Northwest Fisheries Science Center

National Marine Fisheries Service

Agency Report to the Technical Subcommittee

of the Canada-U.S. Groundfish Committee

April 2013

Review of Agency Groundfish Research, Assessments, and Management

A. Agency Overview

The Northwest Fisheries Science Center (NWFSC) provides scientific and technical support to the National Marine Fisheries Service (NMFS) for management and conservation of the Northwest region's marine and anadromous resources. The Center conducts research in cooperation with other federal and state agencies and academic institutions. Five divisions, Conservation Biology, Environmental Conservation, Fish Ecology, Resource Enhancement and Utilization Technologies, and Fishery Resource Analysis and Monitoring, conduct applied research to resolve problems that threaten marine resources or that deter their use. At the current time the Environmental Conservation and Resource Enhancement and Utilization Technologies Divisions are being restructured to form a single new division. The Center's main facility and laboratories are located in Seattle. Other Center research facilities are located in Pasco, Big Beef Creek, Mukilteo, and Manchester, Washington; Newport, Hammond, and Clatskanie, Oregon.

The Fishery Resource Analysis and Monitoring Division (FRAMD) is the source for most of the research reported by the NWFSC to the Technical Subcommittee of the Canada-US Groundfish Committee. The FRAMD works in partnership with state and federal resource agencies, universities, and the groundfish industry to achieve a coordinated groundfish program for the West Coast.

FRAMD consists of a multi-disciplinary team with expertise in fishery biology, stock assessment, economics, mathematical modeling, statistics, computer science, and field sampling techniques. Members of this program are stationed at the NWFSC facilities in Seattle and in Newport, Oregon, with some Observer Program staff located in California. Together, they work to develop and provide scientific information necessary for managing West Coast marine fisheries and strive to provide useful and reliable stock assessment data with which fishery managers can set ecologically safe and economically valuable harvest levels. FRAM researchers develop models for managing multi-species fisheries; design programs to provide information on the extent and characteristics of bycatch in commercial fisheries as they look at methods to reduce fisheries bycatch; characterize essential habitats for key groundfish species; and employ advanced technologies for new assessments.

During 2012, FRAMD continued to: implement a West Coast observer program; conduct a coast wide survey program that includes West Coast groundfish acoustic, hook and line, and trawl surveys; develop new technologies for surveying fish populations; and expand its stock assessment, economics, and habitat research. Significant progress continues in all programs.

For more information on FRAMD and groundfish investigations, contact the Division Director, Dr. Michelle McClure at Michelle.McClure@noaa.gov, (206) 860-3381.

Other Divisions at the NWFSC are:

The Conservation Biology Division is responsible for characterizing the major components of biodiversity in living marine resources, using the latest genetic and quantitative methods. It also has responsibility for identifying factors that pose risks to these components and the mechanisms that limit natural productivity. The Division's multi-disciplinary approach draws on expertise in the fields of population genetics, population dynamics, and ecology.

The Environmental Conservation Division (ECD) conducts nationwide research on the effects of chemical pollution and harmful algal blooms on habitat quality and fisheries resources. ECD is also a leader in NMFS' National Marine Mammal Health and Stranding Response Program's bio-monitoring and quality assurances projects.

The Fish Ecology Division's role is to understand the complex ecological linkages among important marine and anadromous fishery resources in the Pacific Northwest and their habitats. The Division particularly places emphasis on investigating the myriad biotic and abiotic factors that control growth, distribution, and survival of important species and on the processes driving population fluctuations.

The Resource Enhancement and Utilization Technologies Division draws together multi-disciplinary groups to address existing and developing challenges of captive rearing of salmon and other marine fish, improved hatchery practices, smolt quality, disease control, and developing technologies for full utilization of bycatch and fish processing waste.

For more information on Northwest Fisheries Science Center programs, contact the Center Director, Dr. John Stein at John.Stein@noaa.gov, (206) 860-3200.

B. Groundfish Studies

1. Research

a) Quantitative video analysis of flatfish herding behavior and effective area swept of a survey trawl

Investigators: K.L. Bosley, D. Bryan, A.C. Hicks, W.W. Wakefield and M. Haltuch

Uncertainty in fish behavior can introduce bias into density calculations from fishery-independent bottom trawl surveys that provide relative abundance estimates and population trends for stock assessments. *In situ* video was used to quantify flatfish behavioral responses to a bottom trawl to determine effective area swept and improve survey and assessment accuracy and precision. The behavior of 632 flatfishes was recorded during four tows. Neither stationary nor reacting fish were randomly oriented with respect to trawl sweeps and over 90% were facing in a direction perpendicular or away from sweeps indicating a herding response. There was no significant effect of fish length on fish orientation or whether it reacted or stayed stationary during the observation. Only 1.3% of fish were observed escaping over or under the sweeps. A generalized linear model was used to estimate that at a distance of 73.8 cm (± 3.4 SE) 50% of observed fish reacted to the sweep. The mean reaction distance for a stationary fish was 36.6 cm (± 2.0 SE). Quantitative analysis clearly indicates that flatfish herding occurs along trawl sweeps and area swept calculations used to provide relative abundance estimates should include a portion of the area swept by the sweeps to improve accuracy.

For more information, please contact Keith Bosley at Keith.Bosley@noaa.gov

b) Can trip limits and time-area closures keep commercial catches of longnose skate and spiny dogfish shark below their harvest limits?

Investigators: D. Erickson, J. Cope and C. Niles

Commercial catches of spiny dogfish shark (*Squalus suckleyi*) and longnose skate (*Raja rhina*) off the U.S. west coast have recently reached levels that would exceed their annual harvest specifications. In general, both are incidentally caught in commercial trawl and fixed gear fisheries targeting other groundfish species. Limited commercial markets exist for these species, so targeting may occur, especially for dogfish shark. Life history characteristics of both species limit their resilience to overfishing. For example, dogfish sharks may not reach sexual maturity until approximately 35 years old, and may produce only 2-16 pups per litter over an 18-22 month gestation period. Such slow dynamics would translate into long recovery times if harvest were to reduce these populations to low levels. Setting appropriate harvest levels is therefore of high importance for these species. The most common management measures used to control fishing mortality for west coast commercial groundfish fisheries are landing ("trip") limits and time-area closures. Such measures may have limited effectiveness for spiny dogfish shark and longnose skate. The geographic distribution of each is broad, extending along the entire

U.S. west coast at depths from < 50 fathoms to > 600 fathoms. In addition, both species are often discarded at sea due to their limited marketability.

The potential use of trip limits and time-area closures to control the fishing mortality of longnose skate and spiny dogfish shark was investigated off Washington, Oregon, and California. The potential efficacy of these management measures was evaluated through analysis of logbook, fish ticket, and at-sea observer data. The authors also discuss the potential impacts such management measures may have on commercial fisheries and coastal communities.

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c) Temporal and spatial summer groundfish assemblages in trawlable habitat off the west coast of the USA, 1977 to 2009

Investigators: J. Cope and M. Haltuch

Increasingly, multispecies interactions are being considered by U.S. management councils during decision making, which highlights the need for identification of fish assemblages across varying spatial and temporal resolutions. On the U.S. West Coast, previous groundfish assemblage analyses have focused either on particular species groups (i.e. *Sebastes)* or limited time frames and/or geographic regions within the groundfish fishery. The present study expands on previous work to identify groundfish assemblages across the full spatial extent of the West Coast groundfish fishery from 1977−2009, by using two fishery-independent trawl surveys. Species assemblages were identified using two clustering methods (partitioning analysis and hierarchical analysis) and two realizations of the data (presence-absence and log+1 transformed catch-per-unit effort, CPUE). The analysis using presence-absence data provides information on species that co-occur while the CPUE data provides information on species that occur at similar magnitudes. Temporally and spatially persistent assemblages were detected by both clustering methods through most years. Assemblages identified using CPUE were often subsets of those identified using presence-absence, indicating that the members of an assemblage may occur together, but not necessarily at the same magnitude, a result that should be considered when choosing the clustering metric. Identification of species assemblages is applicable to bycatch models and informative when evaluating the implementation of spatial management measures, and thus germane to current challenges faced by marine resource managers.

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d) Feeding ecology of juvenile rockfishes off Oregon and Washington, based on stomach-content and stable-isotope analyses

Investigators: K. Bosley, T. Miller, R.D. Brodeur, K.M. Bosley, A. Van Gaest and A. Elz

The feeding habits of pelagic, juvenile rockfishes (*Sebastes* spp.) collected off Oregon and Washington during 2002 and 2006, were examined using stomach-content and stable-isotope analyses. The predominant species were darkblotched (*S. crameri*), canary (*S. pinniger*), yellowtail (*S. flavidus*), and widow (*S. entomelas*) rockfishes. Stomach-content analysis revealed that darkblotched rockfish had highly variable diets, and canary, yellowtail, and widow rockfishes exhibited a high degree of overlap. Multivariate analysis revealed significant differences in diet based on distance from shore, fish size, and species. Stable-isotope analysis showed all species were feeding at about the same trophic level within each year, with a 1.5‰ difference in δ15N between years. Depleted δ13C values indicate that the juveniles that were collected likely resulted from offshore spawning, and were subsequently advected or migrated onto the shelf, representing a potentially important cross-shelf transport of carbon to the shelf. Comprehensively, these results add to our understanding of some of the important environmental factors that affect young-of-the-year rockfish during their pelagic phase.

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e) Relating groundfish biomass, species richness and community structure to the presence of corals and sponges using NWFSC bottom trawl survey data

Investigators: K.L. Bosley, K.M. Bosley, C.E. Whitmire and A.A. Keller

Some cold-water corals and sponges occur in such dense aggregations that they provide structurally complex habitats which support a diverse assemblage of associated invertebrates and fish. In many cases, marine fishes have been linked to the presence of epibenthic invertebrates, although the specific nature of this relationship is often unknown. The Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl Survey has collected approximately 250 coral specimens per year since 2006, and has identified, on average, 200 sites (of 750) per year where sponges are present. For this study we investigated the relationship between these two groups of epibenthic invertebrates and their associations with demersal fish using trawl survey data from 2003-2010, when the survey covered continental shelf and slope waters from Cape Flattery, Wash., to the Mexican border. Regression models were used to correlate fish biomass and species richness with coral and sponge densities. Fish biomass was correlated with sponge density, but the relationship was not precise ($P<0.0001$, $R^2=0.043$). No other significant correlations were uncovered among these variables. Multivariate analyses were used to assess fish community structure in relation to coral and sponge densities, and to environmental parameters including depth, latitude and bottom temperature. There were strong correlations between species composition and both depth and bottom temperature, but no strong correlations with coral or sponge densities. Indicator species analysis was done to determine species that were associated with four levels of sponge and coral densities (high, medium, low and zero). Shortspine thornyhead, rosethorn

rockfish and greenspotted rockfish were associated with high sponge catches, while flatfishes were typically associated with the absence of sponges. Shortspine thornyhead, Dover sole, longspine thornyhead, aurora rockfish and darkblotched rockfish were associated with high coral catches, and rex sole, English sole, and greenstriped rockfish with the absence of corals. These results provide information about broad-scale associations between corals, sponges and demersal fish that may be useful for developing studies that are specifically focused on the function of corals and sponges as habitats for fish, and the role they may play in their life-histories.

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f) A stable isotope-based perspective on the contribution of prey to Humboldt squid (*Dosidicus gigas*) in the northern California Current

Investigators: T.W. Miller, K.L. Bosley, J. Shibata, R.D. Brodeur, K. Omori and R. Emmett

Diet studies have shown Humboldt squid *Dosidicus gigas* to be aggressive opportunistic predators, yet this approach has provided only a limited and potentially biased view of their trophic feeding behavior. As an alternative, we measured the $\delta^{13}C$ and $\delta^{15}N$ of *D. gigas* and their prey from the northern California Current ecosystem (NCC) and applied stable isotope Bayesian mixing models (Stable Isotope Analysis in R [SIAR]) to assess if *D. gigas* isotopically matched NCC or southern California Current (SCC) migratory end-members and to examine the proportional trophic contributions of prey groups from the NCC to their diet. For the trophic SIAR model, cluster analysis of prey taxa by their respective $\delta^{13}C$ and $\delta^{15}N$ values was first applied to consolidate prey into groups, which were then incorporated into the model as source groups to the diet mixture. Model results from examination of NCC and SCC migratory end-members indicated greatest contributions from the NCC system, suggesting *D. gigas* was more integrated with the regional NCC isotopic signature. From the trophic SIAR model, the results indicated mixed but lower trophic-level feeding by *D. gigas* relative to previous diet-based studies, with greatest contributions from macrozooplankton, ichthyoplankton, and nekton such as juvenile rockfish, market squid, sand lance, and juvenile Pacific hake. Sensitivity analyses of the SIAR model based on varying isotopic fractionation factors of $\delta^{13}C$ and $\delta^{15}N$ showed that proportional contributions of prey to squid diets were resilient to change.

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g) Distribution, biomass and size of grooved Tanner crabs (*Chionoecetes tanneri*) from annual bottom trawl surveys (2003–2010) along the U.S. west coast (Washington to California)

Investigators: A.A. Keller, J. H. Harms, J.C. Buchanan

Catch and distribution of grooved Tanner crab (*Chionoecetes tanneri* Rathbun, 1893) from the Northwest Fisheries Science Center's bottom trawl survey (55–1280 m) were

examined along the U.S. west coast (lat. 32°30′N–48°30′N). Grooved Tanner crabs were present in 28% of tows and occurred primarily at depths from 300 to 1280 m. Annual biomass (metric tons, mt) indices and density (kg km^{-2}) estimates for the population varied significantly throughout the study area and within five International North Pacific Fisheries Commission (INPFC) statistical areas. Highest estimates occurred in the Monterey INPFC area (lat. 36°N–40°30′N) and within the 601–800 m depth interval. Depth distribution varied by year and coast-wide catch-weighted average depths (m) were significantly correlated with average annual Pacific Decadal Oscillation (PDO) indices (2003–2010), a measure of Pacific climate variability. Annual mean carapace widths (CW), measured from 2005 to 2010, were always greater for males (96.9–113.9 mm) relative to females (85.3–95.8 mm). Size frequency distributions varied by year with strong recruitment for both sexes apparent in 2010. Grooved Tanner crabs were partially segregated by depth and stage. Males and females were found in all depth intervals but the average depth of adult females was significantly shallower (756 m) than adult males (837 m); adults were significantly shallower than subadult female (907 m) and subadult male (927 m) crabs.

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h) Variation is age and growth of greenstriped rockfish (*Sebastes elongatus*) along the U.S. west coast (Washington to California)

Investigators: A.A. Keller, K. Molton, A.C. Hicks, M. Haltuch and C. Wetzel

Greenstriped rockfish, *Sebastes elongatus*, are a common commercial and recreational species often taken as bycatch in commercial fisheries off the U.S. west coast. We evaluated weight-length relationships and size-at-age using von Bertalanffy growth models for greenstriped rockfish sampled along the U.S. west coast from 2003 to 2008. Based on regression analyses, populations were subdivided into two depth strata (55–122 m and 122–450 m) and four geographic regions (48°10' N – 48°28' N, 40°26' N – 48°10' N, 34°27’ N – 40°26' N, and 32°30' N – 34°27' N) and differences in length, age, and growth examined by gender. Strong evidence of variation in weight-length relationships was found north and south of Cape Mendocino (40°26' N) but little variation was noted for depth or gender. In contrast, variations in von Bertalanffy growth models were highly dimorphic between sexes with consistent patterns across depth and geographic regions. Females grew more slowly and reached larger asymptotic sizes (L_∞, cm) relative to males in all regions examined. Asymptotic size for both males and females tended to increase at higher latitude and increased depth. However, the smallest asymptotic sizes occurred in the region from Pt. Conception to Cape Mendocino, CA (34°27' N – 40°26' N), rather than lower latitudes south of Pt. Conception (32°30’ N – 34°27' N). Greenstriped rockfish growth coefficients (k, yr^{-1}) exhibited a more complex pattern. Higher growth coefficients were associated with regions within the northern California Current System characterized by high productivity.

i) Variations in Eastern North Pacific demersal fish biomass based on the U.S. West Coast groundfish bottom trawl survey (2003–2010)

Investigators: A.A. Keller, J. Wallace, B. Horness, O. Hamel and I. Stewart

In response to declining biomass of Northeast Pacific ground - fish in the late 1990s and to improve the scientific basis for management of the fishery, the Northwest Fisheries Science Center standardized and enhanced their annual bottom trawl survey in 2003. The survey was expanded to include the entire area along the U.S. west coast at depths of 55–1280 m. Coast-wide biomass and species richness significantly decreased during the first eight years (2003–2010) of this fishery-independent survey. We observed an overall tendency toward declining biomass for 62 dominant taxa combined (fishery target and nontarget species) and four of seven subgroups (including cartilaginous fish, flatfishes, shelf rockfishes, and other shelf species), despite increasing or variable biomass trends in individual species. These decreases occurred during a period of reduced catch for groundfish along the shelf and upper slope regions relative to historical rates. We used information from multiple stock assessments to aggregate species into three groups: 1) with strong recruitment, 2) without strong recruitment in 1999, and 3) with unknown recruitment level. For each group, we evaluated whether declining biomass was primarily related to depletion (using year as a proxy) or environmental factors (i.e., variation in the Pacific Decadal Oscillation). According to Akaike's information criterion, changes in aggregate biomass for species with strong recruitment were more closely related to year, whereas those with no strong recruitment were more closely related to climate. The significant decline in biomass for species without strong recruitment confirms that factors other than depletion of the exceptional 1999 year class may be responsible for the observed decrease in biomass along the U.S. west coast.

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j) Shifts in condition and distribution of eastern North Pacific flatfish along the U.S. west coast (2003–2010)

Investigators: A.A. Keller, V. Simon and M. Bradburn

Flatfish condition indices and distribution were examined along the U.S. west coast (55–1280 m) in relation to environmental variability and biomass using data from ten frequently occurring species collected in annual groundfish surveys from 2003 to 2010. The study was conducted during a period characterized by a cooling trend in the northern California Current system and by declining biomass for flatfish in general. Annual condition indices for six species (arrowtooth flounder, Dover sole, English sole, Pacific sanddab, petrale sole, and rex sole) were significantly related either to large-scale climatic indices (Pacific Decadal Oscillation, Multivariate El Niño–Southern Oscillation Index, North Pacific Gyre Oscillation) and/or annual biomass levels. Condition was most closely related to environmental effects rather than either biomass alone or both variables, with condition typically higher during cool climatic conditions. A similar analysis revealed that changes in distribution (measured as variation in annual catch-weighted mean latitude, longitude, depth and temperature) tended to be best described by

models incorporating environmental effects and biomass rather than either variable alone. Linear trends in the center of distribution along a southeast-northwest axis were significant for seven species (arrowtooth flounder, deepsea sole, Dover sole, flathead sole, Pacific sanddab, petrale sole, and slender sole) with a tendency for flatfish to be displaced towards the southeast as environmental conditions shifted from warm to cooler conditions and biomass declined. A spatial distribution analysis indicated that for the majority of species (80%) the greatest magnitude of displacement (km) occurred when the centers of biomass were compared between environmental-phases (average annual displacement 34 km) rather than changing biomass levels (average displacement 24 km). Taken together both approaches revealed that environmental changes and variation in biomass play significant roles in flatfish distribution.

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k) Analysis of fishery-independent hook and line-based data for use in the stock assessment of bocaccio rockfish (*Sebastes paucispinis*)

Investigators: J.R. Wallace, J.H. Harms and I.J. Stewart

Fishery-independent surveys are an important source of information for stock assessment and management worldwide. Research surveys often use trawl gear to capture commercially valuable species and calculate indices of relative abundance or density. However, many species of interest do not occur in direct contact with the bottom, or occur in areas where high-relief habitat precludes trawl operation. This paper introduces a standardized hook and line survey for rockfish conducted by NOAA Fisheries' Northwest Fisheries Science Center in the Southern California Bight. The survey uses fishing gear similar to that used in many recreational fisheries to sample approximately 120 locations covering a wide range of depths and habitats. To provide an example of how these data can be analyzed for direct inclusion in stock assessments, we standardize catch rates of bocaccio rockfish from 2004–2008 using a Bayesian Generalized Linear Model to account for site, fishing time, survey vessel, angler, and other statistically significant effects. Results indicate that the bocaccio stock vulnerable to this survey in the Southern California Bight has shown a relatively flat trend over recent years. Length frequency distributions indicate the presence of several strong cohorts that should be detectable in future stock assessments of bocaccio for use in U.S. West Coast groundfish management. This survey is the only available tuning index for the adult portion of the bocaccio population in recent years as historically used recreational catch per unit effort indices have been compromised due to changes in bag limits and other management restrictions.

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l) Distribution and life history characteristics for vermilion rockfish (*Sebastes miniatus*) and its cryptic pair, sunset rockfish (*S. crocotulus*) in Southern California

Investigators: J.H. Harms, J. Hempelmann, O. Rodriguez, M. Head, R.M. Barnhart, P. McDonald, J.A. Benante and A.A. Keller

Recent genetic research by Hyde et al. (2008) at NOAA Fisheries' Southwest Fisheries Science Center identified a cryptic pair of the vermilion rockfish from specimens collected along the U.S. West Coast and suggested some depth and biogeographic partitioning between the two species. Using specimens and catch data collected during the hook and line survey, NWFSC researchers analyzed depth and latitudinal differences and similarities between vermilion and sunset rockfish and developed unique life history characteristics for the two species. These include age at length, annual growth estimates, length-weight relationships, and age at maturity. This information can be combined with the unique indices of abundance outlined in the previous paper to support separate stock assessments for vermilion and sunset rockfish.

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m) A fishery-independent multi-species examination of recent population trends for key species of shelf rockfish (Genus: *Sebastes*) in Southern California

Investigators: J.R. Wallace, I.J. Stewart and J.H. Harms

Fishery-independent surveys are an important source of information for stock assessment and management worldwide. Research surveys often use trawl gear to capture commercially valuable species and calculate indices of relative abundance or density. However, many species of interest do not occur in direct contact with the bottom, or occur in areas where high-relief habitat precludes trawl operation. This research was undertaken during a standardized hook and line survey for rockfish conducted by NOAA Fisheries' Northwest Fisheries Science Center (NWFSC) in the Southern California Bight. The survey uses fishing gear similar to that used in many recreational fisheries to sample approximately 120 locations covering a wide range of depths and habitats. The methods described in Harms et al. (2010) were applied to hook and line survey data for six important species of shelf rockfish to generate fishery-independent abundance indices, including the first unique indices for vermilion rockfish (*S. miniatus*) and its cryptic pair, sunset rockfish (*S. crocotulus*). This survey is the only available ongoing tuning index for the adult portion of many structure-associated shelf rockfish species in the region, as historically-used recreational catch per unit effort indices have been compromised due to changes in bag limits and other management restrictions.

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n) Recent developments: Southern California shelf rockfish hook and line survey

Investigators: R.M. Barnhart, J.H. Harms and J.A. Benante

The Fisheries Resource and Analysis and Monitoring Division of the Northwest Fisheries Science Center conducts an annual hook and line survey for shelf rockfish (Genus: *Sebastes*) in the Southern California Bight. The project, which began in 2002, targets demersal rockfish species associated with rocky, untrawlable habitats that are generally not sampled well by the division's other groundfish monitoring cruises. The hook and line survey is a collaborative effort with Pacific States Marine Fisheries Commission and

the sportfishing industry in southern California. The time series of catch-per-unit-effort data and associated biological data are used to calculate an index of relative abundance for several important rockfish species including bocaccio, vermilion rockfish, greenspotted rockfish, and speckled rockfish. Bocaccio and vermilion rockfish, two primary species of interest, have been encountered at over 65% of survey sites in every year of the survey. Survey personnel are currently working with the NWFSC Genetics & Evolution Program to develop separate indices of abundance for vermilion and sunset rockfish by analyzing the finclips collected from each of the vermilion rockfish complex specimens collected during sampling.

Recent efforts include expanding the collection of environmental and oceanographic data during sampling including the acquisition of seawater temperature, dissolved oxygen, salinity, and turbidity information at depth from survey sites. These data may provide informative covariates reducing uncertainty associated with the model used to estimate indices of abundance and may also be useful in tracking shifts in oceanographic regimes in the region. In addition, the past two years work has been conducted to estimate size at maturity for the vermilion, sunset, and bocaccio rockfish. Efforts to collect video habitat information and further develop genetic biopsy hooks continue to move forward. The survey is improved by its collaboration with the sportfishing industry and has strengthened the working relationship between NOAA Fisheries and stakeholders in the region.

o) Environmental sampling, hypoxia and the Northwest Fisheries Science Center's Cooperative U.S. West Coast Groundfish Bottom Trawl Survey

Investigators: A. A. Keller, W.W. Wakefield, V. H. Simon, J.A. Barth, and S. Pierce

The NOAA NMFS Northwest Fisheries Science Center (NWFSC) currently conducts a number of groundfish research and monitoring projects that are cooperative and collaborative with the fishing industry. These include a West Coast Groundfish Bottom Trawl Survey (WCGBTS), a hook and line survey of shelf rockfishes in the Southern California Bight, pelagic trawl surveys of juvenile groundfishes, and acoustical optical pilot surveys of pelagic rockfishes in untrawlable habitats. In the context of such cooperative research programs, advancements in sampling technologies have allowed new types of data to be collected during traditional NMFS surveys. For example, environmental sensing packages are attached to trawls and record a full array of environmental parameters (e.g., depth, temperature, salinity, dissolved oxygen, chlorophyll fluorescence, turbidity, and light). These improved environmental sensing capabilities have led to collaborations with academic partners and with the developers and manufacturers of sensing packages. In 2007, the NWFSC added an environmental sampling program to the WCGBTS that included collaboration with physical oceanographers at Oregon State University. This program was initiated, in part, in response to hypoxia that was observed on the continental shelf of the Pacific Northwest, in a region not previously characterized by hypoxic conditions. Fishery and environmental sampling is conducted from chartered commercial trawlers from 55 to 1280 meters and from the U.S.–Canada border to the U.S.–Mexico border. A nested

sampling design encompasses the oxygen minimum zone of the California Current as well as a known hypoxic area on the continental shelf off the Oregon coast.

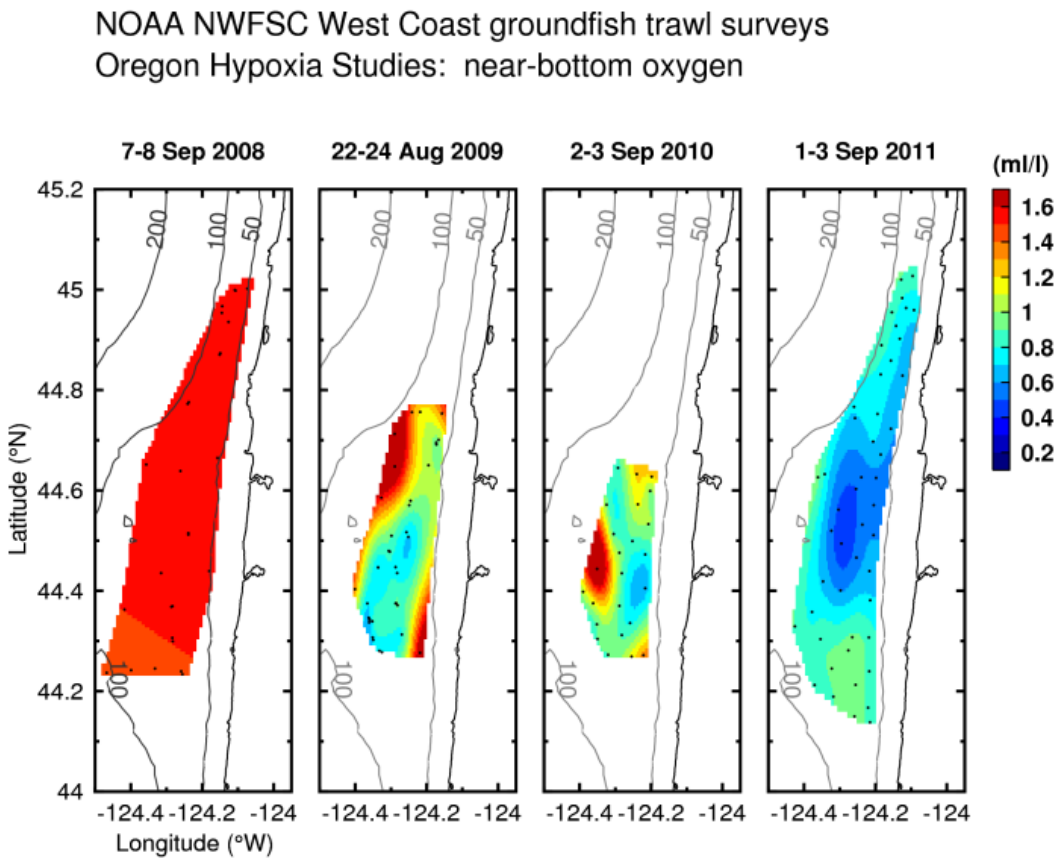

Figure 1. Varying concentrations of near-bottom dissolved oxygen (ml l^{-1}) are shown during late summer from 2008 through 2011 on the continental shelf of the Pacific Northwest off Oregon, in a region not previously characterized by hypoxic conditions. Moderate to severe hypoxia was noted in 2009 – 2011.

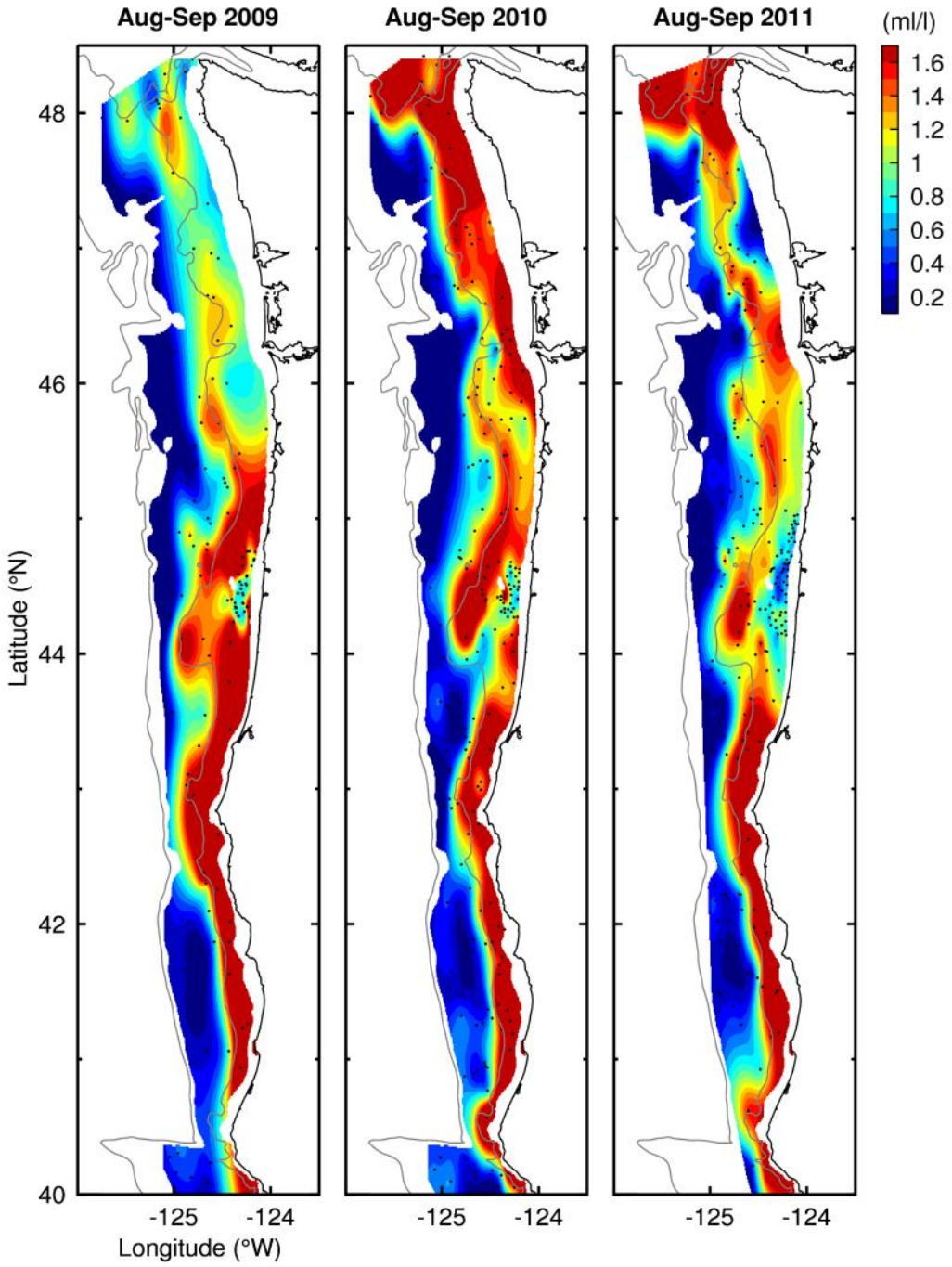

Figure 2. Distribution of near bottom oxygen concentration over a greater extent of the Northeast Pacific from 2009 to 2011 collected during bottom trawl surveys. Sampling indicates low DO in deep water within the OMZ during in all years and varying levels of low oxygen in shallower offshore of both Washington and Oregon by year.

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p) A review of essential fish habitat for Pacific coast groundfish

Investigators: W.W. Wakefield, M.M. McClure, and K. Griffin

A review of Essential Fish Habitat (EFH) for 91 species of Pacific coast groundfish was ongoing in 2012. Some of the key products developed for this review are now available to the public. Initial EFH designations were based on best available data developed from 2002 to 2005; NOAA's National Marine Fisheries Service (NMFS) implemented these designations in May 2006. Beginning in 2010, the Pacific Fisheries Management Council (PFMC), Northwest and Southwest Fisheries Science Centers, and the NMFS Regions initiated the next 5-year review for EFH provisions of the groundfish Fishery Management Plan. In Phase I of this process, new and relevant information were compiled and summarized for the review. Sources of information included published scientific literature and unpublished scientific reports, solicitation of data from interested parties, and the review of previously unavailable or inaccessible data sets. Coast-wide maps were updated for (1) bathymetry and interpreted groundfish habitat types, (2) the distribution and extent of commercial fishing effort (as potential impact to EFH), (3) the distribution and relative abundance of biogenic habitat (i.e., sponges and corals), and (4) spatial management boundaries (as potential mitigation of impacts). This complete body of information, in the form of a written report and supporting Internet data catalog, was presented to the PFMC, its advisory bodies and the public at the Council's September 2012 meeting (Phase I Report: http://www.pcouncil.org/groundfish/background/document-library/pacific-coast-groundfish-5-year-review-of-efh/; online data catalog: http://efh-catalog.coas.oregonstate.edu/overview/). NMFS is currently conducting an analysis of the information in the Phase I Report, and will deliver a synthesis to the Council in April 2013. During Phase II, the Council will solicit proposals to modify EFH and Habitat Areas of Particular Concern (HAPC). If the Council decides to amend EFH, Phase III of the process will begin and may require an amendment to the groundfish Fisheries Management Plan. This 5-year review represents a major update of the groundfish habitat assessment for the California Current and will have research and management applications well beyond satisfying the regulatory guidelines associated with EFH.

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2. Stock Assessment

a) Stock assessment model development

Stock Synthesis (SS) is an assessment model in the class termed integrated analysis and is the basis for West Coast groundfish assessments and many other assessments around the world. SS is built with a population sub-model that simulates a stock's growth and mortality processes, an observation sub-model to estimate expected values for various types of data, and a statistical sub-model to characterize the data's goodness of fit and to obtain best-fitting parameters with associated variance. It includes a rich feature set including age- and size-based population dynamics and the ability to specify observational phenomena, such as ageing imprecision. Model parameters can vary over time or be specified as functions of environmental data. SS includes routines to estimate MSY and exploitation levels that correspond to various standard fishery management targets. It supports assessments spanning several geographic areas and can use tag-recapture data. A customizable harvest policy is used to conduct a forecast in the final phase of running the model. The model is coded in ADMB (www.admb-project.org). SS is included in the NOAA Fisheries Assessment Toolbox (http://nft.nefsc.noaa.gov/) incorporating a graphical user interface developed by Alan Seaver (NEFSC). It is now at version 3.24j as of November 2012).

In 2012 Stock Synthesis was featured in the following non NWFSC publications as well as numerous publications reported below in section 10:

MacCall, A.D., Teo, S.L.H. *in press*. A hybrid stock synthesis- Virtual population analysis model of Pacific bluefin tuna. Fisheries Research. *special edition.*

Maunder, M.N., Punt, A.E. *in press.* A review of integrated analysis in fisheries stock assessment. Fisheries Research. *special edition.*

Punt, A.E., Maunder, M.N. *in press*. Stock Synthesis: Advancing stock assessment application and research through the use of a general stock assessment computer program. Fisheries Research. *special edition.*

Stewart, I.J., Hicks, A.C., Taylor, I.G., Thorson, J.T., Wetzel, C., Kupschus, S. *in press.* A comparison of stock assessment uncertainty estimates using maximum likelihood and Bayesian methods implemented with the same model framework. Fisheries Research. *special edition.*

Whitten, A.R., Klaer, N.L., Tuck, G.N., Day, R.W. *in press*. Accounting for cohort-specific variable growth in fisheries stock assessments: A case study from south-eastern Australia. Fisheries Research. *special edition.*

For more information, please contact Richard Methot at Richard.Methot@noaa.gov

b) Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management

Investigators: R. Methot and C.R. Wetzel

Stock Synthesis (SS) is a statistical age-structured population modeling framework that has been applied in a wide variety of fish assessments globally. The framework is highly scalable from data-weak situations where it operates as an age-structured production model, to complex where it flexibly incorporates multiple data sources and accounts for biological and environmental processes. SS incorporates compensatory population dynamics through use of a function relating mean recruitment to spawner reproductive output. This function enhances its ability to operate in data-weak situations and enables SS to estimate fishery management quantities such as fishing rates that would provide for maximum sustainable yield and to employ these rates in forecasts of potential yield and future stock status. Complex model configurations such as multiple areas and multiple growth morphs are possible, tag-recapture data can be used to aid estimation of movement rates between areas, and most parameters can change over time in response to environmental and ecosystem factors. SS is coded using Auto-Differentiation Model Builder, so inherits powerful capability to efficiently estimate hundreds of parameters using either maximum likelihood or Bayesian inference.

For more information, please contact Richard Methot at Richard.Methot@noaa.gov

c) Hiding or dead? A computationally efficient model of selective fisheries mortality

Investigators: I. Taylor and R. Methot

100 years after Rosa Lee (1912) showed that higher mortality on faster growing fish can alter length-at-age distributions in fish populations, we present a computationally-efficient and parsimonious method for modeling size-selective mortality within a commonly-used assessment model, Stock Synthesis. Stock Synthesis allows the normal distribution of length-at-age to be partitioned into three or five overlapping platoons with slow, medium, or fast growth trajectories. The platoons are tracked separately in the model, and experience different degrees of size-selective fishing pressure and mortality, but are assumed to be unobservable except through changes in the length distribution. Simulations are used to explore this phenomenon in conjunction with dome-shaped selectivity, an alternative explanation for observing fewer than expected large fish in sampled data, but with very different implications for population productivity. For data simulated both with and without platoons, misspecification of the assumptions about growth are found to bias model results, with selectivity often incorrectly identified as the cause of fewer observations of larger fish. Trends in dome-shaped selectivity were explored as a potential diagnostic of model misspecification.

For more information, please contact Richard Methot at Richard.Methot@noaa.gov

d) A stock-recruitment relationship based on pre-recruit survival illustrated with application to spiny dogfish shark

Investigators: I. Taylor, V. Gertseva, R. Methot, and M. Maunder

Understanding the relationship between abundance of spawners and subsequent recruitment is one of the central issues in fisheries stock assessment. We developed a new, pre-recruit survival based stock–recruitment model that enables explicit modeling of survival between embryos and age 0 recruits, and allows the description of a wide range of pre-recruit survival curves. The model is especially useful for low fecundity species that produce relatively few offspring per litter and exhibit a more direct connection between spawning output and recruitment than species generating millions of eggs. The proposed model provides additional flexibility in the stock–recruitment options that may be explored in any fishery stock assessment, and it is now available within the Stock Synthesis assessment platform. In this paper, we describe the mathematical formulation of the new stock–recruitment model, explain how this model can be specified within Stock Synthesis, and use it to model the stock–recruitment relationship of the spiny dogfish shark in the Northeast Pacific Ocean. We compare the results of the application of our new stock–recruitment model, with those from traditional Beverton–Holt relationship, and illustrate why the new approach is more appropriate for this species.

For more information, please contact Richard Methot at Richard.Methot@noaa.gov

e) Stock Synthesis training workshop at the Institute of Marine Science in Lysekil, Sweden

Investigators: A.C. Hicks and I. Taylor

The workshop provided an overview of Stock Synthesis, a fisheries assessment model used to conduct fish stock assessments on the west coast, such as Pacific hake, sablefish, various soles, and many species of rockfish. Stock Synthesis, originally developed by NMFS Senior Scientist Rick Methot, is now used in many U.S. stock assessments because it integrates data from many sources, regardless of the amount of data available for a stock, and has the ability to incorporate different factors into its analyses, such as changes in biology or fishery behavior over time. As a result of the workshop, assessment models using Stock Synthesis are now being developed for at least 4 species, including Black Sea turbot.

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f) Extending catch-only Stock Synthesis models to include indices of abundance

This work provides an extension of the Stock Synthesis (SS) catch-only method (SS-CO or SSS (Cope 2012)) by including indices of abundance, and in a couple of cases, length composition data. The resultant catch limits and other management quantities of this extended SSS model (exSSS) is compared against the category 1 assessment base case models to indicate how well these data-limited models perform relative to assessments considered “the best available science”.

For more information, please contact Jason Cope at Jason.Cope@noaa.gov

g) Spawning biomass reference points for exploited marine fishes, incorporating taxonomic and body size information

Investigators: J.T. Thorson, J.M. Cope, T.A. Branch, and O.P. Jensen

Surplus production represents the processes that affect sustainable fishery harvest and is central to the ecology and management of marine fishes. Taxonomy and life history influence the ratio of spawning biomass at maximum sustainable yield to average unfished spawning biomass (SBMSY/SB0), and estimating this ratio for individual stocks is notoriously difficult. A database of published landings data and stock assessment biomass estimates was used to determine that process errors predominate in this data set by fitting a state–space model to data from each stock individually. Multispecies process-error models were then fit while treating SBMSY/SB0 as a random effect that varies by taxonomic order and maximum length. The estimated SBMSY/SB0 = 0.40 for all 147 stocks is intermediate between the values assumed by the Fox and the Schaefer models, although *Clupeiformes* and *Perciformes* have lower and *Gadiformes* and *Scorpaeniformes* have higher SBMSY/SB0 values. Model selection supports the hypothesis that large-bodied fishes for a given taxonomic order have relatively higher SBMSY/SB0. Results can be used to define reference points for data-poor fisheries or as input in emerging assessment methods.

For more information, please contact James Thorson at James.Thorson@noaa.gov

h) Development and application of an agent-based model to evaluate methods for estimating stock abundance for shoaling fishes such as Pacific rockfish (*Sebastes* spp.)

Investigators: J.T. Thorson, I. Stewart and A. Punt

Bottom trawl sampling is used to estimate trends in stock abundance for groundfishes worldwide including Pacific rockfishes (*Sebastes* spp.). However, trawl sampling efficiency varies spatially, and the distribution of groundfish populations may change among easy- and difficult- to-survey areas over time. These concerns have prompted interest in using underwater vehicles (UVs), for which catchability is likely to decrease less in rocky habitats. In this study, we use simulation modeling to evaluate the abundance trends arising from bottom trawl sampling given density-dependent habitat selection and spatially-varying catchability. We first demonstrate that relative abundance indices in this case will generally be biased measures of changes in population abundance. We also propose and evaluate a sampling design that combines data from bottom trawl and UV gears. Combined sampling has greater precision than UV sampling, lower bias than bottom trawl sampling, and is robust to moderately-violated assumptions regarding sampling strata or spatial catchability. We conclude by recommending future research that could test the assumptions under which combined sampling is a feasible solution to spatially-varying catchability.

For more information, please contact James Thorson at James.Thorson@noaa.gov

i) Applied science for informed management: The supporting role of NWFSC science in Pacific west coast groundfish management

As appointed stewards of our nation's marine ecosystems, NOAA's National Marine Fisheries Service counts among its goals sustainable fisheries and recovered protected species. These goals prescribe a balance among the following objectives: maintenance of healthy fisheries, elimination of overfishing, rebuilding of overfished stocks, and increasing the long-term economic and social benefits to the nation. This complex task requires the comprehensive expertise of biologists, fisheries scientists, economists, social scientists, and policy analysts to help inform the Pacific Fishery Management Council's (PFMC) management decisions. The author described one aspect of this process: how NWFSC data and analytical products provide science-based information critical to advising management actions in the socially, culturally, and economically important Pacific west coast groundfish fishery.

For more information, please contact Jason Cope at Jason.Cope@noaa.gov

j) Change we can perceive in: Using the concepts of "status", "scale", and productivity" to interpret changes in management quantities across stock assessments as applied to U.S. west coast groundfishes

Investigators: J.M. Cope, O. Hamel, C. Niles, J. DeVore, E.J. Dick, J. Grebel, and R. Jones

Fisheries stock assessments provide the scientific information used to calculate management quantities (e.g., maximum sustainable yield, the overfishing level, and time to rebuild) for application in precautionary fisheries management. Uncertainty in data inputs and model specification, though, can change our perception of a stock's population dynamics from assessment to assessment, and thus the resultant management quantities. These changes can be complex and technical in nature, sometimes resulting in what may seem to be contradictory outcomes. For instance, a new assessment may demonstrate that an overfished stock is more depleted than previously determined, yet able to support higher forecasted catches. Changes in assessment results like these have been particularly consequential to the Pacific Fishery Management Council's efforts to rebuild overfished stocks. Three general stock assessment concepts that help reconcile such apparent management contradictions include: (1) "Status" refers to what proportion of a stock's abundance remains since fishing began; (2) "Scale" describes the absolute level of biomass; and (3) "Productivity" is the internal capacity of a population to grow. These three dimensions are represented using simple metrics. Changes in these metrics from assessment to assessment explain directional changes in the management quantities. This method was applied to six groundfishes currently under the Pacific Fishery Management Council's rebuilding plans. This approach allows one to anticipate and interpret changes in important management quantities without requiring a detailed understanding of the

technical complexities involved in modeling past, current, and future trends in stock status and abundance.

For more information, please contact Jason Cope at Jason.Cope@noaa.gov

k) Advice for estimating fishery management reference points given low frequency between-year environmental variability

Investigators: M.A. Haltuch, A.E. Punt, and M.W. Dorn

There is strong evidence that low frequency between-year environmental variability, in addition to fishing, is able to affect fish population abundance via recruitment. However, scientific advice regarding catch limits is often based on control rules that depend on the estimation of biomass reference points which typically do not explicitly consider the effects of trends over time in reference points caused by environmental variability. Harvest rates based on commonly used biological reference points such as the level of un-fished spawning biomass (B0), the current size of the stock in relation to B0, and BMSY that are sustainable under current environmental conditions may be unsustainable under different environmental conditions. Although several methods exist for estimating biomass reference points, it is unclear which of these are most robust to the effects of long term, low frequency environmental variability. Therefore, simulation is used to evaluate alternative estimators, which differ in terms of how the stock–recruitment relationship is modeled, and whether explicit estimators or proxies are used for B0, the steepness of the stock–recruitment relationship, and current spawning biomass relative to B0. The simulations consider three life histories: a long-lived unproductive rockfish, a moderately long-lived and productive flatfish, and a moderately long-lived and productive hake with highly variable recruitment. Results indicate that in the presence of low frequency autocorrelated forcing of recruitment, biomass reference points should be based on average recruitment and/or dynamic B0 if catch and survey data are available for at least one full period of the environmental variable. In contrast, previous analysis suggests that in the absence of autocorrelated environmental forcing of recruitment, and if the available catch and survey data do not span at least, in this case, 50 years which is one full period of the environmental variable, biomass reference points should be based on the fit of the stock–recruitment relationship. Life history affects the estimability of biomass reference points, which are more difficult to estimate for species with more rapid dynamics such as hake. The method used to calculate the reference points given the results of a stock assessment has a larger effect on estimability than the configuration of the stock assessment method, for the three stock assessment model configurations investigated in this study.

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l) Projecting U.S. west coast sablefish (*Anoplopoma fimbria*) recruitment under global climate change scenarios

Investigators: M.A. Haltuch, N.A. Bond, and M.J. Schirippa

U.S. west coast sablefish (*Anoplopoma fimbria*) recruitment has been correlated with changes in July sea surface height (SSH) measured at Crescent City, CA. This SSH index has been correlated with zooplankton abundance and previous research suggests that feeding conditions as indexed by zooplankton abundance and SSH are the mechanism driving sablefish recruitment. Given that the SSH-recruitment relationship has held up over time it was evaluated as a component of the 2011 sablefish stock assessment model. Assessment results found that the use of the environmental index did not have a large effect on model results due to the reasonably consistent signals from fishery and survey data sources regarding year-class strengths. This analysis focuses on using multi-decadal SSH forecasts to allow management to better respond to shifts in productivity before they occur, rather than refining our 'hindsight' further. Future environmental conditions, as manifested by changes in the timing, dynamics and productivity of the California current ecosystem, via climate change, or cycles similar to the historical period, are considered a significant source of uncertainty in the stock status projections. Therefore, this project investigates methods for scaling between the currently used local environmental covariate and larger scale measurements of SSH such as those produced by SODA for past conditions and IPCC-class climate models for future conditions. This project then produces long term projections of the sablefish population under alternative global climate change scenarios using the 2011 stock assessment to assess possible directional changes in sablefish recruitment on multi-decadal time scales.

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m) A California current bomb radiocarbon reference chronology and petrale sole age validation

Investigators: M.A. Haltuch, O.S. Hamel, K.R. Piner, P. McDonald, C.R. Kastelle and J.C. Field

As petrale sole (*Eopsetta jordani*) is a valuable groundfish harvested in the California Current, proper ageing is important for its assessment and management. This study presents the first bomb radiocarbon reference chronology for the California Current and petrale sole age validation. Break-and-burn and surface ages are negatively biased by approximately 1 year and 2–3 years, respectively. The reference and validation curves are more variable and show a lag in the rate of radiocarbon increase in comparison to most other time series of bomb radiocarbon in marine systems. Upwelling in the California Current produces a lagged rate of increase in radiocarbon levels owing to the introduction and mixing of radiocarbon-depleted deep waters with surface waters that interact with the atmosphere. The variable and lagged rate of radiocarbon increase in the petrale sole data may be due to their spending a substantial portion of their first year of life in areas subject to variable upwelling, illustrating the importance of using reference curves for age validation that are region and species specific when possible.

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n) Evaluating the law and policy of rebuilding overfished groundfish at the Pacific Fishery Management Council

Investigators: C. Niles, J. Budrick, J.M. Cope, E.J. Dick, D.L. Erickson, J. Grebel, R. Jones, R.A. Kosaka, L. Mattes, H.J. Reed, E.C. Waters

The Pacific Fishery Management Council (PFMC) manages eight groundfish stocks under rebuilding plans, all but one being rockfishes of the genus *Sebastes*. The Magnuson Stevens Fishery Conservation and Management Act (MSA) requires the rebuilding to be "as short as possible" (i.e. by closing the fishery) unless delay is justifiable based on specific factors, with the "the needs of the fishing communities" being the most prominent. The MSA limits delay to 10 years for stocks able to rebuild that quickly, yet is ambiguous on the outer time limit for stocks that cannot.

The rebuilding rockfishes present extreme circumstances for these MSA rebuilding provisions. Even absent fishing, some would not be expected to rebuild for decades. The incidental catch allowed in support of commercial and recreational targeting of other groundfish extends the expected rebuilding timeline decades longer for some species. These long rebuilding times have attracted 10 years of litigation. The courts have overturned individual rebuilding plans on two occasions, most recently in April 2010. On both occasions, the courts' main finding was that the long rebuilding times place disproportionate emphasis on short-term economic concerns.

The rebuilding plans are of consuming focus at the PFMC. The authors focused on key aspects of the courts' analysis while providing context for two related presentations on the PFMC's rebuilding experience. They evaluated the courts' treatment of rebuilding against the principles of fisheries science and management and show how the lines between law, science, and policy have blurred. Particular attention was paid to the assumption about overemphasis of short-term economics and how this assumption has gone untested. The authors then argue for analysis of the MSA's rebuilding provisions based on long-term conservation tradeoffs.

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o) Analysis of fishery-independent hook and line-based data for use in the stock assessment of bocaccio rockfish (*Sebastes paucispinis)*

Investigators: J. Wallace, J. Harms, I. Stewart

Fishery-independent surveys are an important source of information for stock assessment and management worldwide. Research surveys often use trawl gear to capture commercially valuable species and calculate indices of relative abundance or density. However, many species of interest do not occur in direct contact with the bottom, or occur in areas where high-relief habitat precludes trawl operation. This analysis introduces a standardized hook-and-line survey for rockfish conducted by the Northwest

Fisheries Science Center in the Southern California Bight. The survey uses rod-and-reel fishing gear similar to that used in many recreational fisheries to sample nearly 100 locations covering a wide range of depths and habitats. To provide an example of how these data can be analyzed for direct inclusion in stock assessments, we standardize catch rates of bocaccio rockfish from 2004 – 2011 using a Bayesian Generalized Linear Model to account for site, fishing time, survey vessel, angler, and other effects. Results are more precise than other indices of abundance that are currently available and indicate the bocaccio stock in the southern California Bight has shown a relatively flat trend over recent years. This survey is likely to be the only available tuning index for recent years as historically-used recreational catch per unit effort indices have been largely compromised due to changes in bag-limits and other management restrictions.

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p) Assessing the quality of life history information in FishBase, a publicly available database

Investigators: J.T. Thorson, J.M. Cope, and W. Patrick

Single-species life history parameters are central to ecological research and management, including the fields of macro-ecology, fisheries science, and ecosystem modeling. However, there has been little independent evaluation of the precision and accuracy of the life history values in global and publically available databases. The authors develop a novel method based on a Bayesian error-in-variables model that compares database entries with estimates from local experts, and illustrate this process by assessing the accuracy and precision of entries in FishBase, one of the largest and oldest life history databases. This model distinguishes biases among seven life history parameters, two types of information available in FishBase (i.e., published values and those estimated from other parameters) and two taxa (i.e., bony and cartilaginous fishes) while accounting for additional variance caused by sex- and region-specific life history traits. For published values in FishBase, the model identifies a small positive bias in natural mortality and negative bias in life span, perhaps caused by unacknowledged mortality caused by fishing. For life history values calculated by FishBase, the model identified large and inconsistent biases. The model also demonstrates greatest precision for body size parameters, decreased precision for values derived from geographically distant populations, and greatest between-sex differences in age at maturity. The authors recommend that parameter estimates be used in future error-in-variables models as a prior on measurement errors. This approach is broadly applicable to global databases of life history traits, and if used, will encourage further development and improvements in these databases.

For more information, please contact James Thorson at James.Thorson@noaa.gov

q) Improved biological realism in the design and analysis of surveys

Ecological research frequently uses survey data to provide interpretable estimates of biological processes and behaviors and information regarding changes in relative

abundance over time. However, the models that are commonly used to analyze survey data are susceptible to errors and biases when biological and behavioral assumptions are violated. Several novel survey analysis methods were tested that are robust to behaviors that are likely to be present for many fish and animal populations worldwide.

A mixture distribution model was examined that incorporates shoaling behaviors for Pacific rockfish and an agent-based simulation model was developed that is used to test the relative accuracy of the mixture distribution and conventional models when estimating an annual index of abundance for shoaling and non-shoaling species. Several sampling designs were proposed that incorporate data from bottom trawl and *in situ* underwater vehicles (ISUVs). Finally, a multi-state, robust design tag-resighting model was developed that accounts for range expansion and skip-nesting behaviors, which is demonstrated by application to sea turtle populations in South Africa.

The mixture distribution models confirm that shoaling behaviors are implicated in the extreme catches that are occasionally observed for Pacific rockfish, and the simulation results demonstrate that the mixture model can improve accuracy of resulting indices of abundance for shoaling species without appreciably increasing errors for non-shoaling species. Simulation modeling shows that the sampling designs for combined bottom trawl and ISUVs can decrease the biases caused by spatially-varying catchability while increasing accuracy compared with trawl sampling. The tag-resighting model supports the hypothesis that an apparent lack of population recovery for leatherback sea turtles is being caused by range expansion rather than longline fishing effort. In summary, increased biological realism in biological models is useful to account for spatial behaviors that are likely to be present for many fish and animal species worldwide.

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r) Ichs, herps, and splines: How approximating time-varying parameters can improve model accuracy and interpretability

Many population dynamics models can be estimated with time-varying parameters. Conventional estimation approaches and software packages for capture-mark-recapture, occupancy, and stock assessment models present the choice between constant and annually varying forms for parameters representing survival, detectability, and abundance (to name a few examples). Time-constant parameters may results in biased estimation, while annually varying forms may not be parsimonious, estimable, or interpretable given available data.

A fixed-knot spline approximation to time-varying parameters was examined, where the Akaike Information Criterion was used to select an appropriate degree of smoothness, which includes both constant and annually varying forms as extreme cases. The simulation modeling was first used with data for 53 species of chondricthyes in Australia to demonstrate the improvements in accuracy and parsimony arising from this approximation in occupancy models. Data for two sea turtle species in South Africa was then used to demonstrate improvements in interpretability arising from this approximation in multistate, robust design capture-mark-recapture models. Other model

types and applications for which this approximation may be appropriate were discussed. These applications can potentially improve accuracy, parsimony, or interpretability for a variety of model and data types.

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s) Growth variability of the splitnose rockfish (*Sebastes diploproa*) in the Northeast Pacific Ocean: Pattern revisited

Investigators: V.V. Gertseva, J.M. Cope, and S.E. Matson

Understanding patterns of somatic growth within populations greatly contributes to fisheries stock assessment. Splitnose rockfish, *Sebastes diploproa*, was reported as having a striking pattern of latitudinal growth variability from studies conducted in the 1980s. We investigated variation in growth parameters of splitnose rockfish by latitude using recent data from the NOAA Fisheries Groundfish Survey (2003- 2008), current ageing techniques, and advanced modeling and statistical methods to provide an updated understanding of growth along this species' latitudinal range. Sex-specific age data were fit to a von Bertalanffy growth function incorporating ageing error, and growth parameters were estimated for 5 areas along the U. S. west coast, specified based on biogeographic boundaries. Resampled values of each growth parameter were then fit to linear models, and Akaike's information criterion (AIC) was used to evaluate hypotheses for growth parameter relationship with latitude. We found that splitnose rockfish exhibited a cline in asymptotic length (L-infinity), with L-infinity increasing with rising latitude. We also found that although the growth coefficient (k) was smallest in the most southern area, there was no apparent cline along the coast; a northward cline in k has previously been reported in the literature. We propose that differences in fishing intensity could be responsible for the cline in L-infinity, as higher fishing pressure in the south could skew the size distribution of the population in that region and reduce southern L-infinity estimates. We also attribute slower growth in the southern area to oceanographic characteristics and low productivity of the area south of Point Conception.

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t) Preliminary life history variability of longnose skate (*Raja rhina*) across two large marine ecosystems: Gulf of Alaska and California Current System

Investigators: C. Gburski, T. Helser, V.V. Gertseva, J.R. King, and D.A. Ebert

The longnose skate, *Raja rhina*, is common in the eastern North Pacific Ocean ranging from the Bering Sea to Baja California and occurs from close inshore to a maximum of 1000 m depth. In the Gulf of Alaska (GOA), it has a maximum total length and age of 145 cm and 25 years, respectively. A directed fishery for *Raja* spp. off Kodiak Island, Alaska was initiated in 2003, ending in 2005. An experimental fishery in Prince William Sound, Alaska was reinstated in 2009. The vulnerability of elasmobranchs to over exploitation from commercial fishing, either from bycatch or a directed fishery, is well-documented. This inter-agency and institutional (AFSC, NWFSC, DFO and

MLML/PSRC) collaborative study quantitatively compares growth and age/size at sexual maturity of the longnose skate across two large marine ecosystems, the GOA and California Current Ecosystem (CCE), on a spatial and temporal scale. Potential environmental (e.g., bottom water temperature) and oceanographic influences on life history traits between the GOA and CCE are also examined. Vertebrae (n=500) for this study were collected off the GOA, British Columbia (BC) 'current break' and U.S. west coast states between 2001 and 2009 from research surveys and via port sampling. Ages were estimated from vertebrae prepared with the standard (unstained) thin sectioning technique in this preliminary study. A new histological (stained) method will be applied to archival vertebrae in the future. Age estimates from the standard technique and a new histological method will be compared to validated ages from a longnose skate 14C study. The methods estimated ages that best fit the validated ages will be used to standardize ageing criteria among agencies therefore optimizing age determination for use in stock assessment and management.

This study was presented at the Western Groundfish Conference in February 2012, in Seattle. This study is a part of larger collaborative study on variability of life history traits of skates across large marine ecosystems.

For more information, please contact Vladlena Gertseva at Vladlena.Gertseva@noaa.gov

u) Summary of stock status for assessed Pacific coast groundfish species

Investigators: J. Hastie, S. Miller, and J.M. Cope

Over the past decade, an increasing number of species have been assessed using methods that allow stock status to be estimated. Some stocks have been found to be in need of rebuilding, and they have had a substantial impact on the management of all sectors of the groundfish fishery. Of these rebuilding stocks, those which have not yet reached rebuilding targets have exhibited continuing growth throughout this period (to the extent that the available data are adequate to discern a trend). A high percentage of the other assessed species, as of their most recent assessments, are either near or above their target levels of spawning potential. The authors summarize trends in the status of assessed Pacific coast groundfish stocks over the last half-century, with particular focus on the recent rebuilding period. They also highlight data, research, and methods that are needed to improve the number and quality of stock-status determinations that are available to inform future management.

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C. By Species, by Agency

The PFMC currently operates under a biennial schedule for the development of stock assessments and management guidance. For all groundfish species except Pacific hake, stock assessments are scheduled for review only during odd-numbered years. The 2012 Pacific hake assessment was reviewed under the auspices of a treaty with Canada for the first time in 2012. A schedule for Stock Assessment Review (STAR) panels for full assessments of species to be conducted in 2013, along with the 2012 Hake Scientific Review Group meeting, is shown in Table 1.

Table 1. 2012 and 2013 Review Schedule for Full Groundfish Assessments.

STAR PANEL	STOCK	AUTHOR(S)	REVIEW PANEL DATES	STAR PANEL LOCATION
Hake SRG* Panel	Pacific hake/ whiting	Ian Stewart Robin Forrest Nathan Taylor Chris Grandin Allan Hicks	February 21-24, 2012	Seattle, WA
Hake SRG* Panel	Pacific hake/ whiting	Allan Hicks Nathan Taylor Chris Grandin Ian Taylor Sean Cox	February 19-22, 2013	Vancouver, British Columbia Canada
1	Data Moderate: Brown, China, Copper, Sharpchin, Stripetail, Vermilion, Yellowtail rockfish; Rex and English sole	Jason Cope E.J. Dick	April 22-26, 2013	Santa Cruz, CA
2	Petrale Sole Darkblotched rockfish	Melissa Haltuch Vlada Gertseva	May 13-17, 2013	Seattle, WA
Updates Data Reports	Bocaccio rockfish Canary rockfish Pacific ocean perch Yelloweye rockfish	John Field John Wallace Owen Hamel Ian Taylor	June 18, 2013	Garden Grove, CA
3	Rougheye rockfish Aurora rockfish	Allan Hicks Owen Hamel	July 8 – 12, 2013	Seattle, WA
4	Shortspine thornyhead Longspine thornyhead	Ian Taylor Andi Stephens	July 22 -26, 2013	Seattle, WA
5	Cowcod Pacific sanddab	E.J. Dick Xi He	August 8-12, 2013	Santa Cruz, CA

*****Scientific Review Group – for international review of Pacific hake under treaty with Canada

1. Shelf Rockfish - West Coast

a) Stock Assessments

No shelf rockfish assessments were conducted during 2012. Full assessments of cowcod and data moderate rockfish species brown, china, copper, sharpchin, stripetail, vermilion, and yellowtail will be conducted in 2013. An update of the 2009 assessment of bocaccio and data reports on canary and yelloweye rockfish will also be conducted in 2013.

Yelloweye rockfish: The complete version of: Status of the U.S. yelloweye rockfish resource in 2011(Update of 2009 assessment model) can be viewed online at:
http://www.pcouncil.org/wp-content/uploads/Yelloweye_2011_Assessment_Update.pdf

For more information on the yelloweye rockfish assessment please contact Ian Taylor at Ian.Taylor@noaa.gov

Widow rockfish: The complete version of: Status of the widow rockfish resource in 2011 can be viewed online at:
http://www.pcouncil.org/wp-content/uploads/Widow_2011_Assessment.pdf

Bocaccio: An update of the 2009 bocaccio assessment will be conducted in 2013 by the SWFSC. The complete version of: Status of bocaccio, *Sebastes paucispinis*, in the Conception, Monterey and Eureka INPFC areas for 2009 can be viewed online at:
http://www.pcouncil.org/wp-content/uploads/Bocaccio_Final_Jan15_2010.pdf

Greenstriped rockfish: The complete version of: Status of greenstriped rockfish (*Sebastes elongatus*) along the outer coast of California, Oregon, and Washington can be viewed online at:
http://www.pcouncil.org/wp-content/uploads/GreenstripedSAFE.pdf

For more information on the greenstriped rockfish assessment, contact Allan Hicks at Allan.Hicks@noaa.gov

Canary rockfish: The complete version of: Status of the U.S. canary rockfish resource in 2011 can be viewed online at:
http://www.pcouncil.org/wp-content/uploads/Canary_2011_Assessment_Update.pdf

For more information on the canary rockfish assessment, contact John Wallace at John.Wallace@noaa.gov

Cowcod: The complete version of: Updated status of cowcod, *Sebastes levis*, in the Southern California Bight can be viewed online at:
http://www.pcouncil.org/wp-content/uploads/cowcod_update_assessment_2009.pdf

Greenspotted rockfish: The complete version of: Status of greenspotted rockfish, *Sebastes chlorostictus*, in U.S. waters off California can be viewed online at:

http://www.pcouncil.org/wp-content/uploads/Greenspotted_Rockfish_2011_Assessment.pdf

2. Slope Rockfish

a) Stock assessments

No slope rockfish assessments were conducted during 2012. Full assessments of darkblotched, rougheye, and aurora rockfish and a data report on Pacific ocean perch will be conducted in 2013.

Blackgill rockfish: The complete version of: Status of the blackgill rockfish, *Sebastes melanostomus*, in the Conception and Monterey INPFC areas for 2011 can be viewed online at:
http://www.pcouncil.org/wp-content/uploads/Blackgill_2011_Assessment.pdf

For more information on blackgill rockfish please contact John Field at John.Field@noaa.gov.

Darkblotched rockfish: The complete version of: Status and future prospects for the darkblotched rockfish resource in waters off Washington, Oregon, and California in 2011 can be viewed online at:
http://www.pcouncil.org/wp-content/uploads/Darkblotched_2011_Assessment.pdf

For more information on darkblotched rockfish please contact Andi Stephens at Andi.Stephens@noaa.gov

Pacific ocean perch: The complete version of: Stock assessment of Pacific ocean perch in waters off the U.S. West Coast in 2011 can be viewed online at:
http://www.pcouncil.org/wp-content/uploads/Pacific_Ocean_Perch_2011_Assessment.pdf

For more information on Pacific Ocean perch, contact Owen Hamel at Owen.Hamel@noaa.gov.

3. Thornyheads

a) Stock Assessments

No thornyhead assessments were conducted during 2012. Full assessments of the shortspine and longspine thonyhead will be conducted in 2013.

For more information on thornyheads, contact Ian Taylor at Ian.Taylor@noaa.gov.

4. Sablefish

a) Stock Assessments

No sablefish assessment was conducted in 2012 and none is planned for 2013. The complete version of: Status of the U.S. sablefish resource in 2011 can be viewed online at:
http://www.pcouncil.org/wp-content/uploads/Sablefish_2011_Assessment.pdf

For more information on sablefish, contact James Thorson at James.Thorson@noaa.gov.

5. Flatfish

a) Stock Assessments

No assessments for flatfish were conducted during 2012. Full assessments of petrale sole, rex sole, English sole, and Pacific sanddab are planned for 2013.

Dover sole: The complete version of: The status of Dover sole (*Microstomus pacificus*) along the U.S. West Coast in 2011 can be viewed online at:

http://www.pcouncil.org/wp-content/uploads/DoverSole_2011_DRAFT_Assessment.pdf

For more information, please contact Allan Hicks at Allan.Hicks@noaa.gov

Petrale sole: The complete version of: Status of the U.S. petrale sole resource in 2010 can be viewed online at:

http://www.pcouncil.org/wp-content/uploads/Petrale_2011_Assessment.pdf

For more information, please contact Melissa Haltuch at Melissa.Haltuch@noaa.gov

6. Pacific Hake

This assessment reports the status of the coastal Pacific hake (or Pacific whiting, *Merluccius productus*) resource off the west coast of the United States and Canada. This stock exhibits seasonal migratory behavior, ranging from offshore and generally southern waters during the winter spawning season to coastal areas between northern California and northern British Columbia during the spring, summer and fall when the fishery is conducted. In years with warmer water temperatures the stock tends to move farther North during the summer and older hake tend to migrate farther than younger fish in all years. Separate, and much smaller, populations of hake occurring in the major inlets of the northeast Pacific Ocean, including the Strait of Georgia, Puget Sound, and the Gulf of California, are not included in this analysis.

This assessment reports a single base-case model representing the collective work of the Joint Technical Committee (JTC). The assessment depends primarily upon the acoustic

survey biomass index (1995, 1998, 2001, 2003, 2005, 2007, 2009 and 2011) for information on the scale of the current hake stock. The 2011 index value is the lowest in the time-series. The aggregate fishery age-composition data (1975-2011) and the age-composition data from the acoustic survey contribute to the assessment model's ability to resolve strong and weak cohorts. Both sources show a strong 2008 cohort, but differ somewhat in the relative magnitude of the weaker 2005 and 2006 cohorts.

The assessment is fully Bayesian, with the base-case model incorporating prior information on two key parameters (natural mortality, *M*, and steepness of the stock-recruit relationship, *h*) and integrating over estimation and parameter uncertainty to provide results that can be probabilistically interpreted. The base-case stock assessment model indicates that the Pacific hake female spawning biomass was well below the average unfished equilibrium in the 1960s and 1970s. The stock is estimated to have increased rapidly after two or more large recruitments in the early 1980s, and then declined rapidly after a peak in the mid- to late 1980s to a low in 2000. This long period of decline was followed by a brief increase to a peak in 2003 (median estimate of 1.29 million mt in the SS model) as the exceptionally large 1999 year class matured. The stock is then estimated to have declined with the aging 1999 year class to a time-series low of 0.38 million mt in 2009. This recent decline is much more extreme than that estimated in the 2011 assessment. The current median posterior spawning biomass is estimated to be 32.6% of the average unfished equilibrium level (SB_0). However, this estimate is quite uncertain, with 95% posterior credibility intervals ranging from historical lows to above the average unfished equilibrium levels. The estimate of 2012 is 0.62 million mt, much smaller than the two estimates in the 2011 assessment (1.87, and 2.18 million mt). This change is largely driven by the very low 2011 acoustic survey biomass index. Recent catch and levels of depletion are presented in figure 3.

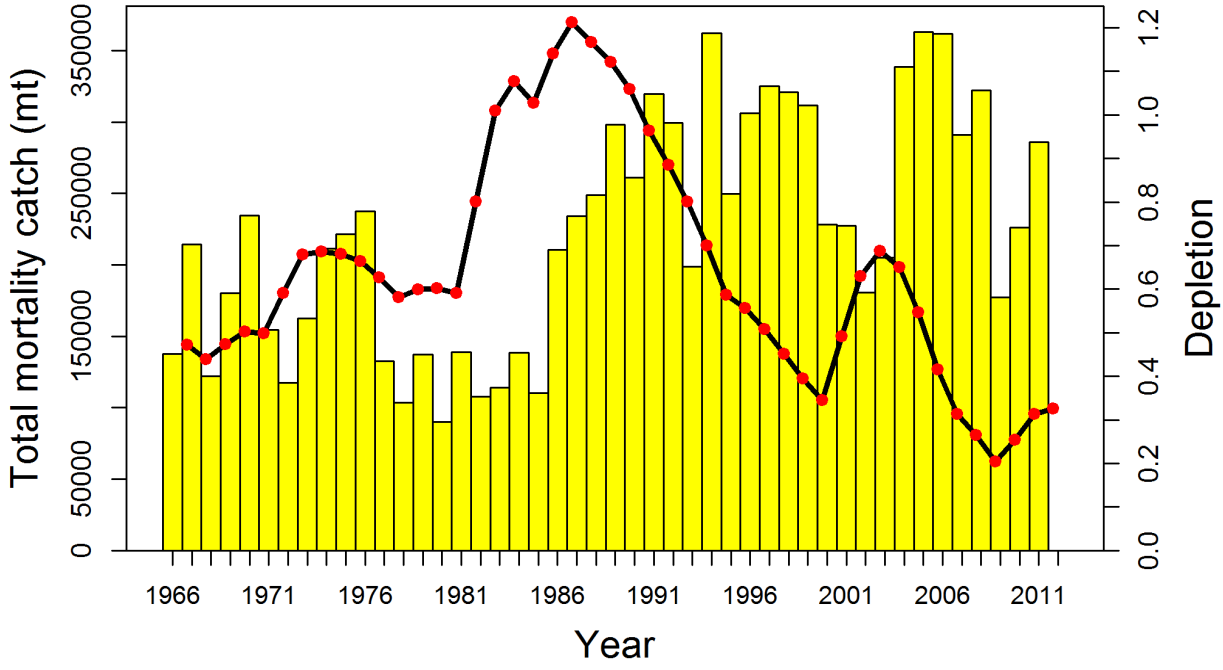

Figure 3. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Pacific hake, 1966-2012.

The complete document: "Status of the Pacific hake (Whiting) stock in U.S. and Canadian Waters in 2012" can be viewed online at:

http://www.nwr.noaa.gov/fisheries/management/whiting/pacific_whiting.html

For more information on the Pacific hake assessment, please contact Allan Hicks at Allan.Hicks@noaa.gov

7. Other species

a) Stock assessments

Cabezon: The complete version of: Status of cabezon (*Scorpaenichthys marmoratus*) in California and Oregon Waters as assessed in 2009 can be viewed online at:

http://www.pcouncil.org/wp-content/uploads/Cabezon09_FINAL.pdf

For more information, please contact Jason Cope at Jason.Cope@noaa.gov

Lingcod: The complete version of: Status and future prospects for lingcod in waters off Washington, Oregon, and California as assessed in 2009 can be viewed online at: http://www.pcouncil.org/wp-content/uploads/Lingcod_Assessment_2009_Final_SAFE_version.pdf

For more information, please contact Owen Hamel at Owen.Hamel@noaa.gov

Spiny dogfish: The complete version of: Status of the spiny dogfish resource off the continental U.S. Pacific Coast in 2011 can be viewed online at:

http://www.pcouncil.org/wp-content/uploads/Spiny_Dogfish_2011_Assessment.pdf

For more information, please contact Vlada Gertseva at Vlada.Gertseva@noaa.gov

D. Other Related Studies

1. The PaCOOS, West Coast habitat data portal

The PaCOOS West Coast Habitat Data Portal and associated server, were conceived in 2005 as a Local Data Access Center (LDAC) of the Integrated Ocean Observing System (IOOS). Funding for its development was provided by the NOAA IOOS Program through the FRAM Division of the Northwest Fisheries Science Center. The database and GIS system had its origin the data collected together for the West Coast Essential Fish Habitat Environmental Impact Statement, which was completed in 2005/2006. Maintained jointly by FRAM and Oregon State University, College of Oceanic and Atmospheric Sciences Seafloor Mapping Laboratory and in collaboration with PSMFC, the portal provides access to data (search, connection, and download), a visualization environment, and integrated navigation tools. The data portal houses an ever expanding array of information including but not limited to geological and geophysical data, benthic habitat maps, fisheries survey datasets, and ocean climatologies. Data access, which includes data searching and metadata harvesting, is provided through IOOS Data Management and Communications (DMAC) compliant pathways such as OPeNDAP, OGC WMS, and ESRI ArcIMS map services. The portal's centerpiece is its unique map viewer environment (http://pacoos.coas.oregonstate.edu/), an online application that provides a map interface to data holdings with custom tools for data downloads and queries. There is a growing user base that includes local, state, and federal agencies within the California Current Large Marine Ecosystem.

The functionality of the PaCOOS data portal is continually being improved and new data sets are being added. During the latter part of 2011 and continuing into 2012, the Active Tectonics and Seafloor Mapping Lab will transition the PaCOOS server from ESRI ArcIMS Internet Map Server software to the current ESRI ArcGIS Server software, and upgrade the application underlying the West Coast Habitat server. Datasets and metadata developed as part of the current Pacific coast groundfish EFH 5-year review will be placed on the PaCOOS West Coast Habitat Server. During the transition period, all new information and updates will be placed on the "Consolidated GIS Data Catalog and Online Registry for the 5-Year Review of Pacific Coast Groundfish EFH (or EFH Catalog for short) at http://efh-catalog.coas.oregonstate.edu/overview/).

For more information, contact Waldo Wakefield at waldo.wakefield@noaa.gov, Chris Goldfinger at gold@coas.oregonstate.edu or Chris Romsos at cromsos@coas.oregonstate.edu

2. Bycatch Reduction Research

Recent Conservation Engineering Work In US West Coast Groundfish Fisheries

Beginning in 2004, the NOAA Fisheries Northwest Fisheries Science Center (NWFSC) initiated a fisheries conservation engineering program within its Fisheries Resource Analysis and Monitoring Division. Through key regional collaborations with the Pacific States Marine Fisheries Commission, Oregon Department of Fish and Wildlife, Alaska

Fisheries Science Center, and the fishing industry, the NWFSC has been able to pursue a wide-ranging array of conservation engineering projects relevant to reducing bycatch and habitat impacts from mobile fishing gear in the west coast groundfish trawl fishery. In the past two years, these projects include: 1) Reducing Chinook salmon, rockfish, and Pacific halibut bycatch in west coast groundfish fisheries using bycatch reduction devices, 2) Bycatch reduction in the ocean shrimp fishery (juv. groundfishes, ESA listed eulachon, megafaunal invertebrates, 3) Providing loaner video camera systems to the fishing industry, 4) Examining selectivity characteristics of codends that differ in mesh size and configuration in the bottom trawl fishery. Much of our current work has been in response to the fishing industries rising concerns over IBQ (Individual Bycatch Quota) for Pacific halibut allocated in the Pacific coast Groundfish Trawl Rationalization Catch Share Program. The trawl rationalization program, starting in January 2011, (through amendments to the Groundfish Fisheries Management Plan) will establish formal Annual Catch Limits (ACLs) and individual catch share quotas. It has been projected that these complex fishery management measures will create increased demand for bycatch solutions in the groundfish trawl fishery. In addition to ACLs, fishing opportunities may also be limited by hard caps or IBQs for non-groundfish species (e.g., ESA Chinook salmon in the Pacific hake fishery and Pacific halibut in the bottom trawl fishery). Bycatch of overfished species in the west coast groundfish trawl fishery has the potential to constrain the fishery such that a substantial portion of available harvest may be left in the ocean.

Reducing Chinook Salmon and Rockfish Bycatch in the Pacific hake Fishery

In 2012, the NWFSC and PSMFC conducted a pilot study testing the efficacy of a flexible sorting grid rockfish excluder in the U.S. Pacific hake fishery. This project was the outcome of a collaborative workshop between agencies and the fishing industry. This study examined two versions of a flexible sorting grid rockfish excluder in the U.S. Pacific hake fishery. The designs tested (design-A and design-B) were developed following a collaborative workshop held between gear researchers and Pacific hake fishing industry participants. Tests occurred off Oregon and Washington during 2012 aboard the F/V Perseverance. A recapture net was used to quantify the escapement of Pacific hake and non-target species. Both designs retained a relatively high proportion of Pacific hake (>93%). However, the two designs did not perform equally with design-B being much more effective at reducing bycatch. Results showed rockfish bycatch was reduced by 70.2% under design-B and only 15.4% under design-A. For both designs, the mean lengths of Pacific hake caught between the codend and the recapture net did not differ significantly. A reduction in the catch of Pacific halibut and Chinook salmon, which are prohibited take species, was also noted. Unfortunately, both designs tested were only effective under slow-to-moderate fish volumes. Under heavy fish volumes both designs tended to clog. Results of this research suggest there is potential for reducing rockfish bycatch in the Pacific hake fishery using a flexible sorting grid excluder.

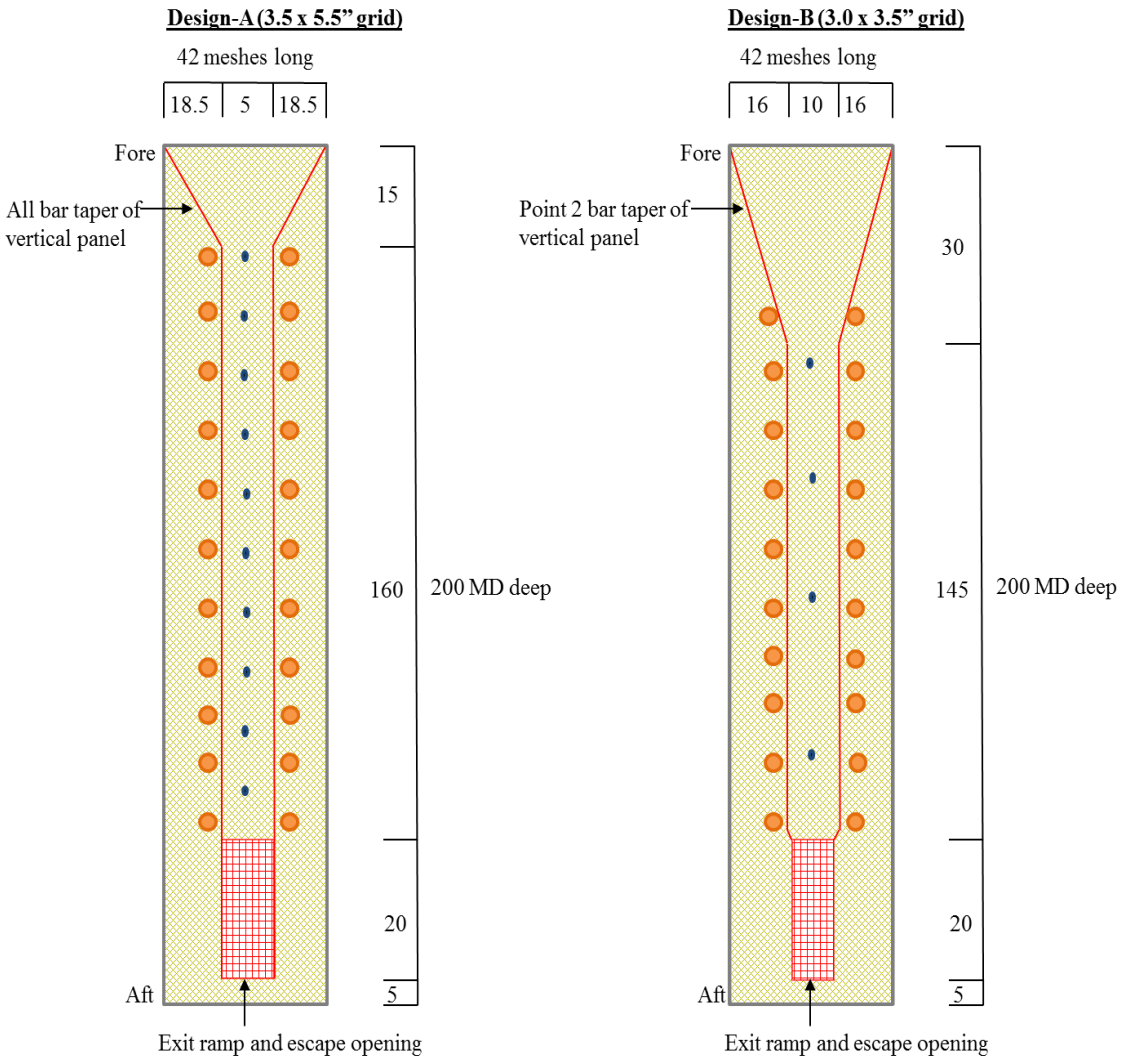

Figure 4. Top view diagram depicting the differences between design-A and B. Solid red lines represent the vertical sorting panels, whereas the red grids represent the exit ramp. The orange circles represent 8" centerhole floats. The blue oval shapes represent the ropes with chaffing gear wedged through them. MD = diamond mesh. Note: this diagram is not drawn to scale.

Figure 5. Photos illustrating results from a tow when testing design-B. Left image shows a portion of the codend catch (mostly Pacific hake), whereas the right top image shows the entire recapture net catch (mixture of rockfishes and Pacific hake). The bottom right image shows baskets of rockfishes sorted (mixture of yellowtail rockfish, widow rockfish, and rougheye rockfish) from the recapture net catch. For this tow the retention of hake was 95.1% while the escapement of rockfishes was 71.1%.

For more information, contact Waldo Wakefield at Waldo.Wakefield@noaa.gov or Mark Lomeli at MLomeli@psmfc.org or visit
http://www.nwfsc.noaa.gov/research/divisions/fram/habitat.cfm

Reducing Pacific Halibut Bycatch in Bottom Trawl Fisheries

In response to fishermen's concern about Pacific halibut bycatch, the NWFSC and PSMFC tested a flexible sorting grid excluder designed to reduce halibut bycatch in the US west coast groundfish bottom trawl fishery. Tests occurred off Washington during 2011 aboard a commercial trawler. A recapture net was used to quantify the retention rates of target and non-target species. Pacific halibut bycatch was reduced 61.6% by weight and 57.0% by numbers. Exclusion was greatest for Pacific halibut weighing more than 4.5 kg. A significant difference in the mean total length was also noted between Pacific halibut caught in the codend and the recapture net, with larger fish occurring in the recapture net. The retention of primary target groundfishes of marketable size ranged from 76.7 to 89.3%. We demonstrated the capability of a flexible sorting grid excluder to reduce Pacific halibut bycatch in the groundfish bottom trawl fishery while retaining a relatively high proportion of the targeted species.

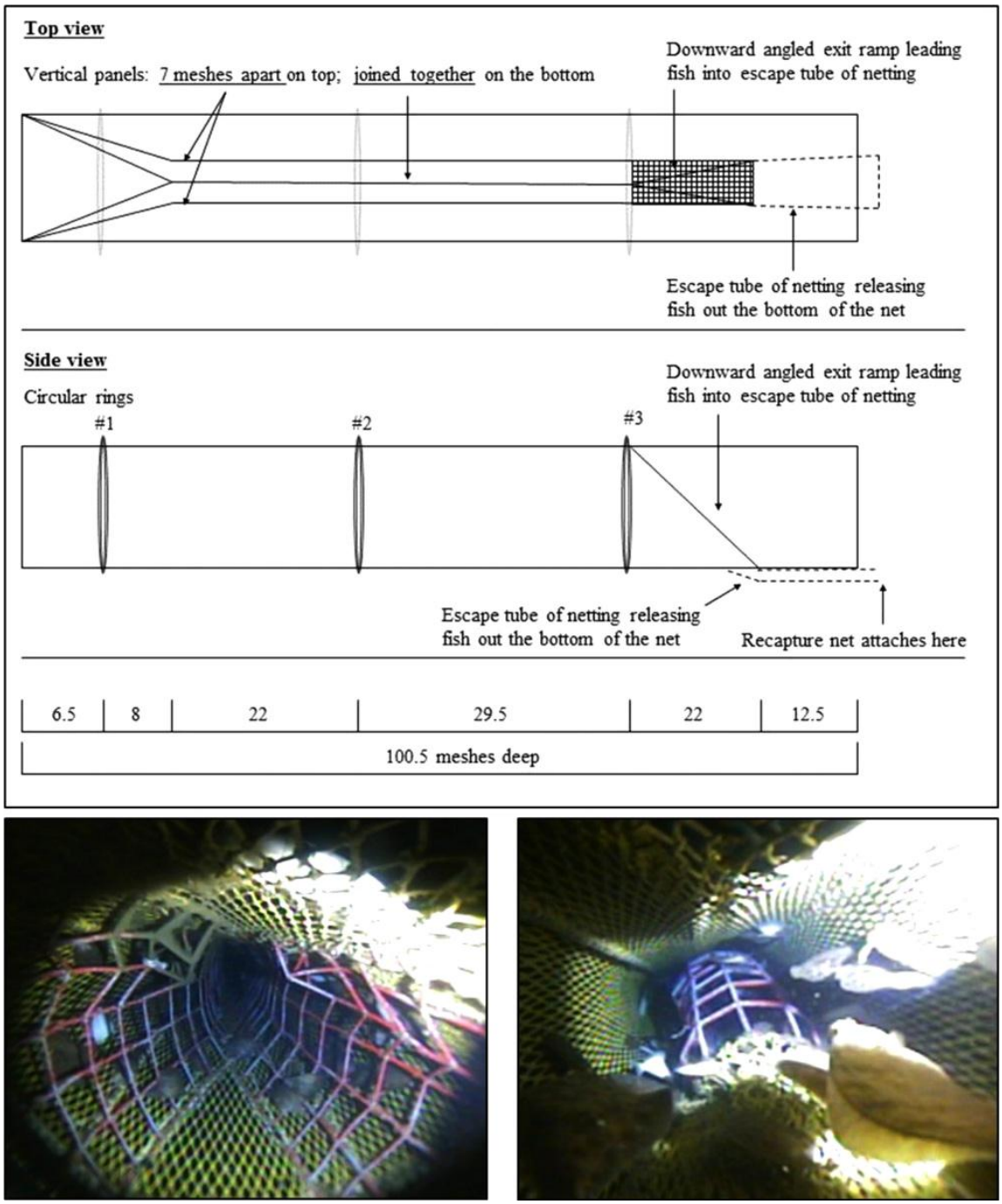

Figure 6. Schematic diagram of the Pacific halibut flexible sorting grid excluder tested (top); aft view of the forward portion of the excluder where fish enter and encounter the device (bottom left); forward view of the downward-angled exit ramp with fish moving aft toward the codend (bottom right).

Figure 7. Comparison of fish caught between the trawl codend and recapture codend during one tow.

For more information, contact Waldo Wakefield at Waldo.Wakefield@noaa.gov or Mark Lomeli at MLomeli@psmfc.org or visit http://www.nwfsc.noaa.gov/research/divisions/fram/habitat.cfm

Providing Direct Observation Video Camera Systems to Fishermen for Use in Evaluating Industry-Designed Approaches to Reducing Bycatch and Impacts to Benthic Habitats

Since 2010, the NWFSC, working in collaboration with PSMFC, has operated an underwater video camera loaner to make systems available to commercial fishers and other sectors of the industry for their use in evaluating industry-designed bycatch reduction devices. In 2011, the NWFSC added two additional video systems to the pool (Figures 8-9). These camera systems have been used extensively across the Pacific hake midwater trawl fishery, groundfish bottom trawl fishery, and the pink shrimp trawl fishery.

For more information, contact Waldo Wakefield at Waldo.Wakefield@noaa.gov or Mark Lomeli at MLomeli@psmfc.org or visit http://www.nwfsc.noaa.gov/research/divisions/fram/habitat.cfm

Figure 8. One of four autonomous direct observation video camera systems developed at the NWFSC.

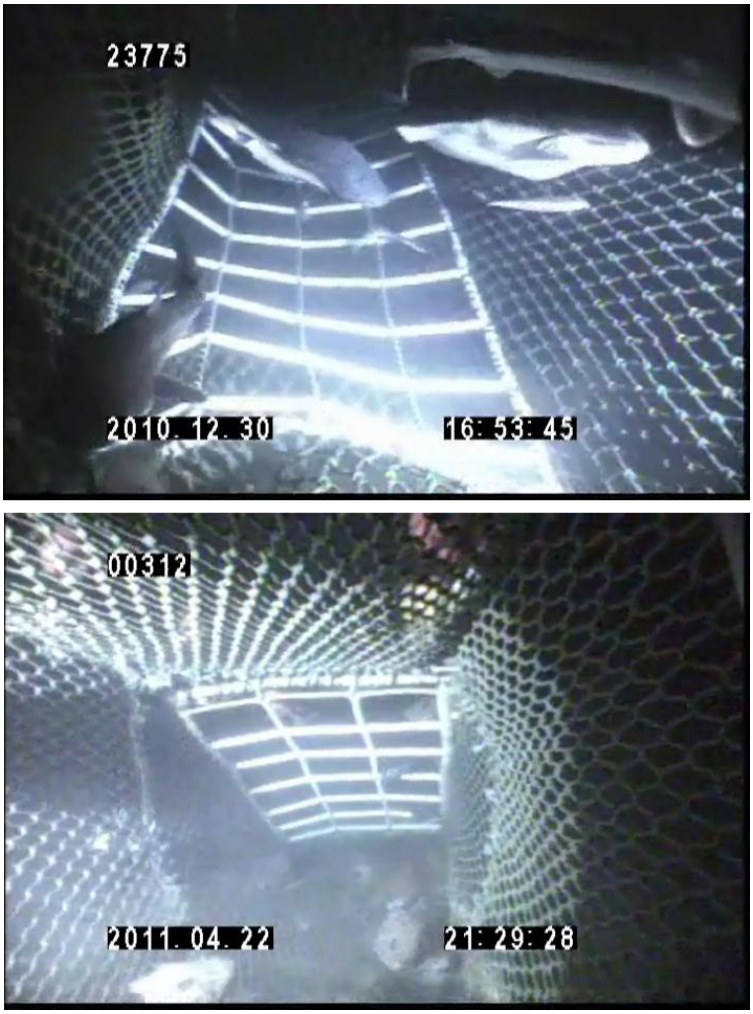

Figure 9. Video frame grabs showing flexible sorting grates developed by the fishing industry to reduce Pacific halibut bycatch in the groundfish bottom trawl fishery. Information gained from the videos was used to improve the performance of the grates.

For more information, contact Waldo Wakefield at Waldo.Wakefield@noaa.gov or Mark Lomeli at MLomeli@psmfc.org or visit
http://www.nwfsc.noaa.gov/research/divisions/fram/habitat.cfm

Effect of mesh size and configuration on codend selectivity in the groundfish bottom trawl fishery

In 2012, the NWFSC, working in collaboration with PSFMC, studied the effect of mesh size and configuration on codend selectivity in the groundfish bottom trawl fishery. This project examined the selectivity characteristics between 4.5 and 5.5" T90 mesh (conventional diamond mesh that has been turned 90° in orientation) and 4.5" diamond mesh codends and evaluated their efficacy at reducing discards in the U.S. west coast groundfish bottom trawl fishery. Findings showed the conventional 4.5" diamond codend was the least effective at reducing discards of juvenile and unmarketable-sized roundfishes and exhibited a relatively high percent loss of marketable-sized flatfishes.

The 5.5" T90 codend was extremely effective at reducing discards of both juvenile and unmarketable-sized flatfishes and roundfishes, however, exhibited a high percent loss of marketable-sized groundfishes. On the other hand, the 4.5" T90 codend retained the highest percentage of marketable-sized groundfishes while effectively reducing discards of juvenile and unmarketable-sized roundfishes, however, it was not as effective at reducing flatfish discards compared to the other codends examined. Results from this research have led fishermen and gear researchers to believe that a 5.0" T90 codend could be effective at reducing the discards of both juvenile and unmarketable-sized flatfishes and roundfishes while maintaining catch levels of marketable-sized groundfishes.

For more information, contact Waldo Wakefield at Waldo.Wakefield@noaa.gov or Mark Lomeli at MLomeli@psmfc.org or visit
http://www.nwfsc.noaa.gov/research/divisions/fram/habitat.cfm

3. Cooperative Ageing Unit

The Cooperative Ageing Project (CAP) operates under a grant from the Northwest Fisheries Science Center to Pacific States Marine Fisheries Commission, and provides direct support for U.S. West Coast groundfish stock assessments by providing fish ages derived primarily from otoliths. In 2012, CAP aged more than 17,000 otoliths from the following species for inclusion in 2013 assessments: Pacific hake, petrale sole, darkblotched rockfish, aurora rockfish and vermillion/sunset rockfish. Work continues through May 2013 on several of those species, as well as rougheye rockfish. CAP also completed over 3,600 age reads of Pacific ocean perch and sablefish, for use in 2015 assessments. CAP continued the practice of recording otolith weights prior to breaking and burning, in support of research into alternative methods of age determination.

For more information, please contact Jim Hastie at Jim.Hastie@noaa.gov

4. Resource Surveys

a) U.S. West Coast Groundfish Bottom Trawl Survey

The NWFSC conducted its fifteenth annual bottom trawl resource survey for groundfish off the coasts of Washington, Oregon, and California. The objective of the 2012 survey was to provide information on the distribution and relative abundance of demersal species within this region at depths from 30 to 700 fathoms. Other biological information necessary to assess the status of groundfish stocks (e.g. length, weight, sex and age structures) was collected throughout the survey period.

The NWFSC chartered commercial fishing vessels to conduct independent, replicate surveys using standardized trawl gear. Fishing vessels *Ms. Julie, Excalibur,* and *Noah's Ark* were contracted to survey the area from Cape Flattery, WA to the Mexican border in Southern California, beginning in the later part of May and continuing through October. Each chartered was for a period of 11-12 weeks with the *Ms Julie* and *Noah's Ark* surveying the coast during the initial survey period from May to July. The *Excalibur,* and *Noah's Ark* operating in tandem, surveyed the coast during a second pass from mid-

August to late October. The survey area was partitioned into ~12,000 adjacent cells of equal area (1.5 nm long. by 2.0 nm lat., Albers Equal Area projection) with each vessel assigned a primary subset of 188 randomly selected cells to sample. An Aberdeen-style net with a small mesh (1 1/2" stretch) liner in the codend was used for sampling. The survey followed a stratified random sampling scheme with 15-minute tows within 2 geographic strata (80% N of Pt. Conception, CA and 20% S) and 3 depth strata. The depth strata were: shallow (30-100 fms), middle (100-300 fms), and deep (300-700 fms). The sample design consisted of 752 sampling locations, with a minimum of 30 tows per strata.

In 2012, we also continued to utilize the FSCS data collection system with updated software applications, and wireless networking. Established NOAA national bottom trawl protocols were used throughout the survey. As in prior years, a series of special research projects were undertaken in cooperation with other NOAA groups and various Universities.

Additional data were collected during the trawl survey for collaborative research projects with several NMFS/academic colleagues: 1) Maternal effects on larval quality in rockfishes – Southwest Fisheries Science Center; 2) Maturity investigations for blackgill rockfish (*Sebastes melanostomus*) – Southwest Fisheries Science Center; 3) Collection of sablefish otoliths, visual maturity information, and finclips for genetic studies along entire coast - AFSC; 4) Record all sightings of basking sharks – Moss Landing Marine Laboratories; 5) Collections of sandpaper skate, *Bathyraja kincaidii* – Moss Landing Marine Laboratories; 6) Collection of any Pacific black dogfish, *Centroscyllium nigrum* - Moss Landing Marine Laboratories; 7) Collection of all unusual or unidentifiable skates, deepsea skate, *Bathyraja abyssicola*, Pacific white skate, *Bathyraja spinossisima*, fine-spined skate, *Bathyraja microtrachys*, Aleutian skate, *Bathyraja aleutica*, and broad skate, *Amblyraja badia*, – Moss Landing Marine Laboratories; 8) Collection of all unusual or unidentifiable sharks including small sleeper sharks, *Somniosus pacificus* - Moss Landing Marine Laboratories; 9) Collection of any chimaera that is not *Hydrolagus colliei*, including: *Harriotta raleighana*, *Hydrolagus* spp. and *Hydrolagus trolli* – Moss Landing Marine Laboratories; 10) Collection of voucher specimens for multiple fish species – Northwest Fisheries Science Center; 11) Collection of vouncher specimens for multiple fish species – Oregon State University; 12) collection of squid species: *Octopoteuthis deletron, Chiroteuthis calyx, Galiteuthis phyllura, Taonius borealis, Vampyroteuthis infernalis, Japetella diaphana, Abraliopsis felis, Histioteuthis heteropsis, Histioteuthis dofleini,* and *Cranchia scabra* – Montery Bay Aquarium Research Institute.

Several other research initiatives were undertaken by the Survey Team including: 1) Use of stable isotopes and feeding habits to examine the feeding ecology of rockfish (genus *Sebastes*); 2) Fin clip collection for various shelf rockfish species; 3) Collection of stomachs for various rockfish species; 4) Collection and identification of cold water corals; 5) Fish distribution in relation to bottom dissolved oxygen concentration in the oxygen minimum zone; 6) Composition and abundance of benthic marine debris collected during the 2012 West Coast Groundfish Trawl Survey from May to October 2012; and 7) Collection of ovaries from hake, aurora rockfish, darkblotched rockfish, sablefish, shortspine thornyheads and canary rockfish to assess maturity.

For more information please contact Aimee Keller at Aimee.Keller@noaa.gov.

b) Southern California shelf rockfish hook-and-line survey

In early Fall 2012, FRAM personnel conducted the ninth hook and line survey for shelf rockfish in the Southern California Bight (SCB). This project is a cooperative effort with Pacific States Marine Fisheries Commission (PSMFC) and the southern California sportfishing industry aimed at developing an annual index of relative abundance and time series of other biological information for structure-associated species of rockfish (genus *Sebastes*) such as bocaccio (*S. paucispinis*), greenspotted rockfish (*S. chlorostictus*), and the vermilion rockfish complex (e.g., *S. miniatus* and *S. crocotulus*) within the SCB.

The F/V *Aggressor* (Newport Beach, CA) and F/V *Mirage* (Port Hueneme, CA) were each chartered for 12 days of at-sea research, with nine biologists participating during the course of the survey. The two vessels sampled a total of 121 sites ranging from Point Arguello in the north to 9 Mile Bank and the US-Mexico EEZ boundary in the south. Approximately 3,314 sexed lengths and weights, 3,209 fin clips, and 3,104 otolith pairs were taken during the course of the entire survey representing 35 different species of fish and 2 invertebrate species.

Several ancillary projects were also conducted during the course of the survey. Ovaries were collected from key species to develop maturity curves. Several dozen individual fish were retained for use in species identification training for west coast groundfish observers and for a genetic voucher program conducted by the University of Washington. Researchers also deployed a new underwater video sled to capture visual observations for habitat analysis, species composition, and fish behavior studies. Work with a patented non-lethal biopsy hook to capture genetic information *in situ* is ongoing.

For more information, please contact John Harms at John.Harms@noaa.gov

c) 2012 joint U.S.-Canada integrated acoustic and trawl survey of Pacific hake and Pacific sardine

The joint U.S.–Canada integrated acoustic and trawl survey was conducted in U.S. and Canadian waters by two U.S. teams (NWFSC/FRAM and SWFSC/FRD) on the NOAA ship *Bell M. Shimada* from 27 June 2012 to 23 August 2012, and by a Canadian team (DFO/PBS) on the CCGS *W.E. Ricker* from 15 August 2012 to 6 September 2012. In addition, a third U.S. team (NWFSC/FRAM and NWFSC/REUT) worked on the fishing vessel *Forum Star* from 28 June 2012 to 11 August 2012 in collaboration with the *Shimada*. The data collected during the survey were processed to provide an estimate of the abundance and spatial distribution of the coastal Pacific hake stock shared by both countries. The survey covered the slope and shelf of the U.S. and Canada West Coast from roughly 35.8°N (in between Morro Bay and Monterey Bay) to 55.3°N (Southeast Alaska and Dixon Entrance) with acoustic transects spaced 10 or 20 nm apart. Acoustic data were collected on the *Shimada* with an EK60 echosounder operating at frequencies of 18, 38, 70, 120, and 200 kHz, on the *Ricker* with a 38-kHz and 120-kHz EK60

echosounder, and on the *Forum Star* with a 38-kHz and 120-kHz ES60 echosounder. The survey resulted in 118 transects with 4,621 nautical miles of acoustical transect that were used for the biomass estimate. Aggregations of adult (age 2+) Pacific hake were detected on 94 transects from the start of the survey, north along the U.S. and Canadian coast, in the Queen Charlotte Sound and Hecate Strait, through Dixon Entrance, and at the southwest tip of Haida Gwaii (known formerly as the Queen Charlotte Islands). Highest concentrations of Pacific hake were observed along the California coast from Monterey Bay to south of Cape Mendocino, from just south of Crescent City, California to the southern Oregon coast, in between Newport and Astoria, Oregon, and in the Dixon Entrance area. Concentrations of Pacific hake were relatively moderate off Washington and Vancouver Island, minimal in Hecate Strait, and essentially absent in southeast Alaska and along the west coast of Haida Gwaii. Midwater trawls equipped with a camera system, along with a bottom trawl, were conducted to verify species composition of observed backscatter layers and to obtain biological information (i.e., size distribution, age composition, sexual maturity). A total of 117 successful trawls (73 by the *Forum Star* and 44 by the *Ricker*) resulted in a total hake catch of 21,406 kg (17,420 kg from the *Forum Star* and 3,986 kg from the *Ricker*). The estimated total biomass of adult Pacific hake in 2012 was 1.381 million metric tons (of which 1.261 million metric tons—or over 91%—was from U.S. waters). With over 51% of the survey-wide observed biomass, age-2 hake were the largest component, followed by age-4 hake at 21%. Age-3 hake came in third at just under 12%.

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5. NOAA Program: Fisheries And The Environment (FATE)

Project Title: Modeling Pacific hake (*Merluccius productus*) summer distribution

Investigators: M. Haltuch, C. Holt, E.C. Clarke and A.E. Punt

Funding obtained via the NOAA Fisheries and the Environment (FATE) Program as well as funding via the Department of Fisheries and Oceans (DFO) Canada, International Governance Strategy Funds during 2010-2011 lead to a joint project between the Northwest Fisheries Science Center (NWFSC) and DFO, Nanaimo focusing on building a model to describe hake distribution during the summer migratory season, with the long term goal of being able to both hind-cast and forecast hake distribution. The motivation for this work is that Pacific hake exhibits strong environmentally-driven inter-annual variation during the stock's annual summer northerly migration that impact monitoring, assessment, and management of hake. Being able to describe and forecast hake distribution could impact management via optimized survey design and planning, resulting in improved estimates of hake distribution and density. Specifically, survey effort could be distributed to minimize (expected) variance given the ability to predict hake distribution and density prior to a survey, resulting in more precise estimates of abundance that form the basis for stock assessment and management advice. Hind-casting hake distribution could also be useful for investigating hake selectivity and availability in the stock assessment model. Essentially, the ability to model hake selectivity as a function of a covariate(s) would reduce the number of parameters in the stock assessment

model. Finally, understanding and forecasting of hake distribution during migration is important for both short-term management decisions and long-term planning under future climate scenarios.

This project is using the depth aggregated hake acoustics survey data (1992-2007) to investigate space (latitude and longitude), population age composition, and environmental drivers of the north-south and cross-shelf distribution of hake along the west coast of North America. A set of hypotheses have been proposed in order to investigate potential mechanisms underlying the hake summertime distribution. The null hypothesis is that the north-south summertime distribution of hake is determined by latitude and the population age structure; and that the cross-shelf distribution of hake is determined by bathymetry. Three hypotheses have been developed that address possible climate mechanisms forcing hake summer distribution. Hypothesis 1 proposes that the intensity and location of the poleward undercurrent impacts the period of active migration, with stronger poleward flow leading to the population moving farther north. Hypothesis 2 suggests that formation and distribution of mesoscale structure in the CCE, e.g. eddies, is different between warm and cool years, impacting the distribution of hake's main prey resource, euphausiids. The hake distribution then tracks the changes in the distribution of euphausiids. Hypothesis 3 concerns the timing of the spring transition and in turn the intensification of upwelling, which impacts the timing and distribution of euphausiid availability and therefore hake distribution. A suite of environmental data from both satellite data on surface ocean conditions (e.g. SST) and regional ocean model (ROMS) outputs (e.g. poleward flow) are being used to test these hypotheses.

A delta general additive modeling (GAM) approach is used to predict hake backscatter. This is a two-step hurdle model consisting of a presence-absence model and a positive data model (all zeroes excluded) and is often used for zero-inflated data. GAMs are extensions of generalized linear models that apply semi-parametric smoothing functions to each independent variable and additively calculate the component response. Zero-inflation is often found in ecological data and needs to be accounted for when modeling abundance data. The hurdle model also has the advantage that it is possible to model different variables for the binary and the positive abundance response, as they can be driven by different processes. In the first step a binomial GAM is used to model the occurrence (presence-absence) of hake backscatter. In the second step lognormal GAMs and variable coefficient GAMs are fit to the positive backscatter (presence data). The variable coefficient GAM allows for the testing of a variable spatial effect of the covariates on hake distribution in the California Current. The two models are merged by multiplying the predictions from both steps, resulting in the final model. Model fits are evaluated using residual plots, deviance explained by the model, and AIC is used for model selection. A runs test for randomness is used to test for problems with autocorrelation in model residuals, to avoid inflating the statistical significance of model results and to decrease the likelihood of type 1 errors (false positives).

The null model is explored by examining the spatial pattern of hake biomass-at-age composition data by applying two spatial indicators, center of gravity (spatial mean location) and the associated inertia (spatial variance). The population age structure is clearly contributing to both within and between year differences in hake distribution. The

centers of gravity for young ages were found at more southerly locations than those of older ages. In warm years and years when there are proportionally more old fish in the population (e.g. 1998) the population is distributed further north. In cold years and years when there are proportionally fewer old fish in the population (e.g. 2001) the population is distributed further south. Based on the exploration of the hake biomass-at-age-and-latitude data and information on hake maturity, the hake age data are classified into juvenile (age 3) and adult categories (age 3+) for further modeling.

Each hake acoustic line transect is treated as the sampling unit for the GAM modeling described above, yielding a model that has hake backscatter summed for each transect and an average spatial scale of 50 to 100 kilometers. GAM model results show that the population age structure, satellite SST and ROMS temperature at depth and pole-ward velocity are drivers of hake distribution, supporting both the null and alternative hypotheses. Model fits are generally good, explaining between 35%-40% of the variability in the data, and runs tests indicate a lack of autocorrelation in the model residuals. Comparisons between the observed and predicted also indicate that the model fits the data well but generally under predicts the level of backscatter observed. Forecasts, in which one year of data are removed from the model and a forecast is made without those data, are reasonable. The final sets of alterative models are being finalized and a peer review publication is in preparation.

The funding for this project ended during September 2011 and alternative funds have not been identified to support further investigations at this time.

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6. Ecosystem Studies

a) Fish Ecology Division Summary Report

The Fish Ecology Division completed four monthly field surveys in 2012 for larval fishes using plankton nets and juvenile fishes using trawls. Sampling in 2012 was done in conjunction with prey field studies resulting in additional sampling on some of the survey lines. Field surveys are used to assess spawning success of a variety of groundfish species in relation to oceanographic conditions and climate variability, with the intent of establishing recruitment success indices to enhance stock assessment. All four cruises were done aboard the chartered fishing vessel *Miss Sue*. All larval and juvenile fish have been sorted and identified for 2012. Preliminary results have shown a substantial increase in the abundance of rockfishes in our plankton nets and trawls in the past year as opposed to last year when they were a dominant species caught. Moreover, there have been moderate increases in flatfish larvae/juveniles of several commercially important species. Gelatinous zooplankton (salps and ctenophores) were substantially lower than in the past two years. We have been examining diets of four of the most common rockfish species using direct stomach and stable isotope analysis and have recently submitted a manuscript on this. We are also continuing to look at the species composition of rockfish based on genetics.

Products:

- Auth, T.D., R.D. Brodeur and J. Peterson. MS. Anomalous ichthyoplankton distributions and concentrations in the northern California Current resulting from the 2010 El Niño and La Niña events. To be submitted to *Progress in Oceanography*.
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- Bjorkstedt, E., R. Goericke, S. McClatchie, E. Weber, W. Watson, N. Lo, W. Peterson, R. Brodeur, S. Bograd, T. Auth, J. Fisher, C. Morgan, J. Peterson, R. Durazo, G. Gaxiola-Castro, B. Lavaniegos, F. Chavez, C.A. Collins, B. Hannah, J. Field, K. Sakuma, W. Satterthwaite, M. O'Farrell, W. Sydeman, S.A. Thompson, P. Warzybok, R. Bradley, J. Jahncke, R. Golightly, S. Schneider, J. Largier, S.Y. Kim, S. Melin, R. DeLong, and J. Abell. 2012. State of the California Current 2011-2012: Ecosystems respond to local forcing as La Niña wavers and wanes. *CalCOFI Rep*. 53:41-76.
- Daly, E.A., R.D. Brodeur, T.D. Auth, and W.T. Peterson. In revision. Winter ichthyoplankton biomass as a predictor of early summer prey fields and ultimate survival of juvenile salmon. Submitted to *Marine Ecology Progress Series*.
- Roegner, G.C., E.A. Daly, and R.D. Brodeur. MS. Surface distribution of brachyuran megalopae and ichthyoplankton in the Columbia River plume during transition from downwelling to upwelling conditions. Submitted to *Cont. Shelf Res*.
- Bosley, K.L, T.W. Miller, R.D. Brodeur, K. Bosley, A. Van Gaest and A. Elz. MS. Feeding ecology of juvenile rockfishes off Oregon and Washington: insights into life history patterns based on stomach content and stable isotope analyses. Submitted to *Mar. Biol.*
- Miller, T.W., K. L. Bosley, J. Shibata, R.D. Brodeur, K. Omori and R.L. Emmett. 2013. A stable isotope-based perspective on the contribution of prey to Humboldt squid (*Dosidicus gigas*) in the northern California Current. In press *Mar. Ecol. Prog. Ser*.

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b) 2012 Integrated Ecosystem Assessment of the California Current

Investigators: P.S. Levin and B.K. Wells, eds.; numerous contributors from the NWFSC, SWFSC and partner institutions

An integrated ecosystem assessment (IEA) is a science support element for ecosystem-based management (EBM); the IEA process involves synthesizing and analyzing information through steps that include scoping, indicator development, risk analysis, and evaluating management strategies. The primary goal of the California Current IEA is to inform the implementation of EBM by melding diverse ecosystem components into a single, dynamic fabric that allows for coordinated evaluations of the status of the

California Current ecosystem. We also aim to involve and inform a wide variety of stakeholders and agencies that rely on science support for EBM, and to integrate information collected by NOAA and other federal agencies, states, non-governmental organizations, and academic institutions. The essence of IEAs is to inform the management of diverse, potentially conflicting ocean-use sectors. As such, a successful California Current IEA must encompass a variety of management objectives, consider a wide-range of natural drivers and human activities, and forecast the delivery of ecosystem goods and services under a multiplicity of scenarios. This massive undertaking will evolve over time.

The 2012 iteration of the California Current IEA focused on 4 ecosystem components (ecosystem integrity, fisheries of groundfish and coastal pelagics, protected species, and vibrant coastal communities) and 11 drivers and pressures of those components; drivers and pressures were broadly binned (e.g., shipping, coastal development, fishing, aquaculture, climate change). The 2012 IEA update is divided into 4 sections that describe: (1) scoping conversations with managers; (2) status and trends of drivers and pressures; (3) status and trends of ecosystem components; and (4) scenario-based evaluation of management strategies. Within the sections are subsections that contain specific analyses. Groundfish-related analyses include: a risk assessment for groundfish to fisheries and non-fisheries threats; status and trends of ecosystem integrity, which features groundfish populations as key indicators; the potential effects of emerging fisheries on several groundfish species; overlap between groundfish stocks and cetaceans; and the system-wide effects of the trawl fishery rationalization.

The 2012 IEA study as a whole is a 900+ page document that is currently in review and will be available some time in 2013 as an online publication, edited by Levin and Wells.

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c) Screening California Current fishery management scenarios using the Atlantis end-to-end ecosystem model

Investigators: I.C. Kaplan, P.J. Horne, and P.S. Levin

End-to-end marine ecosystem models link climate and oceanography to the food web and human activities. These models can be used as forecasting tools, to strategically evaluate management options and to support ecosystem-based management. Here we report the results of such forecasts in the California Current, using an Atlantis end-to-end model. We worked collaboratively with fishery managers at NOAA's regional offices and staff at the National Marine Sanctuaries (NMS) to explore the impact of fishery policies on management objectives at different spatial scales, from single Marine Sanctuaries to the entire Northern California Current. In addition to examining status quo management, we explored the consequences of several gear switching and spatial management scenarios. Of the scenarios that involved large scale management changes, no single scenario maximized all performance metrics. Any policy choice would involve trade-offs between stakeholder groups and policy goals. For example, a coast-wide 25% gear shift from

trawl to pot or longline appeared to be one possible compromise between an increase in spatial management (which sacrificed revenue) and scenarios such as the one consolidating bottom impacts to deeper areas (which did not perform substantially differently from Status Quo). Judged on a coast-wide scale, most of the scenarios that involved minor or local management changes (e.g. within Monterey Bay NMS only) yielded results similar to Status Quo. When impacts did occur in these cases, they often involved local interactions that were difficult to predict a priori based solely on fishing patterns. However, judged on the local scale, deviation from Status Quo did emerge, particularly for metrics related to stationary species or variables (i.e. habitat and local metrics of landed value or bycatch). We also found that isolated management actions within Monterey Bay NMS would cause local fishers to pay a cost for conservation, in terms of reductions in landed value. However, this cost was minimal when local conservation actions were part of a concerted coast-wide plan. The simulations demonstrate the utility of using the Atlantis end-to-end ecosystem model within NOAA's Integrated Ecosystem Assessment, by illustrating an end-to-end modeling tool that allows consideration of multiple management alternatives that are relevant to numerous state, federal and private interests.

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d) Cumulative impacts of fisheries in the California Current

Investigators: I.C. Kaplan, I.A. Gray, and P.S. Levin

Ecosystem-based fisheries management calls for the consideration of the indirect and cumulative effects of fishing, in addition to estimating direct fishing mortality. Here, we quantify such effects of fishing fleets, and their interactions, using a spatially explicit Atlantis simulation model of the food web and fisheries in the California Current. Simulations testing the effects of single fleets suggested that bottom trawl, fixed gear, and hake (*Merluccius productus*) trawl primarily have direct impacts on their target and bycatch species. Few indirect effects from these three fleets extended through predator–prey links to other parts of the food web. In contrast, effects of the purse seine fleet extended beyond the three groups it harvested, strongly altering the abundance of predators, planktonic prey, and benthos. In terms of nine ecosystem attributes, our experiments involving single fleets identified six fleets that caused the bulk of negative impacts. Specific fleets impacted different aspects of the ecosystem, for instance with groundfish gears causing reductions in piscivore abundance, and hake trawl and purse seine increasing krill through reducing abundance of planktivores. In terms of interactions among fleets' effects, the vast majority of effects were simply additive – the combined effect of two fleets was simply the sum of the individual fleets' effects. The analyses offer one way to sharpen the focus of ecosystem-based fisheries management in the California Current, emphasizing impacts and interactions of particular stressors.

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e) Integrating diet and movement data to identify hot spots of predation risk and areas of conservation concern for endangered species

Investigators: E.J. Ward, P.S. Levin, M.M. Lance, S.J. Jeffries, and A. Acevedo-Gutierrez

Effective management of threatened and endangered species requires an understanding of how species of conservation concern are distributed spatially, as well as the spatial distribution of risks to the population, such as predation or human impacts (fishing, pollution, and loss of habitat). Identifying high-risk areas is particularly important when designing reserves or protected areas. Our novel approach incorporates data on distribution, movement, and diet of a generalist marine predator (harbor seals) to identify and map hot spots of predation risk for an endangered prey species (rockfish). Areas with high concentrations of seals (including some current marine reserves) are also estimated hot spots for rockfish predation. Although marine reserve planning currently targets areas with good habitat and low human disturbance, our modeling suggests that future terrestrial and marine reserve design may be made more effective by incorporating other components of the food web that either directly or indirectly interact with target species.

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f) Potential overlap between cetaceans and commercial groundfish fleets operating in the California Current large marine ecosystem

Investigators: B.E. Feist, M.A. Bellman, E.A. Becker, K.A. Forney, M.J. Ford, and P.S. Levin

Many cetacean populations are confronted by many anthropogenic threats, including commercial whaling, anthropogenic noise, vessel collisions, gear entanglement, resource competition, habitat disturbance and global climate change. There is evidence that commercial fishing activities can have both direct (e.g., gear entanglement and bycatch) and indirect effects (e.g., prey reduction, noise) on cetaceans. However, few studies have addressed the potential vulnerability of a given cetacean species to an entire fishing fleet operating over a large marine ecosystem. In this study, we overlaid spatially explicit multi-year mean predicted densities of 11 cetacean species and one species guild within the California Current Large Marine Ecosystem with West Coast Groundfish Fishery commercial fishing effort data for fixed-gear, at-sea hake midwater trawl, and bottom trawl fleets. We quantified the exposure of each species to each fleet type by multiplying the predicted mean cetacean density by the measured fishing fleet effort. We found that there was large interspecific and interfleet variability in the overlap between cetaceans and fishing fleets. While many of the species had relatively low overlap rates, others had substantial exposure to some of the fishing fleets, particularly those species with more nearshore distributions. While direct mortality from these fleets has been documented to be low, our results suggest there is opportunity for fisheries interactions with some cetacean species, particularly in the fixed gear fleets. Our analyses are an important first step in generating formal risk assessments for quantifying the population impacts of

various fishing fleets on cetacean species that occur in the California Current Large Marine Ecosystem.

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g) Combining fishing and acoustic monitoring data to evaluate the distribution and movements of spotted ratfish *Hydrolagus colliei*

Investigators: K.S. Andrews and T.P. Quinn

Direct and indirect methods have been used to describe patterns of movement of fishes, but few studies have compared these methods simultaneously. We used 20 years of trawl survey data and one year of acoustic telemetry data to evaluate the vertical and horizontal movement patterns of spotted ratfish *Hydrolagus colliei* in Puget Sound, WA, USA. Densities of large ratfish (≥ 30 cm) were higher at the deepest depths trawled (70 m) during daylight hours, whereas densities were similar across depth zones (to 10 m) at night. Acoustic tracking of ratfish showed distinct diel patterns of movement and activity level; ratfish moved into shallow, nearshore habitats at night from deeper, offshore habitats during the day and made ~3 times more moves at night than day in shallow habitats. Broader spatial patterns depended on where ratfish were tagged: one tag group remained in one general location with few excursions, whereas a second tag group moved within a 20-km band with some individuals moving > 90 km. These data will help inform food web models' abilities to quantify interspecific interactions between ratfish and other components of their community.

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h) Ecosystem-level consequences of movement: the predatory impact of spiny dogfish in Puget Sound.

Investigators: K.S. Andrews and C.J. Harvey

Spatio-temporal patterns of species abundance influence the strength of trophic interactions, while movement of individuals helps determine those patterns of abundance. Thus, understanding movement is a basis for quantifying interactions within a food web. In Puget Sound, Washington, USA, the North Pacific spiny dogfish *Squalus suckleyi* is an abundant top predator with a diverse, generalist diet. Coastal dogfish populations make seasonal north−south migrations, but populations in inland waters are thought to be more resident. In this study, we combined acoustic telemetry and bioenergetics modeling to determine patterns of movement and to quantify seasonal variation in the predatory impact of dogfish in Puget Sound. All tagged dogfish migrated out of Puget Sound in the winter and were absent until the following summer. Individuals that returned to Puget Sound in subsequent years showed consistent timing and duration of residence across years, but these metrics varied across individuals. Incorporating movement data into the bioenergetics model resulted in a 70% decrease in the predatory impact of dogfish in the

winter and a 30% decrease in the summer, compared to a year-round resident Puget Sound population. Incorporating metrics of movement into food web or ecosystem models will increase our understanding of species interactions and will improve our ability to predict changes in food web dynamics under various environmental and management scenarios.

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i) An empirical movement model for sixgill sharks in Puget Sound: combining observed and unobserved behavior.

Investigators: P.S. Levin, P. Horne, K.S. Andrews, and G. Williams.

Understanding the movement of animals is fundamental to population and community ecology. Historically, it has been difficult to quantify movement patterns of most fishes, but technological advances in acoustic telemetry have increased our abilities to monitor their movement. In this study, we combined small-scale active acoustic tracking with large-scale passive acoustic monitoring to develop an empirical movement model for sixgill sharks in Puget Sound, WA, USA. We began by testing whether a correlated random walk model described the daily movement of sixgills; however, the model failed to capture home-ranging behavior. We added this behavior and used the resultant model (a biased random walk model) to determine whether daily movement patterns are able to explain large-scale seasonal movement. The daily model did not explain the larger-scale patterns of movement observed in the passive monitoring data. In order to create the large-scale patterns, sixgills must have performed behaviors (large, fast directed movements) that were unobserved during small-scale active tracking. In addition, seasonal shifts in location were not captured by the daily model. We added these 'unobserved' behaviors to the model and were able to capture large-scale seasonal movement of sixgill sharks over 150 days. The development of empirical models of movement allows researchers to develop hypotheses and test mechanisms responsible for a species movement behavior and spatial distribution. This knowledge will increase our ability to successfully manage species of concern.

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j) Scale and pattern of broadnose sevengill shark *Notorhyncus cepedianus* movement in estuarine embayments.

Investigators: G.D. Williams, K.S. Andrews, S.L. Katz, M.L. Moser, N. Tolimieri, D.A. Farrar, and P.S. Levin.

The detailed movements of 32 acoustically tagged broadnose sevengill shark *Notorynchus cepedianus* were documented in and around north-east Pacific Ocean estuarine embayments from 2005 to 2007. Arrangements of passive acoustic receivers allowed analysis of movement at several spatial scales, with sex and size examined as

possible factors influencing the pattern and timing of these movements. *N. cepedianus* exhibited a distinctly seasonal pattern of estuary use over three consecutive years, entering Willapa Bay in the spring, residing therein for extended periods of time during the summer and dispersing into nearshore coastal habitats and over the continental shelf during the autumn. *N. cepedianus* within Willapa Bay showed spatio-temporal patterns of segregation by size and sex, with males and small females using peripheral southern estuary channels early in the season before joining large females, who remained concentrated in central estuary channels for the entire season. Individuals displayed a high degree of fidelity not only to Willapa Bay (63% were documented returning over three consecutive seasons), but also to specific areas within the estuary, showing consistent patterns of site use from year to year. Cross-estuary movement was common during the summer, with most fish also moving into an adjacent estuarine embayment for some extent of time. Most winter and autumn coastal detections of *N. cepedianus* were made over the continental shelf near Oregon and Washington, U.S.A., but there were also examples of individuals moving into nearshore coastal habitats further south into California, suggesting the feasibility of broad-scale coastal movements to known birthing and nursery grounds for the species. These findings contribute to a better understanding of *N. cepedianus* movement ecology, which can be used to improve the holistic management of this highly mobile apex predator in regional ecosystems.

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k) How does the definition of 'home range' affect predictions of the efficacy of marine reserves?

Investigators: N. Tolimieri, K.S. Andrews and P.S. Levin.

Understanding how animals use space is fundamental to the employment of spatial management tools like marine protected areas (MPAs). A commonly used metric of space use is home range—defined as the area in which an individual spends 95% of its time and often calculated as 95% of the utilization distribution (UD), which is a probabilistic map describing space use. Since home range represents only 95% of an animal's time, it is important to understand whether the other 5% matters to the design of MPAs. We developed an MPA-population model for lingcod *Ophiodon elongatus* that examined the population recovery under six characterizations of space use ranging from one mean home range to nine real lingcod UDs. Mean home range and similar estimates (based on the area in which a fish spent 95% of its time) predicted higher biomass and numbers relative to the more complete analysis of space use like the UD (which represented 99.99% of a fish's time) and underestimated the size of reserves necessary to achieve the same level of recovery of biomass. Our results suggest failing to account for the full extent of a fish's time overestimates the effectiveness of marine reserves.

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l) Linking changes in mean trophic level of groundfishes to ecosystem structure and function on the U.S. west coast

Investigators: N. Tolimieri, J.F. Samhouri, V. Simon, B.E. Feist, and P.S. Levin

Indicators, which are an essential component of ecosystem-based management, need to be linked to changes in the structure and function of ecosystems. Mean trophic level (MTL) is an ecosystem indicator that measures the relative abundance of species across a spectrum of trophic levels. The ubiquity and causes of a general decline in the MTL of fisheries catch through time have engendered much attention. However, the consequences of this pattern for broader ecosystem structure and function remain virtually unexplored. We document a decline in the ecosystem MTL of groundfishes along the Pacific U.S. Coast from 2003-2011, the proximate cause of which was a decrease in the biomass of higher trophic level groundfishes. Using a food web model, we illustrate how these shifts in ecosystem structure may have resulted in short-term positive responses by competitors and many lower trophic level species in the broader ecosystem. In the longer-term, the model predicts that initial patterns of prey release may be tempered in part by lagged responses of non-groundfishes, higher trophic level species, such as salmon and seabirds. While ecosystem functions related to specific groups like piscivores (excluding high TL groundfishes) changed, aggregate ecosystem functions altered little following the initial reorganization of biomass, probably due to functional redundancy within the predator guild. Efforts to manage and conserve marine ecosystems will benefit from a fuller consideration of the information content contained within, and implied by, fisheries-independent trophic level indicators.

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m) Beta diversity of demersal fish assemblages in the north-eastern Pacific: interactions of latitude and depth.

Investigators: M.J. Anderson, N. Tolimieri, and R. Millar.

Knowledge of broad-scale global patterns in beta diversity (i.e., variation or turnover in identities of species) for marine systems is in its infancy. We analyzed the beta diversity of groundfish communities along the North American Pacific coast, from trawl data spanning 32.57°N to 48.52°N and 51 m to 1341 m depth. Analyses were based on both the Jaccard measure and the probabilistic Raup-Crick measure, which accounts for variation in alpha diversity. Overall, beta diversity decreased with depth, and this effect was strongest at lower latitudes. Superimposed on this trend were peaks in beta diversity at around 400-600 m and also around 1000-1200 m, which may indicate high turnover around the edges of the oxygen minimum zone. Beta diversity was also observed to decrease with latitude, but this effect was only observed in shallower waters (<200 m); latitudinal turnover began to disappear at depths >800 m. At shallower depths (<200 m), peaks in latitudinal turnover were observed at ~43°N, 39°N, 35°N and 31°N, which corresponded well with several classically observed oceanographic boundaries. Turnover with depth was stronger than latitudinal turnover, and is likely to reflect strong

environmental filtering over relatively short distances. Patterns in beta diversity, including latitude-by-depth interactions, should be integrated with other biodiversity measures in ecosystem-based management and conservation of groundfish communities.

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n) Larval rockfish survival decreases in an elevated CO_2 environment

Investigators: S. Norberg, D.S. Busch, and P. McElhany

Information regarding the effects of high-CO_2 environments on fish is limited. In vertebrates, high levels of environmental pCO_2 can lead to lethal hypercapnia-induced acidification of intracellular body fluids. Fish can tolerate brief exposures to high pCO_2 because of their ability to accumulate buffering ions from the water through transport across cell membranes. Larval fish, which must meet the large daily energy requirements for growth and development, may not be able to contend with the extra energetic expense of increased ion transport. We explored the impacts of CO_2 on growth, development, and survival of China rockfish (*Sebastes nebulosa*) larvae. We reared larvae in three different pH treatments: 7.70, 8.05, and 8.10. These conditions approximate past (280 ppm), present (400 ppm), and future (1000 ppm) global average atmospheric pCO_2 levels. Larvae exposed to high pCO_2 had significantly lower survival over a 20-day period (21%) than larvae exposed to moderate pCO_2 (70%). After two weeks of exposure to treatment conditions, larvae that survived in high pCO_2 were shorter than larvae in moderate and low pCO_2, though they had greater body depth than larvae in moderate pCO_2. At the end of the experiment, larval size and shape was similar in all treatments. However, otolith diameter relative to body size in larvae reared in moderate pCO_2 treatments was significantly larger than those reared in high and low pCO_2. From these results, we conclude that high pCO_2 conditions negatively impacted the growth, development and survival of larval China rockfish.

For more information, please contact Paul McElhany at NOAA's Northwest Fisheries Science Center, Paul.McElhany@noaa.gov

o) Spatial and seasonal variation in $\delta^{15}N$ and $\delta^{13}C$ values in a mesopredator shark, *Squalus suckleyi*, revealed through multitissue analyses.

Investigators: J.C.P. Reum and T.E. Essington

We used variance decomposition to explore the importance of body size, sex, location, and sampling period as predictors of intrapopulation variation in $\delta^{15}N$ and $\delta^{13}C$ values in spiny dogfish *Squalus suckleyi* from the Puget Sound–Strait of Georgia basin. Isotopes in two tissues with long (dorsal white muscle) and short (liver) isotopic turnover rates (~1 year and ~3–4 months, respectively) were sampled to evaluate whether the relative importance of each variable differed depending on the time span over which diet information was integrated. Significant spatial variation was observed in both muscle and liver isotopic composition, whereby location uniquely explained 25 and 17 % of the total

variance, respectively. The remaining variables explained considerably less variation in both tissue types. Furthermore, evidence of seasonal isotopic shifts in $\delta^{15}N$ and $\delta^{13}C$ values was apparent, but differed widely in direction and magnitude among groups. These findings suggest that members of spiny dogfish schools may share a common feeding history, possibly by spending extended time periods (weeks to months) foraging in a spatially fixed region. Another explanation is that individuals may move and feed in aggregations that exist for extended periods. These complex group-level patterns suggest that even for large-bodied, motile predators such as sharks, population-level diet estimates derived from averaging isotope ratios of individuals collected from only a few locations may poorly reflect the true population mean.

For more information, please contact Jon Reum at NOAA's Northwest Fisheries Science Center, Jonathan.Reum@noaa.gov

p) Season and prey type influence size dependency of predator−prey body mass ratios in a marine groundfish assemblage

Investigators: J.C.P. Reum and M.E. Hunsicker

Marine and freshwater food webs are strongly structured by size-dependent predator−prey interactions. Predator−prey body mass ratios (PPMR) are important parameters in size-based food-web models, but studies evaluating the temporal stability of PPMR or its relationship to predator feeding modes are scant. Using a large data set of predator−prey pairs from a diverse demersal fish community sampled in summer, fall, and winter, we showed that community-level PPMR varied with predator mass in a nonlinear (dome-shaped) manner. PPMR was higher in the summer relative to the fall and winter for all predator body size classes regardless of whether prey were fish or invertebrate. Further, the size dependency of PPMR was dome-shaped for invertebrate prey but positive and linear for fish prey. We empirically show that community-level PPMR is dynamic rather than fixed, which is in agreement with general expectations set by simulation studies of biomass spectra. However, we are presently unable to identify the specific processes underlying these patterns. Size-based models of marine ecosystems offer considerable promise over traditional taxa-based approaches, and our analyses provide insight into major patterns of variation in PPMR in a temperate marine system.

For more information, please contact Jon Reum at NOAA's Northwest Fisheries Science Center, Jonathan.Reum@noaa.gov

q) Variability in rockfish (*Sebastes* spp.) fecundity on the California coast: species contrasts, maternal size effects, and spatial differences

Investigators: S.G. Beyer, S.M. Sogard, C.J. Harvey, and J.C. Field

Investigators studied the reproductive ecology of three rockfish species residing in the California Current System: chilipepper, *Sebastes goodei*, yellowtail, *S. flavidus* and speckled rockfish, *S. ovalis*. Females were sampled from four locations along the coast of California in the winter spawning seasons (November through March) of 2009, 2010 and

2011 to assess temporal and spatial effects on fecundity. Maternal size and age were positively correlated with relative fecundity (Φ_{rel}, larvae per g somatic weight) for all three species and indicated a disproportionately greater reproductive output by older, larger females. Yellowtail rockfish had the highest absolute and Φ_{rel}, the greatest maternal size effect, and produced the smallest eggs. Size-dependent Φ_{rel} relationships were incorporated into published stock assessment models that originally assumed egg production to be directly proportional to spawning biomass. The updated models showed a reduction in larval output when large, old females were removed from the population by fishing for both chilipepper and yellowtail rockfish. In addition, fecundity varied spatially among sampling sites (chilipepper and yellowtail) and by year (chilipepper). Speckled rockfish lacked adequate sample size to assess spatiotemporal trends in fecundity. Chilipepper and speckled rockfish produced multiple broods annually in Southern California and to a lesser extent in Central California, complicating estimates of annual fecundity. Egg production was positively correlated with female condition, indicating environmental variability in oceanographic conditions and productivity may drive changes in fecundity and reproductive strategy (i.e. single verses multiple broods) in these species.

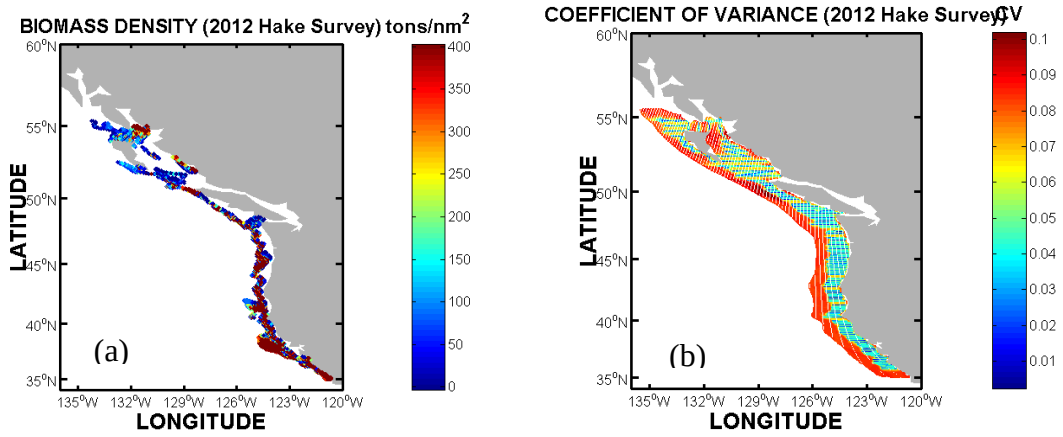
For more information, please contact Ms. Sabrina Beyer at NOAA's Southwest Fisheries Science Center, Sabrina.Beyer@noaa.gov

7. Acoustic Modeling and Research

a) Refinement of the EchoPro software package with inclusion of a geo-statistical technique (kriging) to process the 2012 Integrated Acoustic and Trawl Survey (IATS) data for hake biomass estimate

The EchoPro software package developed in FY11 has been refined to increase flexibility and reduce program complexity. It reads the Nautical Area Scattering Coefficient exported from EchoView (Myriax) and can provide length-, age-, and sex-structured biomass estimates promptly. Data processing is totally independent of any Oracle database and the processing cycle is much shorter. In addition, because the 2012 hake biomass estimate was obtained using kriging (a geostatistical method and local estimator used to interpolate a spatially distributed quantity in an unobserved location), the coefficient of variation (CV) was provided at the same time (Figures 10a, 10b). Kriging has been considered suitable for estimating fish abundance and precision by an ICES Study Group. In addition, a sensitivity analysis of the biomass estimate in terms of the stratification scheme, kriging grid cell resolution, kriging variables, and the kriging parameters was performed which indicated that the biomass estimate was robust.

For more information, contact Larry Hufnagle at Lawrence.C.Hufnagle@noaa.gov



Figures 10a and 10b. Kriging maps of 2012 hake survey estimated biomass and coefficient of variation (CV) maps. (a) kriged biomass distribution (1.38 mmt); (b) kriging CV distribution (4.75%).

b) Development of an age-1 hake index and analysis of historical data

An age-1 index for Pacific hake is under development, with a preliminary analysis of 2003 to 2011 data concluded February 2011. This analysis included an overall index of abundance as well as a spatial component of age-1 echosign. This index of abundance was joined to the 1995–2001 historic AFSC data set of age-1 abundance. Initial results indicate that the age-1 index was consistent with major recruitment events; however, more years of data and a full spatial analysis are needed. Currently, work is proceeding on converting historic 1995–2001 echogram data, with hopes to get a full spatial component similar to that in spatial years. Also, as the adult hake biomass estimate is currently calculated using kriging methods, but the age-1 index currently is calculated using simple linear interpolation, a goal is for the age-1 index to incorporate kriging as well eventually.

For more information, contact Larry Hufnagle at Lawrence.C.Hufnagle@noaa.gov

c) Application of low-frequency broadband technology to acoustic characterization of fish

The goal of the proposed research is to develop a technology capable of discriminating Pacific hake from other marine species using a commercially available broadband echosounder system (EdgeTech SB-0512i wideband FM sub-bottom profiler operating between 500 Hz and 12 kHz). The broadband system can provide a much improved signal-to-noise ratio (SNR) and range resolution with pulse compression technique. Most importantly, it can provide a wide spectrum that covers a large range of acoustic resonance frequencies for adult hake, a swimbladder-bearing fish species.

During the 2012 Joint U.S.-Canada Integrated Acoustic and Trawl Survey of Pacific hake (*Merluccius productus*) and Pacific sardine (*Sardinops sagax*), total of 11 deployments were conducted off the NOAA Ship *Bell M. Shimada*. Echograms showing several hake aggregations off Washington coast are shown in figure 11. A field calibration of the broadband system was conducted prior to the survey on an earlier research cruise funded by the Office of Naval Research (ONR) on the R/V Oceanus (figure 12).

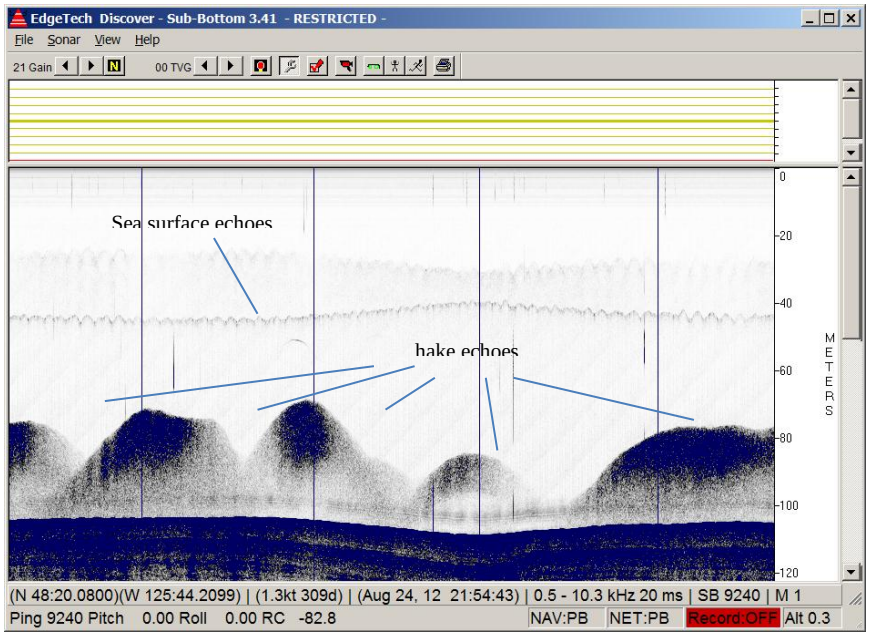


Figure 11. Raw echograms of a series of Pacific hake aggregations.

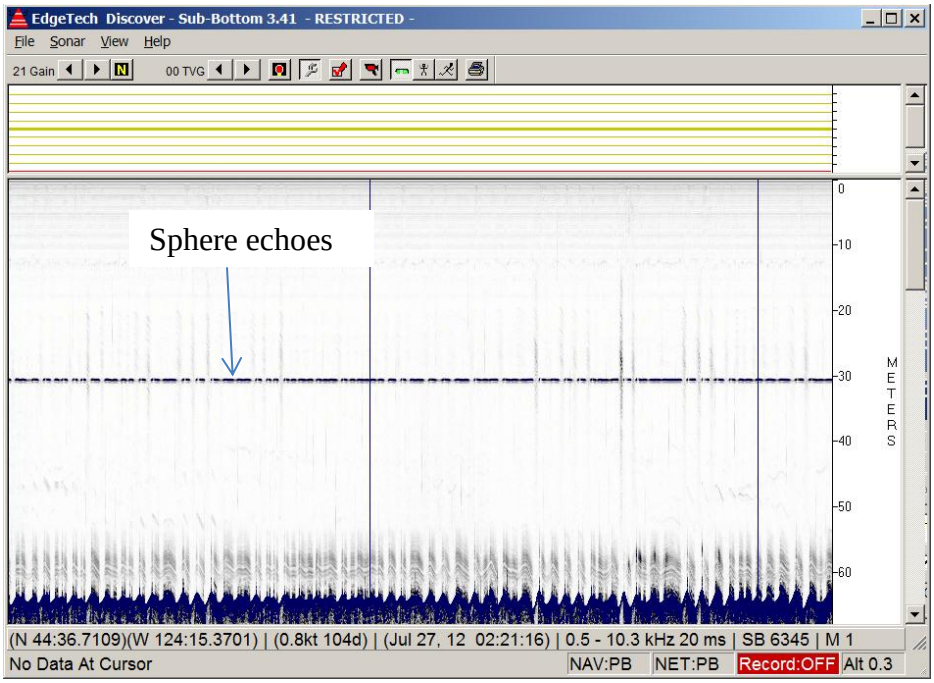


Figure 12 Echogram showing echoes from the calibration sphere AL300 (300-mm diameter).

The schools classified as "hake" were aggregated between 60 and 100 m from the towfish. The EdgeTech broadband system was towed at about 40 m at about 2.5 knots, i.e., fish schools were between 100 and 150 m depths. The aggregations at similar locations and depths were trawled within 10 days but were not sampled just prior and post to the deployment of the EdgeTech system. However, based on the characteristics of the echogram, aggregations were thought to be hake.

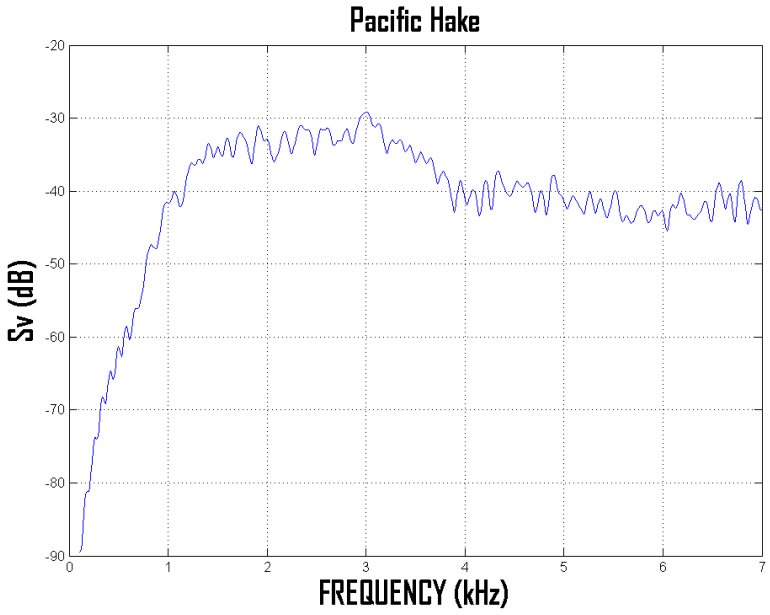


Figure 13. Sv of the "hake" aggregation.

The frequency response of S_v of the "hake" aggregations is shown in figure 13. Note that the frequencies corresponding to "peaks" of S_v for "hake" are very broad spanning from about 1.2 to 3.4 kHz, indicating that the aggregations were "hake" with a wide length distribution, could be bi-modal with mixed age class.

For more information, contact Larry Hufnagle at Lawrence.C.Hufnagle@noaa.gov

8. Economic Data Collection and Analysis

a) Why economics matters for understanding the effects of climate change on fisheries

Investigators: A.C. Haynie and L. Pfeiffer

Research attempting to predict the effect of climate change on fisheries often neglects to consider how harvesters respond to changing economic, institutional, and environmental conditions, which leads to the overly simplistic prediction of "fisheries follow fish". However, climate effects on fisheries can be complex because they arise through physical, biological, and economic mechanisms that interact or may not be well understood. Although most researchers find it obvious to include physical and biological factors in predicting the effects of climate change on fisheries, the behavior of fish harvesters also matters for these predictions. A general but succinct conceptual framework for investigating the effects of climate change on fisheries that incorporates the biological and economic factors that determine how fisheries operate is presented. The use of this framework will result in more complete, reliable, and relevant investigations of the effects of climate change on fisheries. The uncertainty surrounding long-term projections, however, is inherent in the complexity of the system.

For more information, please contact Lisa Pfeiffer at Lisa.Pfeiffer@noaa.gov

b) From krill to convenience stores: forecasting the economic and ecological effects of fisheries management on the U.S. West Coast

Investigators: I.C. Kaplan, J. Leonard

There is a need to better understand the linkages between marine ecosystems and the human communities and economies that depend on these systems. Here those linkages are drawn for the California Current on the US West Coast, by combining a fishery ecosystem model (Atlantis) with an economic model (IO-PAC) that traces how changes in seafood landings impact the broader economy. The potential effects of broad fisheries management options are explored, including status quo management, switching effort from trawl to other gears, and spatial management scenarios. Relative to Status Quo, the other scenarios here involved short-term ex-vessel revenue losses, primarily to the bottom trawl fleet. Other fleets, particularly the fixed gear fleet that uses pots and demersal longlines, gained revenue in some scenarios, though spatial closures of Rockfish Conservation Areas reduced revenue to fixed gear fleets. Processor and wholesaler

revenue tracked trends in the bottom trawl fleet, which accounted for 58% of total landings by value. Income impacts (employee compensation and earnings of business owners) on the broader economy mirrored the revenue trends. The long-term forecast (15 years) from the Atlantis ecosystem model predicted substantial stock rebuilding and increases in fleet catch. The 15 year projection of Status Quo suggested an additional ~$27 million in revenue for the fisheries sectors, and an additional $23 million in income and 385 jobs in the broader economy, roughly a 25% increase. Linking the ecological and economic models here has allowed evaluation of fishery management policies using multiple criteria, and comparison of potential economic and conservation trade-offs that stem from management actions.

For more information please contact Isaac Kaplan at NOAA's Northwest Fisheries Science Center, Isaac.Kaplan@noaa.gov

c) The role of charter boat operations in fishing communities: a social and economic analysis of the marine charter boat fleet in Oregon and Washington

This study utilizes results from a Washington and Oregon marine charter survey to characterize the current composition, estimate the economic contribution, and examine the existing economic conditions of the charter industry. Historically, the chief target species of the industry was salmon. Despite negative shocks to salmon allocations and abundance, fees for recreational salmon fishing trips remain the largest source of revenue for charter businesses in Washington and Oregon. While salmon recreational fishing is the largest single source of revenue, other sources such as groundfish recreational fees and halibut fees combined represent 65% of revenue. The cost and earnings estimates obtained from the survey are used to create a charter industry sector in IMPLAN (IMpact analysis for PLANning) software. Our economic contribution estimates using primary data are considerably higher, particularly for employment, than prior research that utilized default IMPLAN sectors.

In assessing their economic conditions, the investigator found that the majority of charter businesses experienced fewer clients in 2006 than during five years prior and had an unfavorable expectation of the future of the industry. Furthermore, charter operators with greater time involved in the industry are less optimistic about the future, which is likely due in part to their use of larger, more powerful vessels that are more costly to operate.

For more information please contact Jerry Leonard at NOAA's Northwest Fisheries Science Center, Jerry.Leonard@noaa.gov

d) West Coast limited entry groundfish cost earnings survey protocol and results for 2008

Protocols and empirical results from an economic cost earnings survey of the West Coast (Washington, Oregon, and California) limited entry groundfish fleet were examined. The surveyed population consisted of owners of active commercial fishing vessels that: 1) landed at least $1,000 from fishing on the West Coast during 2008 and 2) had a limited entry groundfish permit. Vessels that participated in the at sea whiting (*Merluccius productus*) fishery but did not participate in any shoreside West Coast fisheries were not surveyed. There

were 255 vessels in the survey population. In-person interviews were completed with owners of 123 vessels, representing a 48% response rate. The response rate was higher for vessels in the limited entry groundfish trawl fleet (57%) than for vessels in the limited entry groundfish fixed gear fleet (39%).

Responses were used for statistical inference on costs, revenues, and vessel operating characteristics (such as crew size and fuel consumption) and represent results for trawl and fixed gear fleets, as well as the primary vessel types in each fleet. For the limited entry groundfish trawl survey respondents, the average vessel had revenue from all sources of $585,041, reported costs of $469,068, economic costs of $507,660, and economic net revenue of $77,381 during 2008. Since economic cost only includes costs incurred prior to the shoreside delivery of fish and does not include shoreside management and administration costs, it provides a measure of economic profit that is biased upward. Amounts such as revenue, cost, and net revenue reflect operations in all fisheries (West Coast and Alaska). Vessels that operated primarily in Alaska fisheries and the West Coast shoreside whiting fishery earned higher economic net revenue than vessels that operated primarily in the West Coast non-whiting groundfish trawl fishery. Vessels that operated primarily in the West Coast non-whiting groundfish trawl fishery earned positive but smaller economic net revenue, on average ($16,562 in 2008).

For the limited entry groundfish fixed gear survey respondents, the average vessel had revenue from all sources of $324,189, costs reported on the survey of $247,003, economic costs of $261,876, and economic net revenue of $62,313 during 2008. As in the limited entry groundfish trawl fleet, the vessels earning the most net revenue were Alaska vessels, which earned per vessel economic net revenue of $422,151. Economic net revenue was lower for vessels that operated primarily in the West Coast limited entry fixed gear fishery. Sablefish fixed gear vessels earned an average economic net revenue of $36,410 in 2008 and other groundfish fixed gear vessels earned an average economic net revenue of $8,641.

For more information please contact Carl Lian at NOAA's Northwest Fisheries Science Center, Carl.Lian@noaa.gov

e) Bycatch risk pools for the West Coast groundfish fishery

Investigators: D.S. Holland and J. Jannot

Individual transferable quotas (ITQs) in multispecies fisheries create incentives for fishermen to avoid bycatch of species for which quota is scarce. However, when bycatch is highly uncertain, individual quota demand and prices may be volatile creating substantial financial risk for fishermen. The US Pacific Groundfish fishery recently introduced an ITQ system with low quotas for several overfished species with highly uncertain bycatch rates. Some fishery participants are considering pooling bycatch quota. While these risk pools reduce risk for individuals they also create moral hazard and adverse selection problems. We present an analysis of key issues of risk pool design.

For more information please contact Daniel Holland at NOAA's Northwest Fisheries Science Center, Dan.Holland@noaa.gov

9. Advanced Technologies

a) Advanced technologies for monitoring fish and their habitat on the U.S. west coast

Investigators: M.E. Clarke, E. Fruh, C.E. Whitmire and H. Singh

The Northwest and Pacific Islands Fisheries Science Centers have worked with researchers at Woods Hole Oceanographic Institution (WHOI) to redesign the Seabed AUV to overcome the difficulty of monitoring fish populations and habitat in rocky areas. Traditional fish monitoring techniques such as bottom trawl surveys have some limitations for assessing groundfish populations and their habitat throughout their range because of the abundance of rugged terrain. Hover-capable bottom tracking AUVs, on the other hand, offer a unique tool that is appropriate for work in such areas. In addition, this group is collaborating with other researchers to gather information to assess multiple technologies in a variety of habitats.

b) Developing the SeaBED AUV to monitor West Coast groundfish and their habitat

Investigators: M.E. Clarke, E. Fruh and C.E. Whitmire

Many of the commercially important species of demersal fish off the U.S. West Coast inhabit rocky habitats of varying relief that are not accessible with traditional survey gears such as bottom trawls. Due to the number and geographic extent of these habitats, and the number of fish stocks that must be assessed on a regular basis, there is a need for cost-effective tools to survey these areas. Over the past several years, we have been developing a SeaBED type AUV (Autonomous Underwater Vehicle) to survey various benthic habitats for fish and biogenic structure-forming invertebrates (e.g., deep-sea corals, sponges). The SeaBED AUV, developed by Hanumant Singh's lab at Woods Hole Oceanographic Institution, is a bottom tracking AUV that collects high-resolution digital still images of the seafloor and associated fauna. This AUV can be deployed from a variety of vessels ranging from fishing boats to larger oceanographic research vessels. The AUV is primarily an imaging platform that can provide high-resolution georeferenced images as well as associated oceanographic information such as temperature and salinity. We have configured the AUV with both orthogonal (vertical) and oblique (forward) perspective cameras to provide multiple views to aid in the identification of fish and invertebrates. Utilizing its very precise inertial navigation system, we have also employed the AUV to validate habitat information interpreted from high-resolution multibeam sonar imagery. Results from initial surveys show that many fish species can be identified from the images and that associations between fish and emergent fauna (e.g, deep-sea corals) can be quantified. The ability to collect precisely positioned still images has also facilitated photo-mosaicing techniques that show a broader view of the relationships between fauna and habitat than by individual images alone. Some limitations of this AUV relative to ROVs and manned submersibles are that samples cannot be collected and that there is more limited navigational control of the AUV during missions. This limits opportunistic adjustments while surveying, but also

minimizes operator chosen diversions from the survey track. In general AUVs have the advantage of being untethered. This can allow the support vessel to conduct other operations in the vicinity thereby maximizing the data that can be collected per sea day. Furthermore, the complexity of operating the SeaBED AUV in relatively deep depths up to 1500 meters is generally less than those for tethered devices.

For more information, contact Elizabeth Clarke at Elizabeth.Clarke@noaa.gov

c) Southern California shelf rockfish hook-and-line survey external review

In April 2012, the design, methods, and analytical techniques associated with the hook and line survey were reviewed through the Center for Independent Experts (CIE). The CIE provided 2 reviewers, and one independent reviewer served as chair of a panel that evaluated the survey. The survey's design and methods received generally favorable remarks, and several new approaches were suggested for generating indices of abundance and addressing issues associated with gear saturation and inter-specific competition for hooks. Survey staff are currently developing a formal response to the recommendations provided by the review panel.

d) Bias in survey results arising from spatially varying bottom trawl gear efficiency, and a proposed solution involving in situ underwater vehicles

Investigators: J.T. Thorson, E.M. Clarke, and I.J. Stewart

Information regarding several intensively managed groundfish species off the U.S. West Coast is obtained from a randomized bottom trawl survey. However bottom trawl survey efficiency varies spatially due to trawl hangs and presumed decreases in bottom trawl efficiency in rocky habitats. In this study, we use simulation modeling to demonstrate that spatially-varying bottom trawl efficiency can result in a biased relative index of abundance if the target stock undergoes changes in spatial distribution over time. We also propose a sampling design that combines information from bottom trawl and in situ underwater vehicles, within a stratified sampling design. This sampling design mitigates biases seen in bottom trawl sampling, but also has greater precision than only using in situ vehicles. We explore how many in situ vehicle samples are necessary each year to obtain major improvements over bottom trawl designs, and discuss future research that is necessary to further explore the proposed sampling design.

For more information, please contact James Thorson at James.Thorson@noaa.gov

10. Observer Data Collection and Analysis

The FRAM West Coast Groundfish Observer Program (WCGOP) continued collecting fishery-dependent data during 2012 on groundfish fleets along the entire U.S. west coast. The groundfish fishery is broken down into two main categories the catch share fisheries and the non-catch share fisheries. The catch share fisheries require 100% observer and shore side monitoring. The non-catch share fisheries require observer coverage upon request and coverage is randomly assigned by fishery and port group.

Table 2. Number of observers deployed by the WCGOP in 2012

2012	
Number of catch share observers	86
Number of non-catch share observers	39

a) Catch Shares

There are three sectors in the catch share program: shorebased, motherships (includes motherships and mothership catcher-vessels), and catcher-processors. All vessels participating in the shorebased sector or acting as mothership catcher-vessels (MSCV's) must carry one observer on all trips. Motherships and catcher-processors carry two observers each trip. The shorebased sector is managed through Individual Fishing Quotas (IFQ's) and includes all vessels that land catch at shoreside processors. Catch shares regulations allow the shorebased sector to use trawl, longline, or pots to harvest IFQ species. The mothership and catcher-processor sectors target Pacific hake using trawl gear and process it entirely at-sea. Motherships and catcher-processors have formed cooperatives to ensure sectors can attain Pacific hake quota without exceeding bycatch caps for overfished species or salmon. Table 3 below provides information on observer activities in the catch share fishery.

Catch Share observers are deployed in the following catch share fisheries:

- All vessels participating in the Shore-based Individual Fishing Quota (IFQ) program including hake and non-hake groundfish trawl and fixed gear vessels
- All motherships participating in the at-sea hake fishery
- All mothership catcher-vessels participating in the at-sea hake fishery
- All catcher-processors participating in the at-sea hake fishery

Table 3. Summary of observer coverage and sea days in the catch share fisheries

DESCRIPTION	SS IFQ Trawl	SS IFQ Fixed Gear	SS Hake	MSCV	A-SHOP
Number of vessels	67	25	24	16	14
Number of trips*	1122	1281	718	37	48
Number of hauls	9215	2214	1594	956	2060
Number of Sea days*	4991		1926	536	1138**
Number of Observers	86		43	20	33

*Includes trips and/or sea days where no fishing activity occurred.
**Includes both Lead and Second observers

Note: Totals as of 2/06/2013. Since data have not been finalized, these could change in the future.

SS IFQ trawl: vessels targeting non-hake groundfish with trawl gear and landing at shorebased processors.
SS IFQ Fixed Gear: vessels targeting non-hake groundfish using longlines or pots and landing at shorebased processors.
SS Hake: vessels targeting hake using trawl gear and landing at shorebased processors.
MSCV: mothership catcher-vessel targeting hake with trawl gear
A-SHOP: motherships and catcher-processors targeting hake using trawl gear

b) Non-catch shares

The observer program collects data in other west coast fisheries that are not part of the catch share program. The program had 1,979 sea days in the non-catch share fisheries in 2012 aboard vessels ranging in size from skiffs to larger fixed gear vessels and depths ranging from less than 20 fm to more than 300 fm.

Table 4. Non-Catch Share sea day summary by fisheries/sectors:

FISHERY DESCRIPTION	SEA DAYS*
CA Halibut	49
CA Nearshore	200
CA Pink Shrimp	56
Limited Entry Sablefish	441
Limited Entry Zero Tier	145
OR Blue/Black Rockfish	84
OR Blue/Black Rockfish Nearshore	161
OR Pink Shrimp	610
WA Pink Shrimp	149
WC Open Access Fixed Gear	84

*Includes sea days where no fishing activity occurred.
Due to its unique data collection circumstances in both the catch shares and non-catch shares fisheries, the program continues to stress safety and data quality.

c) Data and analytical reports

The data collected by observers is used to improve total catch estimates, primarily for fish discarded at-sea. The data are used in assessing a variety of groundfish species, by fisheries managers, and by other fishery, protected resource, and other scientists.

Summaries of data collected on observed trips are routinely published on the NWFSC web site. All WCGOP reports can be obtained at:
http://www.nwfsc.noaa.gov/research/divisions/fram/observer/datareport/index.cfm.

For more information, please contact Jon McVeigh at Jon.McVeigh@noaa.gov

11. Recent Publications

Anderson, M.J., Tolimieri, N., Millar, R. 2013. Beta diversity of demersal fish assemblages in the north-eastern Pacific: interactions of latitude and depth. PLoS One. In press.

Andrews, K.S., Harvey, C.J. 2013. Modeling growth and reproduction of chilipepper rockfish under variable environmental conditions. Marine Ecology Progress Series 473:247-260.

Andrews, K.S., Quinn, T.P. 2012. Combining fishing and acoustic monitoring data to evaluate the distribution and movements of spotted ratfish *Hydrolagus colliei*. Marine Biology 159: 769-782.

Bosley, K.L., Bosley, K.M., Whitmire, C.E., Keller, A.A. 2012. Relating groundfish biomass, species richness and community structure to the presence of corals and sponges using NWFSC bottom trawl survey data. *17th Western Groundfish Conference, Seattle, WA, February 7-10, 2012.*

Bosley, K.L., Miller, T., Brodeur, R.D., Bosley, K.M., VanGaest, A., Elz, A. (In revision) Feeding ecology of juvenile rockfishes off Oregon and Washington, based on stomach contents and stable isotopes. Mar. Biol.

Bradburn, M. 2102. Light availability during bottom trawls affects catchability of Eastern Pacific groundfish species. *17th Western Groundfish Conference, Seattle, WA, February 7-10, 2012.*

Bryan, D.R., Bosley, K.L., Hicks, A.C., Haltuch, M.A., Wakefield, W.W. 2013. Quantitative video analysis of flatfish herding behavior and effective area swept of a survey trawl. ICES J Mar Sci.

Cope, J.M. 2012. Extending catch-only Stock Synthesis models to include indices of abundance. Submitted to the data-moderate methods review panel. Assessment Methods for Data-Moderate Stock Review Panel. 62 p.

Cope, J.M. 2012. Informing fisheries management in resource-limited situations. Use of Reference Points for Bycatch Risk Assessment of Marine Megafauna: Workshop I. *Invited speaker, La Jolla, CA, March 7.*

Cope, J.M. 2012. Applied science for informed management: The supporting role of NWFSC science in Pacific west coast groundfish management. *Thematic speaker, NWFSC 3rd Science Symposium, March 14.*

Cope, J.M. *in press*. Implementing a statistical catch-at-age model (Stock Synthesis) as a tool for deriving overfishing limits in data-limited situations. Fisheries Research. *special edition.*

Cope, J.M., Haltuch, M.A. 2012. Temporal and spatial summer groundfish assemblages in trawlable habitat off the west coast of the USA, 1977 to 2009. Marine Ecology Progress Series 451: 187-200.

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