.056	0	0	0.015	0.035	0.005
	0.015	0.01	0	0	0	0	0	0	0	0	0
	0.025	0	0.00505	0.00505	0	0	0.01515	0.050505		0.12121	

```
         0.080805       0.060605       0.055555       0       0       0.01515 0.03535 0.00505
         0.01515 0.0101 0       0       0       0       0       0       0       0       0
1990     1       8       0       0       13.3736 0       0.007   0.014   0.007   0.007   0
         0.014   0.021   0       0       0.075   0.137   0.048   0.027   0.041   0.048   0.027
         0.021   0       0       0.007   0       0       0       0       0       0       0
         0       0.006845        0.013695        0.006845        0.006845        0
         0.013695        0.020545        0       0       0.07534 0.136985        0.047945
         0.027395        0.041095        0.047945        0.027395        0.020545        0
         0       0.006845        0       0       0       0       0       0       0
1991     1       8       0       0       98.928  0.001   0.017   0.105   0.181   0.085   0.037
         0.018   0.012   0.007   0.005   0.001   0.002   0.005   0.002   0.006   0.004   0.005
         0.006   0.002   0       0.001   0       0       0       0       0       0       0
         0.001   0.016695        0.10482 0.18089 0.08534 0.037105        0.017625
         0.012055        0.00742 0.004635        0.000925        0.001855        0.004635
         0.001855        0.00649 0.00371 0.004635        0.005565        0.001855        0
         0.000925        0       0       0       0       0       0       0
1992     1       8       0       0       107.3552        0.013   0       0.002   0.004   0.008
         0.031   0.049   0.084   0.096   0.094   0.036   0.007   0.011   0.013   0.021   0.008
         0.01    0.007   0.004   0.004   0       0       0       0       0       0       0
         0       0.013   0       0.00175 0.0035  0.00788 0.030645        0.049035        0.08406
         0.09632 0.093695        0.0359  0.007005        0.01138 0.01313 0.021015        0.00788
         0.00963 0.007005        0.0035  0.0035  0       0       0       0       0       0
         0       0
1993     1       8       0       0       80.608  0.003   0.003   0.001   0.005   0.002   0
         0.001   0.002   0.034   0.129   0.16    0.058   0.032   0.009   0.017   0.016   0.016
         0.008   0.001   0       0       0       0       0       0       0       0       0
         0.003   0.00343 0.00114 0.004575        0.002285        0       0.00114 0.002285
         0.03432 0.12929 0.16018 0.05835 0.032035        0.00915 0.01716 0.016015
         0.016015        0.008005        0.00114 0       0       0       0       0       0
         0       0       0
1994     1       8       0       0       11.5416 0       0.008   0.008   0       0.016   0.016
         0       0       0       0.008   0.024   0.119   0.19    0.079   0.016   0.016   0
         0       0       0       0       0       0       0       0       0       0       0
         0       0.007935        0.007935        0       0.01587 0.01587 0       0       0
         0.007935        0.023805        0.119045        0.190475        0.079365        0.01587
         0.01587 0       0       0       0       0       0       0       0       0
         0       0
1995     1       8       0       0       45.0672 0.294   0.026   0.003   0.026   0.013   0
         0       0       0.003   0       0.006   0.023   0.032   0.035   0.019   0.006   0.003
         0.006   0.003   0       0       0       0       0       0       0       0       0
         0.294   0.025805        0.003225        0.025805        0.0129  0       0       0
         0.003225        0       0.00645 0.02258 0.032255        0.03548 0.01935 0.00645
         0.003225        0.00645 0.003225        0       0       0       0       0       0
         0       0       0
1996     1       8       0       0       43.4184 0.056   0.014   0.002   0.007   0.014   0.08
         0.11    0.07    0.045   0.009   0.002   0.002   0.009   0.023   0.033   0.012   0
         0.005   0.002   0       0.002   0       0       0       0       0       0       0
         0.056   0.01408 0.002345        0.00704 0.01408 0.07981 0.110325        0.07042 0.0446
         0.009385        0.002345        0.002345        0.009385        0.02347 0.03286
         0.011735        0       0.00469 0.002345        0       0.002345        0       0
         0       0       0       0       0
1997     1       8       0       0       26.564  0.025   0       0.004   0       0       0
         0       0.018   0.065   0.062   0.094   0.058   0.036   0.029   0.033   0.047   0.025
         0.004   0       0       0       0       0       0       0       0       0       0
         0.025   0       0.00362 0       0       0       0       0.018115        0.065215
```

```
        0.06159 0.0942  0.05797 0.03623 0.028985        0.032605        0.0471  0.02536 0.00362
        0       0       0       0       0       0       0       0       0       0
1998    1       8       0       0       34.0752 0.003   0       0.003   0.005   0.019   0.008
        0.005   0.005   0.005   0.024   0.054   0.1     0.078   0.043   0.065   0.046   0.027
        0       0.008   0       0       0       0       0       0       0       0       0
        0.003   0       0.0027  0.005405        0.018915        0.008105        0.005405
        0.005405        0.005405        0.02432 0.05405 0.1     0.078375        0.04324 0.06486
        0.045945        0.027025        0       0.008105        0       0       0       0
        0       0       0       0       0
1999    1       8       0       0       62.6544 0.171   0.035   0.055   0.059   0.027   0.018
        0.014   0.014   0.004   0.002   0.016   0.02    0.025   0.014   0.012   0.014   0
        0       0.002   0       0       0       0       0       0       0       0       0
        0.171   0.03529 0.0549  0.05882 0.02745 0.017645        0.013725        0.013725
        0.00392 0.00196 0.015685        0.019605        0.02549 0.013725        0.01176
        0.013725        0       0       0.00196 0       0       0       0       0       0
        0       0       0
2000    1       8       0       0       26.564  0.003   0.017   0.024   0.017   0       0.003
        0.035   0.059   0.052   0.118   0.108   0.017   0.031   0       0.007   0.003   0
        0.003   0       0       0       0       0       0       0       0       0       0
        0.003   0.01736 0.024305        0.01736 0       0.00347 0.03472 0.059025        0.05208
        0.118055        0.107635        0.01736 0.03125 0       0.00694 0.00347 0       0.00347
        0       0       0       0       0       0       0       0       0       0
2001    1       8       0       0       30.228  0.15    0       0       0       0       0
        0.004   0.02    0.012   0.024   0.051   0.051   0.059   0.039   0.02    0.035   0.024
        0.004   0.004   0.004   0       0       0       0       0       0       0       0
        0.15    0       0       0       0       0       0.003935        0.019685        0.01181
        0.02362 0.05118 0.05118 0.059055        0.03937 0.019685        0.03543 0.02362
        0.003935        0.003935        0.003935        0       0       0       0       0
        0       0       0
2002    1       8       0       0       34.9912 0.011   0       0.005   0.013   0       0.005
        0.005   0.011   0       0.008   0.011   0.053   0.163   0.11    0.067   0.027   0.005
        0       0.003   0.003   0       0       0       0       0       0       0       0
        0.011   0       0.005345        0.013365        0       0.005345        0.005345
        0.010695        0       0.00802 0.010695        0.053475        0.1631  0.109625
        0.06684 0.026735        0.005345        0       0.00267 0.00267 0       0       0
        0       0       0       0       0
2003    1       8       0       0       85.7376 0.088   0.089   0.146   0.073   0.041   0.005
        0.001   0       0       0       0.005   0.006   0.008   0.018   0.01    0.005   0.005
        0       0       0       0       0       0       0       0       0       0       0
        0.088   0.089195        0.145725        0.07286 0.041455        0.005025
        0.001255        0       0       0       0.005025        0.00628 0.007535
        0.017585        0.01005 0.005025        0.005025        0       0       0       0
        0       0       0       0       0       0       0
#
# Age composition data
20      # number of age bins
1       2       3       4       5       6       7       8       9       10      11      12
        13      14      15      16      17      18      19      20
2       # number of unique ageing error matrices to generate
# ageing error matrix- for now, setting to -1 to set equal to true age (plus 0.5), but I can try to work up a
matrix later if more age data are ultimately used..
0.644   1.288   1.932   2.576   3.22    3.864   4.508   5.152   5.796   6.44    7.084   7.728
        8.372   9.016   9.66    10.304  10.948  11.592  12.236  12.88   13.524  # this is the
surface v. break and burn bias from Pearson 1991
```

0.0767 0.1534 0.2301 0.3068 0.3835 0.4602 0.5369 0.6136 0.6903 0.767 0.8437 0.9204
     0.9971 1.0738 1.1505 1.2272 1.3039 1.3806 1.4573 1.534 1.6107 # these are
standard errors at age based on Pearson 1991
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
     -1 -1 -1 -1 -1 -1 -1 -1 -1 # sets mean age =
true age+0.5
0.0767 0.1534 0.2301 0.3068 0.3835 0.4602 0.5369 0.6136 0.6903 0.767 0.8437 0.9204
     0.9971 1.0738 1.1505 1.2272 1.3039 1.3806 1.4573 1.534 1.6107 # these are
standard errors at age based on Pearson 1991
3 # number of age observations- currently only using 1991, but there is other age data that could possibly be used as well.
format of line below is is year- season- type- gender- partition- ageerro matrix to use- Lbin lo- Lbin high- N samp (here number of tows from which ages came)- and the data- as with length it is in % frequency (sum to 1), females, then males

# year	season	type	gender	partition	ageermat		Lbinlo	Lbinhigh		Nsamp	1
	2	3	4	5	6	7	8	9	10	11	12
	13	14	15	16	17	18	19	20	1	2	3
	4	5	6	7	8	9	10	11	12	13	14
	15	16	17	18	19	20					

#
next is age data from 1980 hydro survey (Miller Freeman)
1980 1 7 0 0 2 -1 -1 5 0 0 0.00604
     0.02416 0.1722 0.20845 0.06042 0.02719 0.00302 0.00302 0.0151 0.02719 0.00604 0.00906
     0.00302 0.00302 0.00906 0.00302 0.00604 0 0 0 0 0.01812 0.09063
     0.13595 0.05438 0.0151 0.00302 0.00302 0.01812 0.02114 0.00906 0.01208 0 0
     0.00906 0.00302 0.01208 0.00906
next age data is from larval survey
1991 1 6 3 0 2 -1 -1 28 0.033898305
     0.090098127 0.185548617 0.064228368 0.018733274 0.010704728
     0.017841213 0.005352364 0.005352364 0.01338091 0.01338091
     0.011596789 0.007136485 0.005352364 0.005352364 0.011596789
     0.008028546 0.008920607 0.002676182 0.003568243 0.04014273
     0.108831401 0.181980375 0.041926851 0.010704728 0.009812667
     0.009812667 0.007136485 0.005352364 0.010704728 0.006244425
     0.005352364 0.002676182 0.004460303 0.006244425 0.007136485
     0.008028546 0.003568243 0.001784121 0.005352364
finally, I'll include the ages from the 2003 NWFSC Combined survey, treat as if from triennial (interesting, the model doesn't seem to "mind"..)
2003 1 3 3 0 2 -1 -1 40 0.1139 0.0746 0.0392
     0.0491 0.0589 0.0019 0.0137 0.0137 0.0078 0.0137 0.0098 0.0196 0.0078 0.0058
     0.0039 0 0.0039 0.0019 0 0 0.165 0.106 0.0255 0.0746 0.0589
     0.0216 0.0098 0.0058 0.0255 0.0039 0.0098 0.0176 0.0098 0.0058 0.0039 0
     0.0078 0 0.0019 0
Mean size at age data
0 # number of size at age observations
environmental data- nothing for now..
0 # num env. Variables
0 # num env. Observations
  999 # end of file

#***
Shortbelly rockfish model control file
setup was based on SS2 ver 1.19 User manual (April 2005)
J Field June 2006
***
2   # number of growth morphs
assign sex to each growth morph
1   # females
2   # males
1   # number of areas (populations)
1   # area for fishery
1   # area for calcofi
1   # area for triennial
1   # area for juvenile survey
1   # area for murre diet
1   # area for larval production
1   # area for hydro survey
1   # area for sea lion diet
0   # migration (0 is off)
0   # time block definitions for time varying parameters (0=off)
3   # last age for M young (all fish should essentially be in one block)
5   # first age for M old
2   # age for growth Lmin
10   # age for growth Lmax
-4   # mortality and growth parameter deviance phase
next are the mortality and growth parameters- seven lines per morph (here, male, female)

# Lo	Hi	Init	Prior	Pr_type	SD	Phase	env-var	use_dev			
		devminyrdevmaxyrdevstdevuseblk blk type									
0.1	0.5	0.26	0.26	0	1	-1	0	0	0	0	0.5
		0	0	# F nat mot young							
-3	3	0	0	0	0.2	-1	0	0	0	0	0.5
		0	0	# F M_old exp. offset							
5	20	15.4	15	0	0.2	-2	0	0	0	0	0.5
		0	0	# F_Lmin							
24	32	25.8	28	0	2	-2	0	0	0	0	0.5
		0	0	# F_Lmax							
0.1	0.3	0.198	0.2	0	0.05	-2	0	0	0	0	0.5
		0	0	# F_VonBert_K							
0.02	0.16	0.1	0.1	0	0.8	-3	0	0	0	0	0.5
		0	0	# F_CV-young							
-3	3	0	0	0	0.8	-3	0	0	0	0	0.5
		0	0	# F_CV-old (rel young)							
-6	3	0	0	0	0.8	-1	0	0	0	0	0.5
		0	0	# M mort young exp. offset							
-6	3	0	0	0	0.8	-1	0	0	0	0	0.5
		0	0	# M mort old as exp. offset							
-3	3	-0.00651	-0.0369	0	0.8	-2	0	0	0	0	0.5
		0	0	# M Lmin exp. offset							
-3	3	-0.06000	-0.0566	0	0.8	-2	0	0	0	0	0.5
		0	0	# M Lmax exp. offset							
-3	3	0.01005	0.0385	0	0.8	-2	0	0	0	0	0.5
		0	0	# M Von Bert K exp. offset							
-3	3	0	0	0	0.8	-3	0	0	0	0	0.5
		0	0	# M CV young exp. offset							
-3	3	0	0	0	0.8	-3	0	0	0	0	0.5
		0	0	# M CV old as exp. offset							

```
# next are the female weight-length coefficients
-3    3    0.00000993   0.00000993   0       0.0000001934  -3    0       0
      0    0    0.5    0       0         # female weight/length alpha
-3    3    3.08   3.08   0       0.0405  -3    0       0       0    0    0.5
      0    0         # female weight/length beta
1     30   14.1   14.1   0       0.8     -3    0       0       0    0    0.5
      0    0         # female maturity logistic inflection (cm)
-3    3    -1.44  -1.44  0       0.8     -3    0       0       0    0    0.5
      0    0         # female maturity logistic slope
-3    3    1      1      0       0.8     -3    0       0       0    0    0.5
      0    0         # eggs/kg relationship- assume= SSB
-3    3    0      0      0       0.8     -3    0       0       0    0    0.5
      0    0    #
-3    3    0.00000997   0.00000997   0       0.0000001934  -3    0       0
      0    0    0.5    0       0         # male wt./leng alpha
-3    3    3.05   3.05   0       0.0405  -3    0       0       0    0    0.5
      0    0         # male weight length beta- same as femal
# pop* gmorph lines - for the proportion of each morph in each area- I am not going to be using this, will
use what looks like defaults..
0     1    0.5    0.2    0       9.8     -3    0       0       0    0    0.5
      0    0         # fraction to morph 1 in area 1
0     1    0.5    0.2    0       9.8     -3    0       0       0    0    0.5
      0    0         # ditto
# pop lines - for the proportion of the population assigned to each area
0     1    1      1      0       0.8     -3    0       0       0    0    0.5
      0    0         # fraction to area 1
# custom-env read
0         # 0- read one setup and apply to all env. Fxns, #1= read a setup line for each Mgparam..
# custon-block read
0         # 0= read one setup and apply to all blocks
# Spawner recruit parameters
1         #SR function, such that 1 is Bev-Holt, others forthcoming..
# Lo   High   Init   Prior   Pr_type SD      Phase
3      30     10     20      0       20      1       # LN of R0..
0.2    1      .65    .65     0       1       -2      # steepness
0      2      1      1       0       1       -3      # sigma-R
-5     5      0      0       0       1       -3      # env. Link
-5     5      0      0       0       1       2       # init equil
0         # env. Variable for link
# recruitment residuals
# start recyear    end recyear     lower limit     upper limit     phase
1960   2005   -3     3       2
# Initial F setup for fleets
0      1      0.01   0.01    0       .01     -3      # one fishery
# Q setup
# add parameter row for each positive entry below (row then column)
# Float (0/1)     # Do-power (0/1) # Do-env (0/1)   # Do dev (0/1)    # Env-var        #Num/Bio (0/1)
0      0      0      0       0       1       # fishery
0      0      0      0       0       1       # CalCOFI
0      0      0      0       0       1       # triennial
0      1      0      0       0       1       # juv survey
0      1      0      0       0       1       # murre diet
1      0      0      0       0       1       # larval production
1      0      0      0       0       1       # hydro survey
0      1      0      0       0       1       # sea lion diet
# LO   Hi     Init   Prior   Pr-type SD      Phase
```

-5	5	-0.635	0	0	0.2	-2	# q for larval prod. fixed at 1
-5	5	0	0	0	1	-2	# q for hydro survey
-5	5	0	0	0	1	-4	# juv survey power factor
-5	5	0	0	0	1	-4	# murre data power factor
-5	5	0	0	0	1	-4	# sea lion power factor

Selectivity and retention parameters - size selectivity
#
CalCOFI and larval survey selectivity fixed to the maturity schedule..
#

# pattern	retention (0/1)	Male (0/1)	Special	
1	0	0	0	# fishery
1	0	0	0	# CalCOFI
1	0	0	0	# triennial
0	0	0	0	# juv survey
0	0	0	0	# murre diet
1	0	0	0	# larval production
1	0	0	0	# hydro survey- set = to triennial
1	0	0	0	# sea lion diet

selectivity and retention parameters - age selectivity

# pattern	retention (0/1)	Male (0/1)	Special	
10	0	0	0	# fishery
10	0	0	0	# CalCOFI
10	0	0	0	# triennial
11	0	0	0	# juv survey_full sel age 0s
11	0	0	0	# murre diet_full sel age 0s
10	0	0	0	# larval production
10	0	0	0	# hydro survey
10	0	0	0	# sea lion diet

selectivity curve parameters
#
next are selectivities- simple logistic (2 param) curve (for now..)

# Lo	Hi	Init	Prior	Pr_type	SD	Phase	env-var	use_dev	dev_minyr		
	dev_maxyr		dev_stdev		use block		block type				
5	30	15	15	0	50	3	0	0	0	0	0
	0	0	# L50- Fishery								
0.01	30	5	5	0	10	-5	0	0	0	0	0
	0	0	# diff 50-95								
5	30	14.1	14.1	0	10	-5	0	0	0	0	0
	0	0	# L50- CalCOFI								
0.01	30	2	2	0	10	-5	0	0	0	0	0
	0	0	# diff 05-95								
5	30	10	10	0	50	3	0	0	0	0	0
	0	0	# L50- Triennial								
0.01	30	2	2	0	10	3	0	0	0	0	0
	0	0	# diff 05-95								
5	30	14.1	14.1	0	10	-5	0	0	0	0	0
	0	0	# L50- larval prod								
0.01	30	2	2	0	10	-5	0	0	0	0	0
	0	0	# diff 05-95								
5	30	15	15	0	10	-5	0	0	0	0	0
	0	0	# L50- hydro survey								
0.01	30	2	2	0	10	-5	0	0	0	0	0
	0	0	# diff 05-95								
5	30	15	15	0	50	3	0	0	0	0	0
	0	0	# L50- sea lion								

-20	20	-5	-5	0	10	3	0	0	0	0	0
	0	0	# diff 05-95								

These are double logistic parameters for sea lion selectivity
INIT, INFL, and SLOPE a

#1	30	15	15	0	10	3	0	0	0	0	0
	0	0	# PEAK								
#0.01	2	.1	.1	0	10	3	0	0	0	0	0
	0	0	# INIT								
#-10	10	1	1	0	10	3	0	0	0	0	0
	0	0	# INFL								
#0.01	10	1.5	1.5	0	10	3	0	0	0	0	0
	0	0	# SLOPE								
#-5	10	-3	-3	0	10	3	0	0	0	0	0
	0	0	# FINAL								
#-10	10	-0.6	-0.6	0	10	3	0	0	0	0	0
	0	0	# INFL								
#0.01	10	1.3	1.3	0	10	3	0	0	0	0	0
	0	0	# SLOPE								
#0.01	10	1	1	0	10	3	0	0	0	0	0
	0	0	# BINWIDTH								

next is the juvenile survey- age

0	0	0	0	0	10	-5	0	0	0	0	0
	0	0	# minimum age- juv								
0	0	0	0	0	10	-5	0	0	0	0	0
	0	0	# maximum age- juv								
0	0	0	0	0	10	-5	0	0	0	0	0
	0	0	# minimum age- murre								
0	0	0	0	0	10	-5	0	0	0	0	0
	0	0	# maximum age- murre								

custom-env read -read_one_setup_and_apply_to_all
0
custom block-read
0   # 0= read_one_setup and apply to all, 1 = custom, see instructions
phase for selex param devs
-4
Max number of lambda phases-read this number of lambda values for each element below
1
0   # this is the sd_offset; value of 0 causes log(like) to omit the +log(s) term, 1 includes for CPUE,
discard, meanbodywt, rec devs
Lambdas- order of reading is CPUE lambda for each fleet and survey..
0   # fishery- are no cpue stats for fishery
1   # CalCOFI
1   # triennial
1   # juv survey
1   # murre diet
1   # larval production
0   # hydro survey
1   # sea lion
discard lambda for each fleet and survey
0   # fishery
0   # CalCOFI
0   # triennial
0   # juv survey
0   # murre diet
0   # larval production
0   # hydro survey

```
0          # sea lion
# mean weight lambda
0          # one for all sources
# length-freq lambdas
1          # fishery
0          # CalCOFI
1          # triennial
0          # juv survey
0          # murre diet
0          # larval production
0          # hydro survey
1          # sea lion
# age freq lambdas
0          # fishery
0          # CalCOFI
0          # triennial
0          # juv survey
0          # murre diet
1          # larval production
0          # hydro survey
0          # sea lion
# size at age lambdas
0          # fishery
0          # CalCOFI
0          # triennial -  this is the only survey with length comp data
0          # juv survey
0          # murre diet
0          # larval production
0          # hydro survey
0          # sea lion
# initial F lambda
0          # fishery
# recruitment deviations lambda
1
# param priors lambda
1
# param dev timeseries lambda
0
# crash penalty for high harvest rates
100
# max F
.9         # there is simply no way exploitation is significant here!
# end of file marker
999
```

Report on the 2006 Assessment of Shortbelly Rockfish in the California Current

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Contents

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Executive Summary

A panel discussed the assessment of shortbelly rockfish in 2006. The Panel met 28-30 June 2006 at the Fisheries Ecology Division of NOAA/NMFS in Santa Cruz. The initial draft assessment was presented to the Panel, additional analyses were requested and carried out, and the Panel discussed the results.

This was a useful assessment which provided a rare and valuable opportunity to study the dynamics of an unfished population and question the assumption of stationarity which underlies most assessments of exploited stocks. It also demonstrated the value of a type of data not much used in fisheries stock assessments: that concerning food habits of predators such as sea birds and marine mammals.

Some recommendations are made concerning analyses that might be useful either in completing the current assessment or in approaching future assessments.

1. Background

This report reviews, at the request of the University of Miami (see Appendix 1), the 2006 assessment of shortbelly rockfish in the California Current. The author was provided beforehand with various documents (Appendix 2) and participated in the meeting which considered the assessment.

2. Review Activities

The review panel met 28-30 June 2006 at the Fisheries Ecology Division of NOAA/NMFS in Santa Cruz. Those attending the meeting included the assessment team, other participants from Santa Cruz, three external reviewers, and a representative of the Groundfish Advisory Panel (Appendix 3).

The initial draft assessment was presented to the Panel, additional analyses were requested and carried out, and the Panel discussed the results. Neither a Panel report nor a final assessment was produced, but the assessment team was given clear suggestions as to what sorts of assumptions should be considered in a final assessment.

3. Findings

3.1 Data

Some of the strengths and weaknesses of the available data sets are apparent even before any assessment modelling. For example, the sea lion length-frequency (LF) data show clear patterns of strong and weak year classes and are thus, on the grounds of this internal consistency, highly informative. The larval survey, which provides the only absolute biomass index, will also make a strong contribution. The murre food-habit index could be seen as of dubious value because of its restricted geographical range, but the fact that it correlates well with the index from the juvenile trawl surveys adds support to it. The triennial survey is not well-suited to a semi-pelagic species like shortbelly. This is of concern, because this survey provides quite a bit of data (indices and LFs) which may mislead the assessment model. These LFs do not show the clear internal consistency of those associated with sea lions (though it is harder to judge consistency with triennial data). The CalCOFI abundance index seems promising (shortbelly larvae occur in nearly half the stations in the standard grid) and is likely to be quite influential because it shows such a strong contrast (the mean value since 1959 is less than 25% of that for the preceding years). However, it assumes the larval production per mature female does not vary significantly from year to year,

which may not be true. Least influential are the hydro-acoustic biomass estimates, which are relative (because the target strength of shortbelly is unknown), highly uncertain (with c.v.s of 0.5), only two in number, and close in time.

A major difficulty for the assessment was the limited and disparate geographic ranges of the data sets (see figure 1 in the draft assessment report). No data set consistently covered the nominal latitudinal range of the assessment, although the CalCOFI index did in some years. Some pairs of data sets were from non-overlapping areas. This should be taken as a prompt to check for conflict between data sets. The most obvious example in this assessment was the potential for conflict in recruitment fluctuations inferred from northern (murre index plus juvenile surveys) and southern (sea lion LFs) data sets. It is always difficult to know to what extent data from a limited area is representative of a broader area. A discussion on p. 9 of the draft assessment report indicates that it will sometimes be very non-representative.

One category of data that was used, in small amounts, but not much discussed during the review, was age frequencies (AFs). The data file in the draft assessment report contained three sources of AFs, each with just one year's data – hydro-acoustic, larval survey and (nominally) triennial – though I understand that at least some of these were sometimes switched off. I think it would be wise to be cautious with such data. With only single years we cannot use the criterion of internal consistency to test their validity. Given the limited range of other data, these AFs could be very influential in estimating the strength of individual year classes. The hydro-acoustic AF must be suspect since, presumably, it does not derive from random fishing. Doubt about the correct selectivity to apply to an AF might be a good reason to avoid using it.

Biomass indices from the food-habit data (murre and sea lions) present a difficulty because they derive from presence/absence observations. This makes them potentially sensitive to saturation (if shortbelly occur in, say, 60% of observations at a given level of abundance, that occurrence can not double if the abundance does). Thus, some sort of transformation is needed to make these indices proportional to abundance. A related problem occurs with the two 0+ indices (murre and juvenile survey), which concern fish of such an early age that they could well still be subject to density-dependent natural mortality. If they are, a transformation is again suggested to induce proportionality. An obvious choice offered by Stock Synthesis II (SS2) is the power transformation (this has one parameter, called the power parameter for catchability). I will say more about estimating these transformations below.

After the review meeting I noticed what appears to be an error in the part of the data file associated with LFs from CalCom and the sea lion data. This error may well have been corrected, without comment, during the review meeting, but I mention it here in

case it was overlooked. For both of these data sets gender was set to 3, implying that separate male and female proportions were available, although the male and female proportions were identical. My reading of the SS2 User Manual suggests that gender should have been set to 0 to signal that sex was not observed.

3.1.1   GLMs

I was interested in the extensive use of generalised linear models (GLMs) in the construction of biomass indices for this assessment, and a little uneasy about some of this. For the food habit data, I have no problem. GLMs are an obvious technique for removing some noise (e.g., due to seasonal changes) from such data. However, there does seem to be some unresolved problem with the sea lion index, for which the year-to-year variation is much smaller than is plausible, given the rather high error estimates and the high recruitment variability indicated by the associated LFs.

It is with the spatially extensive surveys (CalCOFI, triennial, and juvenile) that I am more concerned, and my concern is that the GLM assumptions are very strong, and perhaps unwarranted. I understand that the juvenile surveys used to be analysed using the more conventional stratified-random assumptions but, after careful consideration, it was decided to switch to the GLM approach some years ago. I have not seen the analyses underpinning this decision, and so am not able to say whether I would find them convincing. I would like just to sound some notes of caution about the use of GLMs for these surveys.

First, with regard to the triennial survey, I would urge consideration of the impossibility of creating silk purses from sow's ears. Bottom trawl surveys are notoriously poor at indexing semi-pelagic species like rockbelly, and the use of GLMs cannot make them any better. GLMs will generally reduce c.v.s, possibly substantially, but we may be deluding ourselves if we believe this indicates a true reduction in uncertainty. On the matter of uncertainty, I think we should have much more certainty in the CalCOFI index for years in which the survey covered the extended grid, than we have for years confined to the original restricted area. The fact that this difference in confidence is not seen in the GLM c.v.s seems, to me, to indicate a weakness in their derivation.

Second, like most models of biological processes, those constructed for these surveys using GLMs will be gross simplifications of reality. We should not assume that because a factor or interaction is found to be *statistically* insignificant, that it is *functionally* insignificant. We may have very little power to detect some of these, and my concern is that this might bias our estimated year effects. Year-area interactions are certain to occur (the penultimate paragraph on p. 9 of the draft assessment report

describes one such) but may or may not be detected. Of course, any interactions with year can be difficult to deal with (because there's no longer a single year effect). Such interactions are automatically dealt with under the simpler assumptions for stratified random surveys.

3.2 Modelling

I was, in general, happy with the modelling approach adopted in this assessment. There was an initial attempt at a coast-wide model and then, when there appeared to be conflict between the north and south recruitment signals, separate models were constructed for these two regions. In this section I present some comments on two important aspects of the modelling.

3.2.1 Estimating the stock-recruitment relationship

In this assessment there were two parameters defining the stock-recruitment relationship: B_0 (or, equivalently, R_0) and h (steepness). Most of what I have to say on these concerns the former parameter. However, I would like to say that in my experience there are very few stock assessments (not including the current one) in which there is clearly sufficient information to estimate steepness. I would recommend that the final assessment for shortbelly include runs in which h is fixed to a suitable default value.

An unusual aspect of this assessment was the comparative lack of information to scale the biomass (i.e., to estimate B_0). In most assessments, trends in biomass are driven by the historical catches, so the assessment infers B_0 by addressing the question "How large must B_0 be to have allowed the historical catches to have caused the trends in biomass (or absolute biomass estimates) that have been observed?". This question seems inappropriate in the current assessment, since there is no fishery for shortbelly rockfish. All biomass fluctuations are effectively assumed to have been driven by variation in recruitment alone, which means that biomass trend data (e.g., from the CalCOFI and triennial surveys) contains no information about B_0, which is determined solely by the single absolute biomass estimate (from the 1991 larval production survey).

It is important to be clear about the meaning of B_0 in stock assessment models. This is widely misunderstood as being the biomass that existed before fishing began (sometimes referred to as the virgin biomass), which is misleading in two ways. First, fish stocks fluctuate, even in the absence of fishing, so that the only sensible definition of B_0 is as the theoretical level about which the biomass would fluctuate in the absence of fishing. Second, it is common in assessment models (including SS2) to force

recruitment deviations to average zero (in log space). This means that R_0 is effectively defined to be the average recruitment over all years in which recruitment is estimated (after correction for the stock-recruit relationship). Now B_0 is calculated as the theoretical biomass that would occur if recruitment was constant at R_0 and there was no fishing. Thus, rather than thinking of B_0 as being associated with the period before fishing, we should think of it as being associated with the years over which recruitment is estimated in the assessment. It is, in some sense, the 'average' biomass that would have occurred over that period had there been no fishing.

There are two important consequences of this view of B_0. First, it shows how artificial it is to set the initial biomass equal to B_0 in stock assessments. This may be defensible, on the grounds of parsimony, in the assessment of a stock for which the historical catches are believed to have had a much greater effect on the stock biomass than has recruitment variation. However, it makes no sense in the current assessment, where all variation is assumed to be due to changes in recruitment and the initial biomass could easily have been well above, or well below, B_0. I believe that the decision, made during the current assessment meeting, to allow $B_{init} \neq B_0$, will have a strong impact on the estimate of current depletion (as measured by the ratio $B_{current}/B_0$). A second consequence is to highlight a weakness of SS2. It is common to estimate recruitment for a wide range of years, but to have reliable recruitment information only for a narrower range. It will often make sense to use only this narrower range of years in defining B_0 (i.e., to force recruitment deviates to average zero only over this narrower range). A useful extension to SS2 would be to allow users to be able to specify the range of years used to define R_0 (and thus B_0), and to allow this to be different from (narrower than) the range of years for which recruitments are estimated. Such a distinction is available in the assessment program CASAL (Bull et al. 2005).

3.2.2 'Tuning' the model

The term 'tuning' was used to describe two different activities during the review meeting. The first was the estimation of transformations to deal with either saturation (for binomial indices) and/or density-dependent mortality (for 0+ indices) (see Section 3.1 above). The second was the process of iterative reweighting to change the relative emphasis placed on different data sets. While I agree in general with the application of both of these techniques, I would like to counsel caution in their use. The main point I'd like to make is that both require some sort of fixed point, or fulcrum, against which to gain leverage in estimation. In the absence of a suitable fulcrum these techniques are better not used.

In the coast-wide assessment, it seemed to me that the fulcrum needed to estimate density-dependent mortality was the sea lion LF data set. This suggested greater variation in recruitment than was indicated by either of the two 0+ indices. Thus, the model had a clear signal to use in estimating catchability power parameters for the two 0+ indices. However, I see no future in trying to estimate these parameters in the north-only model, where there seemed to be no such fulcrum. Nor do I see any point in trying to estimate both saturation and density-dependent mortality, which are confounded in this assessment. The best I think that can be done is to estimate a single parameter which allows for the joint effect of these two processes.

When in doubt about the existence of a plausible fulcrum I suggest profiling on the power parameter(s). In the case of the coast-wide model, I would expect this to identify the sea lion LF data as the fulcrum by showing how, as the power parameters depart from their null values, the fit to this data set degrades, and the fit to the 0+ indices improves.

With regard to iterative reweighting, I think the required fulcrum is usually a subset of the data sets whose error c.v.s (or effective sample sizes) are pre-judged to be already reasonable; the smaller the collection of data sets that is to be reweighted, the better. Another point to be made is that reweighting is better suited to large data sets (usually LFs or AFs). For a biomass index with only 10 or 20 observations it is difficult to say whether a mismatch between the estimated and expected values of rmse (root-mean-square error) is an indication of incorrect c.v.s (i.e., a need to reweight) or just a poor estimate of rmse from a small sample.

Ideally, stock-assessment decisions should be objective. In practice, this is often not possible, and I believe it is quite reasonable to intervene in an iterative reweighting to ensure that its effect is not counter to the expert judgement of the scientists involved. In other words, it is proper to prevent the up-weighting of data sets that are believed to be suspect and/or the down-weighting of those that are thought to be reliable. I suspect that such an intervention was needed at times in the shortbelly assessment. In recent hoki assessments in New Zealand, the model has had difficulty in fitting the strong downward trend in a particular trawl survey index (the lack of fit being indicated as much by a trend in residuals as by an rmse that was too high). Rather than increasing the c.v.s for this data set (as would be suggested by iterative reweighting), the Hoki Fisheries Assessment Working Group decided it would be better to do the opposite, to ensure that the model better reflected what was deemed to be an important signal in the data (Francis 2006b). That seems to me a quite proper intervention.

3.2.3 Contribution of individual data sets

One of the important tasks of those involved in stock assessments is to gain an understanding of the contribution of each data set. We need to understand which data sets are influential, and amongst influential data sets, which model outputs they are influencing (and in which direction). This information, in conjunction with some idea of the reliability of each data set, is important in interpreting the assessment. To this end, there are two techniques that I would recommend.

The first is a sensitivity analysis which successively leaves out one data set at a time. This quickly identifies data sets with little influence and is most useful with minor data sets (e.g., the AFs in the current assessment). The second is profiling on key parameters. This helps to understand how well such parameters are determined, and what compromise is involved in their estimation (i.e., which data sets 'prefer' a lower or higher value of the parameter, and which data sets are 'indifferent' to it).

One particular reason for mentioning these techniques is the very high recruitment that was estimated for 2003 (I think) in some of the later model runs presented to the review. My suspicion is that this estimate was driven by the peak of small fish in the LF from the 2004 triennial survey, and is probably unreliable.

4. Conclusions

4.1 The assessment

This was an interesting assessment which provided a rare and valuable opportunity to study the dynamics of an unfished population. To some extent our approach to the management of fisheries is based on the assumption that we understand the behaviour of populations that are not fished. Assessments like this allow us to examine that assumption. Although the data presented some problems (concerning representativeness and areal coverage), these were no greater than is common in many fisheries assessments that are deemed adequate for use in managing stocks.

The food habit data from sea lions and murres made important contributions to the assessment. Although there was some doubt about the abundance index derived from the sea lion data (see above), the associated length frequencies were clearly informative, and the murre 0+ index seemed also to be useful. It would be worthwhile to consider whether such food habit data could be useful in other assessments. In the present assessment these data are important in suggesting north-south differences in recruitment.

Some aspects of this assessment question the assumption of stationarity that underlies most stock assessments. As an example of the use of this assumption note that estimates of depletion (which determine whether a stock is deemed to be overfished) are based on the assumption that the relationship between the spawning stock and recruitment (and thus the definition of B_0) does not vary with time. Both 0+ indices used in this assessment suggest that recruitment after about 1990 was lower, by around one order of magnitude, than that before that date. This pattern is supported by a decline in the CalCOFI index through the 1990s. Another apparent non-stationarity is evident in the early part of the CalCOFI index (the mean value since 1959 is less than 25% of that for the preceding years). Finally, I note that there is some evidence of a substantial increase in sea lion abundance over the period covered by this assessment (I understand that current pup counts are an order of magnitude higher than those in 1975). This raises doubt over the assumption that natural mortality is time invariant. Clearly, any conclusions that might be drawn from the results of this assessment will depend strongly on how we interpret these indications of non-stationarity.

4.2   Future work

I conclude by mentioning several analyses that I think would be worth pursuing, either in completing the current assessment, or in future assessments. Some other suggestions are included in the preceding text.

It may be worth bootstrapping the triennial LFs to get an idea of how well these are determined. When this was done recently with LFs based on observer data in the New Zealand orange roughy fishery, strong correlations were found within the LFs (i.e., p_{iy} was strongly correlated with p_{jy}, where p_{iy} and p_{jy} are the estimated proportions in the ith and jth length bins in year y) (Francis 2006a). The effect of these correlations was to make the mean length for each LF much more uncertain than would be implied from the bootstrap-estimated c.v.s for the individual LF proportions, p_{iy}. The effect of this analysis of the triennial LFs could be to suggest their down-weighting in the assessment.

The shortbelly growth curve should be re-estimated after appropriate fractional ages have been assigned to all observations. The data used for the assessment were treated as if all age-length observations were made in the middle of the year (i.e., a fractional age of 0.5 y was assumed for all observations), which I understand not to have been the case. This reanalysis may lead to a better fit to the left-hand ends of LFs in the stock assessment.

It would be useful to obtain some measure of uncertainty for the areal-expansion factor used to scale the larval-production biomass estimate up to the total area for the coast-wide assessment. This will have no effect on the point estimates from the assessment. However, it would affect uncertainty estimates obtained either from the inverse Hessian or from profiling key parameters.

If there is to be extensive use in West Coast assessments of LFs that are inferred (e.g., from otoliths in sea lion scat) rather than observed, it might be worth extending SS2 to include an associated error matrix (analogous to the ageing-error matrices). On this topic, I wonder how the conversion was made from otolith length to fish length. I am assuming that a one-to-one mapping was made between each otolith length measurement and the most probable fish-length bin. If so, that might explain why the observed sea lion LFs appeared to be more peaked than those estimated in the assessment model. Perhaps a better way would be to assign an LF probability distribution for each otolith length measurement.

Future assessments of shortbelly rockfish should consider using information about long-term changes in the abundance of key predators (particularly sea lions and murres) to drive changes in the mortality caused by these predators.

APPENDIX 1: Statement of Work

This appendix contains the Statement of Work that formed part of the consulting agreement between the University of Miami and the author.

Rationale

The Center for Independent Experts (CIE) has participated extensively in the Stock Assessment Review (STAR) Panels developed for West Coast groundfish stock assessments in 2005. The Fisheries Ecology Division (FED), at the Southwest Fisheries Science Center conducted an additional assessment that was not requested by the Pacific Fisheries Management Council (PFMC), and was not a part of the traditional stock assessment review process. This assessment was done on the shortbelly rockfish, *Sebastes jordani*, an unfished but ecologically important species with the distribution centered off of southern and central California. There is evidence to suggest that the population has undergone significant fluctuations in abundance over the last several decades, presumably in response to variations in ocean conditions. As this unfished stock might be considered the equivalent of a "control" rockfish population, the results of this assessment may be informative with regard to the understanding the potential causes and consequences of natural population variability on exploited rockfish populations throughout the California Current.

General

External, independent review of West Coast groundfish stock assessments has been an essential part of the fisheries management process. However this review is not being conducted on an assessment that is intended to directly provide management advice, as there are currently no important management decisions to be made for this unexploited species. Because the Council review process could not fit this assessment into the standard STAR review schedule, we have sought the opportunity to review this assessment separately. As such, this assessment is not intended to provide the basis for management of groundfish on the West Coast in the short term (tactical) sense; rather it is intended to investigate the role that ecosystem interactions may play in the management of west coast fisheries.

This review (including Terms of Reference, etc.) will be similar to reviews conducted under the West Coast STAR process (as described in the PFMC Terms of Reference, to be provided), however with a smaller number of reviewers. Currently, we anticipate two to three independent reviewers on this panel, one of whom will be the CIE reviewer. Groundfish Management Team (GMT) and Groundfish Advisory

Subpanel (GAP) advisors from the PFMC would not be formally included in this review panel, however representatives from both of these advisory bodies will be invited to participate.

The CIE expert should have experience in population dynamics and stock assessment of groundfish, and past experience reviewing west coast groundfish assessments would be beneficial. The expert should have specific experience in the integrated analysis type of modeling approach, using ADMB, age-and size-structured models, use of MCMC to develop confidence intervals, and use of Generalized Linear Models to process survey and logbook data for use in assessment models. Although the modeling framework for this model is the same as most of the west coast groundfish models reviewed in 2005 (e.g., a maximum likelihood modeling framework using Stock Synthesis 2, SS2), the focus of the assessment and the types of data used in the assessment diverge modestly. For example, the model uses information from both larval and juvenile abundance surveys (both of which have been used in other west coast groundfish assessments) as well as seabird and sea lion food habits studies (which have not been used in past assessments). Similarly, the authors have devoted more time and effort to understanding and quantifying past population trends, rather than identifying potential future yields, again based on the fact that the assessment was not formally requested by the PFMC.

Documents to be provided to the CIE reviewer prior to the review include the following:

·   Current draft stock assessment reports;

·   Most recent previous stock assessments and reviews;

·   Groundfish Stock Assessment and Review Process Terms of Reference;

·   An electronic copy of the data, the parameters, and the model used for the assessments (if requested by reviewer);

·   Additional supporting documents, primarily in the form of subset of published research papers directly relevant to this effort.

The reviewer's duties shall not exceed a maximum of 14 days: several days prior to the meeting for document review; a two and one-half day meeting to review the documentation, model, and model results; and several days following the meeting to complete the written report. The meeting will be held at the main conference room of

the Southwest Fisheries Science Center's Santa Cruz Laboratory, between June 28 and June 30, from 8:30 a.m. to 5:00 pm for the first two days, and from 8:30 a.m. to 12:30 p.m. on the last day. The format of the meeting will consist of an initial presentation of data sources, modeling assumptions and model results, followed by discussions of the different approaches and the opportunity to alter the model and/or conduct new analyses as appropriate. The CIE reviewer's report is to be based on the reviewer's findings. The reviewer's tasks consist of the following:

1)   Become familiar with the draft stock assessments and background materials for the model.

2)   Actively participate in the review.

3)   Comment on the primary sources of uncertainty in the assessment.

4)   Comment on the strengths and weaknesses of current approaches.

5)   Recommend alternative model configurations or formulations as appropriate.

6)   No later than July 14, 2006, submit a written report[1] consisting of the findings, analysis, and conclusions to Dr. David Die, via email to ddie@rsmas.miami.edu, and to Mr. Manoj Shivlani, via email to mshivlani@rsmas.miami.edu. See Annex 1 for additional details on the report contents and organization.

Annex 1: Contents of the Reviewer's Report

1.   The report shall be prefaced with an executive summary of findings and/or recommendations.

2.   The main body of the report shall consist of a background, description of review activities, summary of findings (addressing the issues raised in this statement of work), and conclusions/recommendations.

3.   The report shall also include as separate appendices the bibliography of all materials provided by the Center for Independent Experts and a copy of the statement of work.

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[1] The written report will undergo an internal CIE review before it is considered final. After completion, the CIE will create a PDF version of the written report that will be submitted to NMFS and the reviewer.

APPENDIX 2:   Materials Provided

Before the review the Panel was provided with electronic copies of the following documents.

The assessment

Field, J.C.; Dick, E.J.; MacCall, A. (2006).Technical description of a population model for the shortbelly rockfish, *Sebastes jordani*, in the California Current (draft dated June 20 2006).

STAR panel process

Anonymous (undated) Groundfish stock assessment and review process for 2005-2006. [Includes terms of reference for STAR panels]

SS2 documentation

Methot, R.D. (2005). Technical Description of the Stock Synthesis II Assessment Program Version 1.17 – March 2005.

Methot, R.D. (2005). User Manual for the Assessment Program Stock Synthesis 2 (SS2) Model Version 1.19 April 27, 2005.

Other papers

Lowry, M.S. & Carretta, J.V. (1999). Market squid (/Loligo opalescens/) in the diet of California Sea Lions (/Zalophus californianus/) in southern California (1981-1995). Calif. Coop. Oceanic Fish. Invest. Rep, 40, 196-207.

Miller, A.K. and W. Sydeman. 2004. Rockfish response to low-frequency ocean climate change as revealed by the diet of a marine bird over multiple time scales. Mar. Ecol. Progr. Ser. 281: 207-216.

Mills, K.L., T. Laidig, S. Ralston and W.J. Sydeman. In prep. Diets of top predators indicate pelagic juvenile rockfish (Sebastes spp.) abundance in the California Current System

Moser, H.G., R.L. Charter, W. Watson, D.A. Ambrose, J.L. Butler, S.R. Charter, and E.M. Sandknop. 2000. Abundance and distribution of rockfish (/Sebastes/) larvae in the southern California Bight in relation to environmental conditions and fishery exploitation. Calif. Coop. Oceanic Fish. Invest. Rep. 41: 132-147.

Pearson, D.E., J.E. Hightower, and J.T.H. Chan. 1991. Age, growth, and potential yield for shortbelly rockfish Sebastes jordani. Fish. Bull. 89: 3: 403-409.

Ralston, S., J.R.Bence, M.B. Eldridge, and W.H. Lenarz. 2003. An approach to estimating rockfish biomass based on larval production, with application to Sebastes jordani. Fish. Bull. 101:129-146.

APPENDIX 3: List of Participants

Participants in the review meeting included the following

Assessment team

John Field, E.J. Dick, Alec MacCall

Other participants from Santa Cruz

Xi He, Meisha Key, Stephen Ralston

External reviewers

Chris Francis, Bill Lenarz, George Watters

Groundfish Advisory Panel representative

Tom Ghio

COMMENTS ON THE 2006 ASSESSMENT OF SHORTBELLY ROCKFISH OFF
CALIFORNIA AND THE JUNE 28-30, 2006 REVIEW

July 13, 2006

William H. Lenarz
PO BOX 251
Kentfield, CA 94914-0251

Introduction

I participated with Chris Francis and George Walters as an external reviewer in a
June 28-30, 2006 meeting at the NMFS, SWFC, FED Santa Cruz Laboratory. The
purpose of the meeting was to review *Technical description of a population model for the
shortbelly rockfish, Sebastes jordani, in the California Current* prepared by John. C.
Field, E. J. Dick, and Alec MacCall. John Field presented all but one section of the
material, which was presented by EJ Dick. John and EJ also ran new versions of the
model after hours and during the meeting as suggested by the participants. Tom Ghio, Xi
He, Meisha Key, and Stephen Ralston also participated.

General Comment

I was very favorably impressed by the work of the assessment authors. They
were very competent and used approaches and software that are accepted as among the
best available. Their presentations generally were concise and easy to understand. Their
attitude was to produce the best product possible, which was evidenced by being very
open to suggestions. I never felt that I was stepping on someone's toes by questioning a
procedure or assumption.

GLM and CalCOFI

While I support most of the work that was done, I agree with Chris Francis that
the use of GLM to estimate main effects can be very misleading. There have been many
advances in the use of GLM since I took a course in experimental design in 1965, but the
fact remains that if a design is unbalanced or worse yet there are no data for some
interactions, main effects are confounded with interactions. Unfortunately, as in the case
of most fisheries data, there were no data for many of the interactions in the CalCOFI
shortbelly larval abundance data.

The spatial density of CalCOFI stations is very course relative to the patchiness of
age 0 shortbelly larvae. There is only one station in the northern region that is reasonably
close to the known areas of shortbelly aggregations. Variability in currents could result
in considerable variation in relative abundance of older larvae at stations not at shortbelly
aggregation locations. My definition of older in this case is more than a few days old. I
would be inclined to only use data from the station located very close to the aggregation
location.

I am also concerned about the variability in location for stations in the southern area (Figure 6). The changing locations could easily account for some of the abrupt changes in abundance that the model can not explain. It may be worthwhile to examine possible relationships between abundance and proximity to features along the shelf break.

The month effects shown in Figure 7 are somewhat different than found in the larval production study. There may be a north south regional difference in seasonality. There also may be a station effect within region. I would be inclined to estimate a seasonal effect for each station.

I agree that the sudden drops in CalCOFI indices in abundance could be at least partially caused by abrupt increases in natural mortality or environmentally caused drops in fecundity. However I don't believe that changes in fecundity are likely to be the cause of the multi-year periods of low apparent abundance. I recommend careful examination of station location and sample dates for possible explanation of the observed variability.

Predator Data

The sea lion data seemed to be useful in identifying strong year classes. The magnitude of the sea lion population and their year around predation on shortbelly suggests that it may be fruitful to attempt to estimate sea lion impacts on shortbelly dynamics. However the marine mammal folks in Seattle are very cautious in using scat data for estimating actual predation rates because of concerns that survivor rates of artifacts vary considerably among prey species.

Predation by sea birds and Chinook salmon may be sufficient to have significant impacts on mortality rates of pelagic juvenile shortbelly. Deviations from the relationship between untransformed juvenile survey and sea bird indices may serve as an index of rate of predation.

Hydro-acoustic Data

The 1977 and 1980 hydro-acoustic estimates of shortbelly abundance were significantly higher than the 1991 larval production estimate. I agree that target strength is not known for shortbelly rockfish. However I participated in the 1980 hydro-acoustic survey and later research cruises. We found much larger concentrations of shortbelly targets in 1980, confirmed by trawling, than I observed in latter years. Thus I am skeptical of model scenarios that produced results indicating that abundance was significantly higher in 1990 than in 1980.

Conclusions

I agree with others at the meeting that the data and modeling were sufficient to conclude that the population(s) of shortbelly rockfish sharply declined between 1990 and 2000. The results indicated the triennial bottom trawl survey did not produce data useful to study shortbelly dynamics. The results suggest caution in using the CalCOFI

estimates. The results also suggest that relative year-class strength and biomass in the north and south regions are not highly correlated, and the two regions should be separately analyzed.

RECENT TECHNICAL MEMORANDUMS

Copies of this and other NOAA Technical Memorandums are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22167. Paper copies vary in price. Microfiche copies cost $9.00. Recent issues of NOAA Technical Memorandums from the NMFS Southwest Fisheries Science Center are listed below:

NOAA-TM-NMFS-SWFSC-396 Assessment of the Pacific sardine (Sardinops sagax caerulea) population for U.S. Management in 2007.
K.T. HILL, N.C.H. LO, B.J. MACEWICZ, and R. FELIX-URAGA
(November 2006)

397 AMLR 2005/2006 field season report: Objectives, Accomplishments, and Tentative Conclusions.
J.D. LIPSKY, Editor
(December 2006)

398 U.S. Pacific marine mammal stock assessments: 2006.
J.V. CARRETTA, K.A. FORNEY, M.M. MUTO, J. BARLOW,
J. BAKER, B. HANSON, and M.S. LOWRY
(January 2007)

399 Monitoring and research needed to manage the recovery of threatened and endangered Chinook and steelhead in the Sacramento-San Joaquin basin.
J.G. WILLIAMS, J.J. ANDERSON, S. GREENE, C. HANSON,
S.T. LINDLEY, A. LOW, B.P. MAY, D. McEWAN, M.S. MOHR,
R.B. MacFARLANE, and S. SWANSON
(February 2007)

400 Extraction of DNA from formalin-fixed cetacean tissues.
K.M. ROBERTSON, C.A. LeDUC, R.G. LeDUC, and P.A. MORIN
(February 2007)

401 Spawning biomass of Pacific sardine (Sardinops sagax) off U.S. and Canada in 2006.
N.C.H. LO, B.J. MACEWICZ, D.A. GRIFFITH, and R.L. CHARTER
(February 2007)

402 Data sources: California habitat restoration project cost analysis.
K.K. HILDNER
(April 2007)

403 Using the California habitat restoration project database to estimate habitat restoration costs for ESA-listed salmonids.
K.K. HILDNER and C.J. THOMSON
(April 2007)

404 Salmon habitat restoration cost modeling: Results and lessons learned.
K.K. HILDNER and C.J. THOMSON
(April 2007)

405 Stock assessment model for the shortbelly rockfish, Sebastes jordani, in the California current.
J.C. FIELD, E.J. DICK, and A. MacCALL
(April 2007)