TRENDS IN ABUNDANCE SURVEYS OF NEARSHORE ROCKY REEF FISHES IN CENTRAL CALIFORNIA 1959-2007

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Abstract

The paucity of fish abundance data has resulted in management decisions in nearshore rocky reef areas of central California based on data-poor stock assessments or none at all. The accuracy of fish stock assessment models can be improved with the inclusion of time-series fish counts and sampling effort data. This study informs fisheries managers on the potential of existing abundance survey data for understanding trends in nearshore rocky reef fishes of central California (Cape Mendocino and Pt. Conception). I included 18 fish species commonly targeted by fisheries in this study area. Nine abundance surveys were analyzed to compare trends, intra-annual precision and sources of variability. I used the generalized linear model (GLM) to create yearly abundance indices from fish count, effort and explanatory variable data collected for each study species. To assess the direction and significance of trends, I used linear regressions based on yearly index values. *S. mystinus, S. miniatus, S. caurinus* and *O. elongatus* were analyzed in greater detail. I found that different abundance survey methodologies often indicated different trends for species. When comparisons could be made, surveys linear trends were statistically different for each species over set time periods. Survey biases likely explain these differences. Significant species trends for surveys were mostly downward in the most recent time-period examined (2004-07). Survey types also sampled species with varying degrees of precision, but each survey has the potential to be useful for management in some way. This analysis of abundance patterns is useful for designing future surveys of these species, and informing management of nearshore rocky reef fishes in a time of increasing fishing pressure on this assemblage.

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1. Introduction

Approximately 78 species of fish are commonly found in subtidal nearshore rocky reef habitats of central California (Eschmeyer and Herald 1983, Cailliet et al. 2000, Allen 2006). Many of these species are not caught in recreational or commercial fisheries. The nearshore rocky reef fishes commonly targeted by fisheries consist of three main groups: nearshore rockfishes (*Sebastes* spp.), seaperches (family Embiotocidae) and solitary predators (families Hexagrammidae and Cottidae). All groups are caught in recreational fisheries, but only nearshore rockfishes and solitary predators are regularly caught in commercial fisheries.

An essential component for maintaining a stable fishery in the nearshore rocky reef habitats of central California is accurate estimates of fish population trends (Hilborn and Walters 1992). Commercial and recreational fishery landings of fishes associated with nearshore rocky reef habitats across California declined markedly from 1980 to 2000 (Schroeder and Love 2002). During that period, the recreational fishery represented a much larger proportion of landings than the commercial fishery for most species. A decrease in recreational catches of central California nearshore rocky reef fishes of approximately 50% for 1982-2001 partly explains the overall downward trend in landings, but these trends reversed and catches have increased for the period 2002-07 (PSMFC 2008). Commercial fisheries in central California increasingly targeted fishes in nearshore rocky reef habitats beginning in 1989, with the establishment of a valuable live-finfish fishery in the region (McKee-Lewis 1998, CDFG 2006). Landings of commercial live-finfish have greatly diminished since 1998, but were still worth $2.2

million in 2006 (CDFG 2007). Reasons for fluctuations in fisheries landings may include relative changes in stock sizes, market dynamics or management regulations.

The Pacific Fishery Management Council (PFMC) manages the central California nearshore fishery in cooperation with federal and state agencies. The federal Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 guides the PFMC in the task of managing fisheries and mandates the use of annual catch limits and accountability measures to end overfishing (PFMC 2007). In response to the directives of this law, fish populations must be classified as healthy or overfished based on data collected on stock abundance patterns and life-history parameters. The National Marine Fisheries Service (NMFS) is responsible for providing fishery and biological data to make these classifications for species whose range includes the 3-200 mile zone offshore. In California state marine waters (3-mile offshore zone), the California Department of Fish and Game (CDFG) is responsible for managing fisheries, enforcing regulations and monitoring biological populations. California's Marine Life Management Act of 1999 was directed towards establishing sustainable fisheries and provides guidance to CDFG for managing state fisheries (Starr et al. 2002). In response to this legislation, CDFG developed a fisheries management plan for the nearshore fishery in 2002, which included biological and fisheries information on 19 fish species (CDFG 2002).

Estimates of the abundance of a species are usually presented to the PFMC in the form of a single-species stock assessment, completed by NMFS researchers. A stock assessment includes information for a given stock on life history, fishery patterns, important environmental factors, as well as past, present and forecasted abundance (Cooper 2006). Fisheries managers can use data provided by stock assessments to guide them in regulating fishing pressure, thus directly affecting the stock size (Hilborn and Walters 1992). The PFMC reviews each potential assessment to ascertain whether several key criteria are met before approving the document for use in management.

The PFMC has currently accepted stock assessments for six central California nearshore rocky reef species: *Sebastes carnatus* (Key et al. 2005) *Sebastes melanops* (Ralston and Dick 2004), *Sebastes pinniger* (Methot and Stuart 2005), *Scorpaenichthys marmoratus* (Cope and Punt 2005), *Ophiodon elongatus* (Jagielo and Wallace 2005) and *Sebastes mystinus* (Key et al. 2007). Assessments for *Sebastes ruberrimus* and *Hexagrammos decagrammus* were accepted by the PFMC, but only for the portions of the populations existing north of central California. An assessment was also completed for *Sebastes miniatus*, but it was not accepted by the PFMC. Publications on the abundance of central California nearshore rocky reef stocks are few in number, are based primarily on fisheries landings data and are limited in spatial and temporal scales (Karpov et al. 1995, Mason 1995, Starr et al. 2002).

A population dynamics model serves as the scientific backbone of current stock assessments (Cooper 2006). Fish counts and associated effort data (e.g. fishing time), among other parameters, are needed for population dynamics models to accurately reflect stock sizes (Haddon 2001). However, without an understanding of the trend of the stock (historical abundance), it is not possible for fishery managers to assess whether the stock is increasing, declining or in equilibrium (Hilborn and Walters 1992). Lack of population abundance trend information, or misinterpretation of the data, risks a stock crash if fishing pressure is not regulated accordingly.

The paucity of available fish abundance data has resulted in management decisions in nearshore rocky reef areas of central California based on data-poor stock assessments or none at all. The most robust stock assessments incorporate time-series stock abundance data or indices of abundance (Haddon 2001). An index of abundance consists of a time-series of field sampling with similar methodologies in the same area for a minimum of two years (or more depending on the species). Demonstrating the relative change in a fish stock over time, these indices are usually derived from field surveys that record fishery removals or species densities in portions of their range (Maunder and Punt 2004). Although the ‘true’ fish stock abundance is unknown in nearshore rocky reef habitats, changes in stocks as estimated by indices of abundance are assumed to be proportional to changes in actual stock abundance (Hilborn and Walters 1992). Comparing several distinct indices of abundance provides a better-supported conclusion about true stock trends. Data on stock abundance are collected by either fishery-dependent or fishery-independent field surveys (Maunder and Punt 2004). Both survey types have been limited in number and scope in the nearshore rocky reef environment.

Fishery-dependent data are collected by commercial or recreational fishing fleets without direction from scientists. Information recorded by fishers, fishery observers, or researchers interviewing fishers may include: catch species, counts and lengths, time expended (i.e. effort), fishing locations, depths and environmental factors (e.g. wave height). Many fishery-dependent databases include data collected in the same areas, with the same techniques, over years or decades. State and federal fishery management groups have amassed fishery-dependent abundance data on nearshore rocky reef habitat fishes, only some of which are included in existing stock assessments. Currently, stock assessments generally rely on population dynamics models that use fishery-dependent surveys as indices of abundance (Maunder and Punt 2004). However, management decisions based solely on fishery-dependent data have often led to overfished populations (VenTresca et al. 2001, Pauly et al. 2002).

Fishery-independent data are derived from scientific studies designed by researchers and carried out with or without the aid of fishers. Rocky outcrops and often dense stands of kelp make traditional fishery-independent monitoring (e.g. trawl surveys) very difficult in central California nearshore waters; other fishery-independent methods have been prohibitively expensive (VenTresca et al. 2001, Cope and Punt 2005). Consequently, fishery-independent data have been limited to small-scale surveys with variable methodologies. Lack of knowledge or confidence in existing fishery-independent surveys as a method of assessing abundance of large areas has kept these data from being used in stock assessments (Pope 1988, Maunder and Punt 2004).

Stock assessments can often be best improved with the addition of indices of abundance with low annual sampling variability (Stefánsson 1996, Helser et al. 2004, Stephens and MacCall 2004). Variability in abundance survey samples can be evaluated through precision analysis. Population dynamics models weight competing indices for a stock based on the relative variability of an index. Thus, lower precision indices influence the final stock biomass trend less than those with higher precision. Fisheries modelers are in some cases unaware of, or have not fully examined, existing field surveys that could be useful for stock assessments. To determine their usefulness, it is helpful to analyze potential indices of abundance for intra-annual precision (i.e. the degree to which survey samples in a given year differ from one another) (Pope 1988).

Current stock assessments require fish abundance survey data to be standardized to account for variability in sampling due to the stock structure or other factors (Maunder and Punt 2004). Specifically, abundance samples of a given stock from different strata (spatial or temporal etc.) may vary due to the uneven distribution or life history of the stock, local ocean conditions or variable sampling methods. This could cause bias in the abundance estimates for a given year. Models help solve this problem by incorporating explanatory variables that account for some of the otherwise unexplained differences among abundance samples of a stock (Maunder and Punt 2004).

The goal of this study was to strengthen the quality of future stock assessments by determining which surveys may be most effective to describe the trends of commonly caught nearshore rocky reef fishes of central California. I identified 35 existing field surveys that contained information on relative abundance of traditionally data-poor nearshore rocky reef communities of central California. I evaluated the potential of all of these surveys to be used as indices of abundance for management of one or more nearshore rocky reef stocks. For those surveys that were suitable, I assessed relative abundance for every species that occurred in a survey. I also calculated yearly precision levels for every species and compared these results among surveys. I then determined which sources of sample variation (i.e. explanatory variables) were significant for each species in each survey, to better understand stock structure and survey bias. Finally, I compared results among surveys to determine whether or not datasets from different surveys yielded similar results.

2. Methods

2.1. Study area

The study area extended from Cape Mendocino (40° 30 N, 125° 0’ W) southward to Point Conception (34° 27’ N, 120° 28’ W) (Fig. 1). This same area, often designated as ‘central California’, is commonly used for management by the Pacific Fishery Management Council (PFMC). The species composition of nearshore rocky reef fishes is relatively consistent through this area. North of this latitude, the species composition changes more dramatically (Leet et al. 2001). Genetic work has also shown a distinct population break for some species at Cape Mendocino (Cope 2004). A southern borderline for central California oceanic conditions and biological community structure occurs at Point Conception (Ebeling et al. 1980, Foster and Schiel 1985).

The nearshore marine environment has been defined by the CDFG California Nearshore Fishery Management Plan (2002) as beginning at the high-tide line and extending to 120 feet (~37 m). However, my study area begins at the low tide line, including only the subtidal nearshore areas. The study area was further defined as including all rocky reef habitats in the nearshore as well as in deeper areas where some surveys collected data on nearshore rocky reef fishes. Rocky reefs compose a substantial portion of the nearshore seafloor off the central California coast. This habitat is defined as areas of consolidated hard rock covering the seafloor as opposed to sand or mud substrate (Allen 2006). Many of these areas are covered by kelp forests (especially *Macrocystis pyrifera*) which serve as additional habitat (Foster and Schiel, 1985). Kelp often spans the entire water column and, although forest densities are highly seasonal, serves as food and shelter for rocky reef biota (Holbrook et al. 1990). Rocky reefs have been demonstrated to concentrate adult individuals of several fish species (Quast 1968, Bond et al. 1999).

2.2. Study Species

I identified 18 fish species that were regularly targeted by fisheries in the nearshore rocky reef habitats of central California (Table 1). Stock assessments focus on species targeted by fisheries because of the need to adopt regulations that will prevent overfishing. Because a main goal of this project was to inform the fishery management process, only fish species regularly caught by fishermen in the central California nearshore rocky reef areas were part of this study. The 'stocks' of all species included in this study, were defined by the latitudinal boundaries of my study area. Although size at recruitment varies among rocky reef species, fish less than 15 cm (a generally accepted minimum size retained by any fishery) were not included in this study.

To determine the regularity with which different abundance surveys sampled each species, I calculated occurrence proportions. Occurrence was the number of samples from a given survey containing a count (one or more) of a species, divided by the total number of samples taken by that survey. These proportions were considered in choosing a smaller group of focus species.

2.2.1. Focus Species

I analyzed abundance data on four fish species in more detail. These 'focus species' were chosen based on: 1) having sufficient data for most surveys to be analyzed;

2) differences in occurrence levels in samples among surveys; and 3) inclusion in prior stock assessments and likelihood of being assessed (or reassessed) in the near future. Focus species were chosen to display the range of analytical results for species sampled by the surveys included in this study. Criteria for the first focus species were: high occurrence in all surveys relative to other study species, an accepted stock assessment that used data from some of the surveys I analyzed, and high likelihood of being reassessed (due to fishery value). The first species was *Sebastes mystinus*. The second species criteria were: significant fluctuation in occurrence among surveys and an accepted assessment that did not use surveys I analyzed. The second species chosen was *Ophiodon elongatus*. Rules for the third species were: moderate occurrence in most surveys and no accepted assessment. The third species was *Sebastes miniatus*. The fourth species needed to have: low occurrence in surveys (but enough to allow for analysis) and no existing assessment. This last focus species was *Sebastes caurinus*.

These four species represent two of the three main groups comprising the study assemblage (i.e. nearshore rockfishes and solitary predators). Seaperch species (family Embiotocidae) were not included as focus species because they were not counted regularly enough to be analyzed in most surveys. However, the three *Sebastes* species chosen do have somewhat different life history patterns (feeding and distribution etc.) relative to one another (Cailliet et al. 2000, Allen 2007).

2.3. Abundance surveys

2.3.1. Survey selection

Determining which current or historic surveys to include in this study required employing several criteria. Survey datasets had to: 1) include abundance measurements in the form of count and effort for at least one of the study species; 2) collect at least two samples each year within the boundaries of central California; 3) conduct at least some sampling in nearshore rocky reef habitats; and 4) contain at least four years of data using the same methodology. Abundance data spanning less than a few years does not provide enough information to confidently depict a population trend for species living multiple years (Edward Dick, National Marine Fisheries Service, pers. comm.). Most nearshore rocky reef species require at least a few years to recruit to the fishery (Allen 2006). Therefore, a minimum criterion of at least four years of data was set for an abundance survey to be analyzed in this study, enough time to assess the impact of a few years of recruitment pulses on the stock.

I initially identified 35 surveys of abundance that collected data on nearshore rocky reef species in central California (Appendix A). Many of these surveys consolidated their datasets into centralized databases, including the California Commercial Port Sampling Program (CALCOM) and Recreational Fisheries Information Network (RecFIN). Several surveys were not included in this study because: 1) data were not yet digitized; 2) permission for use could not be obtained; 3) effort data were not consistently collected; or 4) they did not sample study species within the study area. Nine surveys fit the necessary criteria to be analyzed in this study and could be obtained

(Table 2). I split one of these datasets into two separate time-spans and combined two others into one longer time-series for analysis. The surveys' time-spans were often quite different (Fig. 2), an important consideration when comparing results among surveys.

2.3.2. Survey Data Organization

For each survey used in analyses, data were organized by excluding all species, samples and explanatory variables that did not fit the criteria for my study. Stephens and MacCall (2004) refer to this process as 'subsetting' the data, or determining what information is useful for the project. Some survey samples within the dataset were removed prior to analysis because they: 1) did not have sufficient effort data; 2) was collected outside the spatial boundaries of the study; 3) did not have data on one or more important explanatory variables; 4) were collected in a variable level with little or no replication (e.g. if only a few samples were taken in winter months for a survey, all samples were removed for that season); or 5) was the only sample for that respective year (only years with more than one sample were used to allow for precision analysis).

Catch and effort data were sorted separately from one another. For fishing surveys, every distinct site recorded was considered a sample. Some surveys recorded catch at several sites fished by a given boat in one day, in others only the port location was recorded and a single trip was a sample. Each transect was considered a sample for SCUBA surveys. For each sample, a positive or zero count (catch or observation) was included for a given species. Effort data often had to be re-formatted before analysis could proceed. All fishing time that was recorded in boat hours at a given site was converted to decimal hours and multiplied by the number of anglers actively fishing to calculate fish catch-per-angler-hour. An assumption of the model was that the amount of sampling effort alone did not change the probability of counting a fish species. In surveys where researchers did not record the number of anglers actively fishing at each site, it was assumed that all anglers fished the entire trip. The volume of water surveyed in each SCUBA transect was determined to calculate fish count density. Once the final set of samples was identified for each dataset, I calculated the proportion of total samples in which each study species was counted at least once.

I also selected categorical explanatory variables to include in analysis, based on information contained in each survey database. Only those variables that I deemed likely to influence the abundance count of a given survey were considered. I created categories for 'year' and 'season' based on sampling dates in all cases. Season was based on calendar dates: winter (December 22nd – March 20th), spring (March 21st – June 21st), summer (June 22nd – September 21st) or fall (September 22nd – December 21st). I grouped survey sampling locations into 'subregions' in most cases, due to the lack of appropriate replication at the more specific sampling sites recorded by the survey. Each additional variable (if applicable) was divided into 2 or more categories, defined with regard to the distribution of samples. In some cases, categories were already chosen by samplers, and these were preserved if replication was sufficient. In all cases, variables (aside from year, season and location) were only included if they were regularly recorded by a given survey. In some cases where a small percentage of samples did not have information on a given explanatory variable, those samples were removed from analysis so that each sample had information on all categories.

Orthogonality in sampling was assessed for each survey dataset by creating tables of sample distributions across explanatory variable levels. I considered sampling to be orthogonal if all data cells for explanatory variable level combinations had at least five samples (e.g. every location in every year must have at least five samples in all seasons sampled). Variable levels (and associate samples) were included unless the number of samples was extremely small (< 10 samples) across all years. All samples for a year were removed from analyses only if sampling for an explanatory variable was non-orthogonal (i.e. many samples in one level, few or none in other levels) *and* the time-series was not broken (e.g. it was the first year of a time-series). It was assumed that if sampling was non-orthogonal for an explanatory variable, differences in abundance estimates among levels could be incorrect due to missing information. In some cases, sampling was orthogonal for some or all variable pairs (e.g. all locations sampled in all years) but not for multiple variable combinations.

The sections below describe the nine surveys analyzed in this survey (and the one dataset I created by combining two surveys). Each section summarizes information on: the groups responsible for collecting data, survey methodologies, survey timespan and how I organized data for each to be analyzed.

2.3.3. CDFG Marine Reserve Fish Density and Habitat Associations (CDFG SCUBA)

The CDFG SCUBA survey was a fishery-independent study by CDFG personnel during 7 years from 1992 to 98. However, only the years 1995-98 (4 years total) were used for my analyses because variable methodologies were used in early years. Samples were collected using different types of SCUBA transects from Monterey to Lopez Pt.

(Big Sur). Only samples collected using 30 m transects were used for analysis. The 30 m transect surveys were not conducted in the years 1992-94, so those years were removed from analysis. Dive buddy pairs swam the length of a benthic transect (near the bottom) and counts for each species were *combined* for the two divers (for detailed methods, see VenTresca et al. 2001). The measure of effort for this survey was the 360 m^3 water volume surveyed.

Explanatory variables for the CDFG SCUBA survey (if significant) were: 'Year', 'Season', 'Subregion', 'Depth Zone' and 'Visibility.' Sampling seasons included: summer or fall. Study sites were all rocky reef habitats (as defined by side-scan sonar) and transects were located at random within these areas. Sampling sites were grouped into subregions, including: Monterey Peninsula, Pt. Lobos Ecological Reserve (PLER), Pt. Sur-North BCER border, BCER, or South BCER Border-Lopez Point. Depth zones were: deep (15.0-23.0 m), medium (12.0-14.99 m), or shallow (4.0-11.99 m). Visibility was: good (6.6-12.2 m), low (0.9-3.99 m), or moderate (4.0-6.5 m). Sampling was non-orthogonal across all levels for variable pairs, so interactions were not tested.

2.3.4. PISCO Collaborative Central Coast Abundance Surveys (PISCO SCUBA)

The PISCO SCUBA survey is an ongoing fishery-independent study by University of California personnel. Data for 1999-2007 were used in my study (9 years total) from Santa Cruz County to Pt. Conception. The Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) utilizes SCUBA surveys to collect data on nearshore fishes following their protocols (http://www.piscoweb.org/). Individual divers swam transects 30 m long by 2 m wide by 2 m high and counted all fish (including juveniles), but only fish above 15 cm were included in this study. The measure of effort for this survey was the 120 m^3 volume surveyed. This survey continued the efforts begun by the CDFG SCUBA survey, beginning sampling the year after this earlier survey ended. However, PISCO sampled a different latitudinal, depth and temporal range, used different transect lengths and only a single diver to count fish on each transect. These methodologies were different enough, that combining the surveys into a single index of abundance would be problematic and probably not acceptable to fisheries managers.

Explanatory variables for the PISCO SCUBA survey (if significant) were: 'Year', 'Season', 'Subregion', 'Level/Depth Zone', 'Visibility' and 'Transect Replicate.' Sampling seasons included: summer and fall. Study sites were all rocky reef habitats and transects were located at random within these areas. Sampling sites were grouped into subregions, including: Santa Cruz County, Monterey Peninsula, South PLER Border-North BCER border, BCER, or Pt. Buchon-Pt. Conception. Depth was recorded for each benthic or midwater transect; I split these into the transect level (benthic or midwater) and the depth zones within which the measurements fell. Level/depth zones were assigned as: benthic shallow (2.0-10.99 m), benthic deep (11-25 m), midwater shallow (1.0-7.99 m), or midwater deep (8.0-19 m). Visibility was recorded for each transect, I categorized measurements as: poor (0-2.99 m), medium (3.0-5.99 m), or good (6.0-26 m). 'Transect Replicate' was a category to indicate whether a given SCUBA transect sample was conducted first or subsequently (i.e. second or higher) for a given date, site and level/depth zone. Transect replicates were categorized as: 1st transect or repeat transect. Sampling was orthogonal only for the variable pair 'Year' and 'Season', therefore this was the only interaction tested.

2.3.5. TENERA Inc. Diablo Canyon Nearshore Reef SCUBA Survey (TENERA SCUBA)

This ongoing fishery-independent survey was designed and carried out by Tenera Environmental, Inc. The survey utilized SCUBA survey methods (CRANE 2004), and was limited to a small cove near Diablo Canyon, California. Data from 1976-2007 were included in my study (32 years total). Survey methodology consisted of two divers surveying a single 50 m x 2 m x 2 m (200 m^3) transect at the same time but starting at opposite ends. A sample consisted of the total fish count for both divers on each transect.

Explanatory variables for the TENERA SCUBA survey (if significant) were: 'Year', 'Season', and 'Transect Replicate'. Sampling seasons included: winter, spring, summer and fall. 'Transect Replicate' was: 1st Transect or Repeat Transect. Depth ranges of transects were recorded but were not used in analysis for this survey because ranges overlapped and differed only slightly. A location variable was not deemed necessary for this survey, since transects were all within the same small cove. Sampling was non-orthogonal across all levels for all variable pairs, so interactions were not tested.

2.3.6. CDFG Central California Marine Sportfish Hook-and-Line Survey (CDFG H&L)

This fishery-independent survey chartered fishing vessels to take scientists to fishing locations as directed from Monterey to Pt. Estero (north of Morro Bay). All fish were identified, measured and counted by scientists aboard fishing vessels. Effort was recorded by CDFG personnel as the number of minutes and anglers fishing at a given site during a trip. The survey was conducted during 17 years: 1978-82, 1985, 1987-89, 1991-94 and 1995-98. Only samples from 1978-82 and 1995-98 were included in my analyses, because other years did not include effort data. All samples from 1985-94 and some samples for 1995-98 were removed from the dataset due to lack of effort records. This survey was split into two different datasets for analysis: 1978-82 (5 years) and 1979-82; 1995-98 (8 years). During 1978-82 samples were taken in all seasons from Monterey to Pt. Estero (Big Sur), while during 1995-98 sampling was only during fall months in Big Creek Ecological Reserve (BCER). Therefore, the time-series 1979-98 represents trends only within BCER (1978 was not included because only one sample was taken in BCER).

Explanatory variables for the CDFG H&L 1978-82 time-series (if significant) were: 'Year', 'Season' and 'Subregion.' Seasons sampled included: winter, spring, summer, or fall. Sampling sites recorded by the survey were grouped into subregions, including: Monterey, Pt. Pinos-Carmel, Pt. Lobos-Soberanes, BCER, Lopez, Pt. Sur-Partington Pt., Jade Cove-Ragged Point or Pt. Sierra Nevada-Pt. Estero. Sampling was non-orthogonal across all levels for variable combinations, meaning interactions between variables were not assessed. The model for the 1979-98 time-series did not include 'Subregion' or 'Season' as variables.

2.3.7. CDFG Creel Survey of CENCAL Spearfish Tournaments (CDFG CENCAL)

The Central California Council of Diving Clubs (known as CENCAL) organized several annual recreational spearfishing tournaments from Cape Mendocino to Pismo Beach. California Department of Fish and Game (CDFG) personnel identified, counted and measured all fishes caught at CENCAL tournaments since 1958, and the survey was ongoing as of 2007. However, several years were not included in my analysis because one or zero samples were taken. A few other years could not be used because the survey did not record all variables included in the final model for this survey. In summary, years included in analyses were 1959-68, 1973, 1975-77, 1980-96, 1998-2006 (40 years total). Individual spearfisher effort expended was the number of hours divers spent searching for and spearing fish. All individual effort times was summed to find the total effort for the meet. A sample for this survey was defined as a single tournament. All of these tournaments required that divers capture fish by free diving (i.e. no SCUBA). Most divers use kayaks to aid in searching for fish during the tournament time limit. Prizes are awarded to divers with the largest, most numerous and most diverse fish catches.

Explanatory variables in the CDFG CENCAL survey (if significant) were: 'Year', 'Season', 'Subregion' and 'Water Conditions.' Sampling seasons included: spring, summer or fall. Only 2 samples were collected from winter months, so samples from this season were not included in analysis. The tournament locations were grouped into subregions to increase the very low replication rate, and included: north (Fort Bragg-San Francisco Bay), central (San Francisco-Carmel), or south (Pt. Lobos-Pismo Beach). 'Water Conditions' was a qualitative rating combining visibility and surge, defined by divers as: poor (low visibility, high surge), fair (moderate visibility and surge), or good (high visibility, low surge). Sampling was non-orthogonal across all levels for variable combinations, meaning interactions between variables were not assessed.

2.3.8. CDFG Commercial Party Fishing Vessel Logbooks (CPFV Logbooks)

The commercial party fishing vessel (CPFV) fishery includes not only the nearshore, but also deeper waters within a few hours boat ride from California harbors. Fish were identified and recorded in logbooks by CPFV crew. The total of kept and released fish was used for analysis. Effort was recorded by CPFV crew as the total number of minutes spent fishing for an entire trip and total number of anglers onboard.

Logbooks were compiled and digitized by CDFG personnel for 1980-2007 (28 years). However, only two nearshore rocky reef species (*O. elongatus* and *S. marmoratus)* were recorded to the species level before 2001. Therefore, only data for 2001-07 were used for analysis (7 years total). In 1980-2001 rockfish species were grouped under the category 'rockfish', whereas all seaperches were recorded as 'surfperch. ' In 2001, three species of nearshore rockfish (*S. mystinus*, *S. carnatus* and *S. pinniger*) as well as *H. decagrammus*, were added as categories on the logbook forms. In 2005, *S. melanops* was added as a category, however, three years of data collection (2005-07) was not enough to include this species in my analysis. Although the category 'rockfish' still remained in logbooks after 2001, I assumed CPFV crew recorded fish to the species level when they were listed as categories on the logbooks.

Explanatory variables for the CPFV Logbooks survey (if significant) were: 'Year', 'Season' and 'Subregion.' Sampling seasons included: winter, spring, summer, or fall. Subregions were constructed using block numbers recorded by CPFV crew indicating where the majority of fishing occurred. Subregions used for this survey were: Cape Mendocino-Pt. Reyes, Pt. Reyes-Pillar Pt., Pillar Pt.-Santa Cruz Lighthouse, Santa Cruz Lighthouse-Pt. Sur, Pt. Sur-Pt. Buchon, or Pt. Buchon-Pt. Conception. Sampling was orthogonal across all levels for variable pairs, but not for 'Year', 'Season' and 'Subregion' together. Interactions between the 'Year' and 'Season', 'Year' and 'Subregion', and 'Season' and 'Subregion' were tested.

2.3.9. PSMFC MRFS / CRFS Dockside Boat Survey (PSMFC Dockside)

In this survey, the Pacific States Marine Fisheries Commission (PSMFC) interviewed recreational anglers at harbors throughout the study area for 1980-2007 (25 years total). Each interview of anglers on Commercial Party Fishing Vessel (CPFV) or private fishing boats was considered a sample. Shore based fishing data was collected by this survey, but not included in my analyses due to the low likelihood of catching study species from shore. The recreational boat fishery covers nearshore waters, but also deeper areas within a few hours boat ride from California harbors. When fishing for rocky reef species, both private and CPFV anglers primarily used similar methods of anchoring or drifting (not trolling) and jigging baits or lures. CPFV trips typically have 20-80 passengers, whereas passenger vessels have 2-5 anglers, both vessel types may actively fish for up to 8 hours in a day. Effort was recorded by CDFG personnel as the number of minutes and anglers fishing for an entire trip (as reported by interviewees). Only fish kept by anglers and identified by PSMFC interviewers were used to calculate catch per hour for a sample. Released fish were not included in catch totals because this was reliant on anglers remembering identifications and numbers caught. Samples were included in analyses if the target species or group (i.e. rockfish) reported to interviewers was any study species or group. A small percentage of anglers told interviewers they were fishing for anything they could catch, often recorded by PSFMC as ‘unidentified.’ These trips were included for analysis, although anglers could have been fishing in locations unlikely to contain nearshore rocky reef species.

The Marine Recreational Fisheries Statistical Survey (MRFSS) covered the years 1980-89 and 1993-2003, whereas the California Recreational Fisheries Survey (CRFS) extended from 2004-2007. Both monitored the same fishery, but the CRFS program sampled more sites, more regularly. Whereas the MRFSS survey recorded the effort of anglers in hours, the CRFS survey used anglers per trip as a measure of effort at high traffic sites and angler hours at less popular sites. I used all sites surveyed by the MRFSS program and only the lower traffic sites from the CRFS program. This resulted in fairly consistent numbers of samples, and similar effort measurements across survey years.

Explanatory variables for the PSMFC Dockside survey (if significant) were: 'Year', 'Season', 'Subregion', 'Distance From Shore' and 'Boat Type.' Sampling seasons included: winter, spring, summer and fall. The location of each dockside interview was recorded by this survey, but not the location of fishing. Samples were split into several subregions based on the dockside interview location, including: Cape Mendocino-Pt. Reyes, Pt. Reyes-South San Francisco, Pacifica-Capitola, Moss Landing-Ragged Pt. or Pt. Piedras Blancas-Pt. Conception. The distance from shore fished during the majority of a boat trip was: less than three miles or more than three miles. The type of fishing boat was: private or charter (CPFV). Sampling for the PSMFC Dockside survey was orthogonal for year and all variable levels, but not for multiple variable combinations (e.g. all subregions and seasons were sampled in 1989, but not all seasons were sampled in the subregion Moss Landing-Ragged Pt.). Therefore, I tested for interactions between 'Year' and 'Season', 'Year' and 'Subregion', and 'Season' and 'Subregion'.

2.3.10. CDFG CPFV On-Board Sampling Program (CDFG Observers)

The CDFG Observers survey was based on the observations of CDFG personnel while onboard CPFVs from 1987-1998. Data for 1987 were not included in my analyses due to non-orthogonal sampling, leaving a time-series of 11 years. Trips were chosen to carry observers at random for major California ports. CPFV trips included nearshore waters, but also deeper areas within a few hours' boat ride from California harbors. Although CPFV trips targeted many different species, the CDFG Observers survey only monitored trips targeting rocky reef species. Therefore, all samples inside the latitudinal range of central California were included in analysis. General fishing methods mirrored those defined for CPFV vessels in the PSFMC Dockside survey. However, effort was recorded by observers, as the number of minutes and anglers fishing at a given site during a trip. In addition, observers recorded, identified and counted any fish caught and returned to the ocean, as well as those kept by anglers. In many cases, only a portion of the anglers were observed on each trip. The sum of released and kept fish for observed anglers was used to determine the catch rate of each sample.

Explanatory variables for the CDFG Observers survey (if significant) were: 'Year', 'Season', 'Subregion' and 'Depth Zone.' Sampling seasons included: winter, spring, summer, or fall. Locations were recorded by the PSFMC Observers survey as sites with coordinates. I grouped these locations into the same subregions as the CPFV Logbooks survey. The depth range fished was recorded by observers as a maximum and minimum depth for each site, but this could not be included in analysis because the time fished at each depth was not recorded. However, observers also recorded whether most fishing occurred deeper or shallower than 40 fathoms (~73 meters) for each sample. 'Depth Zone' categories included: less than 73 meters or more than 73 meters. The depth range of samples used for this survey was 3-275 meters, however only 3% were over 150 meters. Sampling was non-orthogonal across all levels for variable combinations except for ‘Year’ and ‘Subregion’, therefore only these interactions were tested.

2.3.11. PSMFC MRFSS/CRFS CPFV Observers Survey (PSMFC Observers)

The PSMFC Observers survey was based on the observations of PSMFC personnel onboard CPFVs across California. The Marine Recreational Fisheries Statistical Survey (MRFSS) covered the years 1999-2003, while the California Recreational Fisheries Survey (CRFS) extended from 2004-present. Together, the MRFS and CRFS observer surveys spanned a total of 9 years. Both monitored the same fishery, but the CRFS program sampled more CPFV trips in a given year. This survey was basically an extension of the CDFG Observers survey, using similar methods except in choosing samples to include. Unlike the CDFG Observers survey, all types of CPFV trips were observed by PSMFC. These included trips targeting salmon (*Oncorhynchus* spp.), tuna (family Scombridae), flatfish (order Pleuronectiformes) as well as nearshore and shelf rocky reef species. Because observers did not record the target group for the trips, it was difficult to sort out the trips focusing on the rocky reef assemblage. All trolling trips were removed, which accounted for most the salmon and tuna trips. Any trip that did not catch at least one species of nearshore rocky reef species was eliminated.

Explanatory for this survey (if significant) were: ‘Year’, ‘Season’ and ‘Subregion’. Variables were collected and categories defined using the same methods as for the CDFG CPFV Observers survey. The depth range of samples used for this survey was 5-340 meters, however only ~0.4% of samples were at depths over 150 meters.

Sampling was non-orthogonal across all levels for variable combinations except for 'Year and 'Season', therefore only interactions between those variables were tested.

2.3.12. CDFG/PSFMC CPFV Observers dataset (All Observers)

I created the All Observers survey by combined data from the CDFG and PSMFC CPFV surveys into a single dataset (1988-2007). Similarities in all aspects of methods for the two surveys make it reasonable to analyze all 20 years of data together. Results did not replace either original (separated) Observers survey, but instead were compared with original surveys and other surveys that sampled the same time-span. The explanatory variables used for this GLM (if significant) were: 'Year', 'Season' and 'Subregion' (defined in CDFG Observers description). This time-series was non-orthogonal for all variable pairs.

2.4. Analysis

The generalized linear model (GLM; Nelder and Wedderburn 1972) is a useful statistical tool for analyzing time-series fisheries data. The technique was first employed by Gavaris (1980) and was adopted by other researchers to develop more accurate stock assessments (Ralston and Dick 2003, Cope and Punt 2005). The GLM is an outgrowth of the classical linear multiple regression model, allowing for non-normal data distributions to be analyzed (McCullagh and Nelder 1989). For a given GLM, inputs included: 1) a response or dependent variable (any measure of fish abundance in this case); 2) the appropriate sampling distribution; 3) a link function; and 4) one or more explanatory variables (Maunder and Punt 2004). I used GLMs to create time-series of relative yearly abundance from population abundance data collected for each study species by field surveys. A GLM that included sampling or environmental variables specific to each survey was fit to abundance data (i.e. fish count and effort). The yearly index values generated by a GLM depict the stock abundance trends as measured by a given survey after removing bias introduced by explanatory variables. Each index value represented the mean of modeled samples within a year.

The error distribution used in GLMs can be continuous (e.g. normal or Gaussian, log-normal, gamma) or discrete (e.g. Poisson, binomial or negative binomial) (Dick 2004). I chose a discrete distribution, the negative binomial (NB), for all GLMs. A primary reason for choosing the NB distribution is its usefulness for datasets containing few or many zero counts to be analyzed (Maunder and Punt 2004). Zero fish counts existed or were common for all of the abundance surveys used in this project (often 40% or more of samples). If not included in models, zero records may invalidate assumptions of the analysis as well as creating difficulties in computations (Lambert 1992, Maunder and Punt 2004). Using the normal or most other distributions requires ignoring zero records when analyzing abundance survey data may, which can bias the resulting index in a positive direction (Maunder and Punt 2004). Therefore, zero records were included in calculating index values. However, some distributions that allow for zeros do not function correctly if the number of zeros is very low (e.g. binomial) (Edward Dick pers. comm.). The NB distribution is not negatively affected by data with many or few zeros.

Discrete distributions such as the NB and the Poisson are useful if the dependent variable is a count of fish caught or observed as opposed to a continuous measurement (e.g. fish weight) (Maunder and Punt 2004). The NB and Poisson distributions are useful for modeling count data of relatively rare phenomena. A histogram of most count data 'tails off' steeply after peaking, demonstrating that higher counts in sampling are less common. A histogram of the NB distribution will tend to tail off even more rapidly than with the Poisson distribution (Hoffmann 2004). Because the majority of the data used for GLMs in this study were moderate to low counts of species, the NB was a reasonable choice of distributions. Data overdispersion may occur if intra-annual sample variance is greater than the mean, a common situation for the abundance data I analyzed. This was another key reason for using the negative binomial distribution, as this distribution reflects the overdispersion not captured by the Poisson (which assumes variance equals the mean) (Seavy et al. 2005). It is also useful to employ the Akaike Information Criterion (AIC) or other model selection criteria to compare the fit of models with different distributions to the same data. The AIC was used to compare models of the same data using the negative binomial and Poisson distributions, and the NB distribution proved to have lower AIC values. The NB distribution, for the purposes of this analysis, can be viewed as a Poisson distribution with a mean that follows the gamma distribution (Hilborn and Mangel 1997).

A link function can be used to relate the linear sum of explanatory variable effects (i.e. the linear predictor term) to the mean value of the response variable (Crawley 1993). The log link, commonly accepted for use with the NB distribution (McCullagh and Nelder 1989), was used in all GLMs. This link function restricts GLM index values to positive numbers, applicable for working with abundance survey data (Agresti 2002).

An abundance survey sample (i) can be modeled by a GLM with negative binomial distribution and log link as:

$\log(\mu) = x_i\beta$

Where x = design matrix composed of all observations and explanatory variables, β = all coefficients (or levels) for each variable (e.g. spring, summer, fall for the season variable) and μ = the true mean response (Dick 2004). Fitted model values are found by: $\mu_i = \mu D_i$, where D is an error term drawn at random from the NB distribution (Dick 2004). To extract the 'year effect' from this model, the index of abundance for each year of a given study (μ_y) was calculated by the equation:

$\mu_y = \exp(\alpha + \beta_y)$

where α is the model intercept and β_y is the regression coefficient for the 'year' variable both back-transformed to display original data scale measurements (Ralston and Dick 2003).

The intra-annual precision of fish count and effort samples was characterized in this study for each species in each survey using a coefficient of variation (CV), defined as: CV = standard error/mean. CVs are dimensionless and scaled to the mean of a given distribution, as opposed to other measures of data variation (Hilborn and Mangel 1997). CVs may vary from zero (highest precision, no variability) upwards. Survey years with less than two associated survey samples were not included in analysis, since there could be no associated variability and a CV could not be calculated (Dick 2004). The log-transformed yearly index values resulting from each negative binomial GLM were back-transformed to the original data format to compute the yearly CV. This step exponentiates the GLM values, allowing the variability of the original data to be analyzed (Dick pers. comm.).

To calculate the CV for each year in a given dataset, I used a jackknife procedure, which has been used in existing stock assessments (e.g. Ralston and Dick 2003). The jackknife (Tukey 1958) is a specialized form of the bootstrap technique, which estimates standard errors for the GLM index values using the same number of iterations as data points (Efron and Tibshirani 1993). Both the jackknife and the bootstrap approximate the bias and standard error of a dataset. Meyer et al. (1986) suggested the jackknife is more efficient, due to smaller number of computations necessary to achieve a similar result.

I considered yearly CVs below 0.30 to represent highly precise intra-annual sampling, while CVs over 0.70 were considered high. Recent stock assessments have viewed data from years with CVs greater than 1.0 as too variable to include in an index (Cope and Punt 2005, Ralston and Dick 2003). In this scenario, the value of the standard error is larger than the mean, and therefore confidence in the index value is low. Years with CVs greater than 1.0 were not removed from analysis or results displays, but should be considered less reliable abundance estimates.

To design a GLM model that best fits a given abundance survey dataset, variable selection analysis was completed for each species. This process compared models of the same dataset using different combinations of explanatory variables (e.g. years, season, location, etc.). Including factors that demonstrate large fish count variation among levels will reduce model variance, evidenced by lower deviance values and AIC scores. However, when non-significant explanatory variables are incorporated in the model, variance may increase due to unnecessary complexity, creating a less precise index

(Maunder and Punt 2004). Analysis of Variance (ANOVA), AIC or Bayesian Information Criteria (BIC) can all be used to evaluate these competing models. The AIC is useful for variable selection in datasets with at least 40 data points (Burnham and Anderson 2002). The BIC may provide results with less bias for large sample sizes (n > 1000) (Burnham and Anderson 2002). To create a model with only those variables that explain a significant amount of fluctuation in data, a 'penalty' term is employed for both AIC and BIC (Hilborn and Mangel 1997). The BIC is calculated similarly to the AIC, but includes a penalty term that increases with sample size, while the penalty term for AIC remains constant. Use of the BIC can reduce the chance of selecting unneeded explanatory variables for GLMs in surveys with large sample sizes.

The GLMs I used tested 'main effects' only. A main effects model assumes that all levels associated with each explanatory variable are independent from one another (i.e. no significant interactions exist) (Krebs 1999). An index of abundance relies on a model with year effects not confounded by interactions with other variables (Maunder and Punt 2004). However, two or more explanatory variables containing multiple levels - as all variables included in this study do – may have interactions among those levels. If interactions occur between 'Year' and any other explanatory variable in the model, the data must be analyzed in a completely different manner for use in an index of abundance to account for this problem. Although methods exist for reformatting data to remove interactions, these are often complex and may also bias results, especially for year and area interactions. Interaction terms were not used in GLMs in my study, but they were tested where appropriate. I tested the interaction terms: 'Year' and 'Season', 'Year' and 'Subregion', and 'Season' and 'Subregion.' The variables tested in these terms were by far the most commonly recorded by surveys, and including other interactions (e.g. 'Visibility' and 'Year') often caused the GLM to crash due to the number of parameters. If sampling was non-orthogonal among variable levels, it could not be confidently concluded that any interaction detected is statistically significant, because the missing data might change the results of any test. In these cases, the significance of interaction terms in GLMs was not reported. If sampling among any variable combinations was orthogonal, the significance of interaction terms was reported.

GLMs for each species in a given survey were simplified by including only explanatory variables that significantly affected the dependent variable. A few different methods for selecting variables to include in GLMs were compared in this study, however, ANOVAs were used to make the final choice of explanatory variables. This model selection method was used based primarily on clarity and efficiency in displaying results. Every variable that was significant using an F-test ($\alpha < 0.05$) was included in the final GLM. The only exception is that I included the variable 'Year' in all GLMs, because the purpose of using GLMs in my study was to detect a trend in abundance data over a time-series. Interaction models were also tested using ANOVAs, indicating whether interaction terms were significant. AIC was also used to indicate which explanatory variables (1st order) and interaction terms (2nd order) were significant in a given model, but results were not reported, as they compared well with ANOVAs. BIC was employed in addition to ANOVAs for testing interactions when sample sizes were greater than 1000, and results are given for comparison.

The downloadable statistical program, R (http://www.r-project.org/), was used for selecting data distributions and explanatory variables and computing GLMs. I created a generic R-script that was tailored to suit each survey's dependent and explanatory variables in calculating the yearly index values and CVs based on original survey data for each species (Appendix B). ANOVAs were computed in R to evaluate the significance of explanatory variables and interaction terms. An R function, called 'STEP', was used to calculate AIC or BIC values for the GLMs. Each GLM was run in R and output was organized into yearly abundance index values and coefficients (variable levels).

To quantitatively assess whether trends were significant, linear regressions were run using yearly abundance index values (from GLMs). A linear regression was completed for each species with year as independent and annual mean abundance index as dependent variable. One regression was done for the full temporal extent of each survey, while others regressions were completed for 1988-2007, 1995-98, 1999-2007 and 2004-07. Slope regression coefficients (β) indicated the direction of linear trends. In tables, any $\beta \geq 0.0001$ was considered positive, $\beta \leq -0.0001$ were negative and values in-between were considered zero. However, only β's with p-values that differed significantly from zero ($\alpha < 0.05$) were considered significant trends. All analyses were completed with SPSS statistical software.

To indicate whether surveys produced similar trends over the same time-period, I compared significant linear regressions for each species. When two significant trends existed for the same species, I used t-tests to determine if the slopes differed. Survey trends were compared for time-periods: 1999-07, 1988-07 and 2004-07. T-tests were calculated using SPSS linear regression, with the GLM yearly index value as the dependent variable and using the interaction term of survey year and survey number (three independent variables) to determine significantly different trends ($\alpha < 0.05$). Only one species in one time period had more than two significant linear trends. These results were compared with an ANCOVA in SPSS, using the interaction term of survey year and survey covariates to indicate whether surveys produced significantly different trends.

Plots were created from yearly indices of abundance values generated through GLMs in R for focus species to evaluate trends qualitatively. In order to plot several survey results on the same scale, yearly index values were standardized before plotting. Standardization was achieved by dividing the mean of all yearly index values for a given species in a given survey into each yearly index value. The resulting yearly values, standardized to the mean, could then be plotted and compared to other surveys of the same species. Unlike other standardization methods (e.g. z-scores) this method of standardization preserves variability among yearly index values by not setting the standard deviation for yearly values. Because GLMs produce a *relative* abundance index, the actual value of a given point on the plot was less important than its position in relation to points for other years (higher, lower or similar). Trendlines were also plotted for linear regressions of abundance data for focus species. Equations for trendlines were based on y-intercepts and slopes from SPSS results to show a more accurate trends, but still used the standardized index values to allow all trends to be clearly visualized. Yearly CVs among surveys were also graphed for focus species, these values were not standardized.

3. Results

3.1. Survey Categories

The surveys I analyzed fit into two main categories, with two subcategories each, based on methodology. Five surveys I analyzed were fishery-dependent. Four were fishery-dependent hook and line surveys, collecting data on recreational boat anglers (PFMC Dockside, CPFV Logbooks, CDFG Observers and PSMFC Observers), the other was a fishery-dependent spearfishing survey (CDFG CENCAL). The remaining four surveys I analyzed were fishery-independent. Three were SCUBA surveys (CDFG SCUBA, PISCO SCUBA and TENERA SCUBA) and one was a fishery-independent hook and line survey (CDFG H&L), split into two time-series for analysis.

3.2. Occurrence of species

The proportion of the survey samples that contained a given species (i.e. occurrence) varied among surveys for many species (Table 3). *Sebastes mystinus* was regularly counted, while *S. auriculatus* and *S. nebulosus* were counted rarely in all surveys. However, *S. rastrelliger*, *S. caurinus*, *S. melanops, S. chrysomelas, S. ruberrimus, S. atrovirens, S. pinniger*, *S. serranoides, Scorpaenichthys marmoratus, Hexagrammos decagrammus, Ophiodon elongatus, Damalichthys vacca* and *Embiotoca lateralis* each varied in occurrence from low to high among surveys. Only *S. mystinus* occurred in more than 50% of samples on average (across all surveys), while *S. atrovirens* occurred in less than 10% of samples on average.

Mean occurrence levels also varied among surveys in many cases. Occurrence levels were derived from vastly different sample sizes among surveys, with over two orders of magnitude separating sample sizes between some surveys (Table 3). However, I assumed that all surveys took enough samples to demonstrate the ability of each methodology to count the study species. The PSMFC Dockside and CDFG CENCAL surveys were the only surveys containing all study species in at least one sample. The CPFV Logbooks survey accounted for only eight species, the fewest of all surveys (likely because not all species were on logbook forms for crew to record). Only the CDFG CENCAL survey counted study species in more than 50% of samples on average (across all species), whereas the PSMFC Dockside and PISCO SCUBA surveys counted study species most rarely on average (in 10% and 11% of samples, respectively).

The number of species counted by each survey, and the proportion that had sufficient data to analyze with GLMs, also fluctuated. The number of species included in GLMs was highest for PSMFC Dockside (15). Other surveys ranged from 10-14 species analyzed with GLMs, while data from CPFV Logbooks and TENERA SCUBA could only be used to run 7 and 3 GLMs, respectively. However, 88% of species sampled by CPFV Logbooks (7 of 8) could be analyzed with GLMs, whereas only 18% (3 of 16) species sampled by TENERA SCUBA could be analyzed.

Some surveys did not sample the same years, but used similar methods, allowing for an assessment of shifts in species occurrence. The CDFG Observers (1988-98) and PSMFC Observers (1999-2007) surveys used very similar methods. Occurrence levels decreased notably (by a factor of 2 or more) from the former to the latter survey for *S. atrovirens, S. caurinus*, *S. ruberrimus, S. pinniger* and *S. nebulosus* (no species increased substantially in occurrence). The CDFG SCUBA (1995-98) and PISCO SCUBA (1998-2007) surveys had somewhat different methodologies, but both used SCUBA and overlapped spatially. *Sebastes marmoratus, H. decagrammus, O. elongatus, S. atrovirens, S. caurinus, S. serranoides, S. melanops, S. chrysomelas, S. nebulosus S. miniatus* and *S. carnatus* decreased in occurrence notably from the earlier to later time-period. *Sebastes rastrelliger*, *S. pinniger*, *S. auriculatus*, *D. vacca* and *E. lateralis* increased in samples by at least a factor of two from the former to latter survey.

3.3. Stock Abundance Trends

Some species exhibited significantly increasing or decreasing abundance trends, as determined by linear regressions of GLM yearly index results (Table 4). Although most species had positive or negative slopes (not zero) based on my definitions, most trends were not significant (31% of species trends for all surveys). No species had significant trends for all surveys sampling them. *Sebastes auriculatus* and *S. mystinus* had regression slopes (β's) trending upward in all surveys (except the TENERA SCUBA dataset), but not all were significant. All significant survey trends were upward for *S. carnatus*, *S. serranoides*, *S. miniatus* and *O. elongatus*. All significant survey trends for *S. pinniger* were downward. *Sebasetes rastrelliger* had GLM results from only one survey, and the trend was flat. The other species were a mix of down, up and flat trends (some significantly, some not).

When all abundance survey years were considered, few patterns in the significance of linear abundance trends were clear among different survey categories (Table 4). Only the PISCO SCUBA survey had a large percentage of significant trends

(42%) for the SCUBA survey category. For the fishery-dependent hook and line category, only the 'All Observers' time-series had a large percentage of significant trends (57%). The other categories (fishery-dependent spearfishing and fishery-independent hook and line) had relatively low proportions of significant trends. The CDFG H&L and CDFG H&L surveys were the shortest and had the fewest significant trends (15% and 10% respectively). In general, surveys with time-spans shorter than nine years or longer than twenty years had relatively few significant linear trends.

Directions of significant linear trends were not consistent among species within survey categories (Table 4). All categories had some species with upward and some with downward trends. However, trends were mostly upward for the fisheries-dependent hook and line survey category and were all upward for the CDFG and PSFMC Observers surveys. It is important to note that the surveys often cover different time periods, thus making the trends applicable only over certain years.

When linear regression results were examined for particular time periods, the number of surveys being considered was reduced and patterns became clearer. All species had at least one significant trend in one time-period I examined, but no species had significant trends for all surveys in any given time-period. In 1988-2007, the significant linear trends for the TENERA SCUBA (1 species) and CDFG CENCAL (5 species) surveys were all downward (Table 5). In contrast, significant trends for the PSMFC Dockside (3 species) and All Observers (8 species) surveys were upward in most cases. In 1995-98, few trends were significant (5 species), and no pattern was clear. Two trends were downward and three were upward, with no species having more than one significant trend among surveys (Table 6). Due to lack of significant trends for 1995-98, these results were not included in further results or discussion. For 1999-2007, all significant trends were upward for the PSMFC Observer survey and the majority of trends were upward for all fishery-dependent hook and line surveys (Table 7). In contrast, the only significant trend for the CDFG CENCAL survey was declining, and the majority of significant SCUBA survey linear trends were downward for this time period. Although few trends were significant in 2004-07, all species had declining trends regardless of survey type except *S. caurinus* and *S. pinniger*, which only had results for fishery-dependent hook and line surveys (Table 8). During each different time period, all survey slopes (significant and non-significant) were rarely all negative or positive for individual species.

When different survey abundance trends were compared for a given species in a particular time-period, β's were often significantly different (Table 9). The four time-periods I chose allowed for 30 unique survey pair comparisons, but only eight unique survey combinations were actually compared because of the low number of significant linear regressions. However, only the CDFG H&L and CDFG SCUBA were not compared with any other surveys. Although trends in the CDFG Observers survey were not directly tested for differences among surveys, it was compared with other surveys as part of the dataset comprising the All Observers dataset. The ten t-tests completed for nine species (50% of study species) indicated all but one were significantly different. Trend slopes differed for *S. mystinus, S. carnatus, H. decagrammus, S. miniatus* and *S. ruberrimus* (1988-2007), *S. serranoides, S. caurinus* and *S.* marmoratus (1999-2007) and *O. elongatus* and *S. atrovirens* (2004-07). Only *S. caurinus* (2004-07) had statistically similar trends (upward) for two different surveys. *S. mystinus* was the only species with more than two significant trends to compare for any time-period. Using an ANCOVA to compare trends for *S. mystinus* in 1999-07 showed these trends were similar (upward).

3.4. Sampling precision

In general, mean CVs were below 1.0 for each species in abundance surveys where the jackknife analysis could be completed (Table 10). In my study this was considered the maximum threshold for useful data. However, abundance survey samples for many species were relatively precise in some surveys (mean CV < 0.30), but highly variable in others (mean CV > 0.70). Only *S. ruberrimus* had mean CVs below 0.30 for all surveys; this species also had the lowest mean CV (across surveys). However, *S. ruberrimus, S. auriculatus, O. elongatus* and *S. mystinus* all had mean CVs below 0.30. *S. atrovirens* and *S. rastrelliger* had the highest CVs on average (> 0.70). All other species had a mix of high, low and mid-range (0.30-0.70) CVs for different surveys.

Mean CVs varied considerably for some surveys (all species) and for some individual species (among surveys). The CDFG CENCAL survey had the highest mean CV (0.82) while the CPFV Logbooks survey samples were the most precise on average (CV = 0.08) (Table 7). The CDFG CENCAL and CPFV Logbook surveys also had the lowest and highest number of samples per year, respectively (Table 3). The CPFV Logbooks survey only had GLM results for eight species, but it was the sole survey with CVs below 0.30 for all species.

Some survey categories had higher precision than others for certain species. SCUBA surveys had low mean CVs (< 0.30) for most species with the notable exceptions of *S. miniatus, S. caurinus* and *O. elongatus*. *Embiotoca lateralis, D. vacca, S.*

chrysomelas and *S. atrovirens* all had clearly lower mean CVs in SCUBA surveys compared to other categories. Fishery-dependent hook and line surveys also sampled most species with high precision. This category had lower mean CVs than other survey categories for *S. miniatus, S. caurinus, S. pinniger, S. nebulosus, S. mystinus* and *O. elongatus*. However, *S. atrovirens* had extremely low precision (mean CV > 1.0) for the CDFG and PSMFC Observer surveys. The fishery-dependent spearfishing category did not have lower CVs than other surveys for any species. However, the CDFG CENCAL survey provided the only GLM abundance index results for *S. rastrelliger*. *S. miniatus* and *S. caurinus* both had especially low precision in this survey (mean CVs > 1.0). The fishery-independent hook and line category did not have the highest precision for any species, with mean CVs for *S. melanops*, *S. pinniger* and *S. marmoratus* exceeding 1.0.

3.5. Explanatory Variables

Nine different explanatory variables were tested for significance in GLMs of central California nearshore rocky reef species. Results of ANOVAs completed for each GLM indicated that most explanatory variables explained differences in fish counts across space and time (variables were significant in 85% of GLMs) (Table 11). The number of GLMs wherein a variable was significant may indicate its relative importance as a predictor, but differences were generally slight. The explanatory variables most commonly recorded by surveys (7 to 8) were: ‘Year’, ‘Season’ and ‘Subregion.’ Of these, ‘Subregion’ was significant in the most surveys (96%), while ‘Season’ was the least commonly significant (78%). ‘Depth Zone’ was tested in some GLMs (2-4 depending on the species), and was significant in a moderately high number of these

(87%). The variables 'Boat Type', 'Distance from Shore' and 'Water Conditions' each were recorded by only one survey, with the first two variables often significant (>85% of GLMs) and the latter less commonly significant (77% of GLMs). Data on 'Visibility' and 'Transect Replicate' were collected from two surveys, with the first factor significant in many GLMs (77%) and the latter rarely significant in GLMs (20%). Variation in the proportion of significant variables across surveys was generally small. All variables were significant in all GLMs for *S. ruberrimus* and *S. auriculatus*, while *S. rastrelliger* had only 50% significant (although 4 were tested). Most species had over 85% of variables significant in GLMs.

Abundance surveys varied little in the proportion of explanatory variables that were significant to GLMs (Table 12). Although differences were not large, fishery-dependent hook and line surveys consistently had larger proportions of significant factors. These surveys also had large sample sizes, but this alone does not seem to determine the relative proportion of significant variables, as the CDFG CENCAL survey had the smallest sample size but a large proportion of significant factors. The proportion of the 'Season' variable and in some cases 'Year' were the main differences in the proportion of significant variables among surveys.

Interactions were also tested for significance in GLMs for five abundance surveys which sampled orthogonally in some or all variables. Results of ANOVAs showed that nearly all interactions that could be tested were significant for 'Year' x 'Subregion', 'Year' x 'Season' and 'Season' x 'Subregion' (Table 13). However, the five surveys where interactions were tested had 4,400-43,000 samples. When interactions were tested using BIC (useful for large sample sizes), most interaction terms were not significant in

GLMs. *Sebastes melanops, S. chrysomelas, S. atrovirens, S. nebulosus, S. auriculatus, D. vacca and E. lateralis* did not have any significant interactions when BIC was used. Interactions were significant for all eight species with results for the CPFV Logbooks survey, even when tested with BIC. When the CPFV Logbooks survey was not considered, *S. caurinus, S. pinniger, H. decagrammus* and *S. marmoratus* also had no interaction terms that were significant when tested with BIC. *Ophiodon elongatus* had only one interaction that was significant (not considering the CPFV Logbooks survey), Season x Subregion in the PSMFC Dockside survey. *Sebastes mystinus, S. serranoides, S. miniatus, S. carnatus* and *S. ruberrimus* had some interaction terms that were significant, and others that were not when BIC was used. Interactions could not be tested for *S. rastrelliger*. In general, yearly sample size was closely related to the significance of interactions for surveys where interactions were tested in this study.

3.6. Focus Species

3.6.1. Sebastes mystinus

Sebastes mystinus (blue rockfish) was analyzed with GLMs using data from all surveys except CDFG SCUBA, which did not attempt to quantify abundance of this species (Table 3). *Sebastes mystinus* occurred in survey samples at proportions over 0.50 in the majority of surveys. The highest occurrence was in the CDFG CENCAL survey (92% of samples), while the lowest was in the PSMFC Dockside survey (32% of samples).

The yearly abundance index values for *S. mystinus* varied relatively greatly over the temporal extent of surveys (Fig. 3). Most surveys' β's were positive when considering all survey years in linear regressions (Fig. 4, Table 14). Slopes were significant for the PISCO SCUBA, TENERA SCUBA, CDFG Observers, PSMFC Observers and All Observers surveys. Significant β's were positive (increasing) among all surveys, except the TENERA SCUBA survey. R-squared values were above 0.45 for all surveys with significant β's (except TENERA SCUBA), but also for the CDFG H&L (1978-82) and CPFV Logbooks surveys (which were not significant). Directions of regression slopes for 1988-2007 were mixed (some negative, some positive), but significant only for the TENERA SCUBA and All Observers surveys. In 1999-2007, slopes were mostly positive for this species, with β's for the PSMFC Dockside, PSMFC Observers and PISCO SCUBA surveys significant. In regressions using data for the most recent time-period analyzed (2004-07), β's were negative for all GLMs except for the TENERA SCUBA survey. However, only the trend for the CDFG CENCAL survey was significant (Table 10). The r^2 values were 0.99 for the CDFG CENCAL survey, 0.89 for the TENERA SCUBA survey and below 0.25 for all other regressions for 2004-07.

Yearly abundance index values often varied among surveys, although major highs and lows were often similar among surveys (Fig. 3). The trend slopes for the TENERA SCUBA, PISCO SCUBA and CDFG CENCAL surveys differed noticeably from other surveys trends across years (Fig. 4, Table 14). Trends for index values of the All Observers survey (combining the CDFG and PSMFC Observers surveys) matched well with trends of both original Observer surveys, indicating it may be reasonable to use this dataset for management. The TENERA SCUBA and All Observer surveys data were compared for 1988-2007 with a t-test that showed these trends were statistically different (Table 9). The TENERA SCUBA decreased, while the All Observers survey increased for this time-period. An ANCOVA comparing significant linear regressions for 1999-2007, demonstrated that abundance trends were increasing similarly. Datasets compared in the ANCOVA were: PSMFC Dockside, PSMFC Observers and PISCO SCUBA.

Intra-annual precision in sampling for *S. mystinus* was one of the highest among study species on average (across all surveys) (Table 14). The CDFG CENCAL survey had the highest yearly CVs and CPFV Logbooks had the lowest for this species. Only the CDFG CENCAL survey had annual CVs above 0.70, and several years were above 1.0 (Fig. 5). The CPFV Logbook, PSMFC Dockside, PSMFC Observers, CDFG Observers, All Observers and PISCO SCUBA surveys had CVs below 0.30 in all years.

In summary, *S. mystinus* was relatively common in all surveys (except the CDFG SCUBA survey). This species had abundance levels that varied greatly from 1959-2007, but linear regression slopes were generally positive for different surveys. However, for the period 2004-07, abundance trend slopes were negative among surveys. Survey agreement was mixed for this species, some significant trends were similar (1999-2007), some different (1988-2007). Intra-annual precision was moderate to high for this species in most surveys.

3.6.2. Ophiodon elongatus

Ophiodon elongatus (lingcod) was counted in all surveys and analyzed for all except the TENERA SCUBA survey (Table 3). This species occurred in a high proportion of samples in the CDFG CENCAL, CDFG H&L and CFPV Logbooks surveys, and was moderately to rarely counted in other surveys. The highest occurrence was in the CDFG CENCAL survey (98%), while the lowest was in the PISCO SCUBA survey (4.0%).

The yearly abundance index values for *O. elongatus* varied relatively moderately over the temporal extent of surveys (Fig. 6). Long term (overall) abundance trends declined after 1980 then stayed relatively stable at lower levels until increasing in 2002, with most surveys indicating a steady decrease in subsequent years. Surveys had mixed β's (negative, positive and zero) for this species when all survey years were considered (Fig. 7, Table 15). Only linear trends for the CDFG Observer and All Observers surveys were significant when all survey years were considered, both increased. R-squared values were 0.38 and 0.56 for the CDFG Observer and All Observers surveys, respectively, the highest values for any survey when all years were considered. For 1988-2007, direction of slopes were also mixed among surveys (negative and positive), with only the All Observers survey trend significant. Slopes in 1999-2007 were mixed β's (negative, positive and zero), but none of these trends were significant. In the most recent time-period analyzed (2004-07), most β's were negative, with the significant trends (CPFV Logbooks and PSMFC Observers) declining. The r^2 values were above 0.90 for both significant trends, much higher than other surveys for this time-period.

Yearly abundance index levels did vary among surveys, but generally tracked each other well across major highs and lows in abundance sampling (Fig. 6). The index trends in the CDFG H&L and CDFG CENCAL surveys diverged noticeably from other surveys in some years. Trends for index values of the All Observers survey (combining the CDFG and PSMFC Observers surveys) matched well with trends of both original Observer surveys, indicating it may be reasonable to use this dataset for management.

Only one t-test could be used to compare survey trends due to few significant linear trends in the time-periods I examined. The PSMFC Observers and CPFV Logbooks surveys trends were significantly different in 2004-07, though both β's were negative (Table 9).

Intra-annual precision in sampling for *O. elongatus* was one of the highest on average (across all surveys) (Table 14). The CDFG H&L (1979-98) survey had the highest mean CVs and the CPFV Logbooks survey had the lowest mean CVs for this species. Only the CDFG CENCAL and CDFG H&L (1979-98) surveys had annual CVs above 0.70, with several years in the CDFG CENCAL survey above 1.0 (Fig. 8). The CPFV Logbook, PSMFC Dockside, PSMFC Observers and CDFG Observers (and All Observers) surveys had CVs below 0.30 in all years.

In summary, occurrence proportions varied from high to low among surveys of *Ophiodon elongatus*. Trends were generally not significant for this species when all survey years were examined, with the only significant long term trend increasing. However, survey data trended downward significantly for two different surveys in 2004-07, though these rates of decline (slopes) were significantly different. Sampling precision varied from moderate to high among surveys, but was clearly higher for fishery-dependent hook and line surveys.

3.6.3. Sebastes miniatus

Sebastes miniatus (vermilion rockfish) was counted in all surveys, but was not analyzed for the TENERA SCUBA and CPFV Logbooks surveys (due to low occurrence) (Table 3). *Sebastes miniatus* occurred in less than 50% of all survey samples except the

CDFG CENCAL survey. Occurrence was highest in the CDFG CENCAL survey (52%), while the lowest was in the TENERA SCUBA survey (1.0%). This species occurred in other surveys moderately to rarely.

The overall trends exhibited by abundance surveys of *S. miniatus* fluctuated relatively moderately over the temporal extent of surveys. Yearly abundance estimates increased for most surveys through time and maximums for ongoing surveys occurred in 2003-07 (except for the CDFG CENCAL survey which peaked in 2000) (Fig. 9). Most surveys' slopes were negative when considering all survey years in linear regressions (except for CDFG H&L 1979-98) (Table 16, Fig. 10). Abundance trends were significant for the PSMFC Dockside, PSMFC Observers and All Observers surveys and all were increasing. The r^2 values were above 0.70 for these significant regressions, but also for the CDFG SCUBA survey regression (which was not significant). For 1988-2007, all β's were positive and slopes of the PSMFC Dockside and PSMFC Observers surveys were significant, both with r^2 values of 0.76. The years 1999-2007 had trends among surveys that were mixed (negative and positive). Slopes for the PSMFC Observers and PSMFC Dockside surveys were significant, with r^2 values of 0.76 and 0.65, respectively. In regressions using data from the most recent time-period analyzed (2004-07), β's were mostly positive, however no trends were significant (Table 16). The r^2 values were above 0.80 for the PISCO SCUBA survey and the PSMFC Observers.

Survey abundance estimates of *S. miniatus* generally varied little in regard to one another for most years (Fig. 9). The abundance plot suggested the CDFG CENCAL survey diverged from other survey trends in many different years, while the PISCO SCUBA survey trended differently than other surveys in 2004-07. Trends for index values of the All Observers survey (combining the CDFG and PSMFC Observers surveys) matched well with trends of both original Observer surveys, indicating it may be reasonable to use this dataset for management. Only one t-test could be used to compare survey trends due to the rarity of significant linear trends in the time-periods I examined. The PSMFC Dockside and All Observers surveys trends were significantly different in 1988-2007, though both β's were positive (Table 9).

Intra-annual precision in sampling for *S. miniatus* was different among surveys (Table 10). The PSMFC Dockside survey had the lowest mean CV and the CDFG CENCAL survey had the highest mean CV. PSMFC Dockside, PSMFC Observers and CDFG Observers (and All Observers) had CVs below 0.30 in all years (Fig. 11). Only CDFG CENCAL and PISCO SCUBA had annual CVs above 0.70, and most years were above 1.0 for CDFG CENCAL.

In summary, *S. miniatus* occurrence was moderate to low in surveys (especially uncommon in SCUBA surveys), but significant trends were up for this species when all survey years were examined. Significant trends were up for 1988-2007, though slopes differed. No trends were significant in the most recent time-period 2004-07, though slopes were generally positive. Sampling precision was high for fishery-dependent hook and line surveys and varied from moderate to low among other surveys

3.6.4. Sebastes caurinus

S. caurinus (copper rockfish) was counted in all surveys and analyzed for all except the TENERA SCUBA survey (Table 3). This species occurred in all survey samples at proportions below 0.50. The highest occurrence was in the CDFG H&L survey (44.8%), while the lowest was in TENERA SCUBA (0.4%).

Abundance estimates of *S. caurinus* fluctuated relatively little among surveys (Fig. 5). The CDFG CENCAL and CDFG H&L (1979-98) surveys were exceptions, showing large changes in abundance over time. Most surveys β's were negative when considering all survey years in linear regressions and all slopes were notably small (Table 17). The PISCO SCUBA and CDFG H&L surveys regression trends were significant, increasing and decreasing, respectively. Both these regressions had r^2 values above 0.65, while all other regression had values below 0.25. For 1988-2007, β's were mostly negative, but none of these slopes were significant. The years 1999-2007 had β's of mixed directions (negative and positive). Slopes for the PSMFC Dockside and PISCO SCUBA surveys were significant, with r^2 values of 0.70 and 0.67, respectively. In regressions using data from 2004-07, some β's were negative and some positive. However, the only trends that were significant were CPFV Logbooks and PSMFC Observers, both were increasing. The r^2 values were above 0.98 for these two significant surveys, but also notably above 0.80 for the PSMFC Dockside and PISCO SCUBA surveys (which were not significant for this time-period).

Trend directions varied among surveys in some years, but were similar in many other years. While the CDFG CENCAL survey index values often varied greatly relative to other surveys, the PISCO SCUBA survey diverged from other surveys mainly from 2006 to 2007 (Fig. 12). Trends for index values of the All Observers survey (combining the CDFG and PSMFC Observers surveys) matched well with trends of both original Observer surveys, indicating it may be reasonable to use this dataset for management.

The CDFG H&L 1979-98 survey showed a trend that clearly differed from other surveys across multiple years (Fig. 13). A t-test of data for the PSMFC Dockside and CPFV Logbooks surveys showed these trends were significantly different in 1999-2007, although both surveys' trends increased during those years (Table 9). A t-test of the PSMFC Observers and CPFV Logbooks indicated these trends were similar for 2004-07.

Intra-annual precision in sampling for *S. caurinus* was different among surveys (Table 10). The CDFG CENCAL survey had the highest yearly CVs, while the CPFV Logbooks survey had the lowest CVs for this species. Many annual CVs in the CDFG CENCAL survey were above 1.0 (Fig. 14). The CPFV Logbooks, PSMFC Dockside and CDFG Observers, and All Observers surveys had CVs below 0.30 in all years. The CDFG H&L (1979-98) survey had CVs below 0.30 in 2 of 8 years, all other surveys had CVs above 0.30 for all years.

In summary, *S. caurinus* occurrence was moderate to low in surveys (especially uncommon in SCUBA surveys). Significant trends were mixed (up and down) for this species when all survey years were examined, while significant trends were up for the period 2004-07. Significant survey trends were different in 1999-2007 but similar in 2004-07. Sampling precision was high for fishery-dependent hook and line surveys and varied from moderate to low among other surveys.

4. Discussion

4.1. Abundance survey bias

A variety of biases, often unique to a given abundance survey, may have influenced the annual GLM index values. Some surveys that had high annual sampling precision may have been biased to a degree that abundance estimates were not reliable. The degree to which bias affected the final abundance estimates likely varied among years for a given survey. Many biasing factors were inherent to survey category methods, but some were specific to individual surveys.

Due to expenses and logistics, SCUBA surveys cannot be conducted at all rocky reefs in all nearshore depths in central California. SCUBA surveys did not sample nearshore depths 25-37 m or latitudes from Half Moon Bay – Cape Mendocino, but were further restricted to fixed sites dispersed throughout the sampling area. The TENERA SCUBA survey was especially limited in depth range (3-11 m) and spatial extent (a small cove area in Diablo Canyon). The CDFG SCUBA and TENERA SCUBA surveys both included the counts of two divers in a single transect over the same time period, so there was potential for overlap in counts (divers recording the same fish twice). However, in the CDFG SCUBA survey divers were observing different portions of the transect width, while in the TENERA SCUBA survey began observations at opposite ends of the transect, so if fish were moving considerably counts may not have overlapped. SCUBA surveys are known to underestimate cryptic fish species, which hide or blend in with surroundings better than other species (Stewart and Beukers 2000). However, this bias would likely be consistent overtime, so trends for these species would still be applicable.

Fishery-independent hook and line surveys were represented only by one survey, which was restricted both spatially and temporally in the study area. The CDFG H&L survey was not conducted north of Monterey or south of Pt. Estero, thus missing a large portion of central California. How sites were chosen was unclear, however, Monterey and Pt. Pinos–Carmel Bay subregions were sampled by far the most often in 1978-82. Samples for 1995-98 were collected only within BCER, making conclusions about stock across central California trends difficult for those samples.

The CDFG CENCAL survey was the only fishery-dependent spearfishing survey. The most important biasing factor for this survey is the very low number of samples collected in any year, and very uneven sampling among seasons and subregions for some years. Through the history of the spearfishing tournaments surveyed, divers were allowed to keep a maximum of four fish per species (with lower limits set if dictated by CDFG regulations). Analysis of average catch per diver for a highly regulated species, *O. elongatus,* indicated divers seldom caught more than current bag limits prior to the start of these regulations (late-1990's). This indicates that changing regulations may not be a strong influence on the trends in the CDFG CENCAL survey data. Although spearfishers usually targeted certain species and larger individuals, this practice was assumed to be fairly consistent across survey years, making trends applicable. In addition, it can be assumed that if individuals of the most desirable size cannot be located, divers will capture fish in the next smaller size class. Thus, changing catch rates for this survey may not necessarily result from widespread fish size changes in the stock across years. Spear technology likely improved over the nearly 50 year timespan covered by this survey, which could increase catch rates. However, this has been relatively unchanging in the last 20 years or more, thus more recent trends should be unaffected. Divers were often split into at least two categories based on their skill level. Although diver skill could affect catch rates, this was not included as an explanatory variable because only total catches for the meet were reported (not divided into skill categories). Analysis showed no relationship between the number of divers in a given spearfishing tournament and catch rates for *O. elongates* ($r^2 = 0.023$). Dive depth was not recorded by the survey, but interviews I conducted with experienced tournament participants indicated the deepest depth regularly sampled was 25 m, with most dives in the 3-15 m range.

Fishery-dependent hook and line surveys included four surveys with a variety of potential biases. Because surveys in this category use bait to attract fish, abundance may be overestimated by concentrating fish beyond their natural densities, as has been shown with other assemblages (Stewart and Beukers 2000). Anglers may also deplete fish from one site then move to a site with greater abundance, thus keeping catch rates high until the entire stock range is depleted. All surveys in this category regularly sampled beyond nearshore depths unless restricted by regulations. Although the occurrence of some study species was much lower beyond the nearshore area, deeper samples targeting study species were included because stock assessments require information on all depths within a stock's range. Because no information was recorded on the target species for the CPFV Logbooks survey, only trips where at least one nearshore rocky reef species was caught were considered. This process removed most trips that fished outside the rocky reef habitat, but also removed samples which targeted study species but did not catch any fish. Although target species were recorded by the PSMFC Dockside survey, some samples each year were recorded as 'undetermined' species targets. These samples were considered in analysis to be conservative, but likely resulted in an underestimate of some species. However, assuming that roughly the same number of anglers report targets as 'undetermined' each year or fished in the wrong area when they are targeting nearshore rocky reef fishes, the rate of underestimation should be similar each year. For the PSMFC Observer survey, some samples may have been considered in analysis that did not target study species, likely underestimating some study species.

4.2. Species occurrence

Occurrence proportion can be used as an indicator of the relative ability of a given survey to sample each species. Differences in species occurrence among surveys likely result from a combination of species life histories and survey methodologies. Results of my analysis, as well as life history studies of this assemblage, indicate that stock densities often vary among species based on subregion, season or bottom depth sampled. Some abundance surveys were restricted to certain depths, seasons or spatial coverage within the study area, possibly reducing occurrence if they missed key portions of stock ranges (relative to broader surveys).

A comparison of each species' occurrence among different surveys helps determine whether abundance differences among the assemblage are due to natural stock structures for the study area. If a species was rare in one survey, but not in another which used different methods, occurrence may be a function of survey methods. Most species had moderate to high occurrence levels in at least one survey, but also low occurrence in at least one survey. Therefore, if a management goal is to maximize the count of a given species in a field survey, it is important to examine occurrence levels before analyzing data or designing future abundance surveys.

Differences in methodologies for fishery-dependent vs. fishery-independent surveys included in this study may partially explain variable occurrence levels for a given species among surveys. Fishery-dependent surveys tend to target specific locations known to produce large numbers of a preferred species, and will often release individual of lower interest. Fishery-independent surveys generally use a randomized design for sample allocation within a given study site, resulting in samples that do not necessarily contain high concentrations of a particular species. Therefore, comparing results for this SCUBA surveys with fishing surveys may indicate whether fishing catch rates are out of proportion to true occurrence. However, a complication arises due to the limitations of SCUBA, especially its inability to regularly sample the deepest 15 meters of the nearshore. Cryptic species, such as *S. marmoratus* and *O. elongates*, will also occur less often in SCUBA surveys. *Ophiodon elongatus*, *S. miniatus* and *S. ruberrimus* occurred regularly in fisheries-dependent angler surveys, but rarely in SCUBA surveys (Table 3). These are relatively large species that are desirable to fisheries, but they are also commonly found in deeper areas not sampled by SCUBA surveys. *Sebastes atrovirens, S. chrysomelas*, *H. decagrammus* and family Embiotocidae were regularly seen by SCUBA surveys and uncommonly caught by fishing surveys. These species are generally found in higher densities in shallower areas of the nearshore and are smaller, perhaps making them less desirable to many anglers.

Explanations as to why abundance surveys had different mean occurrence levels (across species) may be related to sample size and location of samples within the study area. Fishery-dependent angler surveys included some samples outside the nearshore area (at least until recent regulation changes), and some samples may not have been from rocky reef habitats due to the potential failure of anglers to fish for target species in the correct locations. This helps explain why these surveys could have lower mean occurrence levels compared to surveys that sampled exclusively within the center of density for most study species (nearshore rocky reef habitats). The main example of this affect in my results was the PSMFC Dockside survey, which had the lowest mean occurrence of any survey. The PISCO SCUBA survey also had low mean occurrence, possibly the result of sampling midwater transects where many study species occur in low densities.

Theoretically, a survey that samples exclusively within the nearshore, samples only in areas that are likely to produce large numbers of the study assemblage and actively seeks out nearshore rocky reef species on every sample should produce the highest species occurrence. This is a possible reason for the CDFG CENCAL survey's relatively very high mean occurrence. Another explanation for this result, is that CDFG CENCAL 'samples' represent a full day of spearfishing catches from many divers. PSMFC Dockside and CPFV Logbooks similarly use a full day and many anglers to compose a sample, CPFV Observers and CDFG H&L use single fishing locations as samples (representing a small area usually, but could be up to a full day of fishing), while SCUBA surveys use a single transect (a relatively very small area and time).

The large declines in occurrence for five species (Table 3) from the CDFG Observers (1988-98) to the PSMFC Observers (1999-2007) survey might be partially due to changing fisheries regulations. In 2000, seasonal and depth zone closures were expanded and bag limits were reduced for many study species in central California. In 2002, the establishment of the Rockfish Conservation Area in central California significantly reduced fishing for my study species beyond 40 m. Samples taken in waters over 40 fathoms (73.2 m) decreased from 40% of the CDFG Observers survey samples to 11% in the PSMFC Observers survey. The sample sizes were similar for these two observer surveys, clearly indicating the PSMFC Observers survey did more sampling in shallower depths where densities were highest for most study species. Although bag limits were considerably lower during the PSMFC Observers survey for many species, this bias was reduced by including bycatch in catch totals for each sample. Additionally, the definition of occurrence is whether a species is present or not in samples (not how many). Therefore, even if trip time was reduced and fewer fish caught, occurrence should be largely unaffected by lower bag limits. However, seasonal or depth closures may affect occurrence proportions if the particular season (or depth) levels closed produced different stock densities.

The CDFG and PISCO SCUBA surveys covered a sequential series of years (1995-98 and 1999-2007, respectively) using SCUBA and sampling was not affected by changing fishing regulations. The PISCO SCUBA dataset time-series extended over twice as many years as the CDFG SCUBA survey, but this does not necessarily bias a comparison of occurrence levels. Other biasing factors probably explained some changes between the two surveys, especially spatial coverage, but likely were not enough to cause the drastic declines in occurrence for most species from the CDFG SCUBA to the PISCO SCUBA survey. The inclusion of midwater transect data for the PISCO SCUBA survey likely resulted in lower overall occurrence of many species in this survey. This is because many species in the study assemblage are more often associated with the benthos than the midwater column so would have lower counts for midwater transects. The use of two divers to count fish on transects by the CDFG SCUBA survey (vs. one on PISCO SCUBA transects) may cause differences. Occurrence levels are not affected if individuals are counted twice in a transect (as is likely with two divers vs. one), but may increase if two divers find more fish (especially different species) on a transect than one diver would. The difference in transect size also may change the likelihood for seeing any species in the assemblage (although the relationship between transect size and fish sightings is not clear). Although these factors are potentially important, worsening ocean conditions and fishing impacts likely contributed to the declines in occurrence.

Success in fitting GLMs to stock abundance data was likely a function of the number of zero samples of a given species. In many cases, GLMs could not be fit for species with low occurrence proportions (< 0.10). This is likely because one or more variable levels included in the model (e.g. a specific subregion) had no positive counts. In these cases the maximum likelihood estimate of the mean did not exist, leading to numerical instabilities when fitting a GLM to this type of data (E.J. Dick pers. comm.). However, there were cases in which low occurrence (as low as 0.02) still allowed GLMs to converge. These cases were exclusively found in surveys with sample sizes over 1000, indicating that larger samples sizes may increase the success rate for fitting GLMs by reducing the possibility of zero counts being clustered in a variable level.

4.3. Stock Abundance Trends

The low number of significant linear trends for most nearshore rocky reef fishes may result from highly variable inter-annual abundance estimates where no clear trend exists, or unchanging abundance estimates across time. It appears that both cases occurred for species in this study. *Sebastes caurinus* had quite variable abundance levels across years for the CDFG CENCAL survey, but fairly consistent index levels for the CDFG Observers survey and both survey trends were non-significant (Table 17, Fig. 12).

The time-span of surveys also seems important for whether trends were significant. Surveys with the highest proportion of significant trends were between 9 and 20 years long. This indicates that analysis of trends with linear regressions may be less appropriate for very short or very long time-series. Surveys of 4 or 5 years may contain a year with an extremely high or low abundance estimate (likely due to survey bias) that greatly influences the trendline (often resulting in a flat trend). Additionally, the relatively long-lived life histories of most study species suggest that large changes in abundance would occur at scales of a decade or more (unless fishing pressure is high). Surveys of 30+ years are more likely to cover periods of both low and high abundance of a species (due to natural cycles or fishing pressure changes), resulting in a flat trend. Longer surveys are very useful, but trends are best understood without linear trends.

There was no clear correlation between the occurrence proportion and the number of significant linear trends for a given species. There is no reason to expect that occurrence would necessarily dictate whether trends would be significant. A species could occur at a low level in samples, but consistently over time and still change in abundance over time.

The direction of significant trends often differed among survey categories for time-periods examined with linear regressions (1988-2007, 1999-2007 and 2004-07).

Abundance trends were generally downward for SCUBA and spearfishing survey categories in all time-periods, while trends were generally upward for fishery-dependent hook and line (except in 2004-07). Although the same species often did not have significant trends for different categories, this pattern may indicate that survey categories sampled species in different ways. SCUBA and spearfishing survey categories count fish visually and do not suffer (or benefit) from a reliance on fishing gear to attract fish, possibly explaining the two categories similarities in trend direction. Trends were generally down for all survey categories in 2004-07. However, the short length of this time-period (4 years) may allow one very low year to influence a given stock trend greatly, suggesting caution in interpreting recent abundance trends. Additionally, a small percentage of trends was significant in 2004-07 (17%), making conclusions for the entire assemblage less certain.

The longer time-periods (1988-2007 and 1999-2007) showed differences in abundance trends as sampled by SCUBA and spearfish categories versus fishery-dependent hook and line surveys that could be caused by changing fishing patterns. Recreational (as opposed to commercial) fishing was the main source of landings for most nearshore rocky reef stocks during the time-periods I examined. After the late-1980's, recreational landings of my study species were considerably lower throughout the 1990's, but evidence exists for a marked increase for 2001-07 (PSMFC 2008). It is possible that recreational anglers initially targeted the deeper areas of the nearshore (> 25 m) and portions of the stock on the continental shelf. In recent years, fishing pressure may have shifted to shallower depths of the nearshore (< 25 m) as deeper areas were depleted, or more likely due to regulatory closures of the shelf. This shift combined with closures of other fisheries may have concentrated effort on the historically less exploited nearshore rocky reef stocks enough to offset (or even increase) overall catch rates. Other important recreational fisheries in California declined in recent years due to low population estimates (and regulatory actions), including the Chinook salmon (*Oncorhynchus tshawytscha*) fishery, leaving nearshore rocky reef fishes as one of the last remaining potential fishery targets.

Declining trends for the majority of species sampled by SCUBA or spearfishing surveys in 1988-2007 and 1999-2007 may reflect a decrease in abundance in the shallower nearshore areas that occurred as a result of increasing fishing pressure. Visual surveys are reliant on fish present in the shallower nearshore areas, unlike hook and line surveys that can attract fish from deeper surrounding areas using bait. Due to the lack of usable catch-at-depth information from hook and line surveys (and no SCUBA surveys beyond 25 m), this hypothesis is difficult to test. A similar situation could exist when considering spatial coverage of sampling. If, for example, stock productions remained high or increased in areas north of San Francisco (where SCUBA surveys are lacking) relative the rest of the study area, trends for hook and line surveys would differ from SCUBA surveys. Because good data on spatial sampling by hook and line surveys exist, this is possible to test, but would require separate GLMs for each part of the region for all species (not done for this study).

Although the pattern of increasing abundance estimates in longer term surveys as determined by catch rates in fishing surveys might suggest improvements in fishing technology, this factor probably minimally influenced most species. Fishery-dependent hook and line methods have been fairly consistent for decades. The only potential improvements would include sonar units (i.e. 'fish finders'), GPS usage and increased boat speeds. Sonar and GPS technology developed and became widespread on fishing vessels in the last two decades. The advantage offered by sonar is questionable due to the difficulty in distinguishing nearshore fish (especially those on the bottom) when they are amongst high relief or kelp forest habitats. Kelp forests themselves (as a fishing location) are easily located visually without the use of fish finders. Sonar would likely be more useful for deeper dwelling species (too deep for kelp forests) in the assemblage, some of which did indeed experience increased catch rates in the last twenty years. The GPS units could allow anglers to more easily relocate high concentrations of desirable species, potentially increasing catch rates. This is especially useful for fishing locations beyond sight of the coast, and this could help explain higher catch rates of some study species in shelf habitats. However, knowledge of which locations in the nearshore areas produced high catch rates is prevalent in the fishing community based on landmarks. For surveys measuring fishing effort by a fishing day, increased boat speed might reduce times, potentially increasing catch rates. However, surveys that recorded hours spent fishing at a given site should not be affected by changes in boat speed.

Shifts in ocean conditions were unlikely to be the cause of the general dissimilarity of trends among survey categories in longer time-spans, but potentially contributed to the declines indicated by all surveys in 2004-07. Large scale oceanographic factors that could affect this assemblage include trends in nutrients and water temperature. Changes in these variables affect the species and relative densities of plankton that form the foundation of the food web for the study assemblage. Changes in plankton density and species composition are at least as important as temperature fluctuations to the nearshore rocky reef food web. Generally, less phytoplankton (and consequently zooplankton) is available in marine water off central California with warmer ocean temperatures, likely due to the corresponding drop in nutrients during the same period (Chavez et al. 2003).

A clear signal from oceanographic factors may be difficult to distinguish in abundance survey data. Major affects of climatology patterns on occurrence of study species can only be identified if surveys spanned years before and after a temperature transition (which did occur for most surveys examined in my study). Due to the high position of the study species in the food web, it is likely that any significant affect on abundance by oceanographic events would be lagged temporally. Although there could be some immediate affects on adults fish (starvation due to reduced prey etc.), affects on survivorship are likely to be highest for larvae or juveniles in the assemblage. Before reaching adulthood, most species in the assemblage feed primarily on plankton, which is the first component of the food web to be impacted by temperature fluctuations. Due to the relatively slow growth rate and long lifespan of study species, impacts on the stocks may require years to be noticeable in abundance survey trends. The lag time is likely to vary depending on the species and the strength of the oceanographic event. Oceanographic factors were not incorporated into GLMs to test effects. This was mainly due to the confounding problem of determining the correct lag period.

Two examples of phenomena that can be detected in water temperature records, but also affect the available plankton, are the Pacific Decadal Oscillation (PDO) and El Niño. Water temperature has been shown to cycle at periods of 30-50 years known as the PDO, a phenomenon caused by Pacific Ocean basin scale climatology processes (Mantua et al. 1997). In the time-period of interest to this study, a cool ocean temperature regime of the PDO occurred 1947-76, a warmer regime existed 1977-1998 and a colder water regime possibly returned for 1999-2007 (Chavez et al. 2003). Previous studies demonstrated an increase in juvenile rockfish abundance in central California since the hypothesized shift to a cool water phase of the PDO (Miller and Sydeman 2004). If this finding is correct, abundance estimates from the surveys would be expected to be increasing five years after the phase transition (depending on lag times of affects). It is therefore unlikely that the PDO explains the mostly downward significant trends in 2004-07. Cycles of the PDO have been punctuated by fluctuations in temperature with periods of 2 to 20 years, called El Niño (warmer) and La Niña (cooler). According to Breaker (2005), El Niño has been a greater influence on central California ocean temperatures than La Niña, and the affect may be detectible for one to several years. Strong El Niño events within the time-scale of this study occurred 1965-66, 1972-73, 1982-83, 1986-87, 1992-93 and 1997-98 (Breaker 2005). Evidence suggests El Niño events negatively affect many of my study species (VenTresca et al. 1995, Miller and Sydeman 2004). The lack of strong events since 1998 suggests this factor is not the cause of the mostly downward significant stock trends in 2004-07.

Other important factors for nearshore fish species abundance include more localized phenomenon such as coastal upwelling, which causes seasonal fluctuations in temperature and nutrients. Upwelling is driven by seasonal winds and creates a colder and more nutrient rich nearshore habitat. Although these conditions typically occur March to August, they vary in intensity on a daily or weekly basis (Breaker 2005). The relative strength of the annual upwelling season (i.e. the number of individual events combined with wind strength during those times) may influence the size of rocky reef fish stocks. However, because this phenomenon occurs most years, the effects of relative upwelling strength may be nearly impossible to detect in abundance patterns. A complete lack of upwelling for an entire year would be much more detectible in trends of study species. In 2005, upwelling off northern California and Oregon was unusually weak, the effects of which were severe for the plankton community as far south as central California (Schwing et al. 2006). This event might have caused starvation to some degree in some of the study species, but the larger impact would likely be on the 2005 larvae and somewhat older juveniles. The influence of poor survivorship in the 2005 (or even 2004) year class would not show up in adult surveys until 2007 at the earliest (but probably not until later years). Therefore, this factor is unlikely to have caused stock declines in 2004-07 among all surveys.

Another potential influence on the assemblage is the relative density of kelp forests across the study area. Kelp exists to some degree year-round in some parts of central California, but reaches maximum density in summer (lowest in winter) and extensive forests are more prevalent south of San Francisco Bay. However, all years are not alike in kelp densities, even in one portion of the study area, and variation in these algal forests as habitat for rocky reef fish species could influence abundance. There is considerable debate in the literature over how relative density of kelp influences density of adult fish of the study assemblage (Quast 1968, Bodkin 1988, Holbrook et al. 1990). There is more certainty over the role kelp forests, especially the kelp canopy, play in the increased survivorship of newly settled juvenile rockfish (Bodkin 1988, Holbrook et al. 1990). Survivorship of either adults or juveniles could affect the overall stock size, so kelp densities are likely to influence abundance trends. However, it is unclear how dense kelp must be to allow enough habitat for juveniles. The patchy nature of kelp forests and the temporal and spatial variability in concentrations of juvenile fish in the central California nearshore makes correlations difficult. Once more, it is important to note that even if a given year is relatively low in kelp across the entire region, it is difficult to determine when the affect on the stock would be detectible by abundance surveys.

The other main explanation for the decreases in abundance in 2004-07 would be fishing pressure. The mostly downward significant trends for fishery-dependent surveys in 2004-07 may indicate the beginnings of overfishing for some species resulting from increased recreational fish landings. These trends may also be the result of increased regulations which may change catch rates for some species, although most regulations had changed by 2002. Only one SCUBA survey trend was significant (decreasing) for 2004-07, which does not offer much evidence for trends from surveys without the influence of regulations.

Notably, the two species with upward trends among surveys in 2004-07 (*S. caurinus* and *S. pinniger*) were sampled solely by fishery-dependent hook and line surveys. While these trends could represent actual increases in abundance, possibly the result of greater protections granted by regulations, there are other possible explanations. Although these species may have relatively large home territories, stocks could be structured such that fishing impacts on deeper areas in previous decades may not have affected shallower areas. It is possible that shallower portions of the stock that were less exploited prior to increased regulations in the late-90's are being increasingly targeted by anglers. This may result in higher catch rates that are not necessarily related to an increase in the total stock size. How long catch rates for these two stocks continue to increase may be based partially on their ability to withstand this change in fishing pressure, which is highly uncertain.

Comparing trends for a single species among surveys for a fixed time-period eliminates the temporal differences among surveys I analyzed, allowing different methods of estimating abundance to be tested. The high number of significant differences between survey trends regardless of species or time-period being considered indicates that different methods produce different abundance trends. Most disparities in survey slopes were attributable to different rates of change in abundance estimates for trends in the same direction. Although this represents less of a divergence than if slopes were trending in different directions (up vs. down), it is still important for managers to know the relative rate at which a stock is increasing or decreasing.

Some differences between survey trends were not surprising. Differences between the TENERA SCUBA survey and the All Observers survey were expected. The former survey counted fish visually and was restricted to depths of less than 3-11 m in a small cove, while the latter was based on catch per hour aboard boats covering depths from ~7-100 m across the latitudinal extent of central California. These disparities would be expected to produce different abundance trends for a variety of reasons. Likewise for the PISCO SCUBA survey as compared with CPFV Logbooks survey.

Other survey trend differences were more unexpected. Reasons for dissimilarities in trends between the PSMFC Dockside survey and Observers surveys (for three species in two time-periods) were not as obvious. Both were fishery-dependent hook and line surveys covering approximately the same latitudinal and depth ranges. The main differences were that the PSMFC Dockside survey includes private vessels (in addition to CPFV vessels sampled by Observers surveys) and does not include released fish (recorded by Observers). However, both these factors could influence the mean catch rates greatly, either reinforcing trends or causing some divergence in trends. Even more surprising was the difference in trends for the CPFV Logbooks survey and the PSMFC Observers (one species in one time-period). These two surveys only sampled CPFV vessels in the same areas and recorded both kept and released fish. Differences were that fish were identified by CPFV vessel crew for the logbooks survey (compared to trained agency personnel for the PSFMC survey), approximately six times more samples were collected by the CPFV Logbooks survey and effort was measured as the hours of a single trip (as opposed to hours spent fishing at each location for the PSFMC Observer survey). The methodology variations for surveys all have the potential to cause trends to diverge when significant trends are compared for a species.

It is important not to extrapolate the significance of nearly every t-test to all survey combinations being different for all species due to the low proportion of comparisons (i.e. some methods may yield the same abundance trends for some species, but could not be tested). For a non-significant survey trend, it is not possible to conclude whether this was similar to other surveys. However, since most surveys I examined had a trend from one time-period included in a t-test (and there was a significant difference), it is probable that each could differ from other surveys if significant trends were available to compare. I did not compare significant survey trends for a given time-period between different species because of the additional uncertainty introduced (although in many cases species exhibited similar trends for a given survey), and the goal of looking at trends for each species individually.

Most regression slopes that differed significantly did not vary in direction, but rather in the steepness of the slopes compared. The two cases in which surveys indicated opposite trend directions were some of the more radically different methodologies. One of these t-tests was for the TENERA SCUBA survey and All Observers survey; the differences between these two approaches to estimating abundance were discussed previously. The other significant trends that were in different directions were for the CDFG CENCAL survey and All Observers survey. Although both were fishery-dependent, the CDFG CENCAL survey sampled visually (as opposed to hook and line for All Observers) in many fewer locations, shallower and much less consistently.

Similar trends among surveys of a given species over the same time-period indicate a higher likelihood that this is an actual abundance trend for this central California stock. When two or more indices of abundance have contradictory trends for a given time-period, it becomes necessary for managers to decide which is more accurate. One method for deciding which survey most accurately tracks changes in stock size, is to examine differences in intra-annual precision levels.

4.4. Sampling precision

Most species data had levels of precision above the minimum criteria to be used in stock assessments (i.e. CV < 1.0) when averaged across survey years, but CVs for a given species often differed greatly based on the survey. This is another indicator of differences in sampling among surveys. Low precision may mean that a species occurred irregularly in the sampling area or the sampling method was not always equally effective in counting a species. There is some indication that occurrence proportion and precision levels of species were correlated (i.e. higher occurrence means higher precision), although this pattern is not consistent for all species.

High intra-annual precision however, does not guarantee high accuracy in stock abundance estimates. If important areas for the stock are not sampled, or the methods yield a consistently biased estimate, accuracy may be low but precision high. If precision levels were relatively high for multiple surveys with different methods, as in *S. carnatus* and *S. mystinus*, this indicates a high likelihood that trends were precise and accurate.

High mean CVs (low precision) for a given species could result from a truly dynamic stock size in a given year, insufficient or inconsistent sampling (spatially or temporally) or incorrect explanatory variables in the GLM used to calculate precision (Pennington and Strømme 1998). Although stock size could conceivably fluctuate within a year due to heavy fishing pressure or an extreme environmental event, the multi-year maturity rate, modest home range and relatively high position of the study species in the food web predicts a relatively stable stock size for any given year. This explains why it is unlikely to have low precision and high accuracy in abundance estimates of the study species for a given year. Only extremely high fishing pressure on a given stock or drastically changing ocean conditions would be likely to cause large variability in intra-annual stock abundance. If a particular GLM lacked a key variable for explaining stock abundance as sampled by a survey (e.g. location), this could cause intra-annual precision levels to appear high. In most cases, data on variables that could impact intra-annual abundance estimates were available and were included in GLMs where significant. One exception (for some surveys) was depth information, which was often not recorded in a manner that allowed inclusion in GLMs (e.g. depths changed during samples).

The most likely explanation for lower precision (i.e. high CVs) in sampling was the sample size of a given survey. The survey with the highest CVs (CDFG CENCAL) had the lowest mean annual sample size, while the survey with the lowest CVs (CPFV Logbooks) had the highest mean annual sample size. However, CPFV Logbooks only had results for seven species, most of which also had relatively low CVs in other surveys. The two species with the lowest mean CVs across surveys (*Sebastes ruberrimus* and *Sebastes auriculatus*), had results from less than half the surveys, but all were among the highest sampling sizes. This is not an unexpected result, as sample size is included in the calculation of CVs. The way sampling was structured could also potentially affect precision if variable levels were sampled very unevenly (e.g. specific seasons or locations) The two surveys with the highest mean CVs (CDFG CENCAL and CDFG H&L) tended to sample unevenly among variable levels.

4.5. Explanatory Variables

In general, most explanatory variables added to the GLM helped explain patterns in fish counts. There are two main reasons why a particular explanatory variable was significant in a GLM: actual stock patterns or sampling bias. The levels that I or the survey creators defined for some variables can describe spatial or temporal patterns in a stock. However, other types of variables (e.g. visibility) are more likely to define the relative likelihood of a species to be counted using a particular survey technique. If these variables are significant for a given GLM, this indicates that levels represent different abundance estimates. However, these differences may be contingent on the years that each GLM includes (i.e. survey time-span).

The high proportion of explanatory variables that were significant in GLMs indicates that the choice of which to include was correct in most cases. The significance of survey ‘Subregion’ in most GLMs indicates that, although my study species exist throughout central California, abundance levels often depend on latitudinal zones within the study area. Because this variable was significant in surveys sampling a relatively small portion of the study area, it is likely that abundance varies on a fairly localized level. ‘Depth Zone’ was significant in most GLMs, although it is defined differently by each survey. Many species in this assemblage are known to concentrate in either deeper or shallower portions of the nearshore (depending on the species) and survey sampling will reflect this stock structure. ‘Boat Type’ was significant for all species in the one survey where this was recorded. This was likely partially due to the overall higher level of fishing experience for CPFV captains compared to private vessel anglers or greater attraction of fish to higher densities of baits made available by CPFV vessels. ‘Visibility’ changes would likely affect identification of species surveyed with visual methods, even though fish were usually counted (or speared) at close distances. ‘Season’ was likely important in predicting catch rates in hook and line surveys due to the decreased ability to maneuver boats and slower transit times in rougher seas of winter and fall months (compared to generally calmer seas in summer and spring), and perhaps lowered feeding rates of stocks (due to increased surge or decreased visibility). Seasons sampled by PISCO and CDFG SCUBA were fewer (summer and fall) than for other surveys, so this could explain why this variable was less commonly significant.

Unlike other variables 'Transect Replicate' was generally not significant in GLMs. It was tested in GLMs for SCUBA surveys to indicate whether fish of any species would be attracted or repulsed by divers in the area. Replicate transects were done on the same day and in close proximity to the first transect, so this should be an effective measure of fish reactions after divers have been in vicinity for some time. Although, this assumes that fish would not react to divers until after the first transect. The fact that this variable did not often prove significant is actually important for SCUBA survey design in that it may eliminates one source of bias from that methodology, divers causing abnormal behavior in fish that could change counts.

Results for AIC, BIC and ANOVAs as applied to variable selection were similar in general, except with very large sample sizes. In these cases, AIC and ANOVAs often indicated 1st order variables (and interaction terms) were significant whereas BIC did not. For very large sample sizes (n > 1000), ANOVAs (as well as AIC) may select more complex models with variables that do not improve the fit of the GLM (Edward Dick, NMFS, Pers. Comm.). BIC does have a bias toward selecting simpler models. However, with extremely large sample sizes (n > 10,000), both methods may select more variables than is necessary (Maunder and Punt 2004). ANOVA was chosen as the most clear and efficient way to relay results for variable significance, however, both ANOVA and BIC results were presented for testing interactions.

If interactions exist between 'Year' and any other explanatory variable in GLMs, results cannot be confidently incorporated into a population dynamics model. This would mean abundance is changing among variable levels (e.g. individual subregions) depending on sampling year, thus complicating any conclusion about trends for a survey time-period. Interaction terms including ‘Year’ were almost always significant where they could be tested with ANOVAs, but not with BIC analysis. Most interactions were found significant according to the BIC when sample sizes were extremely large (n > 400 samples per year), which indicates that perhaps even this criteria is too sensitive to clearly indicate which interactions are truly affecting the annual abundance index. Another way to examine interactions is to use ‘interaction plots’ of a given variables’ levels (e.g. seasons) across survey years to assess differences among levels. In many cases where interactions were significant (either according to ANOVAs or BIC), this was apparently due to a single variable level diverging from the others in one or two years of the survey. This indicates that in the cases where interactions were significant, they may not have much affect on the abundance index overall.

I did not remove interactions from GLMs in this thesis due to their uncertain affect on indices, and the inadequate methods of removing them and still meet the study goals. One way to remove interactions is to apply a weighting factor to basically average all levels of a given explanatory variable, as described in Maunder and Punt (2004) for month x year interactions, and in Quinn et al. (1982) for area x year interactions. A proper weighting term is often difficult to choose, and in some cases researchers have resorted to splitting the stock up spatially or temporally (Punt et al. 2000). Because my study aimed to analyze central California stock abundance, splitting data for a given stock into smaller subregions to run different GLMs without the ‘Subregion’ variable (for ‘Year’ x ‘Subregion’ interactions) would not be appropriate. Furthermore, movements by some fish species between subregions may be enough to bias independent analysis of locations. These complications, and the desire to fulfill the stated goals of the survey (i.e.

not split survey samples spatially), influenced my decision to indicate where interactions may exist but allow managers, who may utilize these data, to decide the best resolution.

The GLM index values I calculated are an attempt to provide the most precise picture of abundance trends for nearshore rocky reef species. Since additivity is assumed in the main effects model, variable levels will always vary the same amount in relation to one another from year to year in the index, therefore this important source of bias is avoided. However, this may not be appropriate if interactions are truly affecting abundance estimates on large scales. Sampling was often non-orthogonal among levels for a given variable recorded by a survey. One of the potential problems resulting from non-orthogonal sampling is that the base level used for calculating the intercept (added to the yearly mean abundance values) may at times not be sampled, thus biasing the index values to varying degrees.

4.6. Focus Species

4.6.1. Species comparisons

The four focus species in this thesis were chosen partly to show how abundance trends and precision might change as a function of their relative occurrence in survey samples. There was no clear correlation in the number of GLMs that could be completed and the occurrence levels for focus species. Although *S. mystinus* did have the highest mean occurrence proportion and number of significant trends among surveys, this pattern did not continue for other focus species (Table 4). However, increased annual precision among these four species may be correlated with greater occurrence levels. This pattern was consistent except that *S. mystinus* had higher mean occurrence than *O. elongatus* but slightly lower mean precision, however this is mainly due to the low precision of *S. mystinus* in the CDFG CENCAL survey. There was no indication that occurrence levels were correlated with the number of significant explanatory variables.

Abundance index year-to-year trends for *S. mystinus* fluctuated greatly within and among some surveys over time relative to other focus species (Fig. 3). Studies have shown that fish stocks that are exploited may vary more than unexploited stocks in abundance over time (Anderson 2008). The additional mortality caused by fishing may tend to disrupt natural cycles in stock abundance (especially making natural decreases in abundance more severe). This may explain the variation in abundance estimates of *S. mystinus* across years, as this was the most heavily exploited species by CPFV fisheries since 1981 (Starr et al. 2002) and was also an important component of the commercial live-fishery of recent decades (Love et al. 2002). Additionally, although *S. mystinus* will eat a variety of prey items, plankton is the main component of this species' diet (Hobson and Chess 1988). Because plankton are much more quickly impacted by changes in water temperature and nutrient availability than the prey of other study species (macro-invertebrates or fish), adult *S. mystinus* may be more rapidly and severely impacted by phenomena such as El Niño as a consequence.

VenTresca et al. (1995) demonstrated a significant negative affect of the 1982-83 El Niño on *S. mystinus* reproductive condition (a possible consequence of decreased fat layers, especially in females). Although correlations between timing of El Niño events and large decreases in my calculated abundance index values are unclear for this species, this possible relationship could help explain variability in year-to-year index values. Temporal locations of major highs and lows in the index values were usually similar among surveys, but these similarities did not translate to similar significant trend slopes in most cases (Table 14, Fig. 4). *Sebastes mystinus* had the largest number of significant trends among study species (Table 4). This was unexpected given the large fluctuations in index values for some surveys of this species. However, the surveys that had significant trends had fewer fluctuations across time and were all between 9 and 20 years, except TENERA SCUBA. It is possible that large cycles of abundance for this species occur on longer time-scales that weren't spanned by surveys with significant trends. Trends during the most recent time-period analyzed (2004-07) were generally down for *S. mystinus*, a likely consequence of the large decrease in abundance estimates for many surveys from 2006 to 2007. This could be an important trend or just another fluctuation similar to those seen in previous decades of abundance data.

Among the focus species, *O. elongatus* had some of the closest agreement in abundance index trends among surveys (Fig. 6-7). Similarities among surveys indicate it may be possible to track abundance trends for this species equally well with any of these datasets. The significant longer time-span abundance increases for *O. elongatus* (mainly the All Observers survey) do not indicate the possibly critical downward trend of many surveys in 2004-07 (Fig. 6, Table 15). This more recent downward trend may be the reason why few longer term linear regressions were significant. It is likely that abundance increases in 2002-03 shown in index value plots and contributing to long-term trend patterns were due to high survivorship of the year class a few years previous. The subsequent decrease for *O. elongatus* may be related to poor juvenile survivorship, fishery impacts or other unknown factors.

Compared to other focus species, *S. miniatus* had one of the most consistent increases in abundance index trends among surveys (Fig. 9-10). Similarity among surveys indicates that it may be possible to track abundance trends for this species equally well with any of these datasets. However, since 2003 the PISCO SCUBA survey indicated a clearly different trend from other surveys (Fig. 9). This PISCO SCUBA survey was the only fishery-independent survey conducted from 2004-07, and the contrast in trends with fishery-dependent surveys indicated a difference in abundance estimates based on survey methods. It should be noted that *S. miniatus* occurred in a low number of samples for the PISCO SCUBA survey.

Annual index values varied relatively little for most surveys of *S. caurinus* compared to other focus species (although the CDFG CENCAL survey index fluctuated greatly) (Fig. 9-10). This lack of inter-annual variability likely explains the low number of significant longer time-span trends for this species. However, in recent years surveys indicated larger changes in abundance for this species (Fig. 9, Table 17). The only significant recent trends were for fishery-dependent surveys, but the trend direction and rate of increase was similar (the only non-significant t-test for any species) (Table 9).

4.6.2. Comparisons with stock assessments

The stock assessment completed (and accepted by the PFMC) by Key et al. (2008) for *S. mystinus*, indicates an overall similar pattern to results of my study. However, the drop in overall biomass around 1975, seen in the population dynamics base model biomass trend for this assessment, was not obvious from the CDFG CENCAL survey trends. The model used in a stock assessment incorporates more data than indices of abundance, but the portion of the biomass curve in the assessment prior to 1980 was not supported by an index of abundance. Instead it was based on fishery removals, mostly recreational landing receipts and sporadic CDFG reports, which did not record fishing effort. Perhaps more importantly, the recent decrease in stock abundance that occurred across nearly all surveys I analyzed was not detected by the assessment. The only abundance indices used in the stock assessment were the CDFG Observers and PSMFC Dockside surveys. Both of these surveys showed an upward linear trend across all the years they surveyed in my study, similar to Key et al. (2008). However, apparently 2007 data were not used in the stock assessment, which represented a large decline in abundance estimates for all surveys I analyzed (except TENERA SCUBA). Another difference in our methods was that the 'Delta-GLM' method was used by Key et al. (2008) for the calculation of yearly index values. This type of analysis combines two different GLMs, one with a continuous distribution and one with a discrete distribution. Mean precision results were similar for each of the datasets used in the stock assessment and the same surveys analyzed in my study (CVs < 0.30). In the data organization done by Key et al. (2008), significant effort was put in to remove all records that would be unlikely to have sampled areas where *S. mystinus* specifically could be caught. My method of removing records was simply based on whether any study species was targeted or likely to be counted in a given sample (if targets were not reported). It appears that both methods produced basically similar results for this species.

The stock assessment completed (and accepted by the PFMC) by Jagielo and Wallace (2005) for *O. elongatus* indicates a somewhat different pattern than results from my study. This assessment tracked trends for the 'southern stock' of *O. elongatus* that included areas from Pt. Conception to the Oregon border (a somewhat larger area than my study area). The stock assessment spawning biomass trend decreased sharply from 1975-1995, then steeply increased until 2005. The main stock declines shown by the data I analyzed were in the early-1980's and subsequent to 2002 (Fig. 6). The assessment biomass model did not indicate a decreasing abundance trend after 2002. One reason for these discrepancies is that none of the datasets used in my study were included in the population dynamics model for this assessment. Instead, the assessment model utilized historical catch records, as well as a commercial trawl fishery logbook index (1977-1997) and the NMFS Triannual Trawl Survey (1977-2001 every 3rd year). Therefore, most yearly index values were not based on an index of abundance for the assessment, and the indices that were used did not extend into the nearshore. The most important difference for management is the divergence in conclusions for my study and the *O. elongatus* assessment subsequent to 2002. One important consideration is that the assessment apparently did not use abundance index data after 2001, so the assessment model would be based on fishery landings for 2002-2005. This type of data could produce quite different results than indices of abundance (which include sampling effort). Also, the 'Delta-GLM' method was used by Jagielo and Wallace (2005) for calculating yearly abundance index values in contrast to the negative binomial GLM for my study. Mean precision results as calculated by Jagielo and Wallace (2005) for the NMFS Trawl Survey index were generally low (0.12-0.33), similar to fishery-dependent but lower than fishery-independent surveys used in my study.

A stock assessment was completed by MacCall (2005) for *S. miniatus*, but was not accepted by the PFMC. Biomass models were deemed untrustworthy by the PFMC, partly due to the recruitment patterns of this species, but also due to a lack of good abundance indices. Trends that were found by this assessment did generally indicate a similar abundance pattern to my study. Recent trends in stock abundance (2004-07) could not be compared with my survey because the assessment only contained data through 2003. The only abundance indices used in the assessment were the CDFG Observers and PSMFC Dockside surveys. Both of these surveys showed roughly similar trends in my study and for MacCall (2005). Mean precision was generally lower for my study in the two surveys used in the stock assessment. CVs were moderate to low for MacCall (2005), but very low (< 0.20) for my results. MacCall (2005) used the 'Delta-GLM' method for calculating yearly index values and CVs compared to the negative binomial GLM used in my analysis, which could cause some differences. Another difference that could affect the index results was the data organization done by MacCall (2005). This involved significant effort to remove all records from areas where anglers would be unlikely to catch *S. miniatus* specifically. I included records if any species in my study assemblage was targeted or likely to be counted in a given sample. However, it appears that both methods produced basically similar results for this species.

4.7. Conclusions and Recommendations

The nine surveys used for analysis in this study often differed with respect to species occurrence, abundance trends, precision or relative importance of explanatory variables, but each provides potentially useful data on one or more central California nearshore rocky reef fish stocks. Because surveys often demonstrated dissimilar trends for a given species, the priorities of particular fisheries managers may dictate which surveys are chosen to include in stock assessments. Because population dynamics models weight indices of abundance with higher precision more heavily in generating a biomass trend, surveys with lower CVs for a given species will be more influential in determining the health of a stock. However, due to biases for each survey category (discussed at length in this thesis), accurate trends are not necessarily determined by the dataset with the lowest sampling precision. If biases are consistent for a given survey, data may be precise but not accurate in depicting stock trends. Therefore, although precision is a useful tool for deciding which surveys might depict the most accurate trends for a given species, it may not be the only one. Considering survey bias, spatial coverage and time-scale of the abundance surveys (i.e. how many and which years were sampled) are also important for management to understand stock trends.

A clear relationship could be seen in my results between yearly sample sizes and intra-annual precision for abundance surveys. The surveys with the highest yearly sample sizes were fishery-dependent hook and line and SCUBA surveys. These surveys also had the highest yearly precision levels for all species. The CPFV Logbooks survey had the largest yearly sample size and highest sampling precision of any survey in the study for the seven species it surveyed. Therefore, future surveys should attempt to collect as many samples as possible to increase precision. In my study, surveys that collected over 500 samples per year had high intra-annual precision levels for most species, but 100 samples per year should be a minimum goal.

Survey types generally sampled some species more precisely than others. The four fishery-dependent hook and line surveys provided more precise data than other survey types for use in managing stocks of: *S. ruberrimus, S. auriculatus, S. pinniger, O.*

elongates, S. miniatus and *S. caurinus*. The three SCUBA surveys provided more precise data other survey types for use in managing stocks of: *E. lateralis, D. vacca, S. atrovirens* and *S. chrysomelas*. All other species were sampled at similar precision levels by SCUBA and fishery-dependent hook and line surveys, so results from these surveys should prove equally useful in understanding abundance trends. The only exception among study species was *S. rastrelliger*. This species was only sampled by the CDFG CENCAL survey, making this the only possible index of abundance for this species, although precision was fairly low.

Although fishery-dependent hook and line surveys were often sampled very precisely, they have important biases. Fishing with bait may overestimate a stock, regulations can change sampling structure, catch rates may stay consistent as anglers progressively deplete locations until a stock suddenly collapses, for which there is some evidence in data for 2004-07. The main alternative to this type of sampling in the nearshore is SCUBA surveys, which also have biases. They often miss cryptic species, some species are attracted or repulsed by divers, and inclusion of midwater transects may more accurately estimate some species but underestimate others. However, SCUBA surveys are not affected by fishing regulations or changing sampling locations.

Fishery-dependent hook and line surveys collected abundance data from all major ports and depths in the study area, as opposed to fishery-independent surveys that were more restricted spatially. The diversity of locations 'sampled' by recreational anglers in these surveys could never be matched by fishery-independent methods such as SCUBA surveys, due to depth restrictions and costs. Fishery-independent surveys only sampled south of San Francisco and north of Diablo Canyon. Abundance surveys of extremely small areas demonstrated species abundance trends that often differed from other survey results. Spatial range of abundance indices is clearly important for management to consider, exemplified by the fact that location (i.e. 'Subregion') was significant in so many GLMs. However, although it would ideal, it may not always be necessary to sample the entire stock area. Although smaller scale surveys were significantly different when compared to larger scale surveys in t-tests, larger scale surveys also differed from one another. Therefore, spatial area alone may not cause differences, but it is unclear how much sampling in the study area was necessary to obtain a sufficient estimate of stocks. It is likely that the area surveyed by the TENERA SCUBA survey is too small to indicate trends for a representative portion of stocks. Randomized design of fishery-independent surveys helps ensure that they sample areas containing large and small densities of a given species. The result is that fishery-independent surveys have the potential to provide the clearest picture of stock abundance throughout the rocky reef habitats of central California.

Fishery-dependent surveys often had long time-series. The CDFG CENCAL survey covered a 48-year time-period, beginning 17 years prior to any other survey. This dataset is the clear choice for fisheries managers interested in abundance data with the largest temporal range and for the period 1959-1975, where no other time-series existed. The CDFG CENCAL survey also had trends for some species that matched other surveys, increasing confidence in data for certain study species during earlier years where no other index of abundance existed. The CDFG Observer and PSMFC Observer datasets complemented each other well because they used the same methods and together make an unbroken time-series of 20 years that will continue to grow. The All Observers time-series I created from these datasets compared well with trends and precision results of each original survey. This time-series has not been utilized in stock assessments and may prove useful to management. The PSMFC Dockside survey began earlier than many surveys (1980), representing a long and continually growing time-series. Although the CPFV Logbooks survey collected data for many decades, only 2001-07 was useful as an index of abundance.

Fishery-independent surveys often, but not always spanned fewer years than fishery-dependent surveys. The TENERA SCUBA survey was the longest time-series of fishery-independent data (32 years), but spatial limitations make this survey little use for large scale stock trend analysis. Although methods were somewhat different, the CDFG SCUBA survey provided data for the four years prior to the start of the PISCO SCUBA survey, making this a 13 year SCUBA time-series for the Monterey and Big Sur area. The PISCO SCUBA survey was the longest fishery-independent time-series that covered a significant portion of the study area, and is the only widespread fishery-independent survey I analyzed that is ongoing, making it currently the most useful survey to compare with fishery-dependent datasets. The CDFG H&L survey was short, but collected data prior to many other surveys (1978-82) and had unique methods (i.e. fishery-independent hook and line).

Given the limited financial resources of researchers studying nearshore fish abundance, it is useful to consider which current surveys might be most useful to understand trends and what future survey methods might be best. Abundance surveys using a similar methodology type (e.g. hook and line) often had different trends for a given study species, but did not trend in opposite directions. Therefore, perhaps two or even one well-designed survey using a given methodology, sampling throughout the study area, might be sufficient.

It is difficult to conclude whether the sole fishery-independent line survey (CDFG H&L) differed from fishery-dependent hook and line surveys because of the lack of t-test that could be used for comparisons. However, abundance index plots did not show any obvious differences, and during 1995-98 trends for the CDFG H&L survey and most other surveys had non-significant trends. Although more evidence is needed, if fisheries-dependent surveys yield the same results and can be conducted more cheaply and on larger spatial scales, fishery-independent hook and line surveys may be unnecessary. Fishery-independent hook and lines surveys currently being conducted by Moss Landing Marine Laboratories and the California Polytechnic University may provide useful data for comparing this type of survey with other fishery-dependent surveys in the future.

Although PSMFC Dockside and CPFV Logbooks data are useful for tracking total fisheries removals for the study assemblage, the CPFV Observer surveys may be most useful as indices of abundance. Observers are trained to accurately record time fished and anglers fishing (effort), released fish (discards), depths and target species at specific sampling sites. Observer surveys are preferable to the other fishery-dependent hook and line surveys that do not provide this level of detail for all samples. However, the depth information currently collected by the PSMFC Observers survey is not adequate for analyses such as those used in my study. If data collection protocols were changed, depth could be a useful variable to include in future models.

The uniquely long time-series represented by the CDFG CENCAL survey, combined with the very low relative expense, suggest that not continuing this survey would be unwise. However it does have important biases, especially the lack of replication in different explanatory variable levels. If more samples could be collected in a given year, results might be more reliable (i.e. precision may increase).

SCUBA surveys may not commonly count some species, but can still demonstrate trends similar to other survey categories for these same species (e.g. *O. elongatus*). To avoid bias in comparing results from these surveys with fishery-dependent abundance estimates, SCUBA surveys would ideally be expanded to cover the entire coast of California. Because SCUBA cannot be used in the deeper areas of the nearshore (and beyond), other fishery-independent visual survey methods should be developed for those areas. Submersibles and ROVs have already been used for estimating fish abundance in California (mainly over the continental shelf). These techniques should be used in consistent surveys of the deeper portions of the nearshore (where possible) to supplement SCUBA surveys.

Abundance indices are lacking for species caught in the nearshore commercial fishery. Although commercial fishing pressure affects many study species much less than recreational fishing, several species are targeted by nearshore commercial operations. NMFS observers have apparently started collecting data on nearshore trips in California, but the time-series is short and samples may be few. This is a potentially useful dataset for future stock assessments of my study species. In the absence of observers, trained personnel sampling commercial boats at ports should include data on fishing effort. Lack of effort data was the main reason data from commercial fishery port sampling efforts could not be used for this study. The use of nearshore commercial logbooks that included effort data would also be preferable to no index of abundance for nearshore commercial fishing.

The divergence of trends from multiple surveys of the same species highlights the importance of methodological differences in abundance surveys. Differences in species life histories, though similar in many respects, may make species more or less likely to be sampled by a particular methodology. My study identified indices of abundance that had not been used in stock assessments, but whose value for stock assessments will vary based on the priorities of managers. Additionally, the focus species I examined did have some different trends in my analysis when compared to existing assessments, especially in recent years. This indicates the potential for indices of abundance from my study to change stock assessment conclusions. Differences are particularly important considering some results from my study indicated stock abundance declines in recent years. The detailed results presented and discussed for the four focus species in this thesis might be generalized to other species in the assemblage with similar characteristics. Similar life history traits (age and growth, feeding, movements, etc.) and level of fishing pressure may indicate that other species would demonstrate the same patterns.

My study results can help fisheries managers prioritize which central California nearshore rocky reef stocks should be considered for future stock assessments. All study species, with the exception of *S. rastrelliger*, had moderate to low mean precision levels for at least one survey analyzed. *Sebastes miniatus, S. atrovirens, S. mystinus, S. melanops, S. ruberrimus, H. decagrammus, S. marmoratus, D. vacca* and *O. elongatus* all demonstrated a significant linear decline in at least one index of abundance during one of the three time-periods I examined. Consequently, these species would be good choices for new or repeat stock assessments in the near future. Some other study species that did not demonstrate declines only had trends results from fishery-dependent surveys, partially due to the inability of existing fishery-independent surveys to sample these species. These species may demonstrate different trends if a fishery-independent survey was constructed that could consistently sample them. The apparent increase in landings of my study species in recent years even with significant temporal and spatial fishing restrictions indicates a shift toward targeting these species. While catch rates may increase in the short-term, the long-term impact of increased fishing pressure on stock sizes is uncertain. As a consequence, continued monitoring and analysis of stock trends is vital to insure nearshore rocky reef fishes do not share the unfortunate fate of many other depleted central California fisheries in recent decades.

The surveys I analyzed in this study will have varying degrees of usefulness as indices of abundance for stock assessment models or other fisheries management. Some surveys collected data that should prove more useful for understanding many study stock trends, while some surveys appear better suited for tracking trends of a small number of stocks. Whether these datasets will change the conclusions of existing stock assessments or provide enough data for future assessments is to be determined by fisheries analysts and managers. Although I analyzed a large amount of data for this study, there are still important gaps that should be addressed by expanding current surveys or designing new ones. To aid in developing future abundance surveys, my study summarized what existing data reveals about these species trends and the relative usefulness of different abundance survey types to better manage this valuable resource.

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Table 1. A list of 18 fish species commonly found on central California rocky reefs and caught by recreational or commercial fisheries (Eschmeyer 1983, Cailliet et al. 2000, Starr et al. 2002, Allen et al. 2006).

Scientific Names	Common Names
Damalichthys vacca	pile seaperch
Embiotoca lateralis	striped seaperch
Hexagrammos decagrammus	kelp greenling
*Ophiodon elongatus**	lingcod
Scorpaenichthys marmoratus	cabezon
Sebastes atrovirens	kelp rockfish
Sebastes auriculatus	brown rockfish
Sebastes carnatus	gopher rockfish
*Sebastes caurinus**	copper rockfish
Sebastes chrysomelas	black-and-yellow rockfish
Sebastes melanops	black rockfish
*Sebastes miniatus**	vermilion rockfish
*Sebastes mystinus**	blue rockfish
Sebastes nebulosus	china rockfish
Sebastes pinniger	canary rockfish
Sebastes rastrelliger	grass rockfish
Sebastes ruberrimus	yellowtail rockfish
Sebastes serranoides	olive rockfish

* Focus species

Table 2. The nine historical and ongoing abundance surveys of nearshore rocky reef fishes within central California used in my study. Survey time-span indicates the range of years for data included in my analysis. The first 4 surveys listed were fishery-independent, the final 5 surveys were fishery-dependent. Different colored rows denote the four main categories of survey methodologies.

Short Survey Name	Research Body/ Data Managers	Dataset/Study Title	Spatial coverage	Survey time-span
CDFG SCUBA	CDFG / Ventresca and Osorio	Marine reserve fish density monitoring and habitat associations	Monterey - Big Sur	1995-1998
PISCO SCUBA	UCSC / Carr and Malone	PISCO Collaborative Central Coast Abundance SCUBA Surveys	Santa Cruz - Pt. Conception	1999-2007*
TENERA SCUBA	TENERA / Jay Carroll	Diablo Canyon Nearshore Reef SCUBA Survey	Diablo Canyon (Patton Cove)	1976-2007*
CDFG H&L	CDFG / VenTresca and Lea	Central California Marine Sportfish Hook-and-Line Survey	Monterey - Big Sur	1978-82 (all sites) 1979-82; 1995-98 (BCER)
CDFG CENCAL	CDFG / Ventresca	CENCAL Spearfish Tournaments Creel Survey	Fort Bragg - Pismo Beach	1959-2006 (most years)*
CPFV Logbooks	CDFG/ Dunlap-Harding	Commercial Party Fishing Vessel Logbooks	All California	2001-2007*
PSMFC Dockside	PSMFC / Van Buskirk	Marine Recreational Fishery Statistical Survey / California Recreational Fisheries Survey - dockside boat interviews	All California	MRFSS 1980-2003 CRFS 2004-2007*
CDFG Observers	CDFG / Wilson-Vandenberg	CPFV On-Board Sampling Program	All California	1988-1998
PSMFC Observers	PSMFC / Van Buskirk	Marine Recreational Fishery Statistical Survey / California Recreational Fisheries Survey - onboard observers survey	All California	MRFSS 1999-2003 CRFS 2004-2007 *
All Observers	CDFG / PSMFC (same as above)	Combined CDFG and PSMFC Observers datasets	All California	1988-2007*

* Ongoing survey

Table 3. Occurrence proportion of study species in abundance survey samples (where a species was counted at least once). Species are ranked by mean occurrence in all surveys. ND = species were not recorded in that survey. Bold values indicate data were used in a GLM. Colors indicate different survey method categories: green = SCUBA, yellow = fishery-independent hook and line, grey = fishery-dependent spearfishing, blue = fishery-dependent hook and line.

Species	CDFG SCUBA	PISCO SCUBA	TENERA SCUBA	CDFG H&L	CDFG CENCAL	CPFV Logbooks	PSMFC Dockside	CDFG Observers	PSMFC Observers	Mean
S. mystinus	ND	**0.439**	**0.490**	**0.485**	**0.920**	**0.763**	**0.319**	**0.636**	**0.537**	0.574
O. elongatus	**0.161**	**0.042**	0.266	**0.481**	**0.980**	**0.633**	**0.260**	**0.587**	**0.329**	0.415
S. serranoides	**0.553**	**0.175**	0.219	**0.639**	**0.740**	ND	**0.117**	**0.355**	**0.213**	0.376
S. carnatus	**0.620**	**0.118**	0.047	**0.605**	0.420	**0.507**	**0.164**	**0.267**	**0.298**	0.339
S. atrovirens	**0.830**	**0.254**	0.437	**0.371**	**0.670**	ND	**0.017**	**0.019**	**0.008**	0.326
H. decagrammus	**0.416**	0.152	0.563	**0.110**	**0.960**	**0.338**	**0.041**	**0.067**	**0.061**	0.301
S. chrysomelas	**0.437**	**0.110**	0.880	**0.103**	**0.603**	ND	**0.023**	**0.012**	0.008	0.272
E. lateralis	0.027	**0.242**	**0.868**	0.000	**0.940**	ND	0.005	0.000	0.001	0.260
S. miniatus	**0.232**	**0.052**	0.010	**0.299**	**0.520**	ND	**0.163**	**0.418**	**0.268**	0.245
S. melanops	**0.335**	**0.125**	0.140	**0.144**	**0.890**	0.149	**0.123**	**0.107**	**0.146**	0.240
S. marmoratus	**0.172**	**0.028**	0.545	**0.192**	**0.950**	**0.101**	**0.042**	**0.049**	**0.030**	0.234
S. caurinus	**0.172**	**0.018**	0.008	**0.430**	**0.400**	**0.373**	**0.087**	**0.335**	**0.116**	0.215
D. vacca	0.025	**0.130**	**0.530**	0.000	**0.950**	ND	0.003	0.000	0.000	0.205
S. ruberrimus	0.002	0.000	0.000	0.113	0.048	ND	**0.162**	**0.688**	**0.256**	0.159
S. pinniger	0.000	0.005	0.000	**0.124**	0.008	**0.237**	**0.103**	**0.469**	**0.163**	0.123
S. rastrelliger	0.002	0.009	0.217	0.016	**0.710**	ND	0.008	0.004	0.003	0.121
S. nebulosus	0.037	0.003	0.002	**0.113**	0.250	ND	**0.065**	**0.185**	**0.096**	0.094
S. auriculatus	0.000	0.006	0.002	0.017	0.071	ND	**0.103**	**0.133**	**0.130**	0.058
Mean Occurrence	0.237	0.106	0.290	0.236	0.613	0.388	0.100	0.241	0.148	0.253
Species counted in survey	15	17	16	16	18	8	18	16	17	
Species analyzed with GLMs	10	12	3	13	13	7	15	15	14	
Survey sample size (total)	483	6398	508	291	126	21657	43253	4462	5217	
Average samples/year	120.75	710.89	15.88	58.20	3.15	3094.00	1730.12	405.64	579.67	

Table 4. Results of linear regression analysis using GLM yearly index of abundance values for 1959-2007. P-values from t-tests are provided with direction of trends based on regression slope (↑ = positive, ↓ = negative, - = -0.0001 to 0.0001). Bold values are significant at the α <0.05 level. Blanks indicate GLM abundance estimates could not be generated, often due to low occurrence in a survey.

Species	CDFG SCUBA	PISCO SCUBA	TENERA SCUBA	CDFG H&L	CDFG H&L	CDFG CENCAL	CPFV Logbooks	PSMFC Dockside	CDFG Observers	PSMFC Observers	All Observers
	1995-98	1999-2007	1976-2007	1978-82	1979-98	1959-2006	2001-07	1980-2007	1988-98	1999-2007	1988-2007
S. mystinus	NA	**0.028↑**	**0.000↓**	0.317↑	0.724↑	0.411↑	0.059↑	0.443↑	**0.002↑**	**0.036↑**	**0.050↑**
O. elongatus	0.690↑	0.713 -		0.966↑	0.120↓	0.243↓	0.176↓	0.481↓	**0.045↑**	0.868↑	**0.000↑**
S. serranoides	0.475↑	0.208↓		0.245↓	0.261↓	0.368↑		**0.040↑**	**0.006↑**	**0.009↑**	**0.005↑**
S. carnatus	0.303↓	**0.003↑**		0.191↑	0.846↑		0.184↓	**0.000↑**	**0.000↑**	0.449↑	**0.000↑**
S. atrovirens	0.216↓	**0.017↓**		0.423↑	0.405↓	0.505↓		0.480 -	**0.032↑**	0.725↓	0.148↑
H. decagrammus	0.256↓			0.269↑		**0.017↓**	0.153↓	0.213 -	0.546↑	0.987↑	**0.016↑**
S. chrysomelas	0.803↓	0.153↓		**0.019↑**		**0.000↑**		0.075 -	0.191↑		
E. lateralis		0.840 -	0.665 -			0.095↑					
S. miniatus	0.144↑	0.457 -		0.946↑	0.061↓	0.247↑		**0.000↑**	0.786↑	**0.002↑**	**0.000↑**
S. melanops	0.906↓	0.707 -		0.448↓		**0.000↓**		0.057↑	0.267↑	0.950↑	0.108↑
S. marmoratus	**0.025↑**	**0.013↓**		0.218↑		0.800↓	**0.000↓**	0.571 -	0.865↑	0.969 -	0.106↑
S. caurinus	0.641↓	0.208↓		0.621↓	**0.010↓**	0.079↓	**0.025↑**	0.322↑	0.385↓	0.355↑	0.233↓
D. vacca		**0.002↓**	0.665 -			0.095↑					
S. ruberrimus								0.845↓	0.414↑	0.818↑	**0.007↓**
S. pinniger				**0.050↓**			0.863↑	**0.000↓**	0.695↓	0.864↑	0.443↓
S. rastrelliger						0.923 -					
S. nebulosus				0.713↑				**0.000↑**	0.303↓	0.202↑	0.422↑
S. auriculatus								**0.039↑**	0.746↑	0.095↑	**0.012↑**
Significant Trends	1	5	1	2	1	3	2	5	5	3	8
Proportion Signif.	0.10	0.42	0.33	0.15	0.14	0.23	0.29	0.33	0.33	0.21	0.57

Table 5. Results of linear regression analysis using GLM yearly index of abundance values for surveys sampling 1988-2007. P-values from t-tests are provided with direction of trends based on regression slope (↑ = positive, ↓ = negative, - = -0.0001 to 0.0001). Bold values are significant at the α <0.05 level. Blanks indicate GLM abundance estimates could not be generated.

Species	TENERA SCUBA	CDFG CENCAL	PSMFC Dockside	All Observers
Sebastes mystinus	**0.000**↓	0.097↓	0.483↑	**0.050**↑
Ophiodon elongatus		0.161↓	0.499↑	**0.000**↑
Sebastes serranoides		0.682↑	0.151↑	**0.005**↑
Sebastes carnatus			**0.001**↑	**0.000**↑
Sebastes atrovirens		**0.019**↓	0.380 -	0.148↑
Hexagrammos decagrammus		**0.010**↓	0.428↑	**0.016**↑
Sebastes chrysomelas		0.071↓	0.686 -	
Embiotoca lateralis	0.155↓	0.082↓		
Sebastes miniatus		0.465↑	**0.000**↑	**0.000**↑
Sebastes melanops		0.133↓	0.131↑	0.108↑
Scorpaenichthys marmoratus		**0.033**↓	0.800 -	0.106↑
Sebastes caurinus		0.431↓	0.658 -	0.233↓
Damalichthys vacca	0.746 -	**0.048**↓		
Sebastes ruberrimus			0.373↓	**0.007**↓
Sebastes pinniger			**0.001**↓	0.443↓
Sebastes rastrelliger		**0.008**↓		
Sebastes nebulosus			0.184↑	0.422↑
Sebastes auriculatus			0.074↑	**0.012**↑
Significant Trends	1	5	3	8
Proportion significant	0.33	0.38	0.20	0.57

Table 6. Results of linear regression analysis using GLM yearly index of abundance values for surveys sampling 1995-98. P-values from t-tests are provided with direction of trends based on regression slope (↑ = positive, ↓ = negative, - = -0.0001 to 0.0001). Bold values are significant at the α <0.05 level. Blanks indicate GLM abundance estimates could not be generated.

Species	CDFG SCUBA	TENERA SCUBA	CDFG H&L	CDFG CENCAL	PSMFC Dockside	CDFG Observers
Sebastes mystinus	NA	0.784↓	0.187↑	0.503↓	0.207↑	**0.042**↑
Ophiodon elongatus	0.690↑		0.825↓	0.943↓	0.863↓	0.785↓
Sebastes serranoides	0.475↑		0.460↑	0.640↓	0.493↑	0.722↑
Sebastes carnatus	0.303↓		0.844↓		0.201↑	0.081↑
Sebastes atrovirens	0.216↓		0.608↑	0.334↓	0.301 -	0.176↑
Hexagrammos decagrammus	0.256↓			0.848↑	0.306↓	0.368↓
Sebastes chrysomelas	0.803↓			0.879↓	0.359↓	0.242↑
Embiotoca lateralis		0.556↓		0.449↓		
Sebastes miniatus	0.144↑		0.173↑	0.197↑	0.429↑	0.399↑
Sebastes melanops	0.906↓			0.938↓	0.768↑	0.753↑
Scorpaenichthys marmoratus	**0.025**↑			0.152↑	0.101↓	0.904↑
Sebastes caurinus	0.641↓		0.819↑	0.757↑	0.292↑	**0.028**↓
Damalichthys vacca		0.953 -		0.563↑		
Sebastes ruberrimus					0.613↑	0.396↓
Sebastes pinniger					**0.036**↓	0.089↓
Sebastes rastrelliger				**0.020**↑		
Sebastes nebulosus					0.211↑	0.870↓
Sebastes auriculatus					0.072↑	0.111↑
Significant Trends	1	0	0	1	1	2
Proportion significant	0.10	0.00	0.00	0.08	0.067	0.13

Table 7. Results of linear regression analysis using GLM yearly index of abundance values for surveys sampling 1999-2007. P-values from t-tests are provided with direction of trends based on regression slope. Blanks indicate GLM abundance estimates could not be generated.

Species	PISCO SCUBA	TENERA SCUBA	CDFG CENCAL	CPFV Logbooks	PSMFC Dockside	PSMFC Observers
Sebastes mystinus	**0.028**↑	0.338↓	0.163↓	0.059↑	**0.034**↑	**0.036**↑
Ophiodon elongatus	0.713 -		0.998 -	0.176↓	0.598↑	0.868↑
Sebastes serranoides	0.208↓		0.303↓		**0.022**↑	**0.009**↑
Sebastes carnatus	**0.003**↑			0.184↓	0.145↑	0.449↑
Sebastes atrovirens	**0.017**↓		0.115↓		0.602 -	0.725↓
Hexagrammos decagrammus			0.183↓	0.153↓	0.810↑	0.987↑
Sebastes chrysomelas	0.153↓		0.092↑		0.694 -	
Embiotoca lateralis	0.840 -	0.840 -	0.158↓			
Sebastes miniatus	0.457 -		0.357↓		**0.000**↑	**0.002**↑
Sebastes melanops	0.707 -		**0.024**↓		0.250↓	0.950↑
Scorpaenichthys marmoratus	**0.013**↓		0.260↓	**0.000**↓	0.840 -	0.969 -
Sebastes caurinus	0.208↓		0.100↓	**0.025**↑	**0.005**↑	0.355↑
Damalichthys vacca	**0.002**↓	0.628↓	0.690↓			
Sebastes ruberrimus					0.707↑	0.818↑
Sebastes pinniger				0.863↑	**0.006**↓	0.864↑
Sebastes rastrelliger			0.961↑			
Sebastes nebulosus					**0.006**↑	0.202↑
Sebastes auriculatus					**0.045**↑	0.095↑
Significant Trends	5	0	1	2	7	5
Proportion significant	0.42	0.00	0.08	0.29	0.47	0.33

Table 8. Results of linear regression analysis using GLM yearly index of abundance values for surveys sampling 2004-07. P-values from t-tests are provided with direction of trends based on regression slope (↑ = positive, ↓ = negative, - = -0.0001 to 0.0001). Bold values are significant at the α <0.05 level. Blanks indicate GLM abundance estimates could not be generated.

Species	PISCO SCUBA	TENERA SCUBA	CDFG CENCAL	CPFV Logbooks	PSMFC Dockside	PSMFC Observers
Sebastes mystinus	0.777↓	0.052↑	**0.031**↓	0.547↓	0.810↓	0.987↓
Ophiodon elongatus	0.184 -		0.669↑	**0.017**↓	0.810↑	**0.026**↓
Sebastes serranoides	0.105↓		0.369↓		0.817↓	0.655↑
Sebastes carnatus	0.920 -			0.115↓	0.100↓	**0.041**↓
Sebastes atrovirens	**0.021**↓		**0.023**↓		0.684 -	0.209↓
Hexagrammos decagrammus			0.356↑	0.183↓	0.162↓	0.206↓
Sebastes chrysomelas	0.392↓		0.226↑		0.188↓	
Embiotoca lateralis	0.148↓	0.261↓	0.170↓			
Sebastes miniatus	0.074↓		0.957↑		0.881↑	0.053↑
Sebastes melanops	0.963 -		0.121↑		0.778↓	**0.035**↓
Scorpaenichthys marmoratus	0.123 -		0.454↑	**0.040**↓	0.389↓	0.266↑
Sebastes caurinus	0.105↓		0.856↓	**0.006**↑	0.073↑	**0.008**↑
Damalichthys vacca	0.148↓	0.261↓	0.170↓			
Sebastes ruberrimus					0.141↑	0.122↑
Sebastes pinniger				0.136↑	0.815↑	**0.038**↑
Sebastes rastrelliger			0.864↓			
Sebastes nebulosus					0.347↑	0.156↑
Sebastes auriculatus					0.156↑	0.091↑
Significant Trends	1	0	2	3	0	5
Proportion significant	0.08	0.00	0.15	0.57	0.00	0.36

Table 9. Comparing linear regression slopes of two significant survey trends for a species (t-tests). The maximum number of surveys which provided data on species is displayed beside time-period column headers. Surveys compared are listed and color coded for upward (green) and downward (red) trend slopes. Dashes (--) indicate < 2 significant trends, not allowing for survey trend comparisons.

Species	1988-2007 (4)	1999-2007 (6)	2004-07 (6)
S. mystinus	TENERA SCUBA vs. All Observers (p =0.04)*	--**	--
O. elongatus	--	--	PSMFC Observers vs. CPFV Logbooks (p =0.04)*
S. serranoides	--	PSMFC Dockside vs. All Observers (p=0.01)*	--
S. carnatus	PSMFC Dockside vs. All Observers (p=0.00)*	--	--
S. atrovirens	--	--	PISCO SCUBA vs. CDFG CENCAL (p =0.00)*
H. decagrammus	CDFG CENCAL vs. All Observers (p=0.00)*	--	--
S. chrysomelas	--	--	--
E. lateralis	--	--	--
S. miniatus	--	PSMFC Dockside vs. All Observers (p=0.00)*	--
S. melanops	--	--	--
S. marmoratus	--	PISCO SCUBA vs. CPFV Logbooks (p =0.00)*	--
S. caurinus	--	PSMFC Dockside vs. CPFV Logbooks (p=0.02)*	PSMFC Observers vs. CPFV Logbooks (p =0.06)
D. vacca	--	--	--
S. ruberrimus	--	--	--
S. pinniger	--	--	--
S. rastrelliger			
S. nebulosus	--	--	--
S. auriculatus	--	--	--

* Indicates significant difference between survey slopes (α<0.05).
** Three surveys had significant slopes, not allowing for comparison with a t-test

Table 10. Species yearly coefficient of variation resulting from jackknife process, displayed as the mean of all years for each survey. Species are ranked by mean occurrence in all surveys (high to low). I designated bold mean values as high annual sampling precision (CV< 0.30) for that species. Color codes: green = SCUBA, yellow = fishery-independent hook and line, grey = fishery-dependent spearfishing, blue = fishery-dependent hook and line.

Species	CDFG SCUBA 1995-98	PISCO SCUBA 1999-2007	TENERA SCUBA 1976-2007	CDFG H&L 1978-82	CDFG H&L 1979-98	CDFG CENCAL 1959-2006	CPFV Logbooks 2001-07	PSMFC Dockside 1980-2007	CDFG Observers 1988-98	PSMFC Observers 1999-2007	All Observers 1988-2007	Spp. Mean
S. mystinus		**0.144**	0.407	0.568	0.412	0.772	**0.035**	**0.124**	**0.163**	**0.163**	**0.137**	**0.293**
O. elongatus	0.424	0.391		0.435	0.591	0.460	**0.035**	**0.112**	**0.123**	**0.139**	**0.111**	**0.282**
S. serranoides	**0.223**	**0.204**		0.433	0.714	0.667		**0.197**	**0.201**	**0.227**	**0.182**	0.339
S. carnatus	**0.234**	**0.197**		**0.218**	0.523		**0.054**	0.312	**0.231**	**0.175**	**0.163**	**0.234**
S. atrovirens	**0.223**	**0.134**		0.493	0.693	0.960		0.454	1.071	1.244	1.079	0.706
H. decagrammus	**0.203**			0.857		0.570	**0.133**	**0.235**	0.314	0.332	**0.285**	0.366
S. chrysomelas	0.419	**0.216**		1.349		0.903		0.304	0.919			0.685
E. lateralis		**0.142**	**0.209**			0.704						0.352
S. miniatus	0.396	0.446		0.476	0.498	1.408		**0.117**	**0.146**	**0.189**	**0.137**	0.424
S. melanops	0.310	**0.256**		1.293		0.719		**0.212**	0.560	**0.257**	0.359	0.496
S. marmoratus	0.305	**0.278**		1.099		0.593	**0.140**	**0.227**	0.444	0.525	0.410	0.447
S. caurinus	0.441	0.541		0.429	0.473	1.597	**0.074**	**0.158**	**0.186**	**0.299**	**0.189**	0.439
D. vacca		**0.259**	0.361			0.463						0.361
S. ruberrimus								**0.145**	**0.108**	**0.208**	**0.117**	**0.144**
S. pinniger				1.278			**0.093**	**0.153**	**0.134**	**0.216**	**0.146**	0.337
S. rastrelliger						0.789						0.789
S. nebulosus				0.868				**0.158**	**0.214**	**0.250**	**0.199**	0.338
S. auriculatus								**0.217**	0.358	**0.096**	**0.266**	**0.234**
Survey Mean	0.318	**0.267**	0.326	0.754	0.558	0.816	**0.081**	**0.208**	0.345	0.309	**0.270**	0.386
Mean samples/year	120.8	710.9	15.9	49.0	6.8	3.2	4917.6	1730.1	405.6	579.7	476.6	

Table 11. The number of surveys wherein explanatory variables were significant for a given species. The number of GLMs (different surveys) in which a variable was significant is first in each cell, with the total GLMs completed that collected that variable provided in parentheses. Blanks indicate variables could not be tested for species GLMs, due to low occurrence of the species or lack of information on a variable (or both).

Species	Year	Subregion	Season	Depth Zone	Visibility	Water Conditions	Boat Type	Distance From Shore	Transect Replicate	Total	Total propor.
S. mystinus	8(9)	8(8)	8(9)	2(2)	1(1)	1(1)	1(1)	1(1)	1(2)	31(34)	0.91
O. elongatus	8(9)	9(9)	7(9)	3(3)	1(2)	1(1)	1(1)	1(1)	0(1)	31(36)	0.86
S. serranoides	7(8)	7(8)	6(8)	2(3)	2(2)		1(1)	0(1)	1(1)	27(32)	0.84
S. carnatus	8(8)	8(8)	7(8)	3(3)	2(2)	1(1)	0(1)	1(1)	0(1)	30(33)	0.91
S. atrovirens	7(8)	7(8)	5(8)	3(3)	2(2)	1(1)	1(1)	1(1)	0(1)	27(33)	0.82
H. decagrammus	7(8)	8(8)	6(8)	1(2)	1(1)	1(1)	1(1)	1(1)		26(30)	0.87
S. chrysomelas	4(6)	6(6)	4(6)	3(3)	1(2)	0(1)	1(1)	1(1)	0(1)	20(27)	0.74
E. lateralis	3(3)	2(2)	3(3)	1(1)	1(1)	1(1)			0(2)	11(13)	0.85
S. miniatus	8(8)	8(8)	8(8)	2(3)	0(2)	1(1)	1(1)	1(1)	0(1)	29(33)	0.88
S. melanops	8(8)	8(8)	7(8)	2(3)	2(2)	0(1)	1(1)	1(1)	0(1)	29(33)	0.88
S. marmoratus	8(9)	7(9)	6(9)	2(3)	2(2)	1(1)	1(1)	1(1)	0(1)	28(36)	0.78
S. caurinus	8(9)	9(9)	6(9)	3(3)	1(2)	1(1)	1(1)	0(1)	0(1)	29(36)	0.81
D. vacca	3(3)	2(2)	1(3)	1(1)	1(1)	1(1)			1(2)	10(13)	0.77
S. ruberrimus	4(4)	4(4)	4(4)	1(1)			1(1)	1(1)		15(15)	1.00
S. pinniger	5(6)	5(6)	5(6)	1(1)			1(1)	1(1)		18(21)	0.86
S. rastrelliger	1(1)	1(1)	0(1)			0(1)				2(4)	0.50
S. nebulosus	4(5)	5(5)	4(5)	1(1)			1(1)	1(1)		16(18)	0.89
S. auriculatus	4(4)	4(4)	4(4)	1(1)			1(1)	1(1)		15(15)	1.00
Total	106(116)	108(113)	91(116)	32(37)	17(22)	10(13)	14(15)	13(15)	3(15)	394(462)	
Total Proportion	0.91	0.96	0.78	0.86	0.77	0.77	0.93	0.87	0.20	0.85	

Table 12. The number of species for which explanatory variables were significant in a given survey in the GLM, identified by ANOVAs. The number of species that had enough data to analyze is provided in parentheses beside the number significant for each cell. No data (ND) indicates this variable was not collected consistently or in a manner allowing it to be included in a GLM. NA indicates a variable was not applicable for that survey methodology. Color codes: green = SCUBA, yellow = fishery-independent hook and line, grey = fishery-dependent spearfishing, blue = fishery-dependent hook and line.

Survey	Year	Subregion	Season	Depth Zone	Visibility	Water Conditions (Vis./Surge)	Boat Type (Charter vs. Private)	Distance From Shore	Transect Replicate	Total	Prop-ortion
CDFG SCUBA	7(10)	9(10)	2(10)	6(10)	7(10)	ND	NA	NA	ND	31(50)	0.62
PISCO SCUBA	9(12)	11(12)	9(12)	12(12)	10(12)	ND	NA	NA	2(12)	53(72)	0.74
TENERA SCUBA	3(3)	NA	2(3)	NA	ND	ND	NA	NA	1(3)	6(9)	0.67
CDFG H&L	10(13)	11(13)	7(13)	ND	ND	ND	NA	ND	ND	28(39)	0.72
CDFG CENCAL	12(13)	13(13)	10(13)	ND	ND	10(13)	NA	ND	NA	45(52)	0.87
CPFV Logbooks	7(7)	7(7)	7(7)	ND	ND	ND	NA	ND	NA	21(21)	1.00
PSMFC Dockside	15(15)	15(15)	13(15)	ND	ND	ND	14(15)	13(15)	ND	70(75)	0.93
CDFG Observers	15(15)	15(15)	13(15)	14(15)	ND	ND	NA	ND	NA	57(60)	0.95
PSMFC Observers	14(14)	13(14)	14(14)	ND	ND	ND	NA	ND	NA	41(42)	0.98
All Observers	14(14)	14(14)	14(14)	ND	ND	ND	NA	ND	NA	42(42)	1.00
Total	106(116)	108(113)	91(116)	32(37)	17(22)	10(13)	14(15)	13(15)	3(15)	394(462)	0.85
Proportion	0.91	0.96	0.78	0.86	0.77	0.77	0.93	0.87	0.27	0.85	

Table 13. The number of surveys wherein interaction terms were significant for a given species. The number of GLMs (different surveys) in which an interaction was significant is first in each cell, with the total GLMs for which interactions were tested provided in parentheses. NA indicates no data was collected on variables in the interaction term or interactions could not be tested due to non-orthogonal sampling. ND indicated or GLMs did not produce valid results.

Interaction Term	Test Used	*S. mystinus*	*O. elongatus*	*S. serranoides*	*S. carnatus*	*S. atrovirens*	*H. decagrammus*	*S. chrysomelas*	*E. lateralis*	*S. miniatus*	*S. melanops*	*S. marmoratus*	*S. caurinus*	*D. vacca*	*S. ruberrimus*	*S. pinniger*	*S. rastrelliger*	*S. nebulosus*	*S. auriculatus*	Total
Year x Season	ANOVA	4(4)	3(3)	2(2)	4(4)	0(2)	3(3)	2(2)	0(1)	3(3)	2(2)	3(3)	3(3)	0(1)	2(2)	3(3)	0(0)	2(2)	1(1)	37(41)
	BIC	1(4)	1(3)	1(2)	1(4)	0(2)	0(3)	0(2)	0(1)	0(3)	0(2)	0(3)	1(3)	0(1)	1(2)	1(3)	0(0)	0(2)	0(1)	7(41)
Year x Subregion	ANOVA	3(3)	3(3)	2(2)	3(3)	1(3)	3(3)	1(1)	0(0)	2(2)	2(2)	3(3)	3(3)	0(0)	2(2)	3(3)	0(0)	2(2)	2(2)	31(33)
	BIC	2(3)	1(3)	1(2)	2(3)	0(3)	1(3)	0(1)	0(0)	1(3)	0(2)	1(3)	1(3)	0(0)	1(2)	1(3)	0(0)	0(2)	0(2)	10(33)
Season x Subregion	ANOVA	2(2)	2(2)	1(1)	2(2)	NA	2(2)	ND	0(0)	1(1)	1(1)	1(1)	1(1)	0(0)	1(1)	2(2)	0(0)	1(1)	ND	17(17)
	BIC	1(2)	2(2)	0(1)	1(2)	NA	1(2)	ND	0(0)	ND	0(1)	0(1)	1(1)	0(0)	0(1)	0(2)	0(0)	0(1)	ND	6(17)
Total	ANOVA	9(9)	8(8)	5(5)	9(9)	1(5)	9(9)	3(3)	0(1)	9(9)	5(5)	7(7)	7(7)	0(1)	5(5)	8(8)	0(0)	5(5)	3(3)	85(90)
	Propor.	1.0	1.0	1.0	1.0	0.2	1.0	1.0	0.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0	0.0	1.0	1.0	0.94
Total	BIC	4(9)	4(8)	2(5)	4(9)	0(5)	2(9)	0(3)	0(1)	1(9)	0(5)	1(7)	3(7)	0(1)	2(5)	2(8)	0(0)	0(5)	0(3)	23(90)
	Propor.	0.4	0.5	0.4	0.4	0.0	0.2	0.0	0.0	0.1	0.0	0.1	0.4	0.0	0.4	0.2	0.0	0.0	0.0	0.26

Table 14. *Sebastes mystinus* linear regression results, using GLM yearly abundance index values as dependent, and survey year as independent variable. Results are given for all survey years (in parentheses) and other time-periods as listed. Precision results (mean survey CV) are provided for full survey extent, bold values are high precision. NA = no attempt made to count this species by the survey.

Survey	Years	Slope	Y-intercept	R^2	F-value	P-value	Mean CV
CDFG SCUBA	(1995-1998)	NA	NA	NA	NA	NA	NA
PISCO SCUBA	(1999-2007)	0.0018	-3.58	0.522	7.637	**0.0280**	**0.144**
	2004-2007	-0.0003	0.68	0.050	0.104	0.7773	
TENERA SCUBA	(1976-2007)	-0.0004	0.97	0.335	16.629	**0.0003**	0.407
	1988-2007	0.0004	1.00	0.489	19.166	**0.0004**	
	1999-2007	-0.0003	0.67	0.131	1.055	0.3385	
	2004-2007	0.0004	-0.71	0.899	17.806	0.0518	
CDFG H&L	(1978-1982)	0.5756	-1137.56	0.324	1.438	0.3165	0.568
CDFG H&L	(1979-1998)	0.0187	-35.41	0.022	0.137	0.7238	0.412
CDFG CENCAL	(1959-2006)	0.0017	-3.13	0.018	0.692	0.4107	0.772
	1988-2007	-0.0126	25.54	0.162	3.106	0.0970	
	1999-2007	-0.0331	66.58	0.295	2.515	0.1638	
	2004-2006	-0.1132	227.34	0.998	415.044	**0.0312**	
CPFV Logbooks	(2001-2007)	0.1904	-380.29	0.542	5.926	0.0591	**0.035**
	2004-2007	-0.1060	214.25	0.205	0.516	0.5472	
PSMFC Dockside	(1980-2007)	0.0049	-9.35	0.026	0.609	0.4433	**0.124**
	1988-2007	0.0097	-19.07	0.033	0.518	0.4826	
	1999-2007	0.0644	-128.67	0.498	6.944	**0.0337**	
	2004-2007	-0.0284	57.65	0.036	0.075	0.8097	
CDFG Observers	(1988-1998)	0.6507	-1293.22	0.666	17.956	**0.0029**	**0.163**
PSMFC Observers	(1999-2007)	0.3511	-701.05	0.490	6.721	**0.0358**	**0.163**
	2004-2007	-0.0115	26.54	0.000	0.000	0.9869	
All Observers	(1988-2007)	0.0737	-145.35	0.197	4.424	**0.0498**	**0.137**
Mean CV (all surveys)							**0.293**

Table 15. *Ophiodon elongatus* linear regression results, using GLM yearly abundance index values as dependent, and survey year as independent variable. Results are given for all survey years (in parentheses) and other time-periods as listed. Precision results (mean survey CV) are provided for full survey extent, bold values are high precision. ND = GLM abundance estimates could not be generated for the survey.

Survey	Years	Slope	Y-intercept	R^2	F-value	P-value	Mean CV
CDFG SCUBA	(1995-1998)	0.0002	-0.36	0.096	0.213	0.690	0.424
PISCO SCUBA	(1999-2007)	0.0000	0.03	0.021	0.147	0.713	0.391
	2004-2007	-0.0001	0.27	0.665	3.979	0.184	
TENERA SCUBA	(1976-2007)	ND	ND	ND	ND	ND	ND
CDFG H&L	(1978-1982)	0.0073	-13.91	0.001	0.002	0.966	0.435
CDFG H&L	(1979-1998)	-0.0263	52.57	0.354	3.292	0.120	0.591
CDFG CENCAL	(1959-2006)	-0.0021	4.45	0.036	1.409	0.243	0.460
	1988-2007	-0.0039	7.94	0.119	0.161	0.161	
	1999-2007	0.0000	0.09	0.000	0.000	0.998	
	2004-2006	0.0291	-58.20	0.247	0.328	0.669	
CPFV Logbooks	(2001-2007)	-0.0173	34.92	0.331	2.477	0.176	**0.035**
	2004-2007	-0.0547	109.95	0.966	57.538	**0.017**	
PSMFC Dockside	(1980-2007)	0.0044	-8.13	0.004	0.030	0.868	**0.112**
	1988-2007	0.0005	-0.87	0.031	0.479	0.499	
	1999-2007	0.0015	-2.92	0.042	0.304	0.598	
	2004-2007	0.0028	-5.47	0.036	0.075	0.810	
CDFG Observers	(1988-1998)	0.0077	-15.02	0.375	5.404	**0.045**	**0.123**
PSMFC Observers	(1999-2007)	-0.0003	0.70	0.022	0.513	0.481	**0.139**
	2004-2007	-0.1194	239.96	0.948	0.026	**0.026**	
All Observers	(1988-2007)	0.0279	-55.41	0.552	22.166	**0.000**	**0.111**
Mean CV (all surveys)							**0.282**

Table 16. *Sebastes miniatus* linear regression results, using GLM yearly abundance index values as dependent, and survey year as independent variable. Results are given for all survey years (in parentheses) and other time-periods as listed. Precision results (mean survey CV) are provided for full survey extent, bold values are high precision. ND = GLM abundance estimates could not be generated for the survey.

Survey	Years	Slope	Y-intercept	R^2	F-value	P-value	Mean CV
CDFG SCUBA	(1995-1998)	0.0003	-0.57	0.732	5.470	0.144	0.396
PISCO SCUBA	(1999-2007)	0.0001	-0.17	0.082	0.621	0.456	0.446
	2004-2007	-0.0003	0.60	0.858	12.119	0.074	
TENERA SCUBA	(1976-2007)	ND	ND	ND	ND	ND	ND
CDFG H&L	(1978-1982)	0.0025	-4.774	0.002	0.005	0.946	**0.299**
CDFG H&L	(1979-1998)	-0.0071	14.35	0.468	5.281	0.061	0.498
CDFG CENCAL	(1959-2006)	0.0021	-4.20	0.035	1.380	0.247	1.408
	1988-2007	0.0077	-15.38	0.034	0.559	0.466	
	1999-2007	-0.0554	111.08	0.142	0.995	0.357	
	2004-2006	0.0008	-1.56	0.005	0.005	0.957	
CPFV Logbooks	(2001-2007)	ND	ND	ND	ND	ND	ND
PSMFC Dockside	(1980-2007)	0.0169	-33.65	0.776	24.243	**0.002**	**0.117**
	1988-2007	0.0091	-18.14	0.759	56.749	**0.000**	**0.139**
	1999-2007	0.0016	-3.11	0.650	27.883	**0.000**	
	2004-2007	0.0004	-0.68	0.014	0.029	0.881	
CDFG Observers	(1988-1998)	0.0003	-0.49	0.009	0.078	0.786	**0.146**
PSMFC Observers	(1999-2007)	0.0012	-2.36	0.759	72.377	**0.000**	**0.189**
	2004-2007	0.0269	-53.65	0.897	17.417	0.053	
All Observers	(1988-2007)	0.0096	-19.04	0.767	59.141	**0.000**	**0.137**
Mean CV (all surveys)							0.378

Table 17. *Sebastes caurinus* linear regression results, using GLM yearly abundance index values as dependent, and survey year as independent variable. Results are given for all survey years (in parenthesis) and other time-periods as listed. Precision results (mean survey CV) are provided for full survey extent, bold values are high precision. ND = GLM abundance estimates could not be generated for the survey.

Survey	Years	Slope	Y-intercept	R^2	F-value	P-value	Mean CV
CDFG SCUBA	(1995-1998)	-0.0007	1.46	0.129	0.297	0.640	0.441
PISCO SCUBA	(1999-2007)	0.0066	-13.26	0.665	9.922	**0.025**	0.541
	2004-2007	-0.0011	2.17	0.801	8.060	0.105	
TENERA SCUBA	(1976-2007)	ND	ND	ND	ND	ND	ND
CDFG H&L	(1978-1982)	-0.0094	18.86	0.091	0.301	0.621	0.429
CDFG H&L	(1979-1998)	-0.0261	52.20	0.693	13.572	**0.010**	0.473
CDFG CENCAL	(1959-2006)	-0.0010	2.06	0.079	3.264	0.079	1.597
	1988-2007	-0.0004	0.89	0.039	0.652	0.431	
	1999-2007	-0.0022	4.37	0.385	3.755	0.101	
	2004-2006	-0.0010	2.01	0.051	0.053	0.856	
CPFV Logbooks	(2001-2007)	-0.0003	0.69	0.215	1.921	0.208	**0.074**
	2004-2007	0.0150	-30.07	0.989	175.739	**0.006**	
PSMFC Dockside	(1980-2007)	0.0027	-5.34	0.123	0.979	0.355	**0.158**
	1988-2007	0.0001	-0.20	0.013	0.204	0.658	
	1999-2007	0.0020	-3.92	0.704	16.645	**0.005**	
	2004-2007	0.0037	-7.39	0.859	12.224	0.073	
CDFG Observers	(1988-1998)	-0.0008	1.55	0.085	0.835	0.385	**0.186**
PSMFC Observers	(1999-2007)	-0.0002	0.44	0.043	1.026	0.322	**0.299**
	2004-2007	0.0207	-41.56	0.984	123.043	**0.008**	
All Observers	(1988-2007)	-0.0006	1.34	0.078	1.520	0.233	**0.189**
Mean CV (all surveys)							0.439

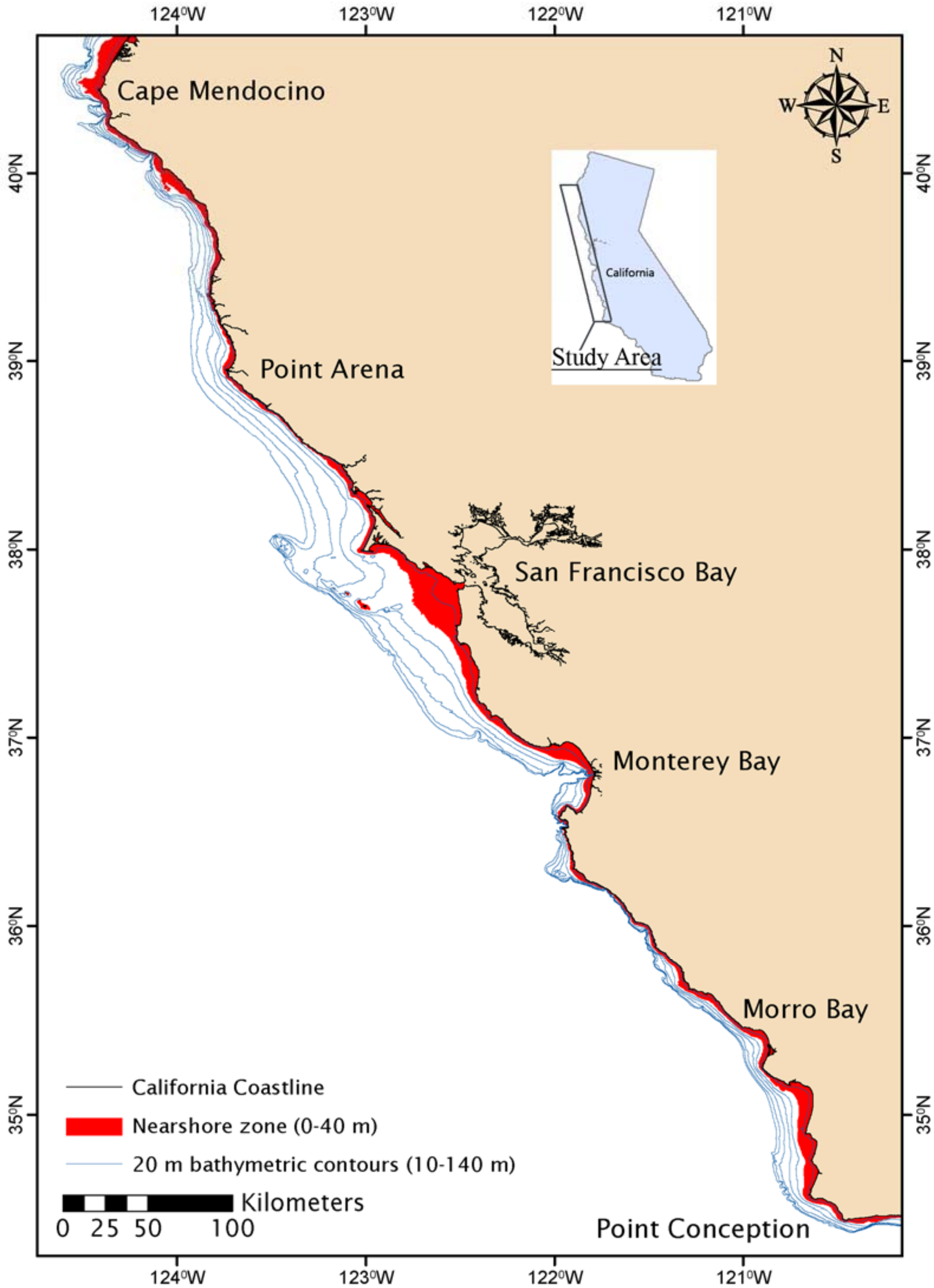

Figure 1. The project study area, central California nearshore (3-40 meters), is highlighted in red. The rocky reef habitats comprise a portion of these depths. Deeper areas are included in some of the surveys analyzed here if they sample the correct species assemblage. The region extends from Cape Mendocino (N40°38 W124°35') at the north end to Point Conception (N 34° 26' W 120° 35') at the south end. Important landmarks in the region and 20-meter ocean bathymetry lines are included.

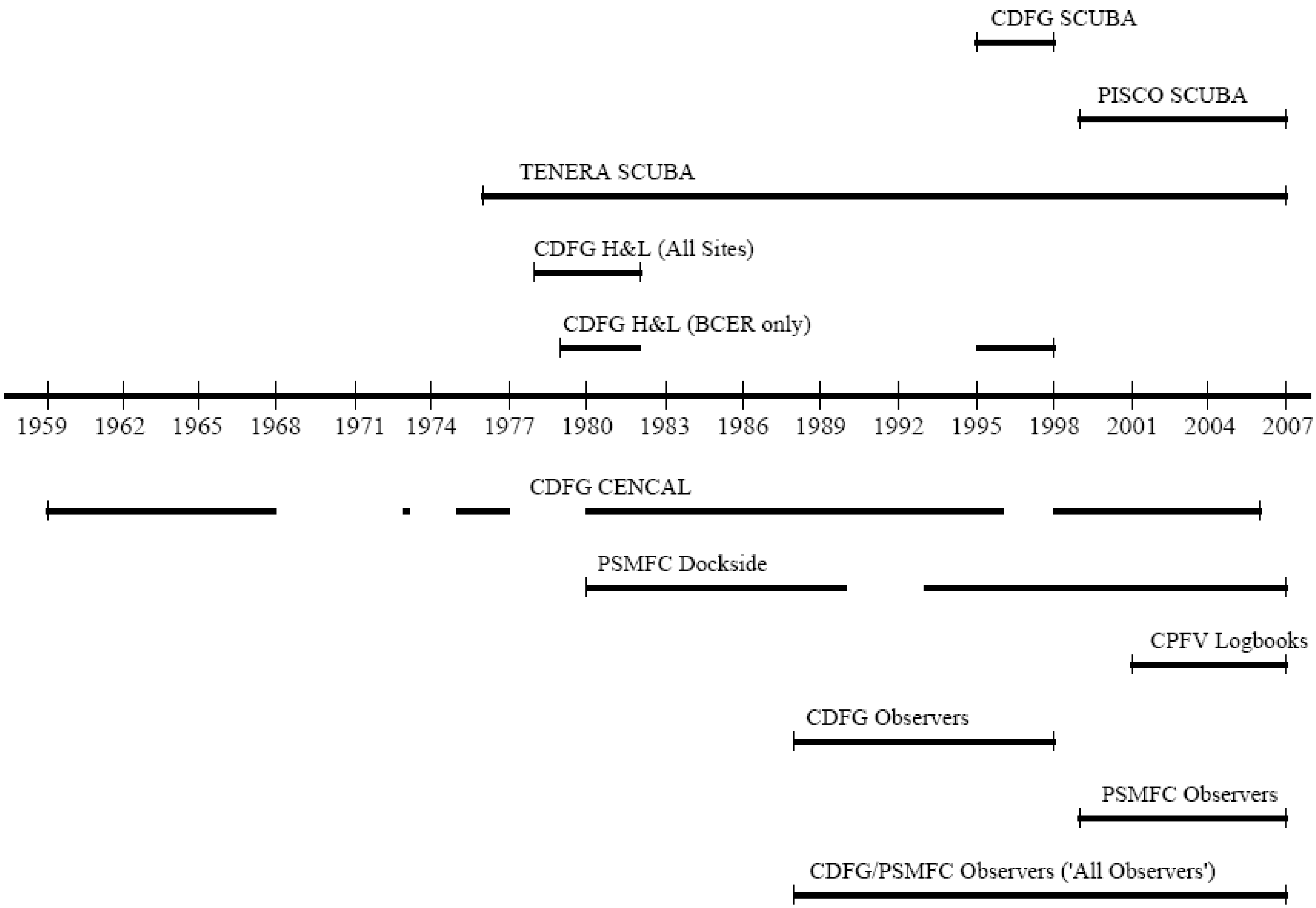

Figure 2. Time-line beginning with year of first survey analyzed in this study and ending with most recent year used for analyses. Broken lines indicate years that were not sampled during the particular survey.

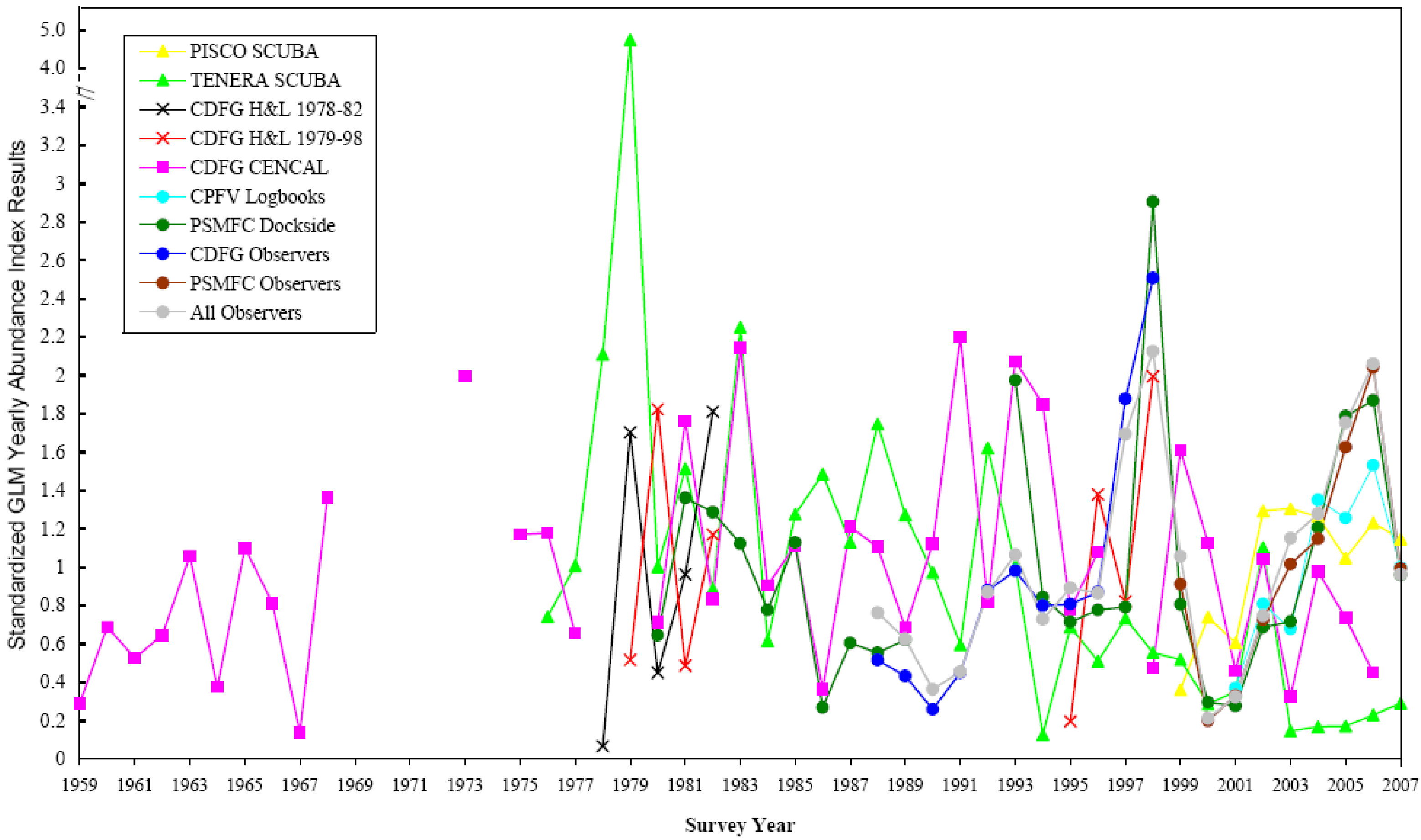

Figure 3. Standardized yearly index GLM model results for *Sebastes mystinus* , as sampled by all surveys in the study except the CDFG SCUBA survey. Each yearly index value was divided by the mean of all values for a given survey, enabling surveys with different index value magnitudes to be plotted together, but still displaying yearly variability.

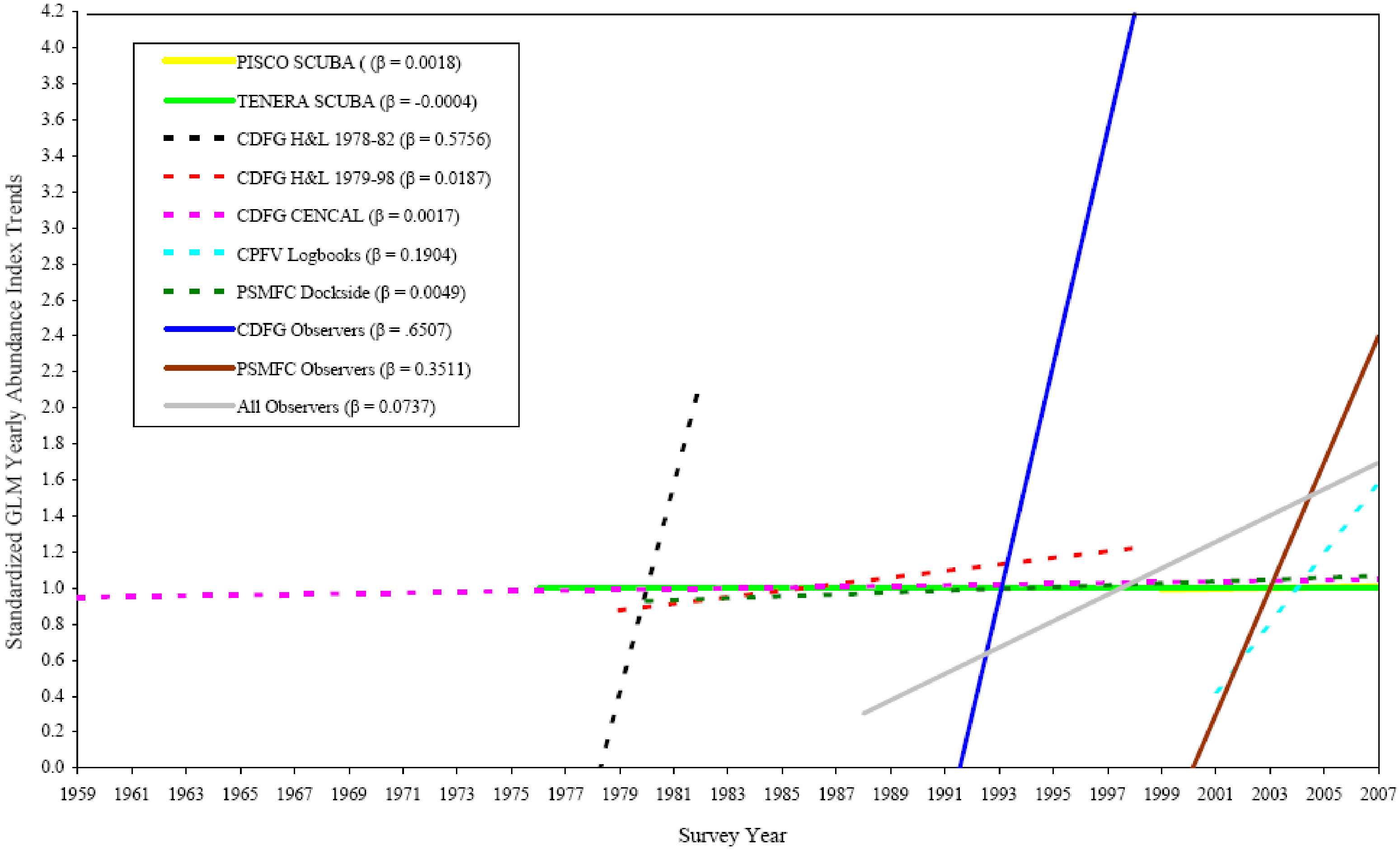

Figure 4. Linear regression trends for surveys of *Sebastes mystinus* using standardized index values and y-intercept from SPSS. Solid lines indicate significant trends, dotted lines are non-significant.

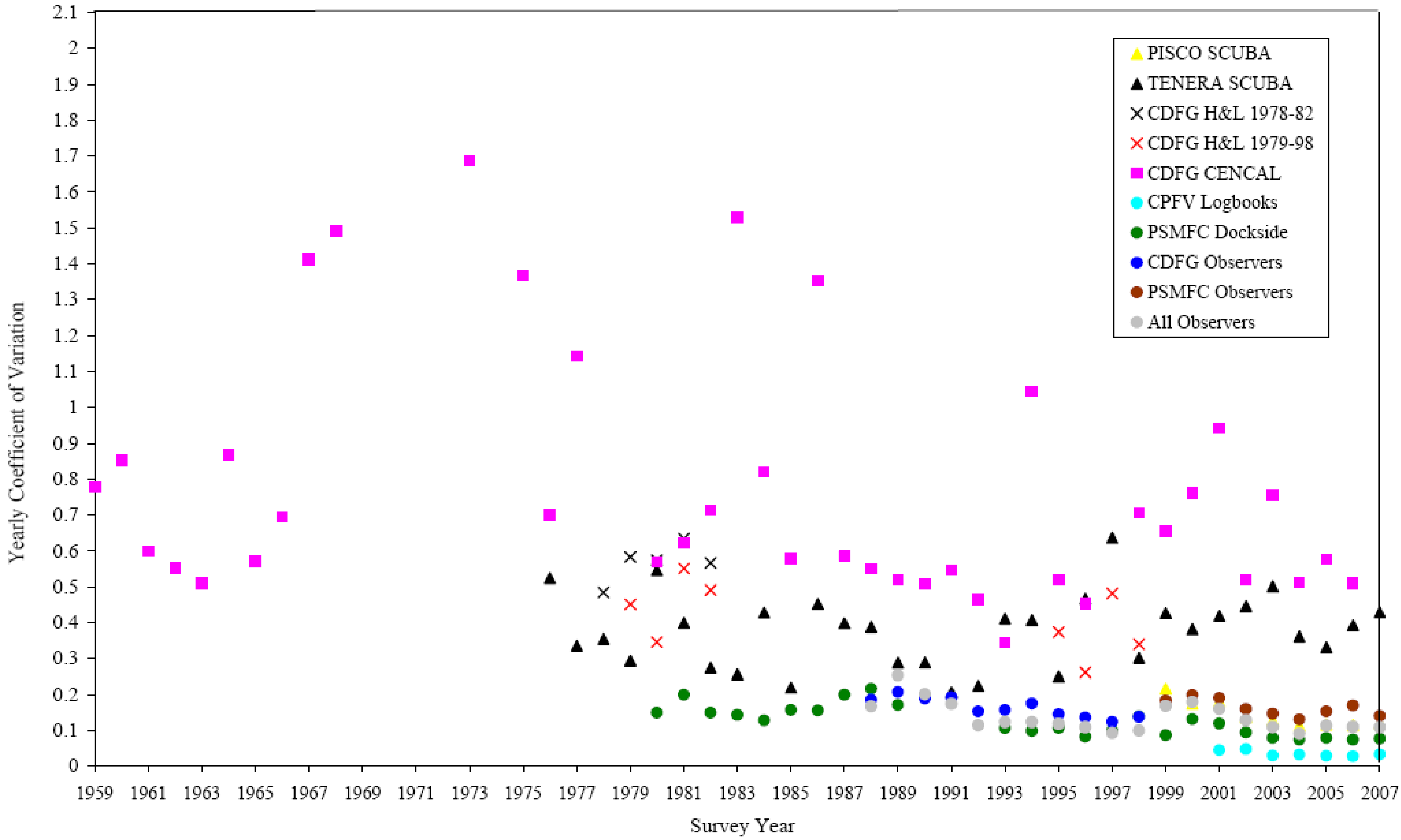

Figure 5. Yearly coefficient of variation (CV) values from GLM model with jackknife, indicating precision in counts of *Sebastes mystinus* , as sampled by all surveys in the study except the CDFG SCUBA survey. CVs below 0.30 indicate highly precise sampling for a year. CVs above 1.0 are considered extremely high and indicate the data are unreliable for that year as an index of abundance.

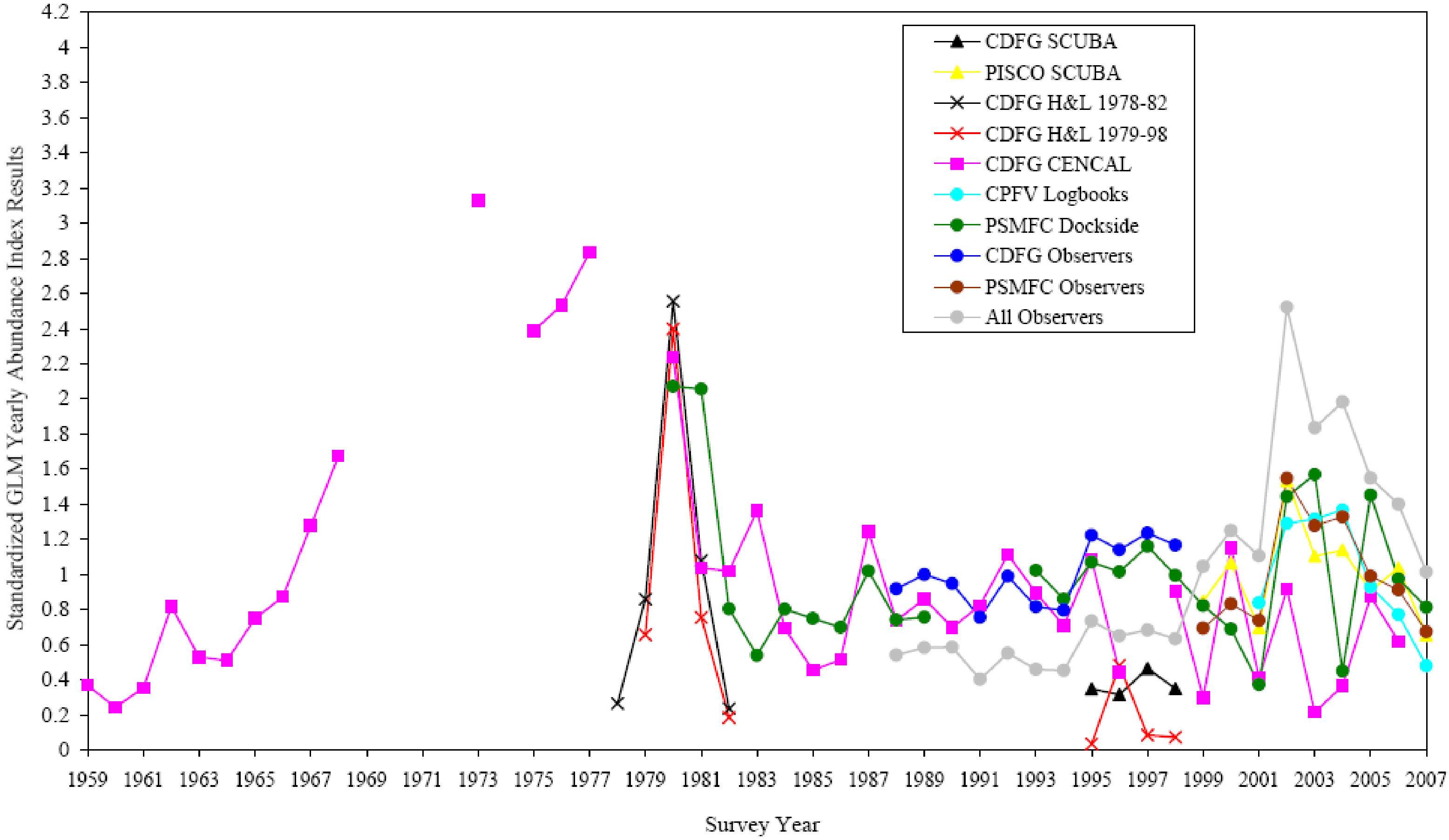

Figure 6. Standardized yearly index GLM model results for *Ophiodon elongatus* , as sampled by all surveys in the study except the TENERA SCUBA survey. Each yearly index value was divided by the mean of all values for a given survey, enabling surveys with different index value magnitudes to be plotted together, but still displaying yearly variability.

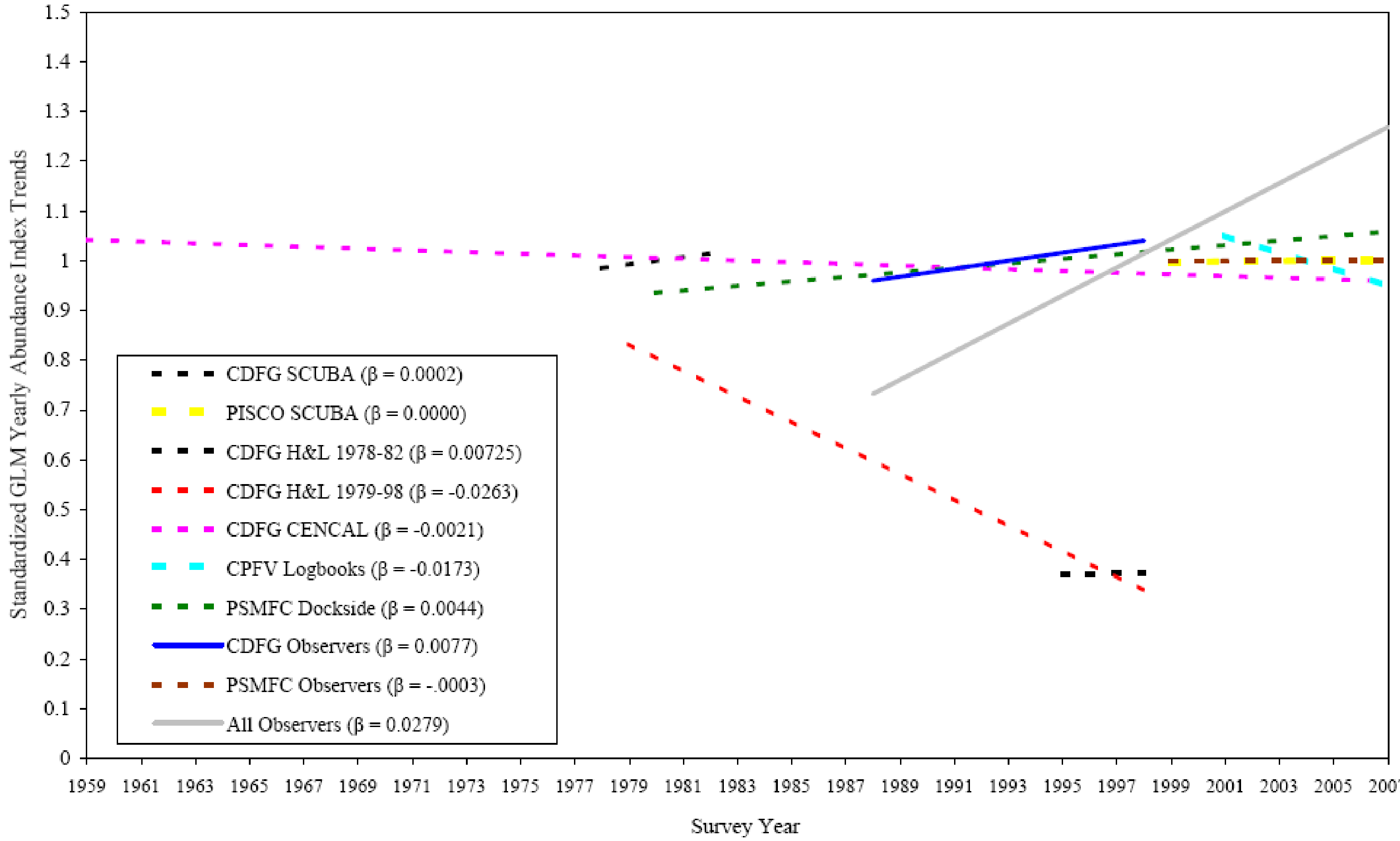

Figure 7. Linear regression trends for surveys of *Ophiodon elongatus* ,using standardized index values and y-intercept from SPSS. Solid lines indicate significant trends, dotted lines are non-significant.

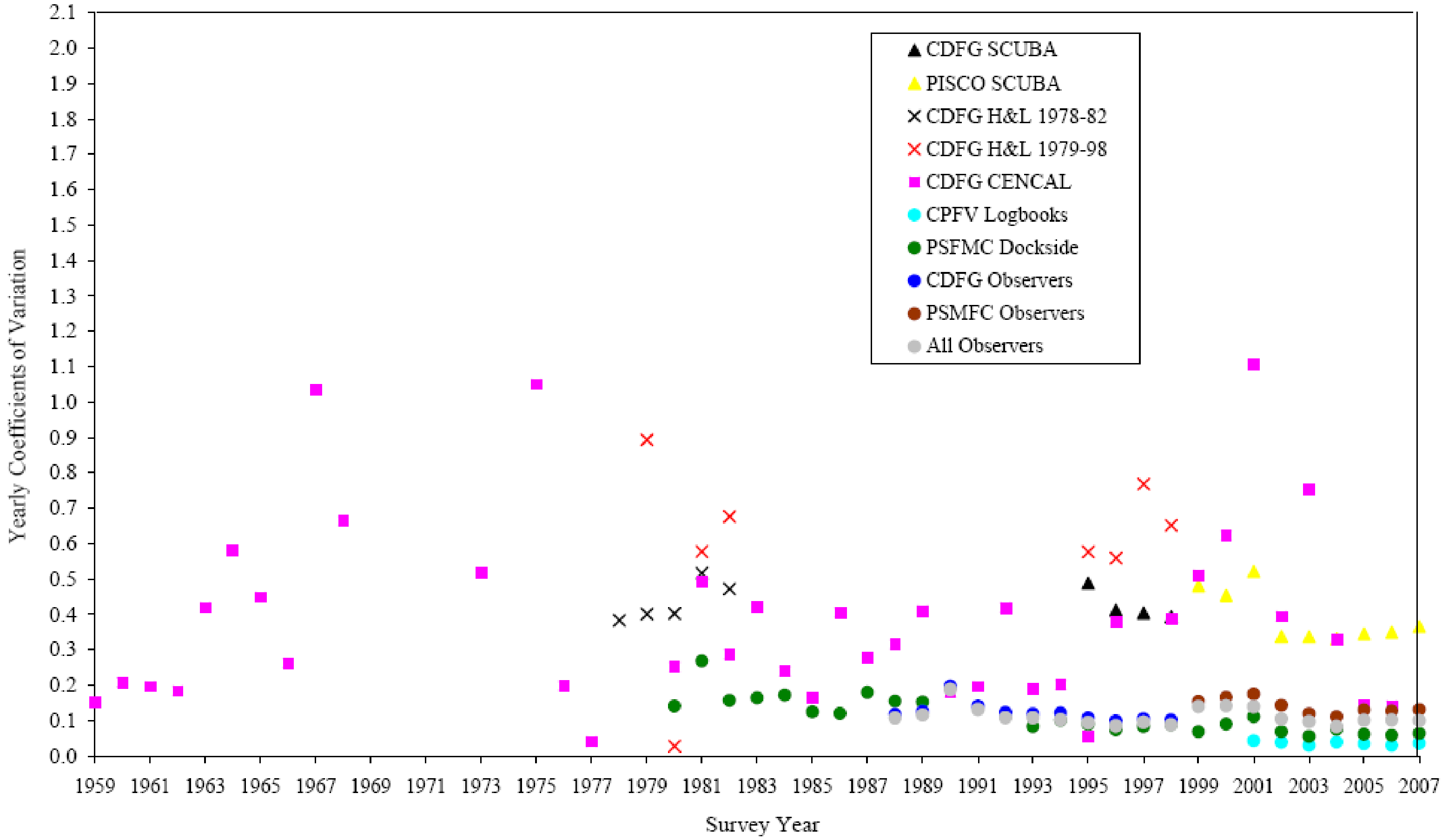

Figure 8. Yearly coefficient of variation (CV) values from GLM model with jackknife, indicating precision in counts of *Ophiodon elongatus* , as sampled by all surveys in the study except the TENERA SCUBA survey. CVs below 0.30 indicate highly precise sampling for a year. CVs above 1.0 are considered extremely high and indicate the data are unreliable for that year as an index of abundance.

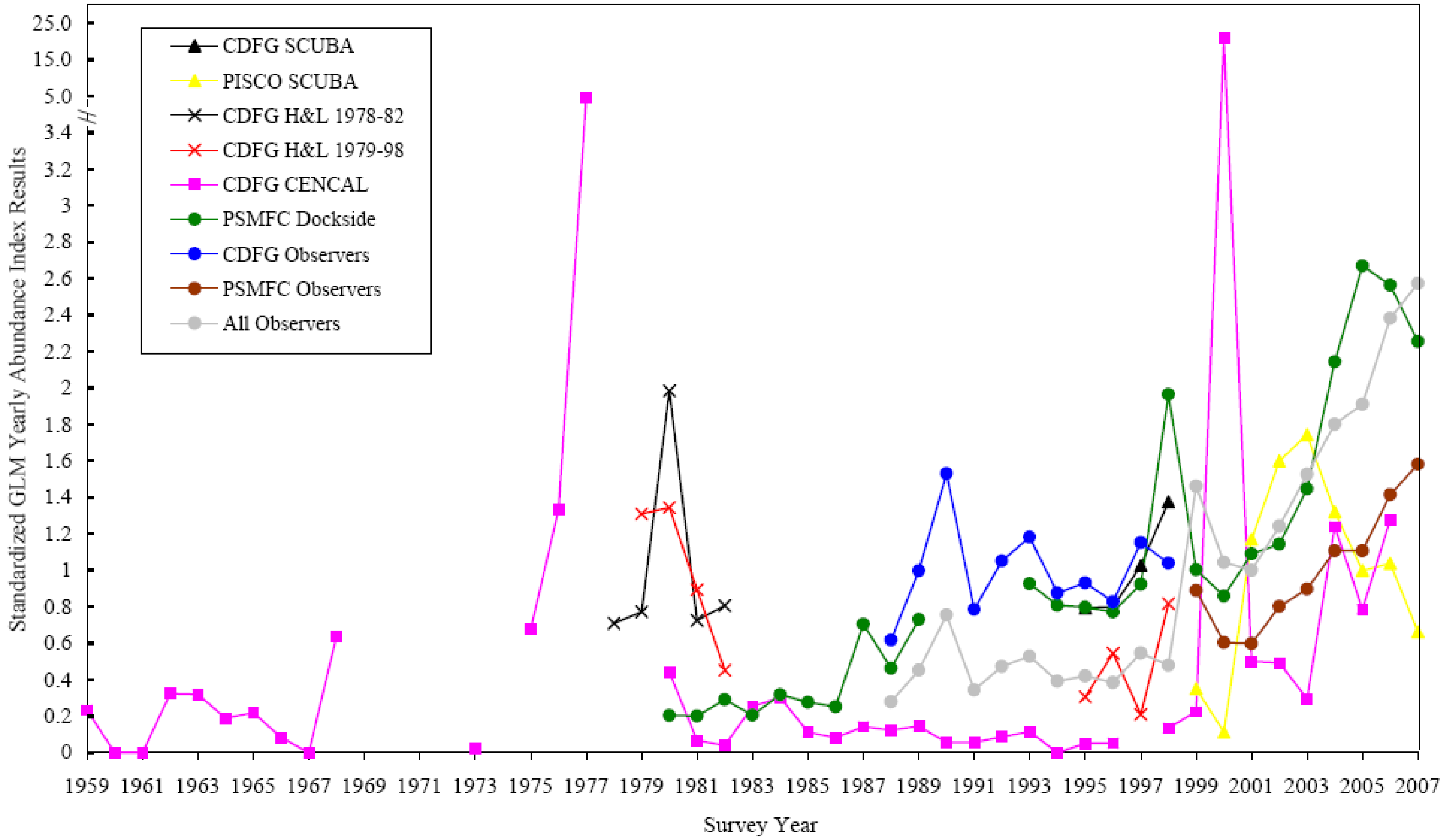

Figure 9. Linear regression trends for surveys of *Sebastes miniatus*, as sampled by all surveys in the study except the CPFV Logbooks and TENERA SCUBA surveys. Each yearly index value was divided by the mean of all values for a given survey, enabling surveys with different index value magnitudes to be plotted together, but still displaying yearly variability.

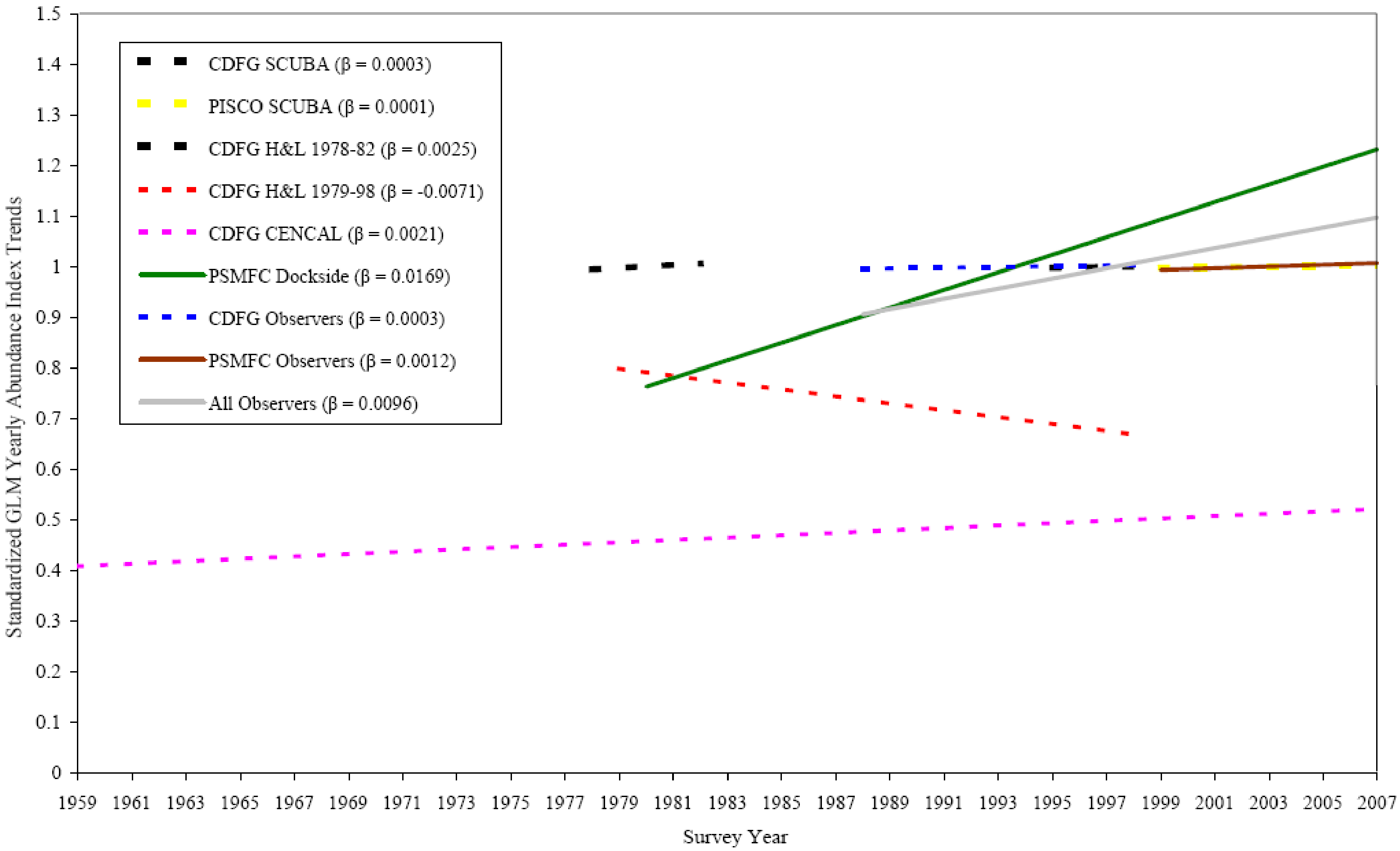

Figure 10. Linear regression trends for surveys of *Sebastes miniatus* , using standardized index values and y-intercept from SPSS. Solid lines indicate significant trends, dotted lines are non-significant.

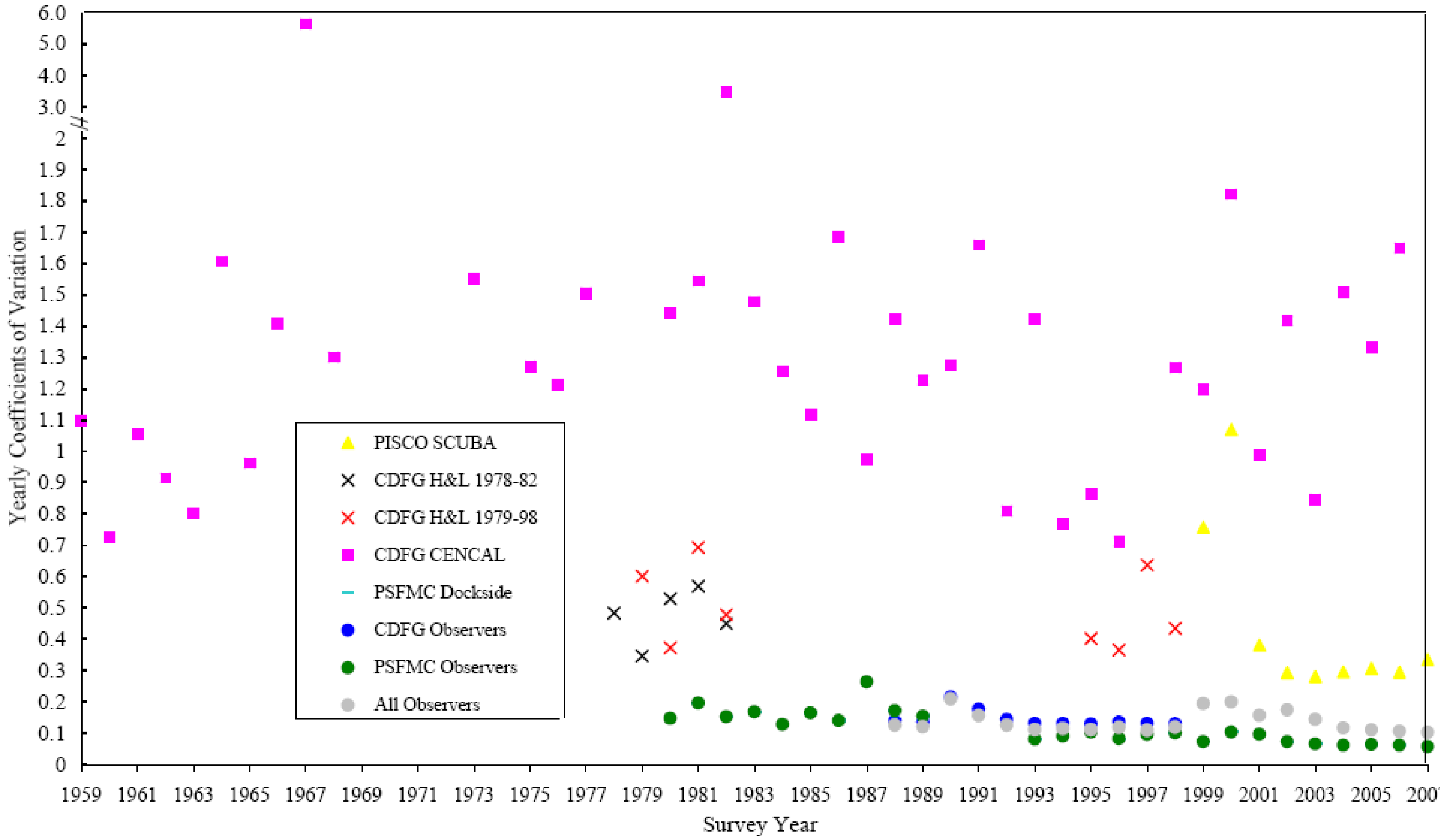

Figure 11. Yearly coefficient of variation (CV) values from GLM model with jackknife, indicating precision in counts of *Sebastes miniatus* , as sampled by all surveys in the study except the TENERA SCUBA survey. CVs below 0.30 indicate highly precise sampling for a year. CVs above 1.0 are considered extremely high and indicate the data are unreliable for that year as an index of abundance.

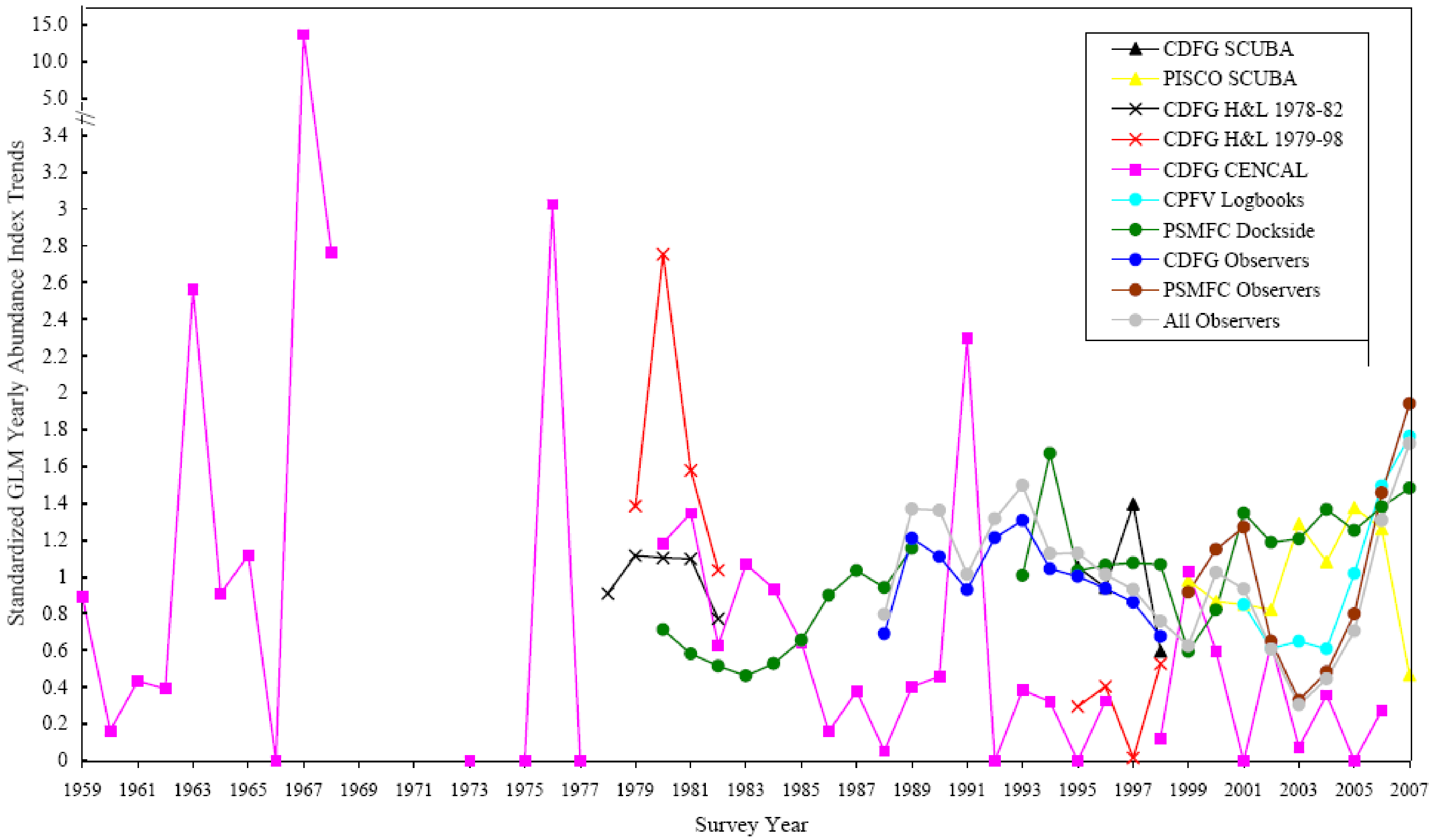

Figure 12. Standardized yearly index GLM model results for *Sebastes caurinus,* as sampled by all surveys in the study except TENERA SCUBA . Each yearly index value was divided by the mean of all values for a given survey, enabling surveys with different index value magnitudes to be plotted together, but still displaying yearly variability.

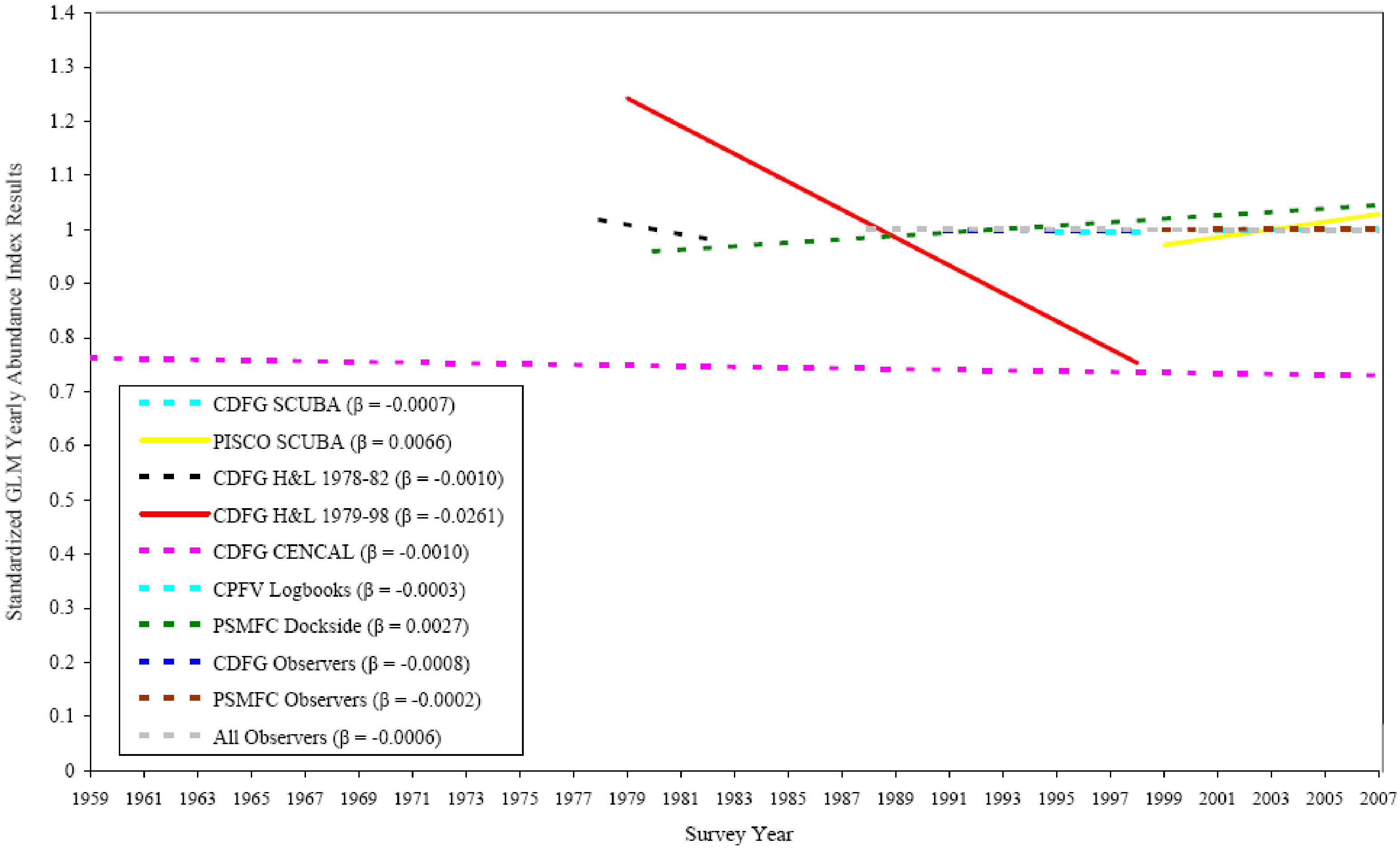

Fig 13. Linear regression trends for surveys of *Sebastes caurinus* , using standardized index values and y-intercept from SPSS. Solid lines indicate significant trends, dotted lines are non-significant.

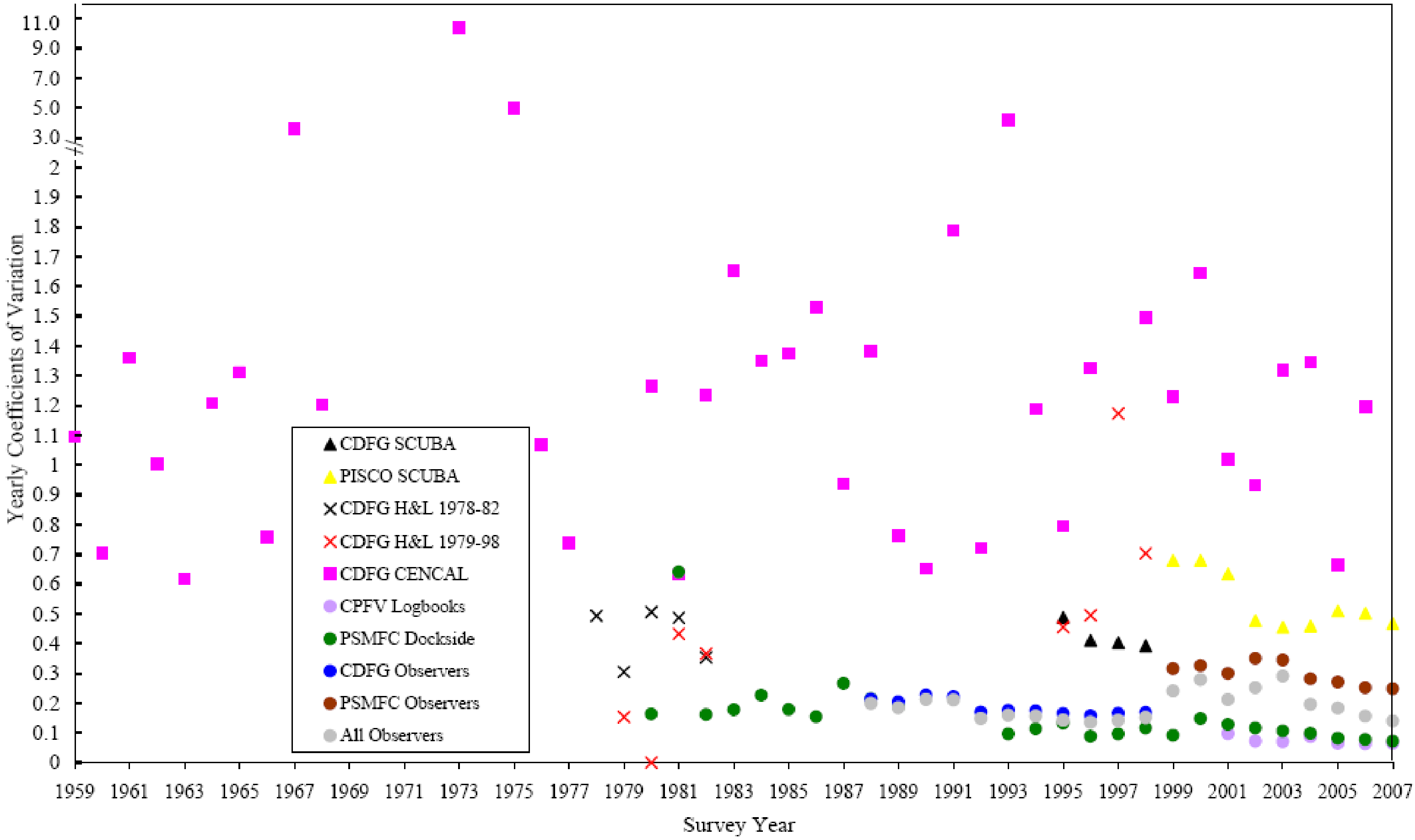

Figure 14. Yearly coefficient of variation (CV) values from GLM model with jackknife, indicating precision in counts of *Sebastes caurinus* , as sampled by all surveys in the study except TENERA SCUBA. CVs below 0.30 indicate highly precise sampling for a year. CVs above 1.0 are considered extremely high and indicate the data are unreliable for that year as an index of abundance.

Appendix A. Past and current fish abundance surveys of kelp forest fish within the study area, spanning at least 4 years. Sources include Caillet et al. 2000 and personal communications with researchers.

Dataset/Study Title	Group/Authors	Data Manager Contact Info	Years
PISCO Collaborative Central Coast Abundance Surveys	UCSC / Carr	Dan Malone: malone@biology.ucsc.edu M. Carr: carr@biology.ucsc.edu	1999-present
Diablo Canyon Nearshore Reef SCUBA Survey	TENERA / Jay Carroll	Jay Carroll: jay@tmre.org or jcarroll@tenera.com	1976-present
Marine reserve fish density monitoring and habitat associations	CDFG / Ventresca	Dave Osorio: DOsorio@dfg.ca.gov	1993-1999
Central Coast Abundance SCUBA Surveys	CDFG / VenTresca and Osorio	Dave Osorio: DOsorio@dfg.ca.gov	various
Submersible surveys of nearshore fishes	CDFG / Lea	Robert Lea: RNLea@dfg.ca.gov	1996-present
Submersible surveys of nearshore fishes	CDFG / Hardy	Christine Pattison: cpattison@dfg.ca.gov	1999-present
H&L surveys / habitat associations of fishes	CDFG / Karpov	Kon Karpov: 707-357-1202 (cell) kkarpov@dfg.ca.gov	1995-present
H&L surveys of nearshore fishes	CDFG / VenTresca and Lea	Deb W.: DWilsonv@dfg.ca.gov Robert Lea: RNLea@dfg.ca.gov	1978-1998
West Coast Groundfish Observer Program (nearshore component)	NMFS Newport station / John Cusick	John Cusick: Jonathan.Cusick@noaa.gov	2004-present
West Coast Groundfish trawl surveys	NMFS Newport station / Aimee Keller	Aimee Keller: (206) 860-3460	1977-present
Big Creek MERRP Skiff Fishery Study/ Commercial dockside CDFG sampling	UCSC / Pomeroy and VenTresca	Mark Readdie: readdie@biology.ucsc.edu, C. Pomeroy: cpomeroy@ucsc.edu	1997-2000
Spearfish Tournaments Creel Survey (CENCAL)	CDFG / Ventresca	Travis Tanaka: TTanaka@dfg.ca.gov	1958 - present
Commercial groundfish monitoring	CDFG / Don Pearson	Don Pearson.: (831) 420-3944 ; don.pearson@noaa.gov	1992-present
Commercial nearshore monitoring	CDFG / Pete Kalvass	Pete Kalvass: 707-964-9078 pkalvass@dfg.ca.gov	1996-present
Recreational hook&line fishery monitoring	CDFG / Kon Karpov	Kon Karpov: 707-357-1202 (cell) kkarpov@dfg.ca.gov	1979-present
Recreational nearshore fishery monitoring	CDFG / Tom Moore	Tom Moore: 707-875-4261 tmoore@dfg.ca.gov	1999-present
Commercial groundfish monitoring	CDFG / Tom Moore	Tom Moore: 707-875-4261 tmoore@dfg.ca.gov	1988-present
Commercial Landing Receipts	CDFG / Joann Eres	Jana Robertson: JRoberts@dfg.ca.gov	1916-present

Appendix A (cont'd)

Dataset/Study Title	Group/Authors	Data Manager Contact Info	Survey Years
Commercial hook&line nearshore fishery monitoring	CDFG / John Mello	John Mello: (707) 441-5755, jmello@dfg.ca.gov	1991-present
Commercial hook&line nearshore fishery monitoring	CDFG / Kevin Walters	John Mello: (707) 441-5755, jmello@dfg.ca.gov	2000-present
Commercial hook&line/ trap nearshore fishery monitoring	CDFG / Jerry Spratt	Jerry Spratt: 831-649-2880 jspratt@dfg.ca.gov	1993-present
Commercial H&L/trap/trawl fishery monitoring	CDFG / Don Pearson	Don Pearson.: (831) 420-3944 ; don.pearson@noaa.gov	2000-present
Commercial H&L/ trap nearshore fishery monitoring	CDFG / Bob Hardy	Christine Pattison: cpattison@dfg.ca.gov	1999-present
CA Commercial Party Fishing Vessel Logbooks	CDFG / Wendy Dunlap	Wendy Dunlap: WDunlap@dfg.ca.gov	1936-present
Recreational nearshore fishery monitoring	CDFG / Christine Pattison	Christine Pattison: 805-772-0114 cpattison@dfg.ca.gov	1999-present
Recreational nearshore fishery monitoring	CDFG / VenTresca	Deb W.: DWilsonv@dfg.ca.gov 831-649-2892	1986-87 ; 99-2000
Recreational nearshore fishery monitoring	CDFG / Bob Hardy	Christine Pattison: 805-772-0114 cpattison@dfg.ca.gov	1976-1983
Recreational wharf fishery / oceanographic data	CDFG / Lea	Robert Lea: RNLea@dfg.ca.gov	1992-?
CPFV On-Board Sampling Program	CDFG / Wilson-Vandenberg	Deb Wilson-Vandenberg: DWilsonv@dfg.ca.gov	1987-1998
CPFV On-Board Sampling Program	CDFG / Hardy	Christine Pattison: cpattison@dfg.ca.gov	1976-1980
Marine Recreational Fishery statistics Survey (dockside)	PSMFC / Van Buskirk	Wade Van Buskirk: Wade_VanBuskirk@psmfc.org; RecFIN website: www.recfin.org	1980-2004
California Recreational Fisheries Survey (dockside)	PSMFC / Van Buskirk	Wade Van Buskirk: Wade_VanBuskirk@psmfc.org; RecFIN website: www.recfin.org	2004-present
MRFSS / CRFS (onboard observers)	PSMFC / Van Buskirk	Wade Van Buskirk: Wade_VanBuskirk@psmfc.org; RecFIN website: www.recfin.org	1999-present
Fitzgerald Marine Reserve H&L monitoring	Fitzgerald Marine Reserve	Bob Breen	1972-1999
Commercial Groundfish Trawl/ Logbook monitoring	CALCOM / Don Pearson	Don Pearson.: (831) 420-3944 ; don.pearson@noaa.gov / Brenda Erwin: berwin@dfg.ca.gov	1978-present

Appendix B. Generic script used in R to calculate abundance indices for each year and explanatory variable levels as well as precision levels of a given species for one survey.

```
library(MASS)
FishData<-read.table('C:/Desktop/CDFGObservers_fishdata.txt', header=T)
FishData[[2]] <- factor(FishData[[2]])
attach(FishData)
jack.data<-FishData
base.model.nb <- glm.nb(Count ~ Year + Season + Region + DepthZone + offset(log(Hours)),data=jack.data, control = glm.control(maxit =
        1000))
base.dummy <- dummy.coef(base.model.nb)
base.effects <- exp(base.dummy[[1]] + base.dummy[[2]])
base.effects1 <- exp(base.dummy[[1]] + base.dummy[[3]])
base.effects2 <- exp(base.dummy[[1]] + base.dummy[[4]])
base.effects3 <- exp(base.dummy[[1]] + base.dummy[[5]])
n<-nrow(jack.data)
error.check <- matrix(NA, nrow=(n+1), ncol=length(names(base.dummy)))
error.check[1,] <- names(base.dummy)
k<-length(dummy.coef(base.model.nb)[[2]])
result.mat<-matrix(NA, nrow=n, ncol=k)
for (i in 1:n){
print(paste("jackknife iteration",i,"out of",n))
tmp.data <- jack.data[-i, ]
tmp.model <- glm.nb(Count ~ Year + Season + Region + DepthZone + offset(log(Hours)),control = glm.control(maxit = 1000), data=tmp.data)
tmp.dummy <- dummy.coef(tmp.model)
error.check[i+1,] <- names(tmp.dummy)
result.mat[i,] <- exp(tmp.dummy[[1]] + tmp.dummy[[2]]) }
summary(error.check)
jack.mean<-apply(result.mat, 2, FUN=mean)
jack.se<-apply(result.mat, 2,
FUN=function(x){sqrt(((n-1)/n)*sum((x-mean(x))*(x-mean(x))))})
jack.cv<-jack.se/base.effects
print(step(base.model.nb))
print(cbind.data.frame(base.effects, jack.cv))
print(base.effects1 <- exp(base.dummy[[1]] + base.dummy[[3]]))
print(base.effects1 <- exp(base.dummy[[1]] + base.dummy[[4]]))
print(base.effects1 <- exp(base.dummy[[1]] + base.dummy[[5]]))
```