NMFS Southwest Fisheries Science Center

Agency Report to the Technical Subcommittee

of the Canada-U.S. Groundfish Committee

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A. AGENCY OVERVIEW

The Southwest Fisheries Science Center (SWFSC) conducts fisheries and marine mammal research at three laboratories in California. Activities are primarily in support of the Pacific Fishery Management Council, the Endangered Species Act (ESA), the Marine Mammal Protection Act (MMPA), as well as a number of international fisheries commissions and conventions. The deputy director of the SWFSC is Dr. Norman Bartoo, and the Science Director is Dr. William Fox. All three SWFSC laboratories have supported the essential needs of the NMFS and the PFMC for groundfish, including as active members of the PFMC's Scientific and Statistical Committee (SSC) and other management teams and advisory bodies.

The Center is headquartered in La Jolla, which hosts three divisions that conduct research on a wide range of Pacific and Antarctic fish, marine mammals, sea turtles, and marine habitats; the Antarctic Ecosystem Research Division (led by Dr. Rennie Holt) , the Protected Resources Division (led by Dr. Stephen Reilly), and the Fisheries Resources Division (led by Dr. Roger Hewitt). The Fisheries Resources Division (FRD) conducts research on groundfish, large pelagic fishes (tunas, billfish and sharks), and small coastal pelagic fishes (anchovy, sardine and mackerel), and is the primary source of groundfish-related research in the La Jolla Laboratory. The La Jolla laboratory is also the primary source of federal support for the California Cooperative Oceanic Fisheries Investigations (CalCOFI) surveys that have taken place along most of the California coast since 1951. Researchers at the La Jolla lab have primary responsibility for ichthyoplankton collections, studies of species abundance and distribution (including responses to climate variability), systematics, and the application of early life history information to stock assessments.

The Fisheries Ecology Division (FED), located in Santa Cruz and directed by Dr. Churchill Grimes, comprises two research branches. The Fisheries Branch (led by Dr. Peter Adams) conducts research (and stock assessments) in salmon population analysis, economics, groundfish, and fishery oceanography. The Ecology branch (led by Dr. Susan Sogard) conducts research on the early life history of fishes, salmon ocean and estuarine ecology, habitat ecology, and molecular ecology of fishes. Specific objectives of FED groundfish programs include (1) collecting and developing information useful in assessing and managing groundfish stocks; (2) conducting stock assessments, and improving upon stock assessment methods, to provide a basis for harvest management decisions for the PFMC; (3) characterizing and mapping biotic and abiotic components of groundfish habitats, including structure-forming invertebrates; (4) disseminating information, research findings and advice to the fishery management and scientific communities; and (5) provide professional services (many of which fall in the above categories) at all levels, including inter-agency, state, national and international working groups.

The Environmental Research Division (ERD), directed by Dr. Franklin Schwing, is located at the Pacific Fisheries Environmental Laboratory (PFEL) in Pacific Grove. The ERD is a primary source of environmental information to fisheries researchers and managers along the west coast, and provides science-based analyses, products, and information on environmental variability to meet the agency's research and management needs. The objectives of ERD are to (1) provide appropriate science-based environmental analyses, products, and knowledge to the SWFSC and

its fishery scientists and managers; (2) enhance the stewardship of marine populations in the California Current ecosystem, and other relevant marine ecosystems, by understanding and describing environmental variability, the processes driving this variability, and its effects on the production of living marine resources, ecosystem structure, and ecosystem function; and (3) provide science-based environmental data and products for fisheries research and management, to a diverse customer base of researchers, decision-makers, and the public. ERD also contributes oceanographic expertise to the groundfish programs within the SWFSC, including planning surveys and sampling strategies, conducting analyses of oceanographic data, and cooperating in the development and testing of environmental and biological indices that can be useful in preparing stock assessments.

B. MULTISPECIES STUDIES

1. Research

Ichthyoplankton Surveys

The FRD, in collaboration with state and academic partners, supports and maintains the CalCOFI ichthyoplankton time series, which extends from 1951 to the present and has been used to study distribution and abundance changes of many fish species in relation to climate and ecosystem change in the California Current region. Since 2002 CalCOFI stations off central California, last routinely sampled in 1984, have been re-occupied during the winter and spring cruises in order to provide improved geographic coverage during the principal reproductive season for Pacific sardine and many of the groundfish species whose spawning distributions extend well north of Point Conception. Over the 55+ years of the CalCOFI time series substantial advances have been made in ichthyoplankton identifications and many currently identifiable species were identified only to the level of genus or above in earlier years.

To increase the consistency of identifications through the time series a project is now underway to systematically work back through the archived CalCOFI ichthyoplankton samples to bring all identifications up to current standards. To date identification updates have been completed from 1972-present. Unfortunately, larvae of most of the rockfish species cannot be reliably identified to species using standard visual techniques. However, because one side of each bongo net sample collected during the Cowcod Conservation Area (CCA) surveys was preserved in ethanol, those larvae can be identified using molecular techniques. Currently, about 25% of the "unidentified rockfish" larvae collected during the CCA surveys have been identified, representing 22 species dominated by squarespot and swordspine rockfishes. The results of this work will greatly enhance the number of species identified in such surveys and assist in the validation of pigment/morphology-based identifications.

Juvenile Surveys

Since 1983 the FED has conducted an annual survey of the distribution and abundance of pelagic juvenile rockfishes, with the goal of providing data for forecasting future recruitment to rockfish

and other species, and to otherwise monitor the physical and biological environment. A number of west coast groundfish stock assessments have historically used this pelagic juvenile index to estimate impending recruitment. In 2004 the geographic coverage of the SWC pelagic juvenile rockfish mid-water trawl survey was expanded substantially, with the addition of new sample lines off of southern and northern California, from San Clemente Island to Point Delgada. As in 2005, pelagic juvenile rockfish catches in the core part of the survey area were at very low levels in 2006, and appeared to be linked to anomalous environmental conditions that included above average sea surface temperatures and delayed upwelling south of Cape Mendocino. The near absence of fish in the core survey area in 2006 seemed to be associated with a redistribution of fish to the north and the south.

At the recommendation of their Scientific and Statistical Committee (SSC), the Pacific Fishery Management Council (PFMC) requested that a workshop be held in order to more formally consider whether data from the SWC survey and a recently initiated NWC survey operated jointly with the Pacific Whiting Conservation Cooperative could be integrated into a single coastwide index, and to evaluate whether or how such data should be used in stock assessments. This workshop was held September 13-15, 2006 in Santa Cruz, CA, and was cosponsored by the Southwest and Northwest Fishery Science Centers. Some general conclusions from the workshop were; 1) for species that are distributed exclusively or predominantly north of Point Conception, data from the 2001-06 combined surveys provide acceptable spatial coverage for creating a coast-wide index, and the combined spatial coverage during 2004-06 is reasonable for all species; 2) The spatial coverage of the SWFSC survey during the 1983-2000 period is largely inadequate to index pre-recruit abundance for most species, particularly where coastwide assessment areas are used in population modeling; and 3) Comparison of methods and patterns in catch rates from the two surveys indicate that they are sufficiently similar that data from the two surveys can be combined to form a single pre-recruit index over the area covered. Additional general conclusions and recommendations, as well as summaries of the presentations from the symposium, are available in a report provided to the PFMC that will be available online in the near future (or contact Steve Ralston, SWFSC or Jim Hastie, NWFSC).

The Early Life History Team is continuing studies of essential fish habitat for newly settled rockfish in Monterey Bay. Using methods of trapping, otter trawling, drop camera surveys, scuba diving censuses and ROV censuses, we are examining a range of habitat types and depths from 20 to 100m. Extremely poor recruitment in 2005 and 2006 has limited our attempts to use video methods of censuses. However, trawling and trapping methods have revealed clear spatial patterns in settlement, with higher densities of YOY rockfish in southern Monterey Bay compared to northern Monterey Bay, and higher densities in deeper regions compared to shallower regions. Low relief mud/sand substrates appear to have nursery value for newly settled rockfishes of several species, with later migration to the high relief rocky substrates typically recognized as adult habitat.

Adult Surveys

The Advanced Survey Technology (AST) and In-Situ Survey groups in FRD have continued efforts to combine acoustic and optical sampling to survey rockfish and evaluate their biotic and abiotic requirements for habitat. The combined methods can provide estimates of biomass and

dispersion by species, throughout the Southern California Bight, with realistic sampling effort (Fig. 1). The ultimate goal of these efforts is to provide data for improving rockfish stock assessments.

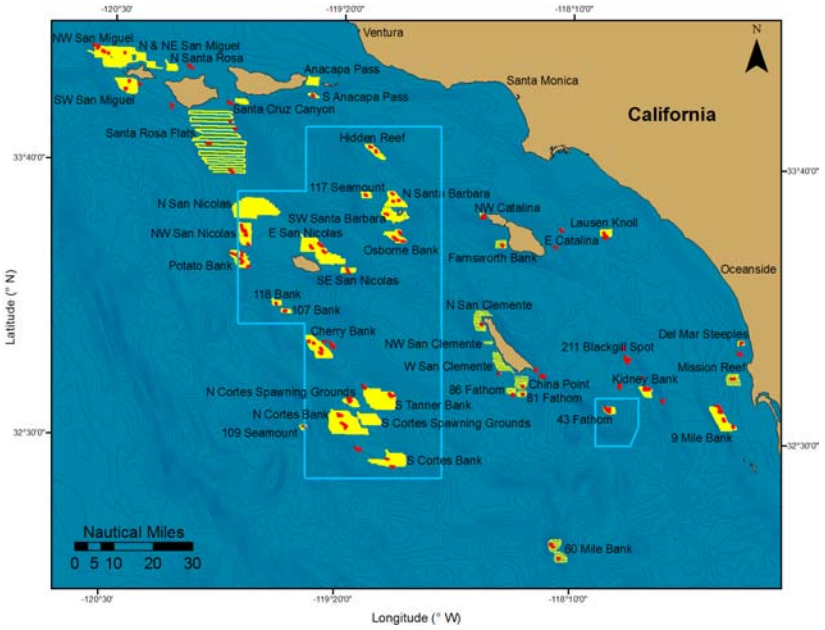

Figure 1. Sites for the 2004-2005 acoustic and optical surveys of rockfish. Multi-frequency echosounder surveys (yellow lines) were conducted from NOAA Ship *David Starr Jordan* and CPFV *Outer Limits*. Still and video cameras, and laser measuring sensors were mounted on a remotely operated vehicle, and deployed (red lines) from *Outer Limits*. Sites where only optical surveys were conducted were surveyed in spring 2006 to examine deep rockfish habitats. Indicated with light blue lines are the boundaries of the Cowcod Conservation Area.

The past year has been dedicated mainly to data analysis and combining the findings of the acoustic and optical surveys. For acoustic data, scattering statistics and frequency-dependence of sound scatter (e.g. Conti *et al*., 2007) were used to resolve fish near the seafloor, identify rockfish, and estimate their number densities. For example, highest rockfish densities were estimated at Potato Bank, NW of San Nicolas Island (~1.4 fish m^{-2}, ~64x10^6 total fish), and 57-Fathom Reef, W of San Clemente Island (~1.3 fish m^{-2}, ~4.2x10^6 total fish). The rockfish densities in each survey area were apportioned to species based on proportions of species estimated from video recorded with a camera mounted on a ROV. Preliminary estimates ranged from 0.42 million cowcod (*Sebastes levis*), to 6.1 million bocaccio (*Sebastes paucispinis*), to 167.2 million squarespot (*Sebastes hopkinsi*), and the dispersions of each species have also been mapped. The preliminary abundance estimates were made assuming means of the optically-measured lengths, and refinements are to be made using the measured length probability density functions. Another area for refinement is the estimation of the total sampling and measurement error.

Additional optical surveys were conducted during April and May 2006 with the aid of partners in the sportfishing industry to fill in missing data at sites of greater depths. The goals were to examine the species compositions at the maximum depth for rockfish, and to confirm depth

ranges for key species (e.g. *Sebastes levis*). A manuscript detailing the depth and substrate associations of rockfish in the Southern California Bight has been produced and will be submitted for publication in May 2007 (Pinkard *et al.*, in prep). Rockfish were found to have species-specific depth and habitat preferences, which varied little by site locations. Species compositions varied by latitude, with the clearest shifts near the northern boundary of Point Conception (e.g. *Sebastes mystinus* found at northern sites). The majority of rockfish species were associated most commonly with low relief reef, but there was a variety of other substrates where rockfish were found (Fig. 2). Optical methods were proven to provide large amounts of information, specifically species compositions and fish lengths, which were used to make abundance estimates from acoustically-derived estimates of rockfish densities.

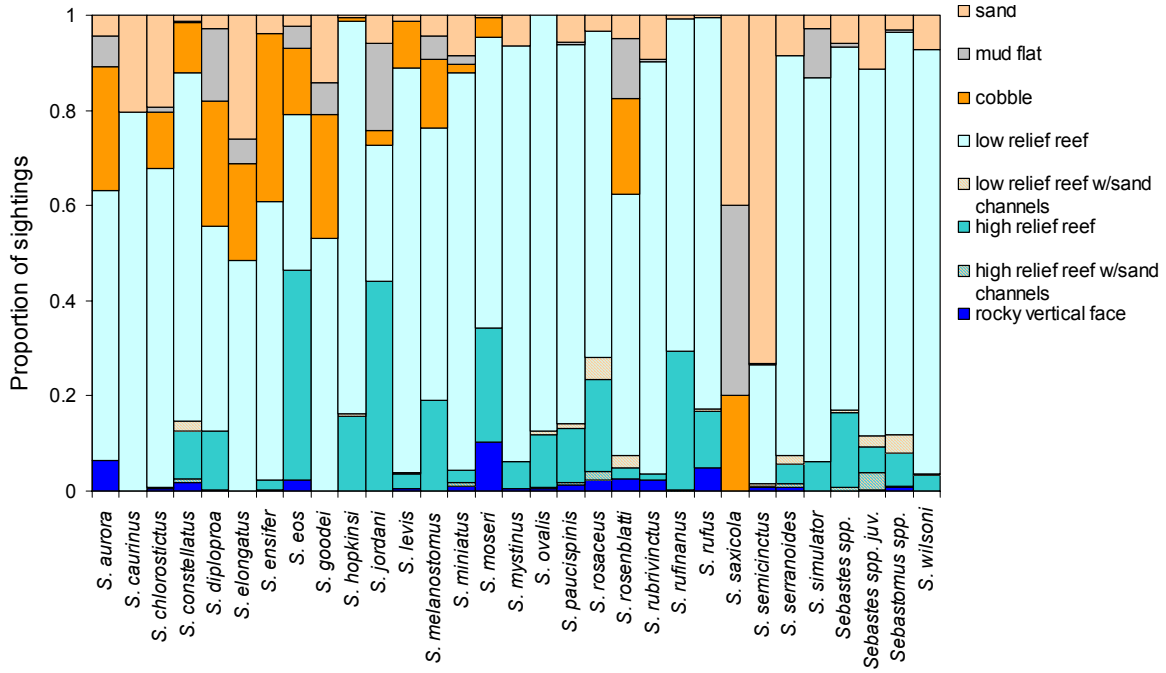

Figure 2. Proportion of individual rockfish species sighted in eight substrate types. Only species sighted during ≥ 5 dives and at total numbers ≥ 50 were included in the analysis.

Over the past year, the Collaborative Optically-assisted Acoustic Survey Technique (COAST) was presented to several audiences for evaluation as a stock assessment tool. The COAST and preliminary results of a pilot survey were first presented to the SWFSC Director Bill Fox; then to Bob Fletcher (President of the Sportfishing Association of California; SCA), and other fishers who are involved in the SCA; and then to a group of stock assessment biologists from SWFSC. Overall, feedback has been positive, and suggestions for improvement have been taken into account. In response to encouragement from fellow scientists and NOAA leaders, the AST and In-Situ Survey groups are currently planning additional COAST surveys of rockfish, and plan to support stock assessment efforts with the results.

2. Stock Assessment Support

Both the FRD and the FED regularly produce stock assessments of groundfish for the PFMC, and support stock assessment science through the maintenance of data systems and the

development of new analytical techniques. The FED works closely with the California Department of Fish and Game (CDFG) to coordinate port sampling efforts and to maintain the CALCOM database, which serves as the source of the data provided to PacFIN by the State of California. The system provides port sampling biologists with Internet access to the database, so that data are entered directly in real time.

Through our liaison with CDFG, the FED also recently acquired a massive amount of historical California landings data on microfiche and original paper, which are currently being digitized through the NESDIS Climate Data Modernization Program. Monthly summaries of landings by block have been processed from 1931 to 1968, and are currently being checked for errors and quality control. Considerably more effort will be necessary to keypunch landing receipt information, but funding is currently dedicated to continue developing this time series into the future.

C. BY SPECIES, BY AGENCY

2. Nearshore Rockfish

i. Research

The Early Life History Team continues to conduct research to evaluate sources of variability in the fitness characteristics of individual larval rockfish, such as the initial size of larvae at parturition, bioenergetic condition as indexed by oil reserves, initial swimming capabilities, growth rates and mortality. Maternal age appears to play an important role in larval success (growth and survival) for some species but not others. Age also appears to influence the timing of parturition, suggesting that older mothers fertilize their eggs earlier than younger mothers. The strength of some of these maternal effects appears to be related to seasonal patterns of parturition timing. We are currently expanding these studies to additional species common in deeper habitats. This issue is widely recognized by researchers and assessment scientists as important in evaluating the productivity and sustainability of West Coast groundfish fisheries, and insights gained from ongoing research will be incorporated into scientific assessments and management advice as it becomes available. In addition to research examining maternal effects, we have completed experiments testing for multiple paternity in kelp rockfish, with the finding that multiple paternity appears to be common.

ii. Assessment

In 2007, FED biologists are assisting in the development of a blue rockfish (*Sebastes mystinus*) stock assessment being led by the California Department of Fish and Game.

3. Shelf Rockfish

i. Research

A study is underway to estimate the spawning biomass of bocaccio (*Sebastes paucispinis*) in the southern California Bight (SCB) using data collected during standard winter CalCOFI surveys and during enhanced ichthyoplankton sampling surveys conducted in the Cowcod Conservation Area (orange polygon in Fig. 3, below). Bocaccio is an overfished rockfish that, based on conventional assessment methodologies, is estimated to be heavily depleted (11% of B0 in 2005). FED staff had previously shown that a credible biomass estimate of shortbelly rockfish (*S. jordani*) was possible based on estimation of total larval production (Ralston *et al*. 2003). For bocaccio, larval abundance data were summarized from the historical CalCOFI data set to reveal seasonality of spawning and the typical distribution of larvae in the SCB. Standard and enhanced ichthyoplankton sampling conducted during 2002 and 2003 were used to generate independent estimates of spawning biomass in those two years through the analysis of larval catch curves. Larval production was then linked to spawner biomass based on information obtained from adult fish recently collected in Ensenada, Mexico (i.e., maturity and fecundity data). The average larval production estimate of spawning biomass during 2002-03 was 10,900 mt, or about 43% higher than that from the 2005 stock assessment.

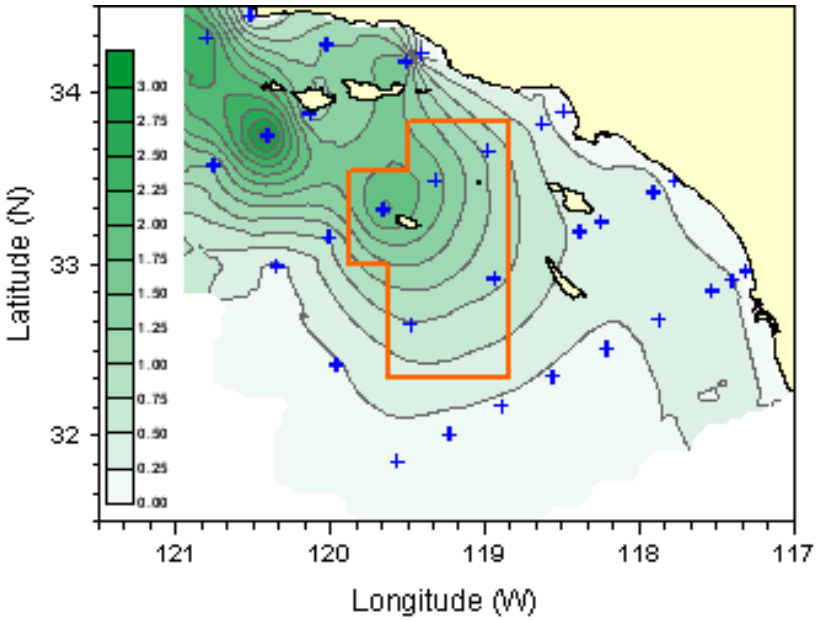

Figure 3: Historical distribution of bocaccio larval abundance (# ≅ 10 m^{-2}) from the CalCOFI database. Shown are contours of the estimated station effects from a Δ-lognormal GLM, with blue "+" symbols indicating actual station locations. The Cowcod Conservation Area is delimited by the orange polygon.

ii. Assessments

In the 2007 stock assessment cycle, the FED is conducting full assessments of bocaccio and chilipepper rockfish, and updates on existing assessments of widow rockfish and cowcod. Bocaccio, chilipepper and the cowcod update will be conducted in the latest version of stock synthesis 2 (SS2), and these models are currently in development. Although the cowcod assessment is being pursued as an update, there is ongoing additional exploration focusing on evaluating location-specific depletion based on spatially explicit catch rate time series from recreational fisheries.

Although not in the current assessment cycle, the FED has also been evaluating catch and life history data for the bronzespotted rockfish (*Sebastes gilli*), a large, relatively rare species that occur mainly in Southern California waters in deep rocky habitats similar to those for cowcod (*S. levis*). Port sampling data and expanded catch histories suggest that while the hook and line fishery has traditionally accounted for most landings, the gillnet fishery grew in the early 80s and accounted for most of the mortality during the period of most rapid decline in the late 1980s and early 1990s. Following this period of high catches, landings plummeted while overall shelf rockfish landings remained relatively high. A preliminary CPUE index based on cowcod effort indicates that the resource may have collapsed in the mid-1980s, and the population could be significantly depleted. Preliminary investigation of the life history of bronzespotted suggest a high vulnerability to fishing. From 119 otoliths compiled from various agency and academic collections, we observed a maximum age of 89 years, with 8 fish older than 55 years, which was the age of the oldest cowcod observed in 260 aged fish for that assessment. The estimated growth rate (K) is among the lowest observed for *Sebastes*, at approximately 0.03. .

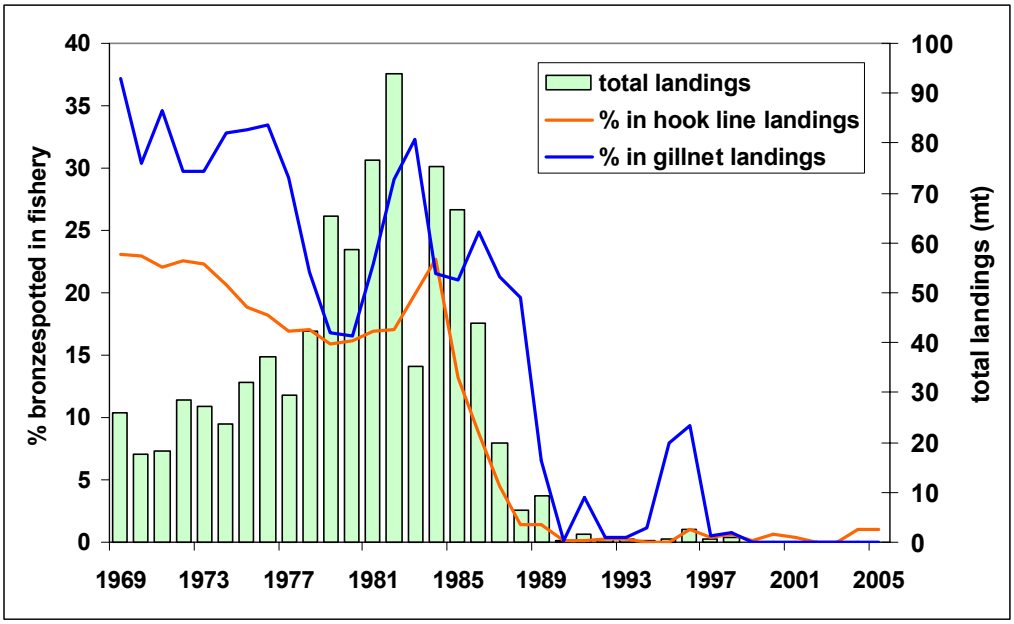

Figure 4. Commercial landings of bronzespotted rockfish in the Southern California Bight. Although sampling data only exists from 1982 onward (previous years were extrapolated), these data show that landings declined severely in the late 1980s, while overall catches of shelf rockfish (including the minor shelf category in which bronzespotted are managed) remained high, and have remained at very low levels since then (average less than 1 ton/year from 1990-1999).

D. OTHER RELATED STUDIES

1. Molecular Genetics

Researchers in the genetics program at the Fisheries Ecology Division have developed a suite microsatellite markers of multilocus nuclear genotypes developed for some 30 rockfish (*Sebastes*) species commonly found in the marine waters off of Central California (Pearse *et al.* 2007). These methods have been demonstrated to accurately assign nearly all individuals to the

species level, and were developed primarily to provide a simple and cost effective approach to identify early life history stages, archived, or forensic samples of *Sebastes* species. The method to be applied uses six microsatellite loci selected from an initial 53 screened loci, using a reference data set comprised of 762 individual fish that amplified at two or more loci, for which a 93.3% success rate in species assignments was achieved in the assignment of unknown fish sampled from outside the basic dataset using fish tissue. Funding was recently secured to apply these methods to identify juvenile rockfish to the species level from trawl surveys in which samples were damaged, as well as to identify rockfish prey remains to the species level in the diets of jumbo squid (*Dosidicus gigas*) and seabirds.

Researchers in the FRD have developed many genetic markers for groundfish, are working to determine stock structure and dispersal distances, and are helping with the design of MPA networks. The laboratory also houses a collection of over 20,000 groundfish tissue samples, which includes virtually all extant rockfish species and DNA extracted from museum specimens. These samples have enabled the completion of a comprehensive and robust phylogenetic hypothesis for the genus (Hyde and Vetter 2007, Fig. 4). This work allowed: (1) major revisions to previous subgeneric classifications based on morphology; (2) assignment of approximate timing of speciation events; (3) evaluation of patterns of species evolution; and (4) the discovery of two "cryptic" species of vermilion rockfish (*Sebastes miniatus*).

In response to the finding of two possible cryptic species, the geographic and bathymetric range of the two putative species of vermilion rockfish were examined (Hyde *et al*. in prep). Additional genetic markers were applied to test for reproductive isolation. The results strongly support the presence of two species, separated primarily by depth of occurrence (Fig. 6). One species occurs from Neah Bay, WA to Punta Baja, Mexico and is found primarily shallower than 100m. The second species is found from Monterey, CA to Punta Colnett, Mexico but is most abundant within the Southern California Bight, deeper than 100m. These results indicate that current depth closures in California are likely overly protecting the species found at depths >100m while placing increased effort upon the shallow, nearshore species. Following the previous study, we initiated a study of genetic connectivity between populations of the shallow, nearshore (<100 m depth) vermilion rockfish species (Hyde and Vetter in prep). A high-degree of genetic heterogeneity was observed among sample locations. Analyses supported a moderate genetic break across Point Conception with weaker breaks observed across Cape Blanco and possibly Cape Mendocino. There was a strong relationship between increasing genetic and geographic distance. The slope of this relationship was used to calculate larval dispersal values. The results suggest limited larval dispersal for vermilion rockfish, similar in magnitude to dispersal values obtained from previous studies on brown, copper, and grass rockfish.

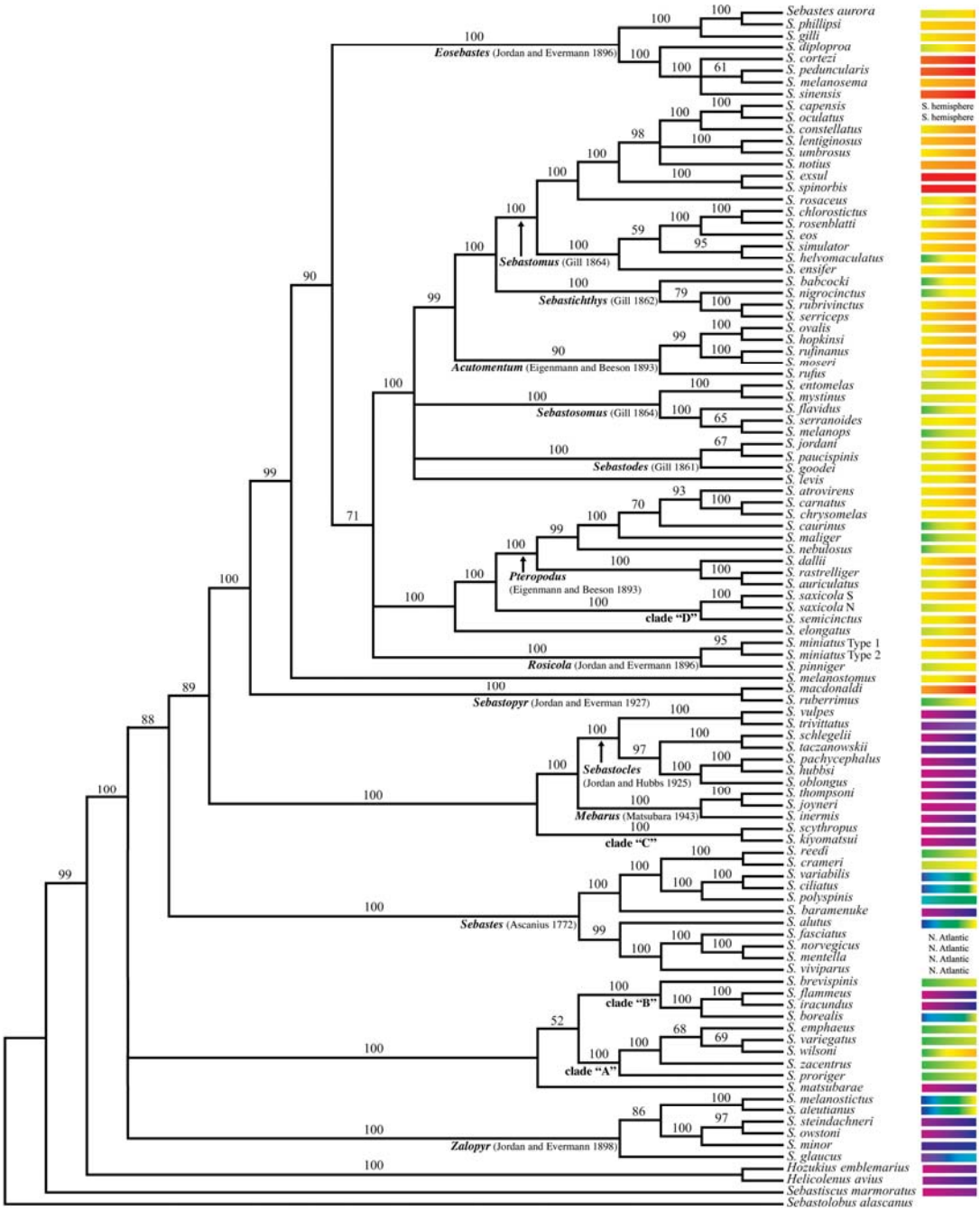

Figure 5. Consensus tree with maximum posterior probability generated from Bayesian posterior analysis using MrBayes v3.1. Numbers above nodes indicate Bayesian posterior probabilities >50%. Color spectrums next to species names indicate common range in reference to Figure 5. Revised sub-generic names are listed below nodes.

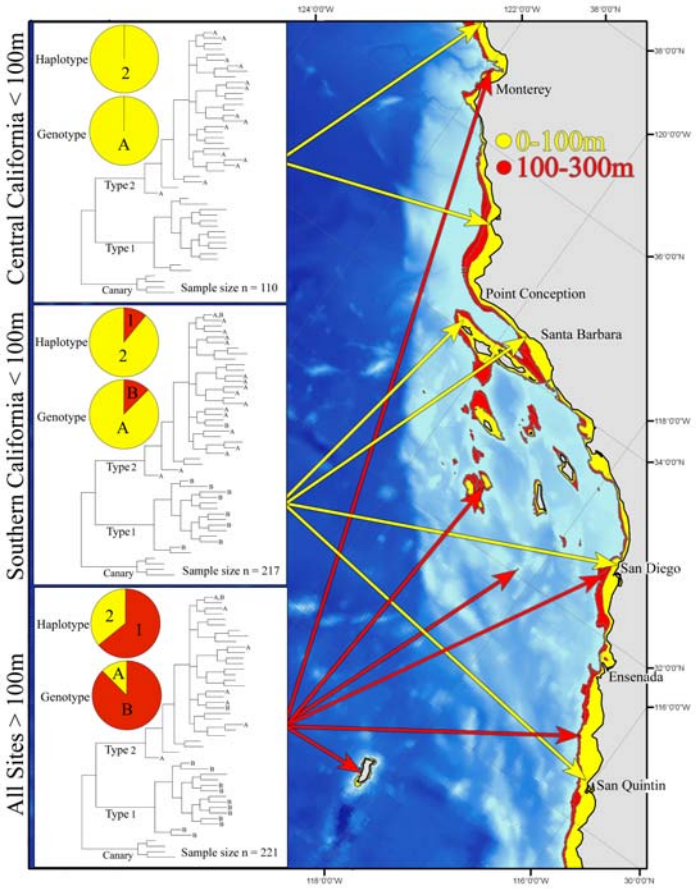

Figure 6. Map showing sampling locations for vermilion rockfish used in this study. Bathymetry is color coded with yellow (0-100m) and red (100-300m). Arrows indicate sampling sites and are color coded by collection depth to match the colored depth contours. Haplotypic (i.e., Type 1, Type 2) and genotypic assignment (i.e., Group A, Group B) for each sample group are presented as pie charts. The consensus Bayesian posterior tree of all haplotypes is presented for each sample group, and haplotypes present in each group are indicated with an A or B, corresponding to genotypic assignment of individuals at that haplotype.

2. Integration of Marine Protected Areas and Fisheries Science

The Santa Cruz Laboratory and the National Marine Protected Areas Science Institute have continued their support of the Science Integration of Marine Protected Areas and Fishery Management Working Group through 2006, and. In order to better understand how fisheries impact ecosystem function with MPAs and how MPAs impact fisheries objectives, the MPA Center Science Institute has been working with a group of fisheries and conservation biologists, sociologists, and economists to develop scientific information that can be integrated with conventional fisheries management strategies. The group was been divided into teams that include fisheries (MPA/ecosystem), connectivity, and natural heritage. Final products from the first phase of this effort are currently being delivered as reports and manuscripts (an example of one such product is below), and a second phase is anticipated which would focus on furthering several or all of the following topics: an MPA-based approach for data poor fisheries management (which would involve using a control rule that used uses fish density within MPAs as an index of unfished abundance); the implications of maternal age effects for MPA-based fisheries management; MPAs as a means of achieving evolutionarily stable harvest strategies; putting MPA/Fisheries science to work: the institutional dimension; assessing indicator performance in three different ecosystems; dynamic pool models and multispecies yield per recruit for multispecies fisheries; and consideration of benthic/pelagic linkages.

One product from these efforts is a simulation study conducted by Steve Ralston and Michael O'Farrell to evaluate the impact of spatial variation in fishing effort on sustainable yield. The purpose of the analysis was to determine what the effect of spatially variable fishing was on long-term yield, by comparing equilibrium yields under spatially heterogeneous fishing to the yields in the homogeneous case. Heterogeneity was modeled by perturbing fishing mortality rates in three areas, which included a reduced impact area, a standard impact area, and an elevated impact area. Fishing rates were perturbed to varying degrees among the areas, i.e., no perturbation (homogeneous fishing), ∀33% (minor), ∀67% (moderate), and ∀100% (extreme). This could be described as the "Goldilocks" design, with low mortality in the reduced impact area, high mortality in the elevated impact area, and standard mortality in the moderate impact zone. Moreover, compensation was modeled in three different ways: (1) larval pool density-dependence, (2) spawner density-dependence, and (3) post-settlement density dependence. Results showed that for the first two compensation scenarios, spatial variation in fishing mortality does not have a major impact on sustainable yield unless perturbations are extreme. Interestingly, simulated yields under the post-settlement compensation scenario indicated that extreme spatial variation in fishing (e.g., marine reserves) could produce yields in excess of the spatially homogeneous case.

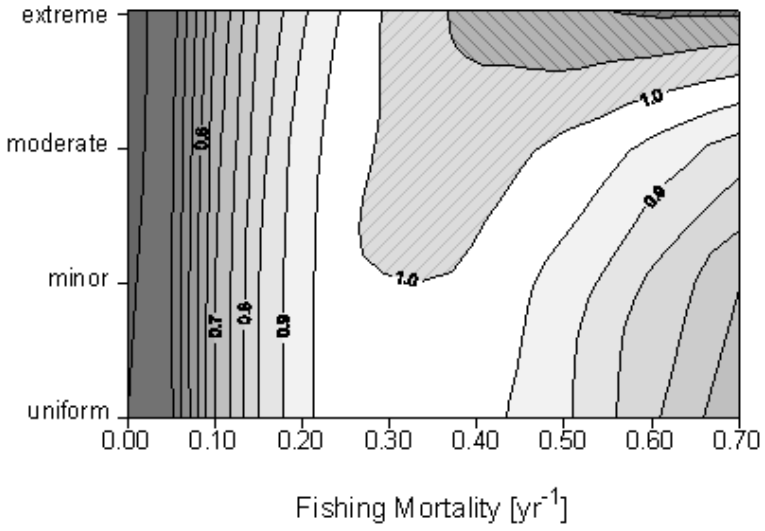

Figure 7: Contour plot of equilibrium yield relative to the homogeneous fishing mortality case for post-settlement compensation. The x-axis indicates the fishing mortality rate within the moderate impact area. The y-axis indicates the degree of perturbation of fishing mortality in the reduced and elevated impact areas. The extreme perturbation results in no fishing in the low impact zone and double the fishing mortality rate in the high impact area.

3. Connectivity of *Sebastes* Populations in California

Christine Peterson, a postdoctoral fellow with Steve Ralston at the FED, has been working on two distinct lines of research loosely related to establishing the extent of demographic and genetic connectivity among populations of winter-spawning *Sebastes* in the California Current. The first study is an evaluation of genetic isolation by distance of pelagic juvenile widow (*S. entomelas*), black (*S. melanops*), and blue (*S.* mystinus) rockfish sampled during the annual

SWFSC/PWCC coastwide midwater trawl survey. Using microsatellite DNA obtained from YOY rockfish collected during 2004-05 from Morro Bay, CA to Newport, OR, she has shown low levels of isolation by distance (e.g., F_{st} # 0.01 over distances of 900 km with no increasing trend), indicating significant genetic connectivity. This research has been conducted in close collaboration with investigators in the genetics laboratory at Santa Cruz. Her other research has been in collaboration with Ralston and Chris Edwards (Ocean Sciences, UCSC), who has a well-developed nested ROMS model of the US west coast. In this study Peterson has developed Lagrangian statistics to describe the fate of "floats" released in the ocean off central California. In particular, she has developed algorithms to estimate retention, dispersion, and connectivity based on outputs of the ROMS model from 2002. Clear patterns have emerged with respect to the advective characteristics of (1) the winter versus summer seasons, (2) the release depth of floats, and (3) the distance offshore of float release. In addition, it has been possible to estimate the ending latitudinal distribution of floats, given starting positions (Fig. 8). This analysis may prove quite useful in establishing the spatial connectivity of regions along the coast and in designing "networks" marine reserves.

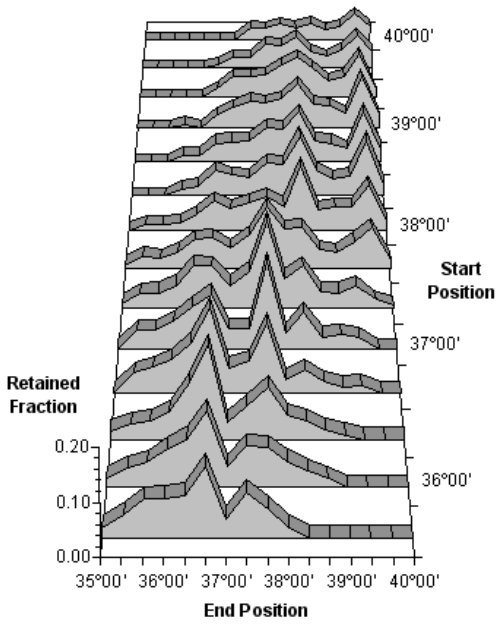

Figure 8: Spatial distribution of passive floats after 5 weeks at liberty during the ROMS reconstruction of the winter season of 2002, given initial release location. Obvious areas of increased retention (36º40'N) and dispersion (37º00'N) are evident.

4. SWFSC/Santa Cruz Lab Groundfish Habitat Ecology Program

The FED has an ongoing research program to implement legislative mandates with respect to Essential Fish Habitat (EFH) and Stock Assessment Improvement for West coast groundfish. This program uses a range of tools, including research submersibles, laser line scan system, and multibeam and side scan sonar. In addition to the Cowcod Conservation Area surveys and the gear intercalibration research described in the Assessments section for shelf rockfish, other ongoing projects include: 1) an evaluation of patterns in groundfish distribution and abundance

and seafloor habitats at a range of spatial scales, being conducted in collaboration with USGS (Anderson and Yoklavich, in press.); 2) characterizing benthic invertebrates that form habitat on deep banks off southern and central California, with special reference to deep sea coral communities (Tissot et al. 2006); 3) an evaluation of the potential for laser line scan (LLS) systems to serve as a bridge between high resolution, limited coverage video survey tools (e.g., remotely-operated vehicle (ROV), occupied submersible, towed sled) and lower resolution, higher coverage acoustic technologies (e.g., multibeam and sidescan sonar) (Amend et al. in press).

5. Economic Studies

The FED's Economics Team is developing a model of fishery dynamics using 1981-2005 vessel- and trip-specific data for all West coast commercial fisheries (including groundfish). This model is intended to: (1) analyze patterns of fishing behavior across space and time, (2) identify biological, economic, regulatory and environmental factors underlying these behavioral changes, and (3) evaluate the cumulative effects of these changes on fishing communities. The project is currently focused on the relationship between fishery behavior and port-level fishery infrastructure. Related efforts include the development of a Bayesian approach to estimating technical efficiency in the limited entry groundfish trawl fleet, in which an analysis is currently focused on the effects of the 2003 trawl vessel buyback program on technical efficiency in that fishery.

The Economics Team is also working in collaboration with the Environmental Research Division on an analysis of the economic effects of the Rockfish Conservation Areas on the groundfish trawl fleet. The ERD has expanded it's mapping of groundfish trawling to cover all of California's offshore waters out to 700 fathoms. Data consists of start and end locations of all tows from trawl logbooks from 1977 to 2005 linked to landings receipts for weight of market species. This year maps were created of the distribution and density of species from the trawl fishery for years before and during rockfish conservation area closures. Files of the 25 different RCA boundaries from 2002 to 2005 were created to overlay these maps. These data are being analyzed to quantify changes in fishing location and effort of the limited entry trawl fleet resulting from the RCA closures, including the spatial distribution of trawling by vessels from each port. This project will include analysis of (a) adaptations made by West coast groundfish trawlers in terms of movement between fisheries, and (b) adaptations by California groundfish trawlers in terms of spatial redistribution of effort and changes in fishing strategies.

6. Predator and ecosystem studies

Jumbo squid (*Dosidicus gigas*) are a large, rapidly growing subtropical cephalopod that have been occasional visitors to the California Current over the last century, however there is evidence that their abundance and distribution has increased between 2002 and 2006. In response to concerns over predation by jumbo squid on commercially important species, 428 stomach samples collected between 2005 and 2006 at various locations and seasons along the U.S. West Coast. Prey were identified using hard parts, primarily squid beaks and otoliths, and prey sizes were estimated where possible (Field et al. in review). While jumbo squid forage primarily on small midwater and forage fishes, they also prey heavily on adult groundfish such as Pacific hake

(*Merluccius productus*), shortbelly rockfish (*Sebastes jordani*), other rockfish, and several species of small flatfish and other groundfish. Pacific hake were the most frequently occurring prey, and were consumed from sizes ranging from less than 3 to over 40 cm. As their ability to prey on larger items suggests potential impacts on ecosystems, their role has also been evaluated in food web models of the California Current. A similar range expansion has been ongoing in the southern hemisphere in Central Chile, where declines in the Chilean hake stock have been partially attributed to predation by jumbo squid.

GROUNDFISH PUBLICATIONS OF THE SWFSC, 2006 - PRESENT

1. Primary Literature Publications

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Ambrose, D. A., **R. L. Charter**, and **S. M. Manion**. 2006. Ichthyoplankton and station data for surface (Manta) and oblique (Bongo) tows taken for California Cooperative Oceanic Fisheries Investigations survey cruises in 2005. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-392. 125 pp.

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