Northwest Fisheries Science Center

National Marine Fisheries Service

NOAA Fisheries

Agency Report to the Technical Subcommittee

of the Canada-U.S. Groundfish Committee

April 2020

I. 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. Four divisions, Conservation Biology, Environmental and Fisheries Sciences, Fish Ecology, and Fishery Resource Analysis and Monitoring, conduct applied research to resolve problems that threaten marine resources or that deter their use. 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; and Charleston, North Carolina.

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 2019, 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, Craig Russell at Craig.Russell@noaa.gov, (206) 860 – 3402.

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 and Fisheries Sciences Division conducts research to assess and reduce natural and human-caused impacts on environmental and human health, and to improve methods for fisheries restoration and production in conservation hatcheries and in aquaculture. Environmental health and conservation research examines environmental conditions and the impacts of chemical contaminants, marine biotoxins, and pathogens on fishery resources, protected species, habitat quality, seafood safety, and human health. Fisheries restoration and aquaculture includes research on the challenges associated with captive rearing, nutrition, reproduction, behavior, disease control, engineering, hatchery technology and larval/juvenile quality for protected, depleted and commercially valuable species.

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.

For more information on Northwest Fisheries Science Center programs, contact the Center Director, Dr. Kevin Werner at Kevin.Werner@noaa.gov, (206) 860 – 6795.

II. Surveys

A. U.S. West Coast Groundfish Bottom Trawl Survey

The NWFSC conducted its twenty-second annual bottom trawl resource survey for groundfish off the coasts of Washington, Oregon, and California. The objective of the 2019 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 two commercial fishing vessels to conduct a reduced survey in 2019 using standardized trawl gear. Fishing vessels Last Straw and Excalibur were contracted to survey the area from Cape Flattery, WA to the Mexican border in Southern California (Figure 1), beginning in the later part of May and continuing through October. Each charter was for a period of 11-12 weeks with the Last Straw surveying the coast during the initial survey period from May to July. The Excalibur 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 2019, we continued to utilize an updated backdeck data collection system with improved software applications, and wireless networking. Programming used to gather data for the groundfish survey was rewritten so that the various components were fully integrated, updated to include multiple sensor streams, and enhanced to increase flexibility for data input from special projects and future undefined data sources. The changes in the back-deck programming, wheel house programming and data QA/QC process resulted in overall improvements to data collection efficiency and anticipated future decreases in time requirements for data to be made available to the Data Warehouse. 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) Collection of voucher specimens for multiple fish species – Northwest Fisheries Science Center and University of Washington;

2) Collection of DNA and/or whole specimens of rougheye rockfish (*Sebastes aleutianus*), blackspotted rockfish (*Sebastes melanostictus*), darkblotched rockfish (*Sebastes crameri*) and

blackgill rockfish (*Sebastes melanostomus*) to reduce uncertainty in the assessment of morphologically-similar west coast rockfish – Northwest Fisheries Science Center;

3) Collect fin clips and other tissues from all Pacific sharks (*Somniosus pacificus*) to examine genetics – NOAA, NWFSC – Cindy Tribuzio;

4) Request for photographs of lamprey scars – Laurie Weitkamp, NWFSC, Conservation Division, Newport;

5) Identify to species all Pacific Lamprey (*Lampetra tridentata*) then collect and freeze each specimen individually – Laurie Weitkamp, NWFSC, Conservation Division, Newport;

6) Identify to species all river Lamprey (*Lampetra ayresii*) then collect and freeze each specimen individually – Laurie Weitkamp, NWFSC, Conservation Division, Newport;

7) Collection of all biological data and specimens of deepsea skate (*Bathyraja abyssicola*) and broad skate (*Amblyraja badia*) - Moss Landing Marine Laboratories;

8) Collect and freeze all specimens of Pacific black dogfish (*Centroscyllium nigrum*), velvet dog shark (*Zameus squamulosus*) and cookiecutter shark (*Isistius brasiliensis*). – Moss Landing Marine Laboratories;

9) Collection of all unusual or unidentifiable skates, Pacific white skate *(Bathyraja spinossisima)*, fine-spined skate (*Bathyraja microtrachys),* and Aleutian skate (*Bathyraja aleutica)* – Moss Landing Marine Laboratories;

10) Collection of all unidentified or rare skates, ray, shark or chimaera– Moss Landing Marine Laboratories;

11) Collection of North Pacific black ghost shark (*Hydrolagus* melanophasma and pointy-nosed blue chimaera (*Hydrolagus trolli*) – Moss Landing Marine Laboratories;

12) Collection of voucher specimens for multiple fish species – Oregon State University;

13) Coral population genetics - Collect whole specimens of *Desmophyllum dianthus* - in 95% ETOH – Cheryl Morrison;

14) Specimen collection for multiple fish speciesfor teaching purposes for the West Coast Observer Program;

15) Collect sex, total length and photograph dorsal side (including close up of dorsal side of snout) for all big skate (*Beringraja binoculata*), California skate (*Raja inornata*) and starry skate (*Raja stellulata*) captured at depths greater than 300 m – Joe Bizzarro;

16) Retain whole specimens of big skate (*Beringraja binoculata*), California skate (*Raja inornata*) and starry skate (*Raja stellulata*) captured at depths greater than 500 m – Joe Bizzarro;

17) Photograph bamboo coral (with ruler for scale) and collect the base if possible – Carina Fish, UC Davis.

Several other research initiatives were undertaken by the Survey Team including:

1) Use of tissue samples stable isotope analysis to examine the feeding ecology of rockfish (darkblotched, canary, blackgill, blackspotted/rougheye, yelloweye, yellowtail rockfishes and cowcod) and other species (sablefish, lingcod, longspine thornyheads, and shortspine thornyheads);

2) Collection of stomachs for various rockfish (darkblotched, canary, blackgill, blackspotted/rougheye, yelloweye, yellowtail rockfishes and cowcod) and other species (sablefish, lingcod, longspine thornyheads, and shortspine thornyheads);

3) Fin clip collection for DNA analysis of various shelf rockfish species;

4) Collect and/or photograph cold water corals;

5) Collect near-bottom dissolved oxygen data to examine relation with fish distribution;

6) Record composition and abundance of benthic marine debris collected during the 2019 West Coast Groundfish Trawl Survey;

8) Collect ovaries and finclips from bank, brown, copper, blackspotted/rougheye, vermilion/sunset rockfishes;

9) Collect whole ovary and finclips from Pacific cod and yelloweye rockfish;

9) Collect ovaries from longspine thornyheads, Dover sole and Pacific hake (and gonads for males) to assess maturity;

10) Collection of prey items for multiple species for stable isotope analysis;

11) Photograph, tag, bag and freeze deep water species such as arbiter snailfish (*Careproctus kamikawi*) and other rare or unidentified deep water species;

12) Macroscopic analysis of maturity of big skate and longnose skate;

13) Collect a photographic quality specimen of arbiter snailfish (*Careproctus kamikawai*);

14) Collect all specimens of sharpnose sculpin (*Clinocottus acuticeps*) for species confirmation.

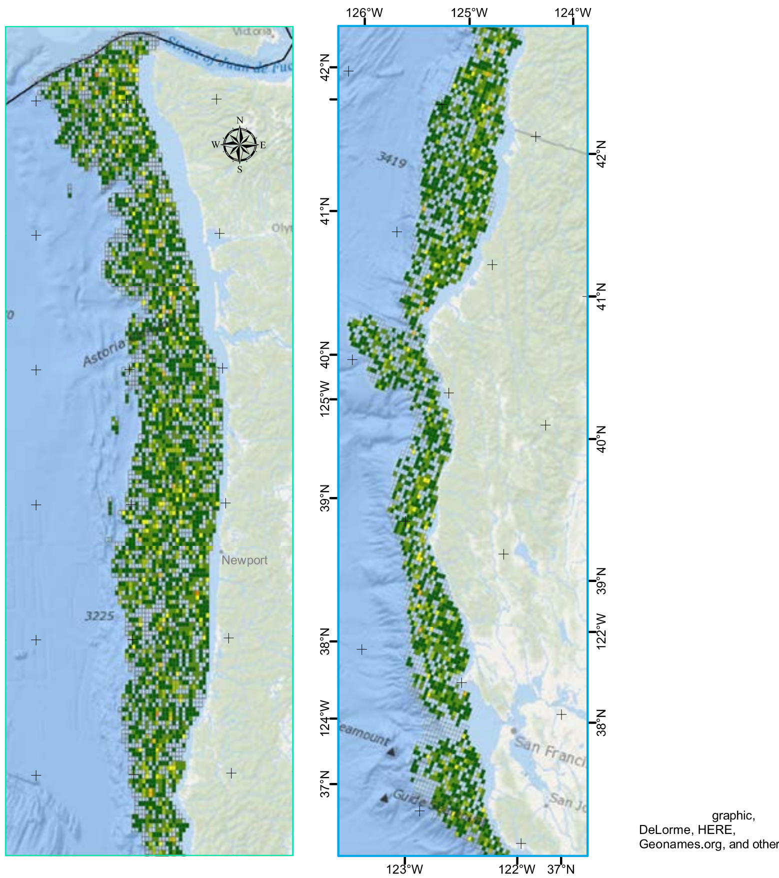


Figure 1. Summary of station locations and frequency for the West Coast Groundfish Bottom Trawl Survey 2003 to 2018.

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

B. Southern California shelf rockfish hook-and-line survey

In early Fall 2019, FRAM personnel conducted the 17th 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 groundfish including bocaccio (*Sebastes paucispinis*), bank rockfish (*S. rufus*), copper rockfish (*S. caurinus*), greenspotted rockfish (*S. chlorostictus*), cowcod (*S. levis*) blue rockfish (*S. mystinus*), speckled rockfish (*S. ovalis*), the vermilion rockfish complex (e.g., *S. miniatus* and *S. crocotulus*) and lingcod (*Ophiodon elongatus*) within the SCB.

The F/V Aggressor (Newport Beach, CA), F/V Mirage (Port Hueneme, CA), and F/V Toronado (Long Beach, CA) were each chartered for 14 days of at-sea research, with 13 biologists participating during the course of the survey. The three vessels sampled a total of 201 sites, as well as experimental sampling at 7 sites, ranging from Point Arguello in the north to the U.S.-Mexico EEZ boundary in the south (Figure 2). The survey sampled a depth range of 20 – 125 fth (37 – 229 m). Data from the survey have informed the stock assessments for several rockfish species and have helped monitor the rebuilding of overfished species such as bocaccio (*S. paucispinis*) and cowcod (*S. levis*). The survey also collects information to support ecosystem-level analyses by capturing visual observations of the seafloor habitat via a towed video sled and by deploying a suite of oceanographic sensors as a component of sampling operations.

Including supplementary experimental sampling at 7 sites, the survey encountered 7,054 individual fish representing 40 species. Overall, catches were reduced from 2018 levels by about 15%. Data collected included 6,994 sexed lengths and weights, 4,304 otolith pairs, 5,702 finclips. Approximately 265 ovaries were collected from 8 different species to support the development of maturity curves and fecundity analysis. 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. The survey made 4 deployments of an underwater video sled to capture visual observations for habitat analysis, species composition, and fish behavioral studies. The survey continued to descend or release and tag all individuals captured at 6 sites located inside federal marine reserves. To date, approximately 911 individuals have been tagged. 2019 marked the third year since implementation of the HookLogger wireless electronic data collection system on board survey vessels. This system networks two mobile tablet workstations on the back deck with a desktop computer inside the galley with each machine writing to a common database using customized UI and networking software. HookLogger has eliminated the need for post-survey manual data entry and has improved data quality by integrating real-time validations and other error checking. The innovation and efficiency of this software and network system was recognized by NOAA by awarding its developers with the agency's Bronze award.

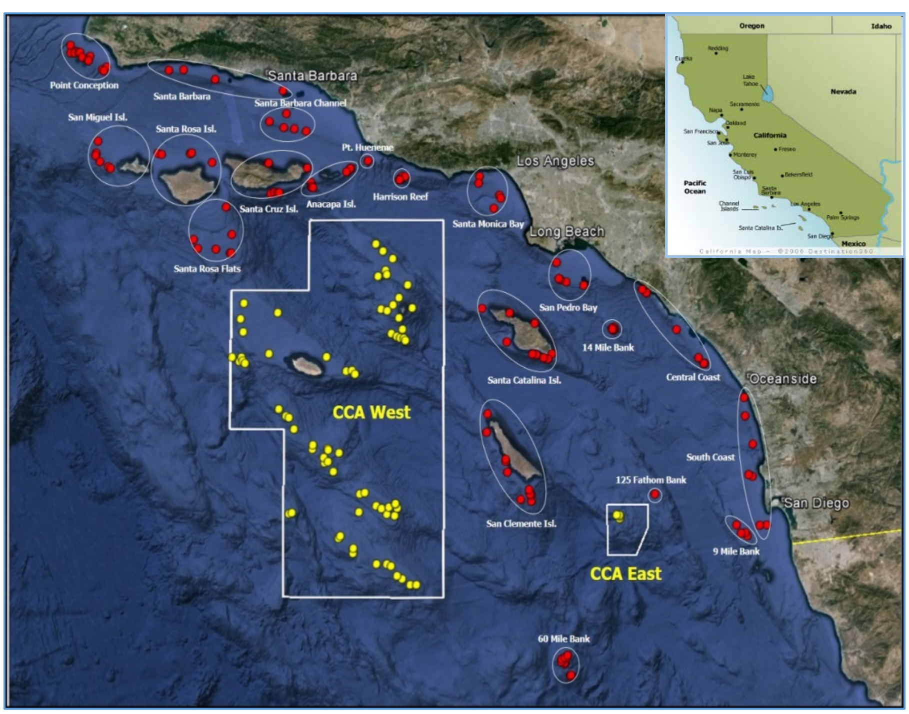


Figure 2. Sampling locations for the 2019 Hook and Line Survey located inside (yellow dots) and outside (red dots) the Cowcod Conservation Areas (CCAs).

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

C) 2019 Joint U.S./Canada Integrated Ecosystem and Pacific Hake Acoustic-Trawl Survey

The Joint U.S./Canada Integrated Ecosystem and Pacific Hake Acoustic-Trawl Survey was conducted in U.S. and Canadian waters by a U.S. team (NWFSC/FRAM) on the NOAA Ship Bell M. Shimada from 13 June 2019 to 20 August 2019, and by a Canadian team (DFO/Pacific region) on the Canadian chartered F/V Nordic Pearl from 17 August 2019 to 15 September 2019. Data collected during the survey were processed to provide an estimate of the abundance and spatial distribution of the coastal Pacific hake (*Merluccius productus*) stock shared by both countries. The survey covered the slope and shelf of the U.S. and Canada West Coast with acoustic transects from roughly 34.4°N (south of Point Conception, California) to 54.8°N (Southeast Alaska and Dixon Entrance) (Figure 3). Transects were oriented east-west (except for transects in Dixon Entrance that were oriented north-south) and were spaced 10 nautical miles (nmi) apart through the north end of Vancouver Island, after which spacing increased to 20 nmi. Acoustic data were collected on the Shimada with a Simrad EK60 scientific echosounder system operating at frequencies of 18, 38, 70, 120, and 200 kHz. On the Nordic Pearl, acoustic data were collected with a Simrad EK60 echosounder operating at frequencies of 38 and 120 kHz. The Shimada collected acoustic data from 78 transects and the Nordic Pearl from 35, resulting in a total survey-wide linear distance of 4,504 nmi of acoustical transects that were used for the Hake biomass estimate. Aggregations of adult (age 2+) Hake were detected on 83 transects, ranging from north of Morro Bay, California (roughly 35.7°N) to north of Vancouver Island (roughly 51.1°N). In U.S. waters, Hake concentrations between roughly 36°N and 39°N were comparatively light. North of 39°N, aggregations of observed Hake sign became more consistent and extensive; areas of strong Hake sign were observed between Crescent City, California and Newport, Oregon. North of Newport, Hake sign diminished but still remained fairly consistent; relatively high amounts were observed south of Astoria, Oregon and along the northern half of Washington State. In Canadian waters, although only modest aggregations of Hake were observed along much of Vancouver Island and no Hake were observed further north, higher concentrations of Hake were observed near the northwest tip of the island and west of Barkley Sound. Midwater trawls equipped with a camera system were conducted to verify species composition of observed backscatter layers and to obtain biological information (e.g., size and sex distribution, age composition, sexual maturity). A total of 93 successful midwater trawls (71 by the Shimada—including four open-codend trawls at the end of the survey to test a new stereo camera system—and 22 by the Northern Pearl) resulted in a combined total hake catch of 32,618 kg (14,813 kg from the Shimada and 17,805 kg from the Northern Pearl). Hake accounted for 88% of the catch in U.S. waters. The estimated total biomass of adult hake in 2019 was 1.723 million metric tons, with approximately 89% (1.531 Mt) of observed biomass located in U.S. waters. The 2019 estimate was roughly 20% larger than the average biomass estimate for all surveys conducted since 1995 (1.723 vs. 1.431 Mt), and represented an increase of 0.3 Mt over the 2017 biomass estimate. Age-3 and age-5 Hake contributed most to the 2019 biomass estimate—combining for almost 57%—followed by age-9 hake.

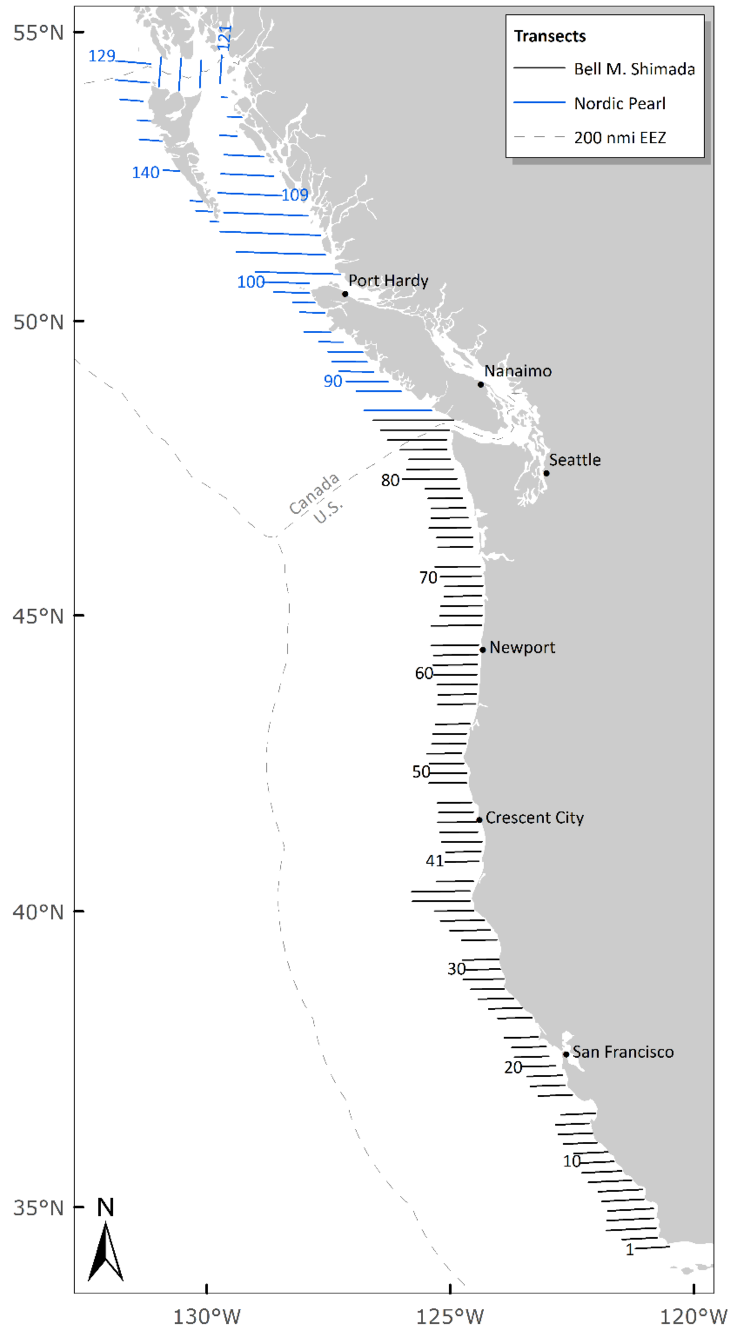


Figure 3. Planned acoustic survey transects in 2019 from roughly 34.4°N (south of Point Conception, California) to 54.8°N (Southeast Alaska and Dixon Entrance).

For more information, please contact Sandy Parker-Stetter at sandy.parker-stetter@noaa.gov.

D. Untrawlable Survey North: comparing different tools for surveying groundfish in rocky habitats

Investigators: Peter Frey, Victor Simon, John Harms, Aimee Keller, Aaron Chappell, Laurel Lam, Keith Bosley, Linda Park, Abi Wells, Matt Blume (ODFW), Leif Rassmuson (ODFW)

Quantitative sampling of groundfish in untrawlable habitats has long been an unrealized goal for managers and fishery stakeholders on the U.S. West Coast. Stock assessors have repeatedly cited this data gap as a source of uncertainty in models, particularly for key fishery-limiting species such as yelloweye rockfish. In November 2019, we tested three visual observation systems as well as environmental DNA (eDNA) collections to compare different methods for sampling groundfish in hard-bottom, rocky habitats of the continental shelf. Our visual tools included two stationary stereo camera systems and a towable camera device developed by research partners at the Alaska Fisheries Science Center and the Oregon Department of Fish and Wildlife. Near-bottom water samples for eDNA analysis of species occurrence were collected using niskin bottles attached to the stationary camera systems and triggered at depth. This project took place over 5 days aboard a chartered commercial fishing vessel at several hard-bottom banks off the central Oregon Coast. During that time we performed 108 drops of each stationary camera system, collected 84 water samples for eDNA analysis, and made 9 tows using the 'TowCam'. While our analysis from this research is ongoing, we have already learned many valuable lessons about the quality of data produced by each system, the feasibility of expanding spatial coverage, and considerations for untrawlable habitat survey design. This research focused on sampling methods and some preliminary results to compare the data from each system. Ultimately, this research is intended to be a first step towards developing an efficient, standardized time series of groundfish in untrawlable habitats to complement existing data sources and improve fishery management.

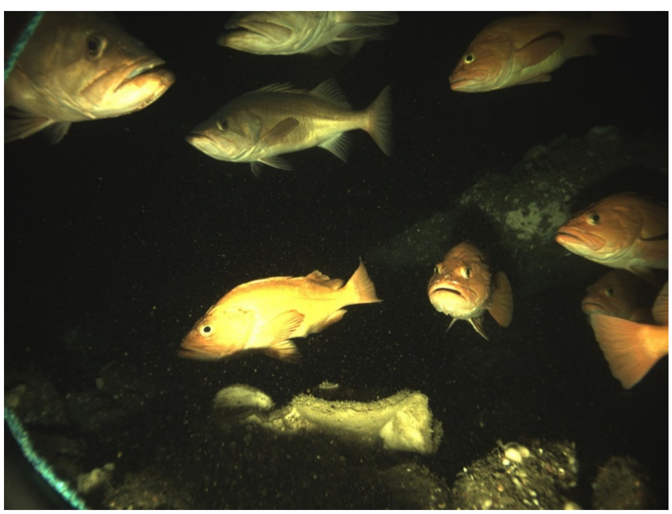


Figure 4. Yelloweye rockfish as seen using the stationary drop camera during the 2019 untrawlable habitat pilot study.

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

III. Reserves

a) Changes in long-lived rockfishes after more than a decade of protection within California's largest marine reserve

Investigators: Aimee A. Keller, John H. Harms, John R. Wallace, Colin Jones, Jim A. Benante, and Aaron Chappell

In 2001, the Pacific Fishery Management Council established two large (10,878 km^2 and 260 km^2) Southern California Bight marine reserves called Cowcod Conservation Areas (CCAs) in response to declining abundance of west coast rockfishes, particularly overfished cowcod. Following closure, no fishery independent monitoring took place for groundfishes within the CCAs through 2013. To assess the impact of the closures, we sampled multiple sites inside versus outside CCAs from 2014 to 2016 via the Northwest Fisheries Science Center's Hook and Line Survey. We investigated variations in catch per unit effort (CPUE), size, length frequency and percent of sites with positive catch for 14 abundant groundfishes (bank, bocaccio, chilipepper, copper, cowcod, greenspotted, lingcod, olive, rosy, speckled, squarespot, starry, swordspine and the vermilion-sunset complex). General Linear Models (GLMs) that included area, year, depth and distance from port revealed significantly greater ($p < 0.05$) CPUE inside CCAs for 11 species. CPUE for lingcod, copper rockfishes and vermilion-sunset was significantly ($p < 0.05$) or near-significantly ($p < 0.1$) lower inside the CCAs. We saw significant ($p < 0.05$) or near-significant differences ($p < 0.10$) in size (12 species) and length frequency distributions (10 species) with larger fish present inside CCAs. The percentage of sites positive for individual species tended to be greater inside CCAs (11 species). We also observed significantly elevated species richness (species per site) and total CPUE inside CCAs. Results indicate larger individuals and greater CPUE for multiple rockfishes inside CCAs either as a result of effective management or perhaps pre-existing conditions.

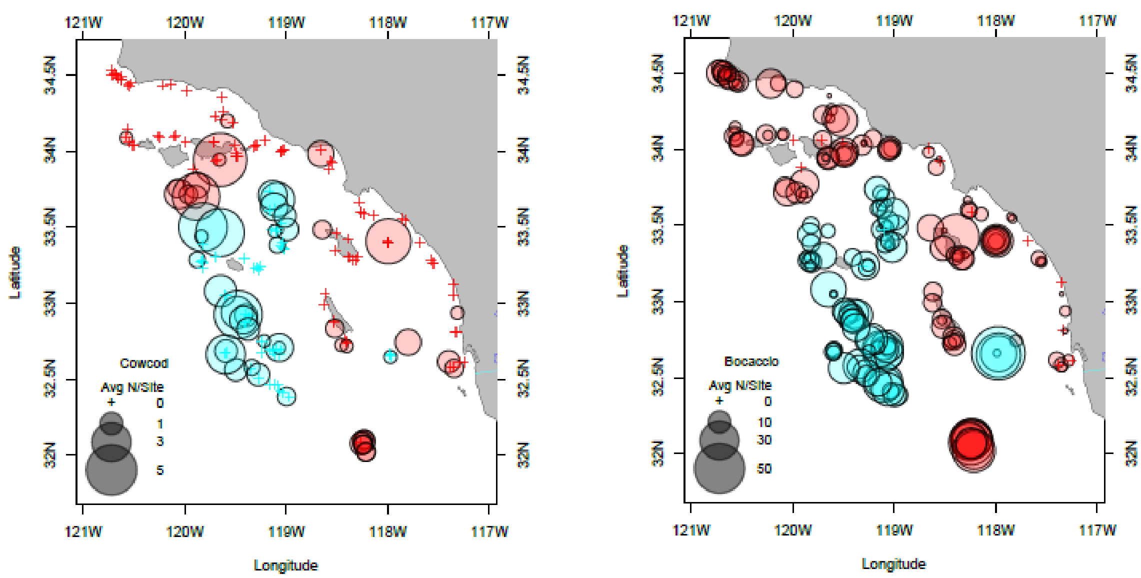


Figure 5. Charts showing distributions and relative abundance (site-specific CPUE averaged across years) inside (blue circles) versus outside (red circles) the CCAs for cowcod and bocaccio Note that the range of CPUE varies as shown in the inset for each chart and + represents zero catch.

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

b) Integrated Ecosystem Assessment support of condition reports for west coast National Marine Sanctuaries

Investigators: G. Williams, J. Brown, C. Caldow, K. Andrews, N. Tolimieri, C. Harvey, and numerous contributors from the NWFSC, SWFSC, Office of National Marine Sanctuaries, and partner institutions

The California Current Integrated Ecosystem Assessment (IEA) team has provided extensive support to the Office of National Marine Sanctuaries (ONMS) toward the development of condition reports for sanctuaries located along the west coast. Sanctuary condition reports are tools employed by NOAA to assess the condition and trends of national marine sanctuary resources. Condition reports provide a standardized summary of resources in NOAA's sanctuaries; drivers and pressures on those resources; current conditions and trends for resources and ecosystem services; and describe existing management responses to the pressures that threaten the integrity of the marine environment. Condition reports include information on the status and trends of water quality, habitat, living resources and maritime archaeological resources, and the human activities that affect them. They present responses to a set of questions posed to all sanctuaries. The reports also rate ecosystem service status and trends. Resource and ecosystem service status are rated on a six-point scale from good to poor, and the timelines used for comparison vary from topic to topic. Trends in the status of resources and ecosystem services are also reported, and are generally based on observed changes in status since the prior condition report, unless otherwise specified.

The primary roles of the IEA team in this collaboration have been: guidance in developing an IEA framework for assessment and management of sanctuaries; the screening of ecosystem indicators and the identification of relevant time series of data; and development of conceptual models of key sanctuary habitats and communities. The first west coast sanctuary condition report to be published that features products from this collaboration is the Channel Islands National Marine Sanctuary condition report in 2019 (citation below); groundfish are broadly represented in indicators and conceptual models under many of the focal questions considered within the Channel Islands condition report.

For more information please contact Mr. Greg Williams at NOAA's Northwest Fisheries Science Center / Pacific States Marine Fisheries Commission, Greg.Williams@noaa.gov.

IV. Review of Agency Groundfish Research, Assessments, and Management

A. Hagfish

B. Dogfish and other sharks

C. Skates

1. No reported research
2. Assessments

a) Longnose skate stock assessment

Investigators: Vladlena Gertseva, Sean Matson, Ian Taylor, Joseph Bizzarro, John Wallace

Longnose skate (*Beringraja rhina*) is broadly distributed from the southeastern Bering Sea to southern Baja California and the Gulf of California. This assessment reports the status of the longnose skate resource off the coast of the United States from southern California to the U.S. - Canadian border. The species is modeled as a single stock, as there is currently no biological and genetic data supporting the presence of multiple stocks within the assessment region.

Longnose skate is a common bycatch skate species in the groundfish demersal trawl fishery on the west coast of the United States. Historically, skates caught on the U.S. west coast have not been marketed as high-priced fishery products. Available information suggests that prior to the mid-1990s, processors primarily accepted only the skinned pectoral fins (often called “wings”), and most boats simply discarded skates as they did not want to go into the effort of winging the skates on board as low ex-vessel prices would not justify the effort. In the mid-1990s however, demand for whole skates increased in California and Oregon, and processors began accepting whole skates for landing; boats started to retain skates if they had space to hold them, which caused a substantial increase in retention rates and landed catch. After a few years, the whole skate market cooled and currently, west coast skates are marketed both whole and as wings, with skate wings sold fresh or fresh-frozen, as well as dried or salted and dehydrated.

This assessment, conducted in 2019, estimates that the stock of longnose skate off the continental U.S. Pacific Coast is currently at 57 percent of its unexploited level. This is above the overfished threshold of SB25% and the management target of SB40% of unfished spawning biomass. The assessment described the dynamics of the longnose skate stock to be slowly declining from the unfished conditions, with a flat trend from the early 2000s

The time series of total mortality catch (landings plus discards) and estimated depletion for longnose skate are presented in Figure 6.

The assessment model captures uncertainty in estimated size and status of the stock through asymptotic confidence intervals estimated within the model. To further explore uncertainty associated with alternative model configurations and evaluate the responsiveness of model outputs to changes in key model assumptions, a variety of sensitivity runs were performed. A major source of uncertainty in the assessment is related to catchability of the west coast Groundfish Bottom Trawl (WCGBT) Survey, which was found to have a large influence on the perception of current stock size. WCGBT Survey catchability in the assessment is estimated using the prior that accounts for multiple factors affecting survey catchability. These factors include latitudinal, depth and vertical availably of longnose skate to the survey as well as probability of catch in survey net path. Uncertainty from WCGBT Survey catchability is reported via alternate states of nature in the decision table, bracketing the base model results.

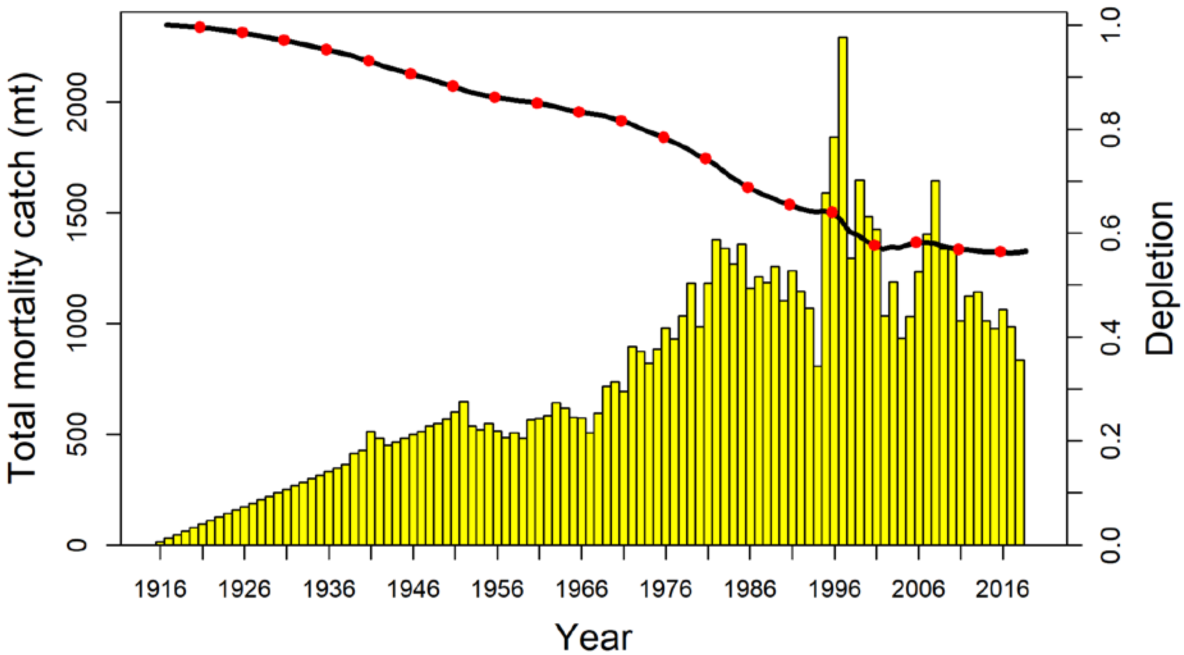


Figure 6. The time series of total mortality catch (bars) and estimated depletion (line) for longnose skate.

For more information on the longnose skate assessment, contact Dr. Vladlena Gertseva at Vladlena.Gertseva@noaa.gov

b) Status of Big Skate (*Beringraja binoculata*) Off the U.S. Pacific Coast in 2019

Investigators: I. Taylor, V. Gertseva, A. Stephens, and J. Bizzarro

Big Skate (*Beringraja binoculata*) is the largest of the skate species in North America with a documented maximum length of 244 cm total length and a maximum weight of 91 kg. The Big Skate is most common in soft-sediment habitats in coastal waters of the continental shelf. The Big Skate is broadly distributed, occurring from the southeastern Bering Sea to southern Baja California and the Gulf of California.

The current assessment is the first for this species on the U.S. west coast. Although the skates are known to be capable of long-distance movements, for purposes of this assessment, the stock is assumed to be a single, unit stock whose dynamics are independent of Big Skate populations off Canada and in the Gulf of Alaska. Big Skate are primarily caught in commercial bottom trawl fisheries. There is a limited market for pectoral fins (skate wings). The majority of Big Skate catch was discarded prior to 1995 when markets for Big Skate and Longnose Skate developed, landings increased, and discarding decreased. Reconstructed history of catch and discards showed total mortality in the range 400-600mt between 1950 and 1995 with reduced mortality in more recent years. The stock assessment was conducted with Stock Synthesis. The assessment is fit to two bottom trawl survey indices of abundance, the Triennial Survey from which an index covering the period 1980-2004 was used here and the West Coast Groundfish Bottom Trawl Survey, which began in 2003 and for which data is available through 2018. Both indices show increasing trends that are not fit well by the model, suggesting that the stock dynamics have been impacted by factors other than fishing. Length and age composition data from the fishery and surveys are fit reasonably well by the stock assessment and provide information on growth. Sex-specific differences in selectivity were included in the model in order to better match patterns in the sex ratios in the length composition data and a new "growth cessation model" was used to model growth as it provided much better fits than the von Bertalanffy growth function. Recruitment is deterministic with steepness of the stock-recruit curve fixed at 0.4. The final model has 44 estimated parameters, most of which are related to selectivity (including sex-specific differences), time-varying retention, and growth (including sex-specific differences).

The scale of the population is not reliably informed by the data due to the combination of surveys that show trends, which cannot be matched by the structure of the model, and length and age data that inform growth and selectivity but provide relatively little information about changes in stock structure over time. Therefore, a prior distribution on the catchability of the WCGBT Survey (centered at 0.701) was applied in order to provide more stable results. The prior distribution is based on a combination of expert judgement and an estimate using fishery catch rates of the fraction of Big Skate biomass unavailable to the WCGBT Survey due to occurring shallower than the 55 m limit of the survey design. Although the assessment model requires numerous simplifying assumptions, it represents an improvement over the simplistic status-quo method of setting management limits, which relies on average survey biomass and an assumption about the fishing mortality associated with maximum sustainable yield. The use of an age-structured model with estimated growth, selectivity, and natural mortality likely provides a better estimate of past dynamics and the impacts of fishing in the future than the status-quo approach.

The 2019 estimated spawning biomass relative to unfished equilibrium spawning biomass is above the target of 40% of unfished spawning biomass at 79.2% (95% asymptotic interval: 65.5%-92.9%) All sensitivity analyses explored also show the stock to be at a relatively high level.

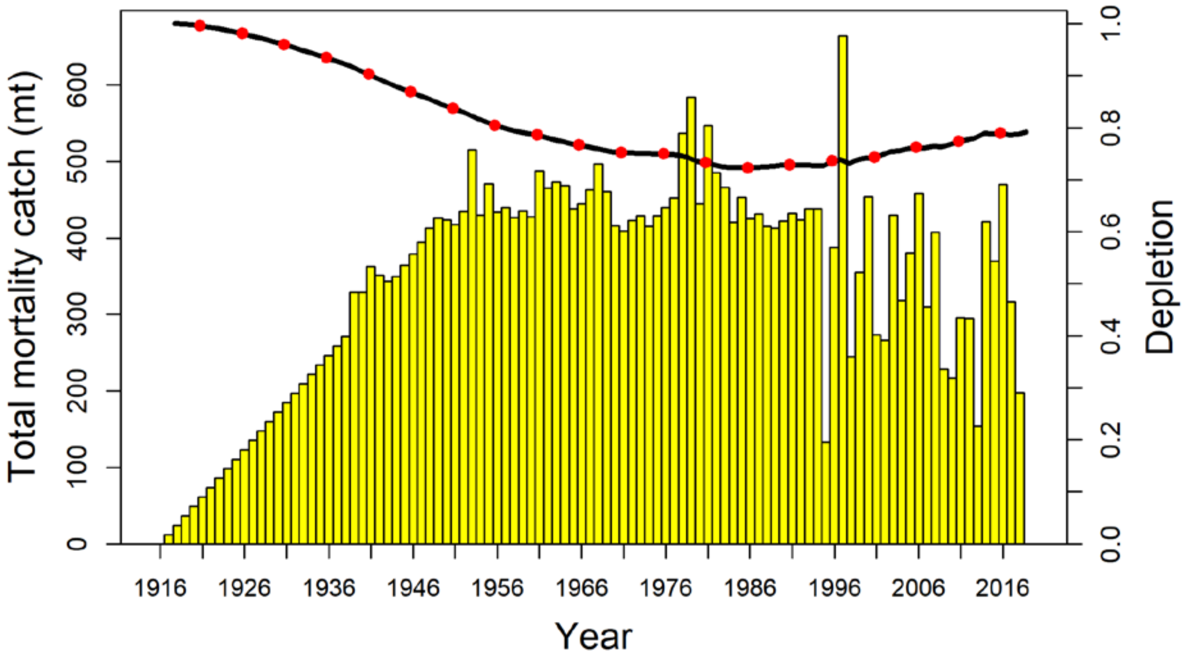


Figure 7. Total mortality catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Big Skate, 1916-2018.

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

D. Pacific cod

E. Walleye Pollock

F. Pacific whiting (hake)

1. Research

a) Pacific Hake Management Strategy Evaluation

Investigator: Kristin Marshall

The Pacific Hake Management Strategy Evaluation (MSE) entered a new iteration in mid-2017. The MSE is a binational effort between the U.S. (NOAA Fisheries) and Canada (DFO) in support of the Pacific Hake/Whiting Treaty. The goals of this iteration of MSE were to: 1) Evaluate the performance of current hake management procedure under alternative hypotheses about current and future environmental conditions, 2) Better understand the effects of hake distribution and movement on both countries' ability to catch fish, and 3) Better understand how fishing in each country affects the availability of fish to the other country in future years.

We developed a spatially explicit (two area) operating model, with age-based movement of fish between areas. Other aspects of the operating model closely resemble the current stock assessment model for Pacific hake. We conditioned this model to the coastwide stock assessment and available country-specific data, including survey biomass, survey age compositions, and fishery age compositions. We worked with the International Hake Treaty management bodies to develop and refine goals, objectives and performance metrics used to evaluate performance. These metrics describe performance in terms of stock status, coastwide catch, catch variability, and spatially explicit exploitation rates.

To address the three goals for the MSE we developed four sets of scenarios to begin to explore how key uncertainties might influence future performance of the current management procedure for hake. These scenarios are: 1) Alternative implementation scenarios that influence how much catch is removed from the stock each year, 2) Future climate scenarios that increase fish movement rates, 3) Alternative selectivity scenarios that change the age composition of catch in each country, 4) Survey frequency scenarios that change how often the acoustic survey is conducted. While each scenario type revealed different sensitivities and tradeoffs, the alternative implementation scenarios had the largest influence on projected stock status and catch. Of the performance metrics we examined, variability in catch was the most responsive across all the scenarios. Assessment error was influenced most by the selectivity scenarios and survey scenarios.

Technical documentation and model output were recently reviewed by the Scientific Review Group of the Pacific Hake Treaty. This new closed-loop simulation model can be used for future MSE questions and applications. The scenarios we explored provide a foundation of results exploring key uncertainties. However, further testing, additional scenarios, and crosses of scenario types may be necessary to more fully explore the model dynamics and to address future questions of interest from hake management bodies.

For more information on the Hake MSE, contact Kristin Marshall (kristin.marshall@noaa.gov)

b) 2018 Unmanned surface vehicle (Saildrone) acoustic survey off the west coasts of the United States and Canada

Investigators: Dezhang Chu, Sandra Parker-Stetter, Lawrence C. Hufnagle, and Stéphane Gauthier

To evaluate the applicability and performance of the Unmanned Surface Vehicles (USVs), the Northwest Fisheries Science Center (NWFSC) and Southwest Fisheries Science Center (SWFSC) of NOAA Fisheries, partnered with NOAA Pacific Marine Environmental Laboratory (PMEL) and the Department of Fisheries and Oceans, Canada (DFO), conducted a coast-wide acoustic survey off the west coasts of the United States and Canada in the summer of 2018 using 5 Saildrones (Saildrone, Inc). The USVs surveyed a total of 5,400 nmi of distance along 124 transects between Vancouver, BC and the Southern California Bight, CA, mirroring the transect design of the NOAA Fisheries Survey Vessel (FSV) Reuben Lasker for the 2018 coastal pelagic species (CPS) survey. The survey design allowed us to compare USV and FSV acoustic data while also evaluating the operational feasibility and performance of the USVs. Despite some initial technical problems with vehicle firmware and navigation, the overall USV operations were stable, reliable, and successful. The performance of the USVs on navigation, operation, and the quality of acoustic data was analyzed and evaluated. The potential applications of using USVs for conducting quantitative ecosystem acoustic surveys is being evaluated.

Figure 8. Saildrone operating at sea off San Francisco, CA

For more information, please contact Dezhang Chu at Dezhang.Chu@noaa.gov

c) Skill and uncertainty of environmentally driven forecasts of Pacific hake distribution

Investigators: Michael J. Malick, Mary Hunsicker, Melissa Haltuch, Sandy Parker-Stetter, Isaac Kaplan, Aaron Berger, Samantha Siedlecki, Nicholas Bond, Albert Hermann, and Emily L. Norton

Changing ecosystem conditions present a challenge for the monitoring and management of living marine resources, where decisions are often made with lead-times of weeks to months. Improvements in the skill of regional ocean models to predict physical ocean states at seasonal time scales provides opportunities to develop early warnings of the biological responses to changing environments and distribution shifts that impact fishery management practices. In this study, we illustrate how regional ocean model predictions can be used in an ecological context using Pacific hake (*Merluccius productus*) summer distribution in the California Current Ecosystem. We used the J-SCOPE regional ocean model to develop 6-8 month lead-time forecasts of thermal conditions at depth, which were then used to force environmentally driven species distribution models for Pacific hake. Using retrospective skill assessments, we show good agreement between hake distribution forecasts and historical observations. Finally, we discuss the utility of using seasonal lead-time ocean predictions in an ecological context to address research questions that can inform current resource management.

For more information, please contact Sandy Parker-Stetter at sandy.parker-stetter@noaa.gov.

d) Sunrise and sunset considerations for daytime surveys

Investigators: Rebecca Thomas, Dezhang Chu, Stephane Gauthier, and Sandra Parker-Stetter

Acoustic surveys are generally designed to match times of day/night when fish are aggregated and acoustically available. However, fish and other organisms may still be vertically migrating during this time period, causing changes in their target strength and ensuing biomass estimate. For Pacific Hake during the summer months, the fish aggregate during the daytime, and the survey is conducted from sunrise to sunset. Changes in Hake backscatter and depth during the initial post-sunrise and final pre-sunset periods were investigated using survey data spanning 15 years. Amid considerable variability, consistent changes in backscatter and aggregation depths were found in the time periods following sunrise and before sunset. The change in TS implied by these changes is described, and contributions from tilt/behavior and swimbladder pressure are considered. Finally, some practical considerations for the survey are examined.

For more information, please contact Rebecca Thomas at Rebecca.Thomas@noaa.gov.

e) The 2017 Joint U.S. and Canada Pacific Hake Integrated Acoustic and Trawl Survey: Cruise Report SH-17-07

Investigator: Steve de Blois

The results presented here are from the 2017 joint U.S. and Canada Pacific hake integrated acoustic and trawl survey. This report provides a brief description of the methods used in the survey and summarizes the distribution, biological composition, and biomass of hake in U.S. and Canadian waters off the Pacific coast. It also summarizes results of acoustic system calibrations, an intervessel calibration (IVC), and secondary survey objectives.

For more information, please contact Steve de Blois at Steve.DeBlois@noaa.gov.

f) Spaced out: Investigating the impact of spatial structure and movement under climate change using management strategy evaluation

Investigators: N. Jacobsen, K. Marshall, A. Berger, and I. Taylor

Fish frequently move across management boundaries, and this movement is likely influenced by environmental conditions. However, fisheries management rarely accounts for fish movement when estimating stock abundance and other related quantities such as the total allowable catch and maximum sustainable yield. Misinformation or changes in movement, such as distribution shifts or altered movement rates resulting from climate change, may induce bias or increase uncertainty for managers. Using the Pacific hake fishery, we apply management strategy evaluation (MSE) to evaluate how alternative hypotheses about spatial stock structure influence how robust management choices are to uncertainty or changes in movement. The MSE employs closed-loop simulations with an operating model that represents real life complexity of hake biology with spatial stock structure mediated by recruitment, age-based movement rates, and fisheries selectivity. The operating model is supplemented by a single-area estimation model similar to the stock assessment model currently used for hake management. By explicitly modeling spatial structure (i.e., movement and spatial recruitment), we show that climate-change-intensified movement of adult hake may cause a median decline in total annual catch and increase annual catch variability, but decrease the risk of fishery closure. The results of the MSE are contextualized in regards to improving current management and assessment of spatially structured fish stocks.

For more information, please contact Kristin Marshall at Kristin.Marshall@noaa.gov

2. Assessment

a) Status of the Pacific (whiting) stock in U.S. and Canadian waters in 2018

Investigtors: A. Berger, C. Grandin, I. Taylor, A. Edwards, S. Cox

This stock assessment reported the collaborative efforts of the official U.S. and Canadian JTC members in accordance with the Agreement between the government of the United States and the government of Canada on Pacific hake/whiting. The assessment reported the status of the coastal Pacific Hake (or Pacific whiting, *Merluccius productus*) resource off the west coast of the United States and Canada for 2017. Coast-wide fishery landings of Pacific hake averaged 226 thousand mt from 1966 to 2016, with a low of 90 thousand mt in 1980 and a peak of 363 thousand mt in 2005. Prior to 1966 the total removals were negligible relative to the modern fishery. Recent coast-wide landings from 2007–2016 have been above the long term average, at 262 thousand mt. Landings between 2013 and 2013 were predominantly comprised of fish from the very large 2010-year class, comprising around 70% of the total removals. In 2016, U.S. fisheries caught mostly 2- and 6-year old fish from the 2010 and 2014 year classes, while the Canadian fisheries encountered mostly 6-year old fish from the 2010 year-class. The Agreement between the United States and Canada establishes U.S. and Canadian shares of the coast-wide TAC at 73.88% and 26.12%.

Data were updated for the 2017 assessment with the addition of fishery catch and age compositions from 2016, reanalyzed acoustic survey biomass and age compositions for 1995 (completing the reanalyzed acoustic survey time series initiated in the 2016 model), and other minor refinements such as catch estimates from earlier years. The assessment used Bayesian methods to incorporate prior information on two key parameters (natural mortality, *M*, and steepness of the stock-recruit relationship, *h*) and integrated over parameter uncertainty to provide results that can be probabilistically interpreted. The exploration of uncertainty was not limited to parameter uncertainty as structural uncertainty was investigated through sensitivity analyses. Pacific Hake displays the highest degree of recruitment variability of any west coast groundfish stock, resulting in large and rapid changes in stock biomass. This volatility, coupled with a dynamic fishery, which potentially targets strong cohorts resulting in time-varying selectivity, and little data to inform incoming recruitment until the cohort is age-2 or greater, will, in most circumstances, continue to result in highly uncertain estimates of current stock status and even less-certain projections of future stock trajectory. Uncertainty in this assessment is largely a function of the potentially large 2014 year-class, which has been observed twice by the fishery but has yet to be observed by the acoustic survey, and uncertain selectivity. However, with recruitment being a main source of uncertainty in the projections and the survey not able to monitor the 2014 year-class until they are 3 years old (i.e., summer 2017), short term forecasts are very uncertain.

The base model estimates indicate that since the 1960s, Pacific hake female spawning biomass has ranged from well below to near unfished equilibrium biomass. The model estimates that the stock was below the unfished equilibrium in the 1960s and 1970s, increased toward the unfished equilibrium after two or more large recruitments occurred in the early 1980s, and then declined steadily through the 1990s to a low in 2000. This long period of decline was followed by a brief peak in 2003 as the large 1999-year class matured and subsequently supported the fishery for several years. Estimated female spawning biomass declined to an all-time low of 0.565 million mt in 2009 because of low recruitment between 2000 and 2007, along with a declining 1999-year class. Spawning biomass estimates have increased since 2009 on the strength of large 2010 and 2014 cohorts and an above average 2008 cohort. The 2017 female spawning biomass is estimated to be 89.2% of the unfished equilibrium level (B_0) with a 95% posterior credibility interval ranging from 37% to 271%. The median estimated 2017 female spawning biomass is 2.13 million mt.

Estimates of historical Pacific hake recruitment indicate very large year classes in 1980, 1984, 1999, and 2010. The U.S. fishery shows that the 2014 year-class comprised a very large proportion of the observations in 2016. Uncertainty in estimated recruitments is substantial, especially for 2014, as indicated by broad posterior intervals. The fishing intensity on the Pacific Hake stock is estimated to have been below the $F_{40\%}$ target except for 1999 when the median estimated fishing intensity was slightly above target. Fishing intensity has been substantially below the $F_{40\%}$ target since 2012. Although the official catch targets adopted by the U.S. and Canada have been exceeded only once in the last decade (2002), fishing intensity is estimated to have not exceeded the target rate in the last 10 years. Recent catch and levels of depletion are presented in Figure 9.

Management strategy evaluation tools will be further developed to evaluate major sources of uncertainty relating to data, model structure and the harvest policy for this fishery and compare potential methods to address them. A spatially explicit operating model is needed, so forthcoming research will focus on how best to model these dynamics, including the possible incorporation of seasonal effects and potential climate forcing influences in the simulations.

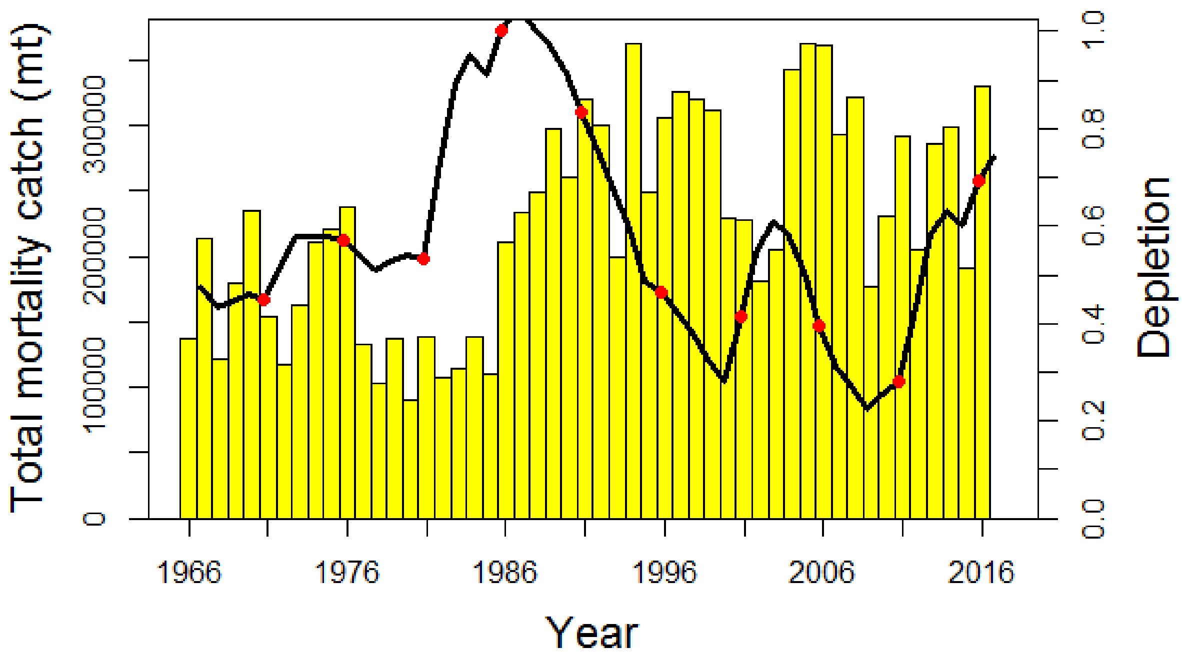


Figure 9. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Pacific hake, 1966-2016.

For more information, please contact Aaron Berger at Aaron.Berger@noaa.gov.

3. Management

Management of Pacific Hake has been under a treaty (The Agreement) between Canada and the United States since 2011. The stock is managed by the Joint Management Committee (JMC) which is made up of fisheries managers and industry representatives from both the U.S. and Canada. These managers receive advice from the JTC and the Scientific Review Group (SRG), which is a committee responsible for the scientific review of the assessment.

G. Grenadiers

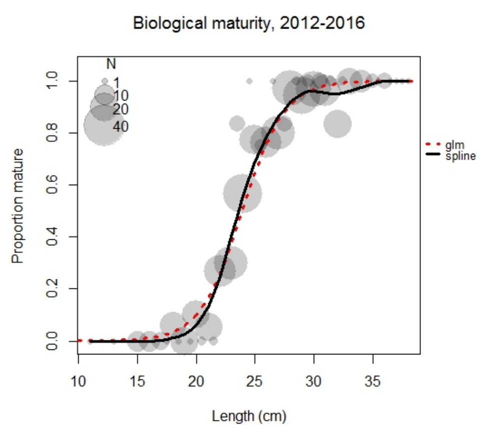
H. Rockfish

1. Research

a) Investigating spatial and temporal variation in reproductive trends in aurora rockfish (*Sebastes aurora*)

Investigators: Melissa A. Head, Jason M. Cope, Sophie H. Wulfing

The authors outline a new method for estimating maturity that incorporates skip or abortive spawning events leading to potentially non-asymptotic behavior in the population maturity schedule. They also introduce a flexible model that captures these functional reproductive changes, including fish that have spawned before but may not in a given year. This new approach aids fisheries managers who seek to understand marine species' responses to different oceanographic regimes over time and space. In an effort to assess shifts in maturity and spawning behavior of west coast groundfish, this new method was used to evaluate spatial and temporal trends in length at maturity, the annual reproductive cycle, and spawning behavior of aurora rockfish (*Sebastes aurora*). Ovaries (n = 538) were collected by the Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl Survey from 2012 – 2016. The authors estimated biological (presence of physiological maturity markers) and functional (potential spawners in a given year) maturity using a standard logistic and the new flexible spline model. The range in estimated lengths at 50% maturity (biological and functional) varied only slightly between the two modelling methods (23.62 – 23.93 and 25.46 – 25.57 cm). They also investigated geographic trends in length at maturity and found ~2 cm difference in functional maturity between fish sampled north (GLM = 26.48 ± 0.82) and south of Cape Mendocino, CA (GLM = 24.74 ± 0.62). Model sensitivity was examined by changing the maturity estimates in the 2013 aurora rockfish stock assessment using these updated data, and resultant maturity estimates from the logistic and spline models at different spatial scales. The new flexible spline model described in this research has the ability to account for skip spawning in adults, and thus is a better method for estimating potential spawners in a given year. Spawning output, but not relative stock status, was sensitive to model choice, spatial resolution, and the updated data.



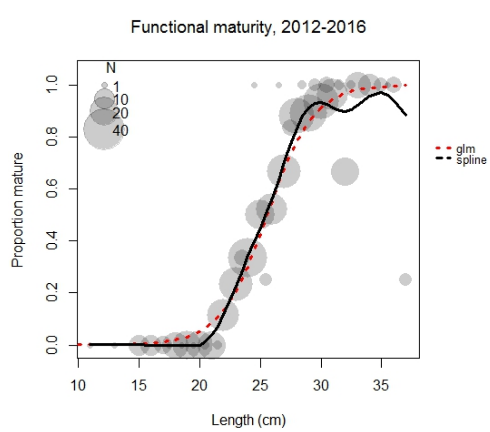


Figure 10. Length (cm) at maturity estimates for Biological maturity coast-wide showing the GLM (red dashed line) and spline (solid black line) fit (upper figure) and Functional maturity coast-wide showing the GLM (red dashed line) and spline (black solid line) (lower figure).

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

b) Addressing cryptic species issues in stock assessments as exemplified by Blue Rockfish (*Sebastes mystinus*) and Deacon Rockfish (*S. diaconus*)

Investigators: J. Bizzarro, E. Gilbert-Horvath, E.J. Dick, A. Berger, K. Schmidt, D. Person, C. Petersen, L. Katutzi, R. Miller, J. Field, J. Garza

The discovery of cryptic species expands our understanding of biodiversity and provides avenues for further study but also presents significant management challenges, as exemplified in the 2017 stock assessment of the Blue and Deacon Rockfish stock complex. Genetic analyses recently demonstrated that the nominal Blue Rockfish, *Sebastes mystinus*, is actually a cryptic species pair that included Deacon Rockfish, *S. diaconus*. We utilized a variety of approaches to estimate and compare species-specific characteristics of the spatial distribution and life history traits of Blue and Deacon Rockfishes. Genetic assignment of modern fin tissues and historic otoliths to species facilitated subsequent analyses. Deacon Rockfish comprised the majority of individuals sampled between Half Moon Bay and Oregon and were uncommon in southern California. Blue Rockfish were more common from Monterey Bay to southern California. Overall, Deacon Rockfish females grew to larger sizes at slower growth rates than Blue Rockfish females but male growth parameters were similar by comparison. Within species, Deacon Rockfish reached larger sizes at slower growth rates in California. Blue Rockfish reached larger sizes at faster growth rates in Oregon, whereas those south of Point Conception grew larger at faster rates than those in northern California. The multidisciplinary nature of this study and the techniques and protocols we established may provide a model for future stock assessment work on cryptic species. *Fisheries Bulletin in press.*

For more information, please contact Aaron Berger at Aaron.Berger@noaa.gov

c) Bomb radiocarbon age validation for California Current (CC) rockfish

Investigators: Melissa Haltuch, Andi Stevens, Owen Hamel, Patrick McDonald, John Field, Craig Kastelle

Otolith-derived ages provide an informative piece of data in fisheries stock assessment in regards to estimating recruitments, growth, and exploitation rates. The research and data needs sections of NWFSC stock assessments routinely identify the need for age-determination and age-validation studies. Historical otolith collections that include fish caught by commercial vessels fishing out of northern California ports during the 1960's until present are available at the SWFSC. These historical samples are ideal for the application of bomb radiocarbon age validation methods that require fish with birth years during the late 1950s through the 1970s. Rockfish are the focus of the bomb radiocarbon analyses due to longevity, and thus the likelihood of large ageing bias and variability at older ages. Ongoing radiocarbon age validation work is focusing on black and canary rockfish with the aim of producing more reliable ageing error matrices that will improve stock assessment's ability to model age imprecision and bias, reducing assessment uncertainty.

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

d) Steepness for west coast rockfishes: Results from a twelve-year experiment in iterative regional meta-analysis

Investigators: James T. Thorson, Martin W. Dorn, Owen S. Hamel

Theoretical and applied research suggests that survival rates during early life stages will increase when spawning biomass is reduced in marine fishes (termed "recruitment compensation"). However, the magnitude of recruitment compensation is generally difficult to estimate for individual fish stocks, and its average value for marine fishes remains highly contested. Scientists and managers for Pacific rockfishes (*Sebastes* spp.) on the U.S. west coast have used a regional meta-analysis to estimate the likely distribution of the steepness parameter of the Beverton-Holt stock-recruit relationship using stock assessment models since 2007, and the method has been updated every two years as new assessments are conducted (i.e., five biennial updates). Here, we provide a short history of this approach, its methodological assumptions, changes in results over time, and ongoing efforts to validate its assumptions. While the regional meta-analysis has been successful in ensuring a consistent approach to treatment of steepness across assessments, the estimates of mean steepness have been unexpectedly variable as the meta-analysis has been updated. Specifically, we show that the estimated average value of steepness for west coast rockfish increased markedly from 2007 (average: <0.6) to 2011 (average: >0.75), before decreasing somewhat again in the 2017 update. We also show that this value has a strong impact on rockfish rebuilding plans, and showcase the example of canary and widow rockfishes, where the estimated rates of rebuilding are strongly influenced by the assumed value of steepness. We conclude by discussing the bias-variance tradeoff between using global and regional meta-analysis, as well as the likely implications of difficult-to-validate assumptions including: (1) no recruitment autocorrelation within each stock; (2) no correlations among stocks; and (3) no bias from individual stocks resulting from mis-specification of the stock assessment models used in the meta-analysis.

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

e) Integrating formal and citizen-science surveys to develop a young-of-year rockfish monitoring plan for the Puget Sound

Investigators: K.S. Andrews, N. Tolimieri, D. Tonnes, R. Pacunski, S. Larson.

The Rockfish Recovery Plan for two species of rockfish in the Puget Sound/Georgia Basin distinct population segment identifies the development of a young-of-year (YOY) abundance index as one its research priorities. We are working with several stakeholders in the region to develop a plan to monitor these individuals across the Puget Sound region. This will include formal site selection of habitats and locations to monitor, a network of individuals and organizations that would be capable of getting out and surveying for YOY at appropriate times during the year. We are also developing analytical tools that will allow for the integration of data collected by both formal scientific surveys and citizen-science surveys. This analysis will determine if agencies and citizen science surveys can able produce an index of YOY abundance using a variety of survey methods or whether a more formal standardization of survey methods needs to be implemented in order to successfully monitor these individuals. This data will be used by the Western Regional Office as one piece of information to help manage and assess the recovery of yelloweye rockfish and bocaccio in the Puget Sound/Georgia Basin region.

For more information please contact Mr. Kelly Andrews at NOAA's Northwest Fisheries Science Center, kelly.andrews@noaa.gov.

f) Survival and movement behavior of yelloweye rockfish in a relatively closed fjord system exposed to low dissolved oxygen levels

Investigators: K.S. Andrews, N. Tolimieri, C.J. Harvey

We tagged 15 yelloweye rockfish *Sebastes ruberrimus* at three locations in Hood Canal with acoustic transmitters to monitor their survival and movement patterns for a period of one year. Three arrays of 5 acoustic receivers were deployed at the locations we captured individuals. These receivers will detect the presence/absence, depth and acceleration of each individual. Each tag emits a unique id code with each transmission of depth and acceleration so that we can monitor the movements of each individual fish. This research has two main objectives. First, we will determine the rate of survival for yelloweye rockfish captured with hook-and-line fishing methods and subsequently returned to the bottom using descending devices. Movement characteristics will determine whether individuals survived the capture event and whether mortality occurred over the following year. Second, we will calculate vertical and horizontal movement characteristics of yelloweye rockfish among these three sites in Hood Canal. This will provide evidence for or against the hypothesis that yelloweye rockfish have very small home ranges and that they do not migrate vertically in the water column like many marine species. Hood Canal is known to experience periods during the year (primarily in autumn months) of very low dissolved oxygen levels and we will use the calculated movement characteristics to investigate whether yelloweye rockfish behave differently under varying levels of dissolved oxygen. Understanding how this species responds to varying environmental conditions will provide necessary information to evaluate potential threats to the recovery of this population and to satisfy criteria for delisting this population from the endangered species list.

For more information please contact Mr. Kelly Andrews at NOAA's Northwest Fisheries Science Center, Kelly.Andrews@noaa.gov.

g) Effects of release timing and location of release on potential larval dispersal for yelloweye and canary rockfish in the Salish Sea.

Investigators: K.S. Andrews, B. Bartos, C.J. Harvey, D. Tonnes, M. Bhuthimethee, P. MacCready

In 2010, three species of rockfish (*Sebastes* spp.) in the Puget Sound/Georgia Basin (PSGB) region were listed under the U.S. federal Endangered Species Act (ESA). Subsequent genetic analyses revealed that yelloweye rockfish *S. ruberrimus* found in these inland waters were genetically differentiated from individuals found on the outer coast, while canary rockfish *S. pinniger* did not show any population structure among these geographic regions. These results confirmed the listing status of yelloweye rockfish as a “distinct population segment” (DPS), whereas canary rockfish in PSGB were not deemed a DPS and were subsequently removed from the Endangered Species List. In this paper, we investigate whether larval dispersal could be a mechanism that contributes to differences in population structure observed between these two rockfish species in Puget Sound. We used an oceanographic model to track larvae of yelloweye and canary rockfish released from sites within and outside of the PSGB region during their 60-day peak parturition period and followed these particles for up to 120 days. Results were similar among both species. Larvae released from sites along the outer coast of Washington state rarely settled within the boundaries of the DPS and larvae released from sites in the Main Basin of Puget Sound, Hood Canal or the Strait of Georgia rarely settled outside of the boundaries of the DPS. Within each species, we observed few differences in the proportion of larvae settling inside vs. outside the DPS depending on age of settlement (90-120 days) or the day of parturition (1-60 days). These results suggest that larval dispersal is not the most likely mechanism responsible for the differences in population structure observed for these two species in PSGB.

For more information please contact Mr. Kelly Andrews at NOAA’s Northwest Fisheries Science Center, Kelly.Andrews@noaa.gov.

2. Assessment

a) Stock assessment update: Status of widow rockfish (*Sebastes entomelas*) along the U.S. west coast in 2019

Investigators: Grant D. Adams, Maia S. Kapur, Kristin McQuaw, Stephanie Thurner, Owen S. Hamel, Andi Stephens, Chantel R. Wetzel

This is an update assessment to last full assessment of widow rockfish (*Sebastes entomelas*) conducted in 2015. Widow rockfish reside in the waters off California, Oregon, and Washington from the U.S. – Canadian border in the north to the U.S. – Mexico border in the south. Widow rockfish inhabit water depths of 25 – 370 m from northern Baja California, Mexico to Southeastern Alaska. Although catches north of the U.S. – Canada border and south of the U.S. – Mexico border were not included in this update assessment, it is not certain if those populations contribute to the biomass of widow rockfish off of the U.S. west coast possibly through adult migration and/or larval dispersion. Total landings of widow rockfish peaked in the early 1980s, increasing from approximately 1,000 metric tons (mt) in 1978 to a peak in landings exceeding 25,000 mt in 1981. After this sudden increase in catch, widow rockfish were given their own market category and often specifically identified in the landings. Uncertainty in species composition is greater in past years, thus landings of widow rockfish are not well known further back in history. The large landings in the early 1980s were curtailed with trip limits beginning in 1982, which resulted in a decline in landings throughout the 1980s and 1990s following sequential reductions 255 in the trip limits. From 2000 to 2003, landings of widow rockfish dropped from over 4,000 mt to about 40 mt and have been slowly increasing since, with a more rapid relative increase starting in 2013, after being declared rebuilt in 2011. Widow rockfish are a desirable market species and it is believed that discarding was low historically. However, management restrictions (e.g., trip limits) resulted in a substantial amount of discarding beginning in 1982. Trawl rationalization was introduced in 2011, and since then very little discarding of widow rockfish has occurred.

The update assessment was conducted using the length- and age-structured modeling software Stock Synthesis (version 3.30, pers. comm. Richard Methot, NMFS). The coastwide population was modeled assuming separate growth and mortality parameters for each sex (a two-sex model) from 1916 to 2019, and forecasted beyond 2019. The data used in the assessment model consisted of survey abundance indices, length compositions, discard data, and age compositions. Model-based biomass indices and length compositions were determined from two different surveys. Length and age data were available for five fisheries (based on gear type). Although there are many types of data available for widow rockfish since the late 1970s, which were used in this update assessment, there is little information about steepness and was fixed at the mean of the prior. Estimates of steepness are uncertain partly because of highly variable recruitment.
The predicted spawning biomass from the base model generally showed a slight decline over the time series until 1966 when the foreign fleet began. A short, but sharp decline occurred, followed by a steep increase due to strong recruitment in 1970 and 1971. The spawning biomass declined rapidly with the developing domestic midwater fishery in the late 1970s and early 1980s. The stock continued to decline until 2001 when a combination of strong recruitment and low catches resulted in a quick increase. The 2019 spawning biomass relative to unfished equilibrium spawning biomass is above the target of 40% of unfished spawning biomass (91.9%), with a low of 36.2% in 2001. The spawning biomass has increased rapidly since the mid-2000s due to low exploitation rates and multiple strong recruitment events in 2008, 2013, and 2014.

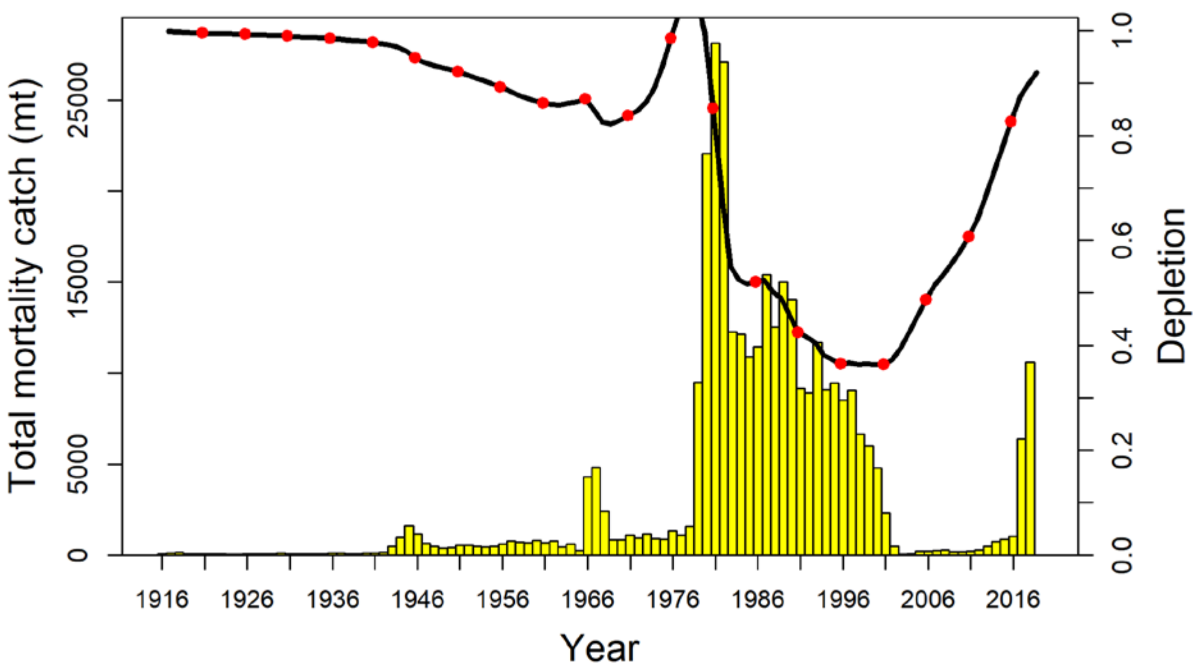


Figure 11. The time series of total mortality catch (bars) and estimated depletion (line) for widow rockfish.

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

3. Management

a) Catch-only Projections

Investigators: Owen Hamel et al.

Catch-only projections were conducted for a number of previously conducted stock assessments, including: black rockfish, blackgill rockfish, blue/deacon rockfishes, brown rockfish, canary rockfish, china rockfish, darkblotched rockfish, Dover sole, lingcod, longspine thornyhead, rougheye/blackspotted rockfishes, shortspine thornyhead, and yelloweye rockfish.

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

I. Thornyheads

J. Sablefish

1. Research

a) Report on the 2018 International Sablefish Workshop

Investigators: K.H. Fenske, A.M. Berger, B. Connors, J. Cope, S. P. Cox, M. Haltuch, D.H. Hanselman, M. Kapur, L. Lacko, C. Lunsford, C. Rodgveller, B. Williams

The Pacific Sablefish Transboundary Assessment Team (PSTAT), comprised of twelve scientists from Canada and the United States, convened April 26-27, 2018 in Seattle, WA for a workshop to discuss sablefish (*Anoplopoma fimbria*) research. Participants included representatives from Alaska Department of Fish and Game, Alaska Fisheries Science Center, Fisheries and Oceans Canada, Simon Fraser University, and the Northwest Fisheries Science Center. The primary objective of the workshop was to bring these scientists from the U.S. and Canada together to discuss range-wide sablefish data, compare stock assessment methods, discuss concerns about sablefish abundance trends, share results of recent and ongoing sablefish research, and to examine the feasibility of developing a set of range-wide operating models (OM) for use in Management Strategy Evaluation (MSE).

Sablefish are a highly mobile, long-lived, commercially valuable groundfish that have high movement rates and range from Southern California to the Bering Sea. Traditional stock assessment and management has taken place at regional levels determined by political boundaries for Alaska federal region, Alaska state region, British Columbia, and the U.S. west coast. Each region assumes that these are closed stocks, however, a recent genetic study suggests that N.E. Pacific sablefish are not genetically distinct within these traditional management areas. This lack of genetic evidence for population structure suggests that regional scale fisheries management may benefit from the consideration of the range-wide structure and dynamics of sablefish (e.g., a range-wide operating model could be developed as a tool for exploring sablefish population structure).

The primary objective of the workshop was to initiate discussion about the development of a range-wide, spatially explicit OM that can be used to explore questions of ecological, biological and management relevance. The PSTAT identified and fleshed out a number of key research activities that need to be undertaken to meet this objective: (1) a synthesis of life history characteristics across the sablefish range, (2) analyses to identify and develop range-wide indices of abundance, (3) evaluation of movement within and among regions, and (4) the development of a panmictic OM based on insights and data from steps 1-3. Steps 1-3 identified above could be developed into stand-alone research products resulting in published manuscripts. Step 4 is a necessary step towards the development of a spatially explicit OM.

A secondary objective of the workshop was to discuss similarities and differences in stock assessment approaches used in each region. The U.S. west coast sablefish assessments are done using the Stock Synthesis modeling platform, with the model beginning in 1900. Sablefish fishery management in British Columbia (B.C.) is based on a management procedure (data collection scheme, assessment approach, and harvest control rule) developed through a MSE process where hypotheses, empirical data, and simulation play a central role in defining management objectives and assessing management performance relative to those objectives. The B.C. sablefish MSE is based on an OM that is fit in AD Model Builder and conditioned on data beginning in 1965. Alaska Department of Fish and Game assesses sablefish in northern southeast inside waters using a yield-per-recruit model scaled to the absolute abundance estimates from a mark-recapture survey, the results of which are used to set the harvest level. Lastly, the Alaska (Federal) sablefish assessment is a custom age-structured model coded in AD Model Builder beginning in 1960.

A draft work plan was developed during the workshop that identified key research priorities moving forward including:

- A range-wide life history synthesis,
- Analysis of range-wide maturation rates,
- Development of range-wide indices of abundance,
- Analysis of range-wide movement,
- Development of a panmictic operating model,
- Development of a spatially-explicit operating model. In addition to these research priorities the group identified the need to work together to secure funding to support ongoing collaborations (e.g., PhD student and funding for in-person meetings) and to develop a common data sharing agreement among regions. The group committed to continue to work together moving forward through regularly scheduled conference calls and email.

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

b) Oceanographic features delineate growth zonation in Northeast Pacific sablefish

Investigators: M. Kapur, M.A. Haltuch, B. Connors, L. Rogers, A. Berger, E. Koontz, J. Cope, K. Echave, K. Fenske, D. Hanselman, A.E. Punt

Renewed interest in the estimation of spatial and temporal variation in fish traits, such as body size, is a result of computing advances and the development of spatially-explicit management frameworks. However, many attempts to quantify spatial structure or the distribution of traits utilize a priori approaches, which involve predesignated geographic regions and thus cannot detect unanticipated spatial patterns. We developed a new, model-based method that uses the first derivative of the spatial smoothing term of a generalized additive model to identify spatial zones of variation in fish length-at-age. We use simulation testing to evaluate the method across a variety of synthetic, stratified age and length datasets, and then apply it to survey data for northeast Pacific sablefish (*Anoplopoma fimbria*). Simulation testing illustrates the robustness of the method across a variety of scenarios related to spatially or temporally stratified length-at-age data, including strict boundaries, overlapping zones and changes at the extreme of the range. Results indicate that length-at-age for Northeast Pacific sablefish increases with latitude, which is consistent with previous work from the western United States. Model-detected spatial breakpoints corresponded to major oceanographic features, including the northern end of the Southern California Bight and the bifurcation of the North Pacific Current. This method has the potential to improve detection of large-scale patterns in fish growth, and aid in the development of spatiotemporally structured population dynamics models to inform ecosystem-based fisheries management.

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

c) Assessing the effects of climate change on U.S. west coast sablefish productivity and on the performance of alternative management strategies

Investigators: M.A. Haltuch, Z.T. A'mar, N.A. Bond, J.L. Valero,

U.S. west coast sablefish are economically valuable, with landings of 11.8 million pounds valued at over $31 million during 2016, making assessing and understanding the impact of climate change on the California Current (CC) stock a priority for (1) forecasting future stock productivity, and (2) testing the robustness of management strategies to climate impacts. Sablefish recruitment is related to large-scale climate forcing indexed by regionally correlated sea level (SL) and zooplankton communities that pelagic young-of-the-year sablefish feed upon. This study forecasts trends in future sablefish productivity using SL from Global Climate Models (GCMs) and explores the robustness of harvest control rules (HCRs) to climate driven changes in recruitment using management strategy evaluation (MSE). Future sablefish recruitment is likely to be similar to historical recruitment but may be less variable. Most GCMs suggest that decadal SL trends result in recruitments persisting at lower levels through about 2040 followed by higher levels that are more favorable for sablefish recruitment through 2060. Although this MSE suggests that spawning biomass and catches will decline, and then stabilize, into the future under both HCRs, the sablefish stock does not fall below the stock size that leads to fishery closures.

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

d) Limitations and applications of macroscopic maturity analyses: A comparison of histological and visual maturity staging in multiple west coast groundfish species

Investigators: Markus A. Min, Melissa A. Head, Jason M. Cope, Jim D. Hastie

Accurate maturity schedules are critical to ensure stock assessment models are able to correctly predict changes in spawning stock biomass. In order to generate updated maturity estimates, the Northwest Fisheries Science Center's (NWFSC) Fishery Resource Analysis and Monitoring (FRAM) Division instituted a reproductive biology program in 2009. This program uses histological analysis of ovaries to determine maturity, a technique that is known to be time consuming and more expensive but also more reliable than the historically used method of macroscopic inspection. As macroscopic maturity data is still being collected by Oregon Department of Fish and Wildlife (ODFW), we evaluated the usefulness of these macroscopic maturity recordings by verifying their accuracy using histological methods. Among the three different species in this study, each representative of a different family of west coast groundfish (flatfish, rockfish, and roundfish), arrowtooth flounder and canary rockfish had a high correspondence between length at 50% biological (physiological) maturity (L50) staged histologically and macroscopically. Sablefish L50 estimates varied significantly between macroscopic and histological methods. Functional maturity (potential spawners in a given year) did not correlate with macroscopic maturity for any of the studied species. In its current form, macroscopic maturity collections have limited application in assessing changes in maturity schedules over time, and a lack of standardization amongst different state departments of fish and wildlife severely hinders any attempt at using macroscopic maturity data to analyze spatial trends in maturity.

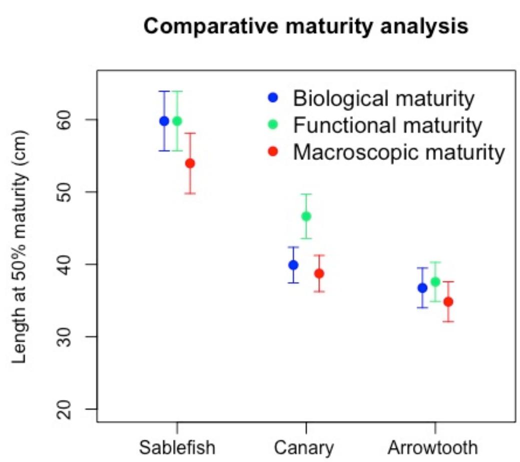


Figure 12. Comparison of L50 estimates calculated using the three different types of maturity data (biological, functional, and macroscopic) for sablefish (*Anoplopoma fimbria*), canary rockfish (*Sebastes pinniger*), and arrowtooth flounder (*Atheresthes stomias*).

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

2. Assessment

a) 2019 Sablefish Stock Assessment

Investigators: M.A. Haltuch, K.F. Johnson, N. Tolimieri, M.S. Kapur, C.A. Castillo-Jordán

This assessment reports the status of the sablefish (*Anoplopoma fimbria*, or 'black cod') resource off the coast of the United States (U.S.) from southern California to the U.S.-Canadian border using data through 2018. The resource is modeled as a single stock, however sablefish do disperse to and from offshore sea mounts and along the coastal waters of the continental U.S., Canada, and Alaska and across the Aleutian Islands to the western Pacific. Their movement is not explicitly accounted for in this analysis.

During the first half of the 20th century, it is estimated that sablefish were exploited at relatively modest levels (Figure13). Modest catches continued until the 1960s, along with a higher frequency of above average, but uncertain, estimates of recruitment through the 1970s. The spawning biomass increased during the 1940s to 1970s. Subsequently, biomass is estimated to have declined between the mid-1970s and the early 2010s, with the largest peaks in harvests during the 1970s followed by harvests that were, on average, higher than pre-1970s harvest through the 2000s. At the same time, there were a higher frequency of generally lower than average recruitments from the 1980s forward. Despite estimates of harvest rates that were largely below overfishing rates from the 1990s forward and a few high recruitments from the 1980s forward, the spawning biomass has only recently begun to increase. This stock assessment suggests spawner per recruitment rates higher than the target during some years from the 1990s forward for two reasons. First, there have been many years with lower than expected recruitment. Second, stock assessment estimates of unfished spawning biomass have been steadily declining in each subsequent assessment since 2007. Estimates of unfished biomass scale catch advice.

The estimates of uncertainty around the point estimate of unfished biomass are large across the range of models explored within this assessment, suggesting that the unfished spawning biomass could range from just under 100,000 mt to over 200,000 mt. This uncertainty is largely due to the confounding of natural mortality, absolute stock size, and productivity. The point estimate of 2019 spawning biomass from the base model is 57,444 mt; however, the 95% interval ranges broadly from 32,776 to 82,112 mt. The relative trend in spawning biomass is robust to uncertainty in the leading model parameters. The 2019 point estimate of spawning stock biomass is 39% of the unfished state (95% interval: 26-52%).

Sablefish recruitment is estimated to be quite variable with large amounts of uncertainty in individual recruitment events. A period with generally higher frequencies of strong recruitments spans from the early 1950s through the 1970s, followed by a lower frequency of large recruitments during 1980 forward, contributing to stock declines. The period with a higher frequency of high recruitments contributed to a large increase in stock biomass that has subsequently declined throughout much of the 1970s forward. Less frequent large recruitments during the mid-1980s through 1990 slowed the rate of stock decline, with another series of large recruitments during 1999 and 2000 leading to a leveling off in the stock decline. The above-average cohorts from 2008, 2010, 2013, and 2016 are contributing to a slightly increasing spawning stock size. The 2016 cohort is estimated to be the largest since the mid-1970s.

Equilibrium yield at the fishing mortality that leads to the maximum sustainable yield (FMSY) is 8,077 mt (4,684-11,470, ~95% interval). Although the estimated productivity and absolute scale of the stock are poorly informed by the available data and are, therefore, sensitive to changes in model structure and treatment of data, all sensitivity or alternate models evaluated showed a declining trend in biomass since the 1970s followed by a recent increase. The spawner potential ratio (SPR) exceeded the fishing mortality target/overfishing level (SPR45%) that stabilizes the stock at the target (i.e., 1-SPR/[1-SPR45%]) during the late 2000s and early 2010s, while since 2015 it has been between 83 and 95%.

Unfished spawning biomass was estimated to be 147,729 mt (109,022-186,436, ~95% interval).

The abundance of sablefish was estimated to have dropped below the target reference point of 40% of this estimated value of unfished spawning biomass during the 2000s and generally remained below the target through 2018. The estimate of the target spawning biomass was 59,092 (43,609-

74,574, ~95% interval), which gives a catch of 7,363 mt (4,269-10,456, ~95% interval). The stock was estimated to be just below the target stock size in the beginning of 2019 at 57,444 mt (32,776-

82,112, ~95% interval). The stock was estimated to be above the depletion level that would lead to maximum yield. The estimate of the stock's current level of depletion was 38.9%.

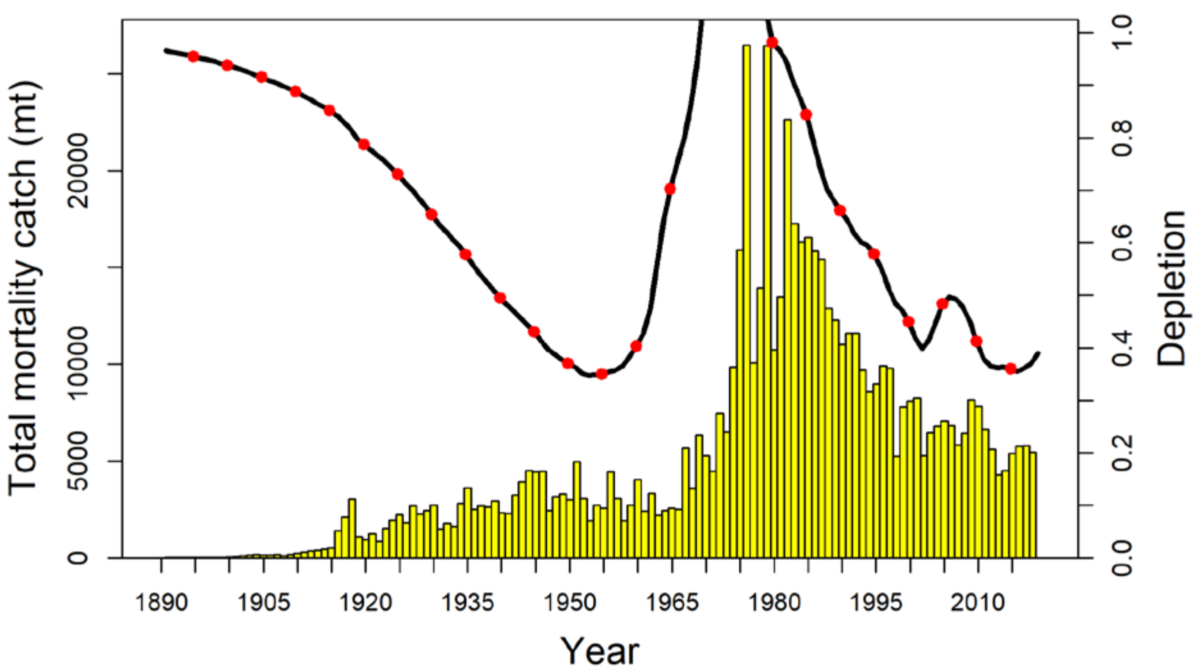


Figure 13. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for sablefish.

3. Management

a) Ecosystem Considerations for sablefish

Investigators: Nick Tolimieri, Chris Harvey, J. Samhouri

We developed an Ecosystem Considerations document as an appendix to the west coast sablefish stock assessment. It provides an analysis and summary of ecological and socio-economic considerations for sablefish. This Ecosystem Considerations section is based on the idea of social-ecological system (SES), which "explicitly acknowledges linkages and feedback between human and biophysical systems". We provide a summary of the SES framework for the California Current. Inclusion of ecological and socio-economic considerations in the sablefish stock assessment will help to move towards an ecosystem-based approach to fisheries management. The SES framework requires that we consider extractive goals and conduct human activities at a level that allows ecological sustainability while also considering human well-being by considering both environmental and human impacts on sablefish, as well as sablefish impacts on the ecosystem and humans.

For more information please contact Dr. Nick Tolimieri at NOAA's Northwest Fisheries Science Center, nick.tolimieri@noaa.gov.

K. Lingcod

1. Research

a) Landscape genomics & life history diversity in lingcod on the U.S. west coast

Investigators: G.C. Longo, L. Lam, B. Brown, J.F. Samhouri, S.L. Hamilton, K. Andrews, G. Williams, M. McClure, K.M. Nichols.

Delimiting intraspecific genetic variation in harvested species is crucial to the assessment of population status for natural resource management and conservation purposes. Here we evaluated genetic population structure in lingcod (*Ophiodon elongatus*), a commercially—and recreationally—important species for fisheries along the west coast of North America. We used 16,749 restriction site associated DNA sequencing (RADseq) markers, in 611 individuals collected from across the bulk of the species range from Southeast Alaska to Baja, Mexico. In contrast to previous population genetic work on this species, we found strong evidence for two distinct genetic clusters, separated latitudinally with a break near The Gulf of the Farallones off central California, and a high frequency of admixed individuals in close proximity to the break. F-statistics corroborate this genetic break between northern and southern sampling sites, although most loci are characterized by low FST values, suggesting high gene flow throughout most the genome. Outlier analyses identified 182 loci putatively under divergent selection, most of which mapped to a single genomic region. When individuals were grouped by cluster assignment (northern, southern, and admixed), 71 loci were fixed between the northern and southern cluster, all of which were identified in the outlier scans. All individuals identified as admixed exhibited near 50:50 assignment to northern and southern clusters and were heterozygous for most fixed loci. Alignments of RADseq loci to three other teleost genomes with chromosome level assemblies show that outlier and fixed loci are heavily concentrated on a single chromosome. Similar genomic patterns have been attributed to chromosomal inversions in diverse taxonomic groups. Regardless of the evolutionary mechanism, these results represent novel observations of genetic structure in lingcod and designate clear evolutionary units that could improve fisheries management.

For more information please contact Dr. Jameal Samhouri at NOAA's Northwest Fisheries Science Center, Jameal.Samhouri@noaa.gov.

b) Assessing the magnitude of rockfish bycatch among bait types while targeting lingcod

Investigators: K.S. Andrews, D. Tonnes

Rockfish in Puget Sound have declined > 70% over the last ~50 years and three species have been listed on the endangered species list. Most commercial fisheries have been ended in Puget Sound and several regulations restricting recreational fishing for bottomfish have been implemented over the last two decades. However, rockfish inhabit similar habitats as other recreationally-targeted species, such as lingcod and halibut and bycatch of rockfish during these fisheries is still a concern for managers trying to recover rockfish populations in the Puget Sound region. Thus, understanding whether there are specific types of bait and/or lures that reduce rockfish bycatch during these fisheries, while retaining similar catch rates for the target species, may provide protection to recovering rockfish populations and additional fishing opportunities. Anecdotal reports from the fishing community suggest that rockfish bycatch is low to non-existent in the lingcod fishery when large flatfish bait is used when compared to small, live baits or artificial lures/jigs. This project has been funded by NOAA's Western Regional Office in order to test whether this hypothesis is true. Preliminary catch data from recreational fishing guides collected in 2014 and 2015 revealed that rockfish bycatch is small when using flounder/sanddab as live bait, but due to confounding variables associated with this data set, the true extent of rockfish bycatch among bait types is difficult to determine. In this project, we will partner with charter boat captains to assess rockfish bycatch in local lingcod fisheries by fishing with different bait types in a controlled experimental design among fishing locations in Central Puget Sound and the San Juan Islands in 2017 and 2018.

For more information please contact Mr. Kelly Andrews at NOAA's Northwest Fisheries Science Center, Kelly.Andrews@noaa.gov.

L. Atka Mackerel

M. Flatfish

1. Research

a) Oceanographic drivers of petrale sole recruitment in the California Current Ecosystem

Investigators: M.A. Haltuch, N. Tolimieri, Q. Lee, M.G. Jacox

This paper investigates environmental drivers of U.S. west coast petrale sole (*Eopsetta jordani*) recruitment as an initial step toward developing an environmental recruitment index that can inform the stock assessment in the absence of survey observations of age-0 and age-1 fish. First, a conceptual life history approach is used to generate life-stage-specific and spatio-temporally specific mechanistic hypotheses regarding oceanographic variables that likely influence survival at each life stage. Seven life history stages are considered, from female spawner condition through benthic recruitment as observed in the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey (age-2 fish). The study area encompasses the region from 40 to 48°N in the California Current Ecosystem. Hypotheses are tested using output from a regional ocean reanalysis model outputs and model selection techniques. Four oceanographic variables explained 73% of the variation in recruitment not accounted for by estimates based exclusively on the spawning stock size. Recruitment deviations were (a) positively correlated with degree days during the female precondition period, (b) positively correlated with mixed-layer depth during the egg stage, (c) negatively correlated with cross-shelf transport during the larval stage, and (d) negatively correlated with cross-shelf transport during the benthic juvenile stage. While multiple mechanisms likely affect petrale sole recruitment at different points during their life history, the strength of the relationship is promising for stock assessment and integrated ecosystem assessment applications.

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

b) Food habit variability of arrowtooth flounder (*Atheresthes stomias*) in the northeast Pacific Ocean

Investigator: Douglas Draper

A diet study of arrowtooth flounder (*Atheresthes stomias*) provided information on the food habits and predator-prey relationships for a northeast Pacific Ocean flatfish described as exhibiting highly piscivorous and opportunistic feeding behavior. Arrowtooth flounder stomachs (n = 472) were collected between 2013 and 2016 from 310 trawls during the Northwest Fisheries Science Center's (NWFSC) west coast groundfish bottom trawl survey (WCGBTS). A total of 299 stomachs (63.3%) contained prey and revealed a highly piscivorous diet across all lengths examined (14 – 71cm). Increased predator length correlated both with an increase in percentage of fish prey consumed and an increase in depth. Smaller, shallower (55-183 m) arrowtooth flounder consumed a relatively high percentage of euphausiids and shrimp. Correspondingly, the larger arrowtooth flounder captured at greater depths (> 184 m) consumed more fish and less shrimp and euphausiids. Arrowtooth flounder from different geographic areas also showed variation among prey, likely resulting from regional differences in prey availability. North of the mean latitude of capture (44.46°N) Pacific hake (*Merluccius productus*) and Pacific herring (*Clupea pallasii*) were the predominant fish in arrowtooth flounder diet, while arrowtooth flounder south of the mean latitude consumed mostly Pacific hake and rockfish (*Sebastes* spp). Euphausiids were also more common in stomachs taken above the mean latitude than in the south. Unidentified teleosts contributed much of the diet across all size, depth, and latitude ranges.

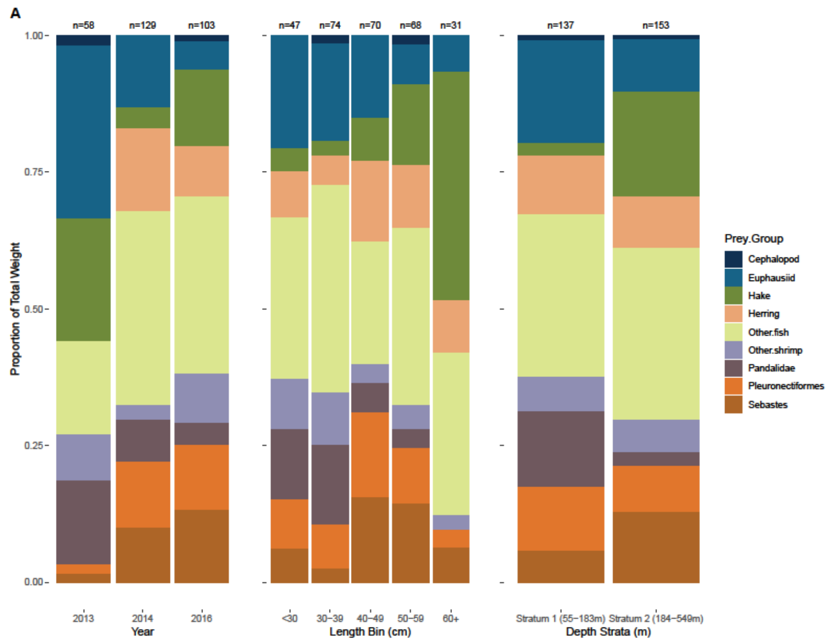


Figure 14. Stacked barplots of diet proportions by weight of arrowtooth flounder prey groups for year, depth strata, and length bins

2. Assessement

a) Status of petrale sole (*Eopsetta jordani*) along the U.S. west coast in 2019

Investigators: Chantel R. Wetzel

Petrale sole were the target of fishing fleets operating off the west coast of U.S. during a winter and summer fishery with high landings starting prior to 1940. The portion of population off the U.S. west coast, which has generally been treated as a single separate stock for assessment and management purposes, was declared overfished in 2009. This assessment was an update assessment, the second conducted since the last full assessment in 2013, assumes that petrale sole off the U.S. west coast are a single, unit stock whose dynamics are independent of petrale sole populations off Canada and Alaska.

The stock assessment was conducted with Stock Synthesis. Data were compiled into four fishing fleets, two catch-per-unit-effort indices, and two fishery-independent indices of relative abundance. The four fishing fleets were commercial trawl fleets segregated by fishing area (California vs. Oregon-Washington) and fishing timing (winter and summer). For these fleets the model included a retention curve and was informed by observer data on discard rates and length-compositions. Several indices of relative abundance were considered during development of the model, including fishery dependent CPUE indices and fishery independent surveys (Triennial survey and the NWFSC shelf-slope survey). The NWFSC shelf-slope survey provides the longest the time series and is considered the most reliable information on population abundance and data. Selectivity was estimated for each modeled fleet using observations of age and/or length composition data. The NWFSC shelf-slope survey age data were included as conditional age-at-length observations (CAAL). For some fleets both the age and length composition data were included. All fleets and surveys were modeled with double normal selectivity parameterizations. The assessment model was structured to have two sexes and it started from an unfished non-equilibrium state in 1876 with annual recruitment deviations estimated to 2018.

The model estimates that the spawning biomass of petrale sole at the start of 2019 was 13,078 metric tons and was at 39% of its unfished level. The trajectory of spawning output has been increasing steadily since about 2010 because of reduced catches during rebuilding and strong recruitments in 2006, 2007, and 2008. The assessment estimates that the stock's spawning biomass hovered at or slightly below the Council's threshold level (12.5% of unfished) for a period extending from approximately the early-1980s to the late-2000s. The estimated dynamics from this update stock assessment are consistent with the prior assessment.

The composition data for petrale sole were weighted according to the McAllister-Ianelli weighting approach with the composition data, combined with the historical stock trajectory, contained information regarding steepness and natural mortality allowing for estimation within the model. Natural mortality by sex was estimated 0.159 and 0.165 yr^{-1} for females and males, respectively. Steepness was estimated at 0.84 and was strongly correlated with the estimated natural mortality parameters. The previous full assessment in 2013 estimated similar parameter values for natural mortality and steepness, resulting in a similar stock trajectory over the assessed years.

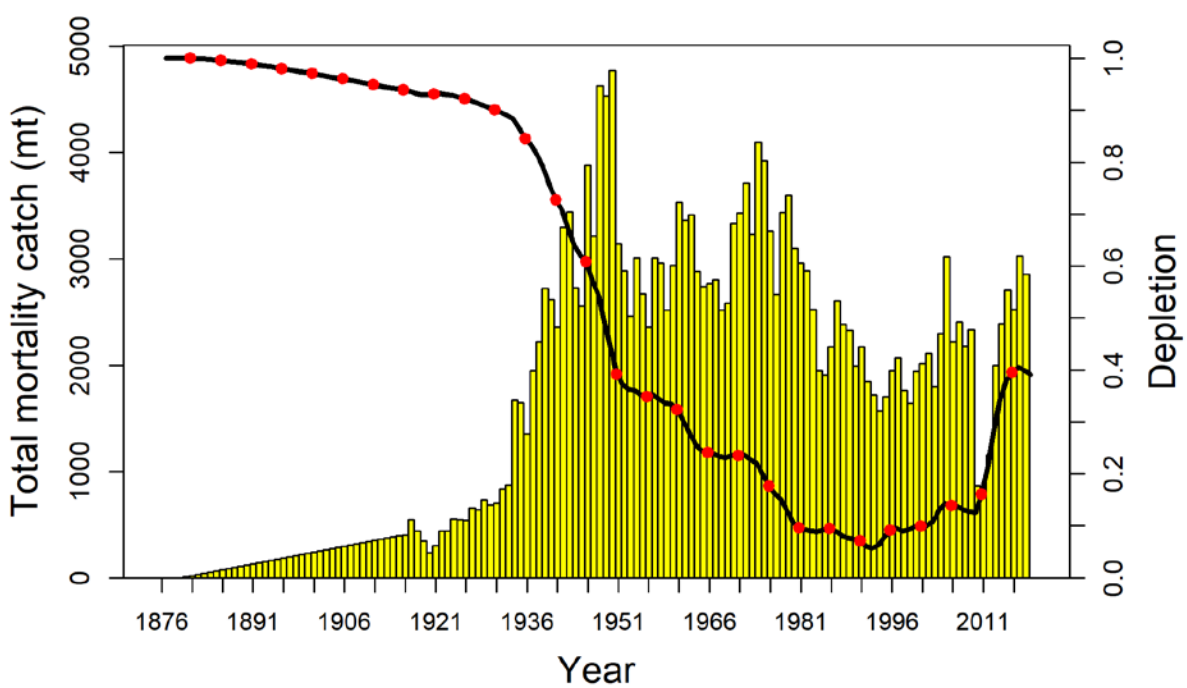


Figure 15. The time series of total mortality catch (bars) and estimated depletion (line) for petrale sole.

For more information, please contact Chantel Wetzel at Chantel.Wetzel@noaa.gov

1. Research

N. Halibut

O. Other Groundfish

1. Research

a) Feeding ecology of select groundfish species captured in the Northwest Fisheries Science Center's west coast bottom trawl survey, using gut contents and stable isotopes

Investigators: Keith Bosley, J. Buchanan, A. Chappell, D. Draper, and K.M. Bosley

We are examining the diets of multiple groundfish species as an ongoing component of the NMFS West Coast Bottom Trawl Survey. Stomachs and tissue samples were collected at sea and preserved for gut content and stable-isotope analyses. We focused on several species of *Sebastes*, sablefish, and some flatfishes, and now have stomach content and stable-isotope data covering multiple years. Yellowtail, darkblotched, canary, sharpchin and stripetail rockfishes prey largely on zooplankton, with euphausiids composing a majority of their diet. Shrimp also contribute significantly to the diets of darkblotched and canary rockfishes, whereas bocaccio, yelloweye and chilipepper rockfishes all share a highly piscivorous diet. Greenstriped and rosethorn rockfishes show a strong preference for benthic prey, greenstriped preferring various shrimp species, and rosethorn preferring a mix of shrimp and galatheid crabs. Finally, widow rockfish and Pacific ocean perch exhibit a more omnivorous feeding strategy, eating a variety of zooplankton, including euphausiids, amphipods, shrimp and gelatinous organisms. Stable isotope values averaged by year indicate that bocaccio and yelloweye rockfish feed approximately one trophic level above Pacific ocean perch and above darkblotched, greenstriped, sharpchin, stripetail and widow rockfishes. All other species in this study feed at mixed trophic levels. Multivariate analyses of diet data show significant differences in diet among species but strong overlap among benthic and bentho-pelagic species. Stable-isotope data also show significant differences among species and years. These results demonstrate the groundfishes in this study are significant consumers in both benthic and pelagic habitats, feeding across multiple trophic levels.

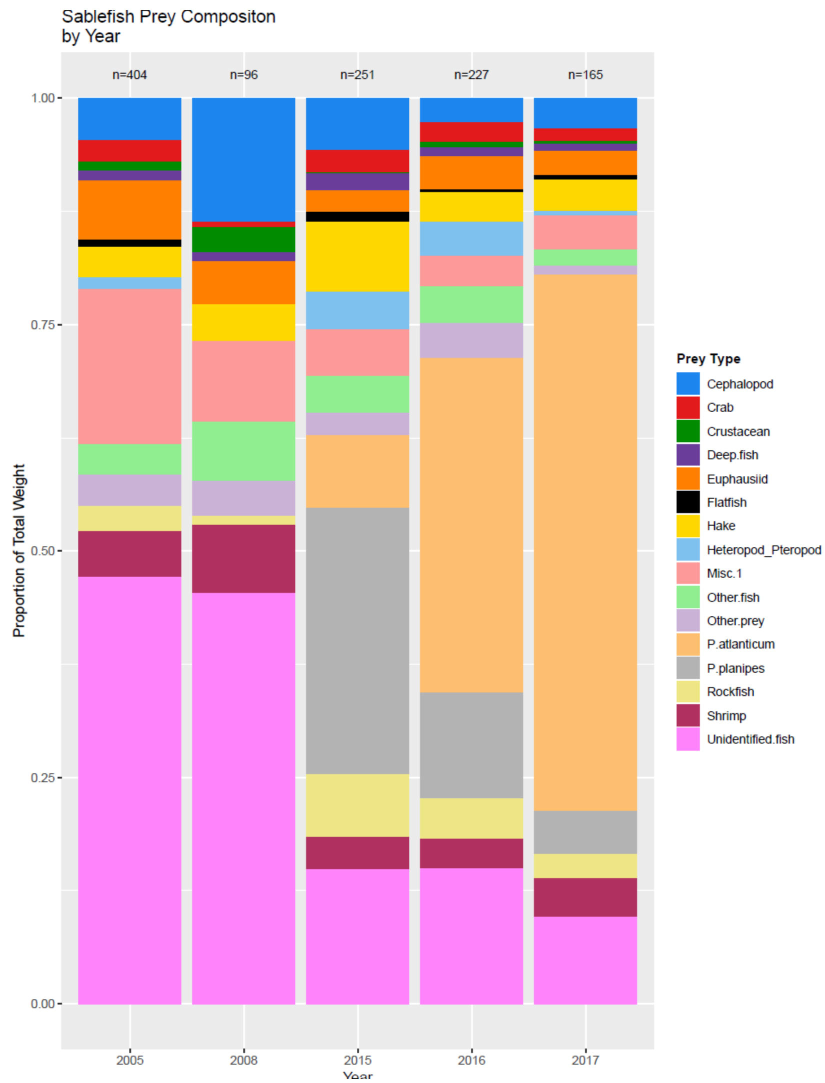


Figure 16. Stacked barplot of diet proportions by weight of sablefish prey groups for 2005, 2008, 2015-2017.

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

b) Resolving associative patterns in life history parameters among marine fish stocks in the Northeast Pacific Ocean

Investigators: Sean Matson, Vladlena Gertseva

Knowledge of life history characteristics in marine fishes, including natural mortality, somatic growth, maturity schedule, productivity and others, is essential for successful management and long-term sustainability of marine resources. Patterns exist among these traits within and among taxa to maximize individual fitness and offspring survival, and trade-offs are typical. In this study, we examined life history data from 42 fishery stocks in the Northeast Pacific Ocean using principal component analysis (PCA) and clustering techniques. We identified discrete clustering patterns of stocks corresponding to ecological, taxonomic, and management criteria. Our results revealed additional resolution for complex structure among stocks based on combinations of life history traits, well beyond what was described before, for the diverse group of Sebastes rockfish, which have not been examined in this context previously. One example is clear differentiation between Sebastes demersal species, and those caught with midwater gear, particularly with addition of stock-specific fecundity data; another is bocaccio rockfish, whose life history patterns our results shed new light on. Our results also provide an empirical basis for grouping stocks in meta-analytic studies, which are often used to inform unknown or difficult to estimate parameters in stock assessment. Our results supported important core aspects of previous studies, and rectified others, among a wide range of stocks including highly migratory, coastal pelagic and groundfish stocks. They also reinforce fishery management strategies grounded in life history, among stocks in the Northeast Pacific Ocean and around the world.

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

2. Assessments

a) Assessing Cabezon (*Scorpaenichthys marmoratus*) stocks in waters off of California and Oregon, with catch limit estimation for Washington State

Investigators: J. Cope, A. Berger, A. Whitman, J. Budrick, K. Bosley, T-S. Tsou, C. Niles, K. Privitera-Johnson, L. Hillier, K. Hinton, M. Wilson

This assessment reports the status of the Cabezon (*Scorpaenichthys marmoratus*) in U.S. waters off the coast of Southern California, Northern California, and Oregon with consideration for setting catch limits in Washington. This is the fourth full assessment of the population status of Cabezon (for some sub-stocks) off the west coast of the United States, but the first in 10 years. The northern California sub-stock and the southern California sub-stock are demarcated at Point Conception, CA. Separation of these spatial sub-stocks is based on distinguishing localized population dynamics, preliminary population genetics results, and is supported by spatial differences in the fishery, the ecology of nearshore groundfish species, management regulations, and is consistent with current state management needs.

Harvest of Cabezon was primarily from recreational fisheries up until the 1990s and 2000s when the onset of the commercial live-fish fishery (mainly longline and hook and line gears) resulted in increased commercial landings. The main removal period in southern California occurred from the 1980s through the mid-1990s, at which point commercial catch became a major source of removals (Figure 17). Catches have steadily decreased since the early 2000s in southern California. Removals in northern California have been fairly steady since the 1950s, with a major peak in the mid to late 1990s due to the onset of the live-fish fishery (Figure 17). Current removals remain around the long-term average. Total landings in Oregon have generally increased through time, including a near doubling of landings with the onset of the commercial live-fish fishery in the late-1990s (Figure 18). Since that time (post-1996), total landings have largely been between 40-60 mt per year, except during 2013-2016 when total landings were closer to 30 mt. Recent landings continue to be dominated by the commercial live-fish and recreational ocean boat fleets, collectively representing 94% of the total in 2018. Cabezon has not been targeted by fisheries in Washington and annual total removals have been less than 12 mt.

The southern (SCS) and northern (NCS) California cabezon substock models are age structured models separated at Pt. Conception, CA. Two fishing sectors (commercial and recreational) and 5 total fleets (2 commercial and 3 recreational) defined the removal history. Data sources included relative indices of abundance, length compositions and a set of conditional ages at length.

SCS Cabezon spawning output was estimated to be 101 mt in 2019 (~95% asymptotic intervals: 19–183 mt), which when compared to unfished spawning output (262 mt) equates to a relative stock status level of 49% (~95% asymptotic intervals: 11–87% in 2019. In general, spawning output has fluctuated over the past few years after a steady increase in early years. Stock size is estimated to be approaching levels not seen since the 1970s. The stock is estimated to be above the management target of $SB_{40\%}$, and has been mostly above this mark since the 2010.

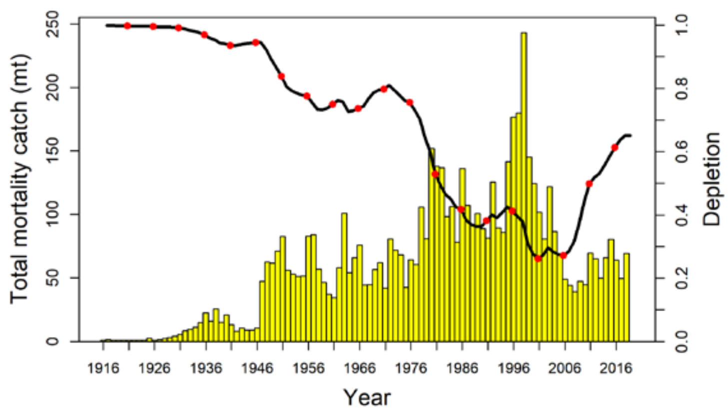
NCS Cabezon spawning output was estimated to be 643 mt in 2019 (~95% asymptotic intervals: 159–1,126 mt), which when compared to unfished spawning output (986 mt) equates to a relative stock status level of 65% (~95% asymptotic intervals: 22–108%) in 2019. The uncertainty in these quantities are very large. In general, spawning output has increased since the late 2000s. Stock size is estimated to be approaching levels not seen since the 1970s. The stock is estimated to be above the management target of $SB_{40\%}$, but measured with high uncertainty, and has been above this mark since around the time of the last assessment in 2009.

The Oregon assessment is structured as a single, sex- and age-disaggregated, unit population, spanning Oregon coastal waters, and operates on an annual time step covering the period 1970 to 2019. The model is conditioned on catch from two sectors (commercial and recreational) divided among 4 fleets, and is informed by four abundance indices, length compositions for each fleet, and age compositions from the recreational fishery, the commercial fishery, and from research surveys.

Cabezon spawning output in Oregon was estimated to be 177 mt in 2019 (~95% asymptotic intervals: 129-226 mt), which when compared to unfished spawning output (335 mt) equates to a depletion level of 53% (~95% asymptotic intervals: 43-63%) in 2019. In general, spawning output has been trending downwards until the early 2000s, after which it became more stable throughout the rest of the time series with a slight increase from 2017 through 2019 due to an above average recruitment estimate for the 2014 year class. Other years with relatively high estimates of recruitment were 1999, 2000, and 2002. Cabezon in Oregon has not been depleted to levels that would provide considerable information on how recruitment changes with spawning output at low spawning output levels. Harvest rates in Oregon have generally increased through time until reaching a more stable (but still variable from year to year) level beginning in the 2000s. The maximum relative harvest rate was 1.16 in 2001 (or 116% of the target level) before declining to around 0.80 in recent years. In 2018, Oregon Cabezon biomass is estimated to have been 1.32 times higher than the target biomass level, and fishing intensity remains lower than the SPR fishing intensity target. Major sources of uncertainty associated with the 2019 Cabezon assessment for Oregon were the size of population scale and value for natural mortality.

The Washington model uses a catch estimator approach to estimate overfishing levels. OFLs for 2021 and 2022, estimated by Simple Stock Synthesis (SSS), are 22.8 mt and 17.3 mt, respectively, given a 2018 depletion of 65% estimated using length-based spawning potential ratio (LBSPR).

Uncertainty in these OFL estimates is also explored and presented in the main document using 15 different scenarios that use three different catch history and five different depletion assumptions. In addition to reporting the median OFLs from each scenario, the scenarios are also combined into two ensembles. One ensemble treats all scenarios as equally plausible and the other weights the 65% depletion assumption and base catch history as more likely. The ensembles only differ by 0.1-0.3 mt from the OFLs produced by the 65% depletion and base catch history SSS run but show much wider uncertainty surrounding the median OFLs. Given the similarities in each approach, using the unweighted version provides the largest measure of uncertainty and may be most consistent with the largest uncertainty assumed for category 3 stocks.



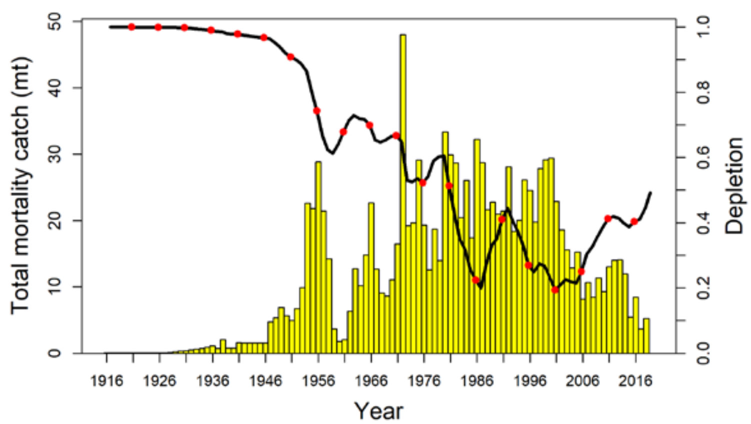


Figure 17. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Cabezon in Southern California (upper) and Northern California (lower), 1916-2018.

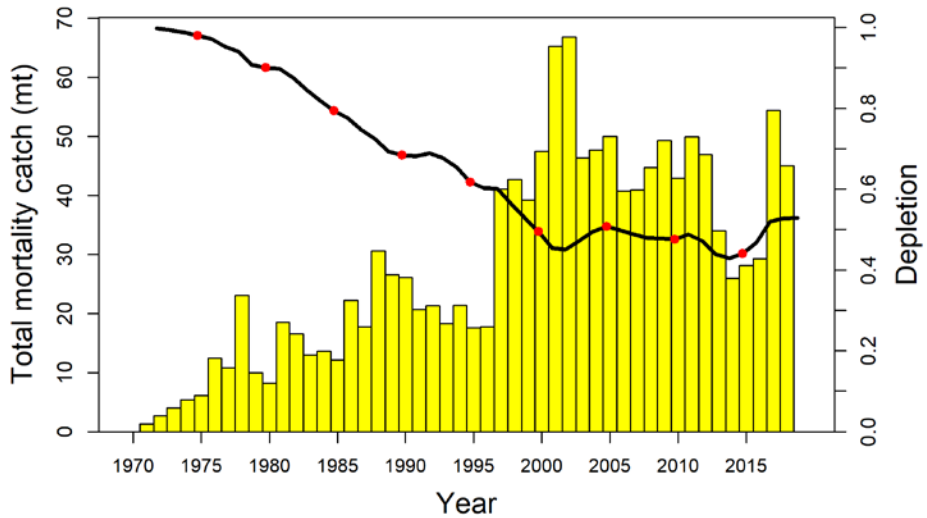


Figure 18. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Cabezon in Oregon, 1970-2018.

For more information, please contact Jason Cope at Jason.Cope@noaa.gov (California and Washington assessments) or Aaron Berger at Aaron.Berger@noaa.gov (Oregon assessment).

V. Ecosystem Studies

A. Socioeconomics

a) Coupled changes in biomass and distribution drive trends in availability of fish stocks to U.S. west coast ports

Investigators: Rebecca L. Selden, James T. Thorson, Jameal F. Samhouri, Steven J. Bograd, Stephanie Brodie, Gemma Carroll, Melissa Haltuch, Elliott Hazen, Kirstin Holsman, Malin Pinsky, Ellen Willis-Norton.

Fishing communities are increasingly required to adapt to environmentally driven changes in the availability of fish stocks. Here, we examined trends in the distribution and biomass of five commercial target species (Dover sole, thornyheads, sablefish, lingcod, and petrale sole) on the U.S. west coast to determine how their availability to fishing ports changed over 40 years. We show that the timing and magnitude of stock declines and recoveries are not experienced uniformly along the coast when they coincide with shifts in species distributions. For example, overall stock availability of sablefish was more stable in southern latitudes where a 40% regional decline in biomass was counterbalanced by a southward shift in distribution of >200 km since 2003. Greater vessel mobility and larger areal extent of fish habitat along the continental shelf buffered northerly ports from latitudinal changes in stock availability. Landings were not consistently related to stock availability, suggesting that social, economic, and regulatory factors likely constrain or facilitate the capacity for fishers to adapt to changes in fish availability. Coupled social–ecological analyses such as the one presented here are important for defining community vulnerability to current and future changes in the availability of important marine species.

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b) Choice sets for spatial discrete choice models in sata rich environments

Investigators: R.L. Hicks, D.S. Holland, P.T. Kuriyama, K.E. Schnier

Failure to properly specify an agent's choice set in discrete choice models will generate biased parameter estimates resulting in inaccurate behavioral predictions as well as biased estimates of policy relevant metrics. We propose a method of constructing choice sets by sampling from specific points in space to model agent behavior when choice alternatives are unknown to the researcher, potentially infinite, and differ according to spatial and temporal factors. Using Monte Carlo analysis we compare the performance of this point-based sampling method to the commonly used approach of spatially aggregating choice alternatives. We then apply these alternative approaches to modelling location choice in the Pacific groundfish trawl fishery which has a complex spatial choice structure. Both the Monte Carlo and application results provide considerable support for the efficacy of the point-based approaches.

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B. Assessment Science

1. Integrated Ecosystem Assessment of the California Current

Investigators: C.J. Harvey, N. Garfield, G.D. Williams, and N. Tolimieri, 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 California Current IEA team develops an ecosystem status report (ESR) of the California Current each year, which describes the status and trends of many ecosystem indicators, including some related to groundfish. The ESR is presented to the Pacific Fishery Management Council and developed into an annual tech memo. ESRs and tech memos can be found at https://www.integratedecosystemassessment.noaa.gov/regions/california-current-region/index.html. Also, the California Current IEA team is conducting in-depth quantitative analysis of ecosystem indicators; assessing the risk posed by natural and anthropogenic stressors to key ecosystem resources and human wellbeing; and evaluating potential management strategies to determine which strategies are most effective in moving the ecosystem toward management goals and objectives, and to identify potential management tradeoffs. Many of these efforts also involve analyses related to groundfish.

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2. 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 2019, CAP production aged 20,318 age structures, production double read 7,977 age structures. Production ages supported the 2019 assessments on Pacific hake, sablefish, petrale sole, big skate and widow rockfish. Resources were also allocated to produce age estimates on anticipated assessments in 2021. CAP continued the practice of recording otolith weights prior to breaking and burning most specimens when possible. Over 11,000 otolith weights were collected in 2019 to support of research into alternative methods of age determination. Four CAP personnel attended the 2019 C.A.R.E conference (Committee of Age Reading Experts) in Seattle Washington.

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3. Modeling

a) The effect of survey frequency and intensity on U.S. west coast stock assessment estimates

Investigators: Owen S. Hamel, Ian G. Taylor, Jason M. Cope, Vladlena Gertseva, Melissa A. Haltuch, Aimee Keller, Andi Stephens, James T. Thorson, John R. Wallace, Chantel R. Wetzel

Fisheries management systems rely on stock assessments to inform management. Stock assessments, in turn, rely on well-designed and comprehensive surveys to provide data necessary to estimate scale and trends in fish populations. Given limited budgets and the financial demands of conducting surveys and the concomitant laboratory and analytical requirements, it is important to consider tradeoffs in designing surveys and evaluate alternative ways to reduce survey effort if required. We conducted a retrospective analysis of the impact of reducing the intensity or frequency of the U.S. West Coast Groundfish Bottom Trawl survey across eleven recently assessed species. Survey effort was reduced by approximately half through either an every-other year survey or reducing the number of vessels from four to two in each year. The influence of the survey reductions on assessment outputs and catch limits depend upon species life history, frequency of occurrence in the current survey, and the data-richness of each assessment. All approaches to reducing survey sampling led to increased uncertainty in stock assessment results, while variability in assessment results among survey configurations was greater for species that are less commonly encountered in the survey, species with less information from other sources, species that have not been heavily exploited, and for data-moderate assessments, which rely more heavily on survey indices.

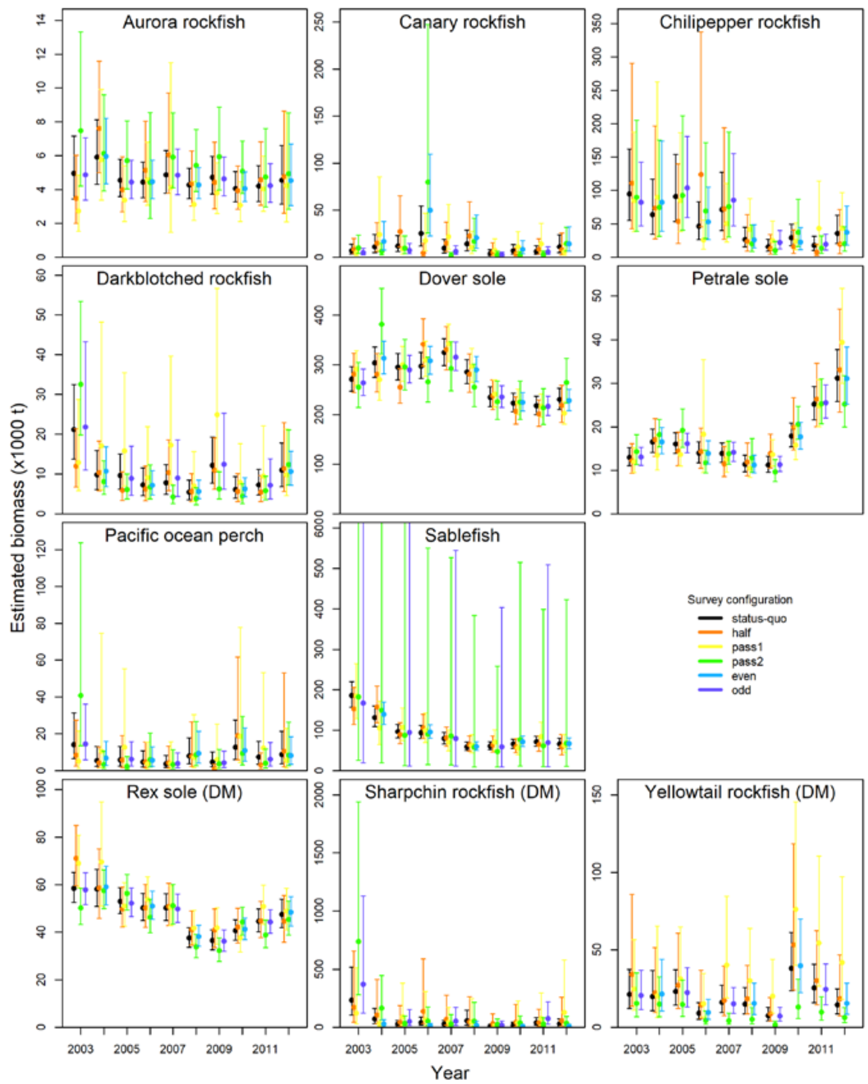

Figure 19. GLMM-derived indices of abundance and 75% lognormal confidence intervals for each survey configuration for each species. "DM" indicates species with Data Moderate stock assessments. The upper limit of the confidence intervals for sablefish that extend beyond the range of the figure are 1,451,000 t and 777,000 t for "odd" in 2003 and 2005, and 1,314,000 t, 1,131,000 t, and 616,000 t for "pass2" in 2003-2005.

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b) Evaluating the consequences of misdiagnosing population structure within spatial stock assessment models

Investigators: K. Bosley, A. Schueller, A. Berger, J. Deroba, D. Goethel, K. Fenske, D. Hanselman, B. Langseth

Contemporary spatially explicit assessment models have the ability to inform fine-scale processes and spatial management of heterogeneous populations. For example, estimates of productivity may be improved by simultaneously modeling individual spawning components instead of aggregating data and parameters across the entire spatial domain. Although spatial models provide a more realistic representation of the true population dynamics, few studies have evaluated the potential risk associated with incorrect assumptions regarding population structure. We simulated the dynamics of a long-lived demersal species (sablefish) under different assumptions of population structure (panmictic, spatial heterogeneity, and metapopulation), then applied various assessment approaches (panmictic, fleets-as-areas, and spatially explicit) to simulated data. Model performance was evaluated for scenarios where the assumptions of spatial population structure in the assessment either matched or incorrectly diagnosed the underlying spatial population dynamics. Parameter estimates were generally unbiased at the system level even when the spatial structure was incorrectly specified, however, area-specific values were often biased unless spatial structure was correctly identified in the assessment model. Fleets-as-areas models performed poorly primarily because the method does not explicitly account for movement or spatial variation in recruitment. Models that incorporated tagging data improved the estimation of area-specific parameters even when the models were misspecified. These results elucidate how incorrect assumptions regarding population structure influence the estimation of key parameters used in fisheries management and which model parameterizations are robust to lack of information on the true population structure. Spatial models are advantageous because outputs are generated at scales relevant to important sources of variability, therefore they can inform spatial management even if incorrectly specified. *ICES.*

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c) Overcoming challenges of harvest quota allocation in spatially structured populations

Investigators: K. Bosley, D. Goethel, A. Berger, J. Deroba, K. Fenske, D. Hanselman, B. Langseth, A. Schueller

Ignoring spatial population structure in the development of fisheries management advice can affect population resilience and yield. However, the resources required to develop spatial stock assessment models that match the spatial scale of management are often unavailable. As a result, quota recommendations from spatially aggregated assessment models are commonly divided among management areas based on empirical methods. We developed a spatially explicit simulation model to 1) explore how variation in population structure influences the spatial distribution of harvest that produces maximum system yield, and 2) contrast the performance of empirical quota allocation methods in approximating ideal spatial harvest strategies. Spatial scenarios that included post-recruitment movement resulted in a broader range of spatial management options (e.g., setting regional total allowable catch) that achieved near maximum system yield compared to scenarios without movement. Stochastic projections showed that using the proportion of total survey biomass in each management area to spatially allocate quota performed best for maximizing system yield when the true spatial structure was unknown, considerably outperforming equal allocation and allocation based on a recruitment index. However, with all methods, area-specific harvest rates sometimes led to unintended depletion within management units. Improved data and understanding of spatial stock dynamics can reduce the need for ad hoc approaches for spatial harvest allocation, allow for a greater range of management options, and increase the efficacy of spatial management procedures.

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d) Exploring the utility of different tag-recovery experimental designs for use in spatially explicit, tag-integrated stock assessment models

Investigators: D. Goethel, K. Bosley, D. Hanselman, A. Berger, J. Deroba, B. Langseth, A. Schueller

The need for spatial stock assessment models that match the spatiotemporal management and biological structure of marine species is growing. Spatially explicit, tag-integrated models can emulate complex population structure, because they are able to estimate connectivity among population units by incorporating tag-recovery data directly into the combined objective function of the assessment. However, the limited scope of many small-scale tagging studies along with difficulty addressing major assumptions of tagging data has prevented more widespread utilization of tag-recovery data sets within tag-integrated models. A spatially explicit simulation-estimation framework that simulates metapopulation dynamics with two populations and time-varying connectivity was implemented for three life history (i.e., longevity) scenarios to explore the relative utility of tagging data for use in spatial assessment models across a range of tag release designs (e.g., annual, historical, periodic, and opportunistic tagging). Model scenarios also investigated the impacts of not accounting for incomplete tag mixing or assuming all fish were fully selected (i.e., that the age composition of tagged fish was unknown). Results demonstrated that periodic tagging (e.g., releasing tags every five years) may provide the best balance between tag program cost and parameter bias. For cost-effective tagging programs, tag releases should be spread over a longer time period instead of focusing on release events in consecutive years, while releasing tags in tandem with existing surveys could further improve the practicality of implementing tag-recovery experiments. However, care should be taken to fully address critical modeling assumptions (e.g., by estimating tag mixing parameters) before incorporating tagging data into an assessment model.

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e) Recent advances in management strategy evaluation: introduction to the special issue "Under pressure: addressing fisheries challenges with Management Strategy Evaluation"

Investigators: D. Goethel, S. Lucey, A. Berger, S. Gaichas, M. Karp, P. Lynch, J. Walter

Management strategy evaluation (MSE) is an increasingly popular tool for developing, testing, and implementing fisheries management regimes, oftentimes utilizing participatory modeling. This special issue, “Under pressure: addressing fisheries challenges with Management Strategy Evaluation”, includes eleven articles highlighting cutting edge MSE approaches and perspectives on improving stakeholder engagement. The special issue is the culmination of a two-session MSE symposium held during the 147th American Fisheries Society Annual Meeting in Tampa, Florida. We summarize the themes from the symposium and special issue articles. Contributions demonstrated that important strides have been made in quantifying and exploring risk (by including more sophisticated multispecies and socioeconomic components), developing and testing data limited harvest control rules, acknowledging and diagnosing limitations of MSE (e.g., identifying exceptional circumstances), and dealing with issues of stakeholder engagement and dimensionality (e.g., determining appropriate representation, communication techniques, and participation levels). Although MSE is a not a panacea for marine policy and resource utilization issues, it is a useful tool for implementing co-management regimes that should become increasingly robust as the multidisciplinary nature of MSE processes continues to expand.

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f) Character of temporal variability in stock productivity influences the utility of dynamic reference points

Investigator: A. Berger

Reference points identify benchmarks, thresholds, or decision points for fisheries management, and are commonly defined by stock status indicators that presume equilibrium population conditions in the absence of fishing (e.g., equilibrium biomass, B_0). However, equilibrium population biomass may be an inappropriate reference level when stock productivity is influenced by environmental change, predator-prey dynamics, ecosystem thresholds, and myriad other factors. Simulations were conducted to compare equilibrium-based (static B_0) and non-equilibrium based (dynamic B_0) indicators of stock status under alternative states of nature driven by time-varying recruitment dynamics (productivity regime), fishing dynamics (mortality regime), and species life history. Using dynamic B_0 often implied a different state of the stock under directional productivity regime shifts, but was more similar to static B_0 reference points under cyclic or white noise productivity scenarios. Uncertainty in stock status arising from incorrectly identifying changes in system productivity generally outweighed the uncertainty associated with initial equilibrium conditions. Empirical results across 18 U.S. west coast groundfish stock assessments indicated predominantly small differences (<10%) between static B_0 and dynamic B_0 indicators of stock status, although in some cases differences were large (up to 72%) or spanned reference points that trigger management action. Although caution is warranted when considering dynamic reference points, this paper shows these approaches are likely to be most useful when stock productivity shifts directionally, if that productivity signal can be correctly ascertained.

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g) Realizing the potential of trait-based approaches to advance fisheries science.

Investigators: L. Barnett, N. Jacobson, J. Thorson, J.M. Cope.

Analyzing how fish populations and their ecological communities respond to perturbations such as fishing and environmental variation is crucial to fisheries science. Researchers often predict fish population dynamics using species-level life-history parameters that are treated as fixed over time, while ignoring the impact of intraspecific variation on ecosystem dynamics. However, there is increasing recognition of the need to include processes operating at ecosystem levels (changes in drivers of productivity) while also accounting for variation over space, time and among individuals. To address similar challenges, community ecologists studying plants, insects and other taxa increasingly measure phenotypic characteristics of individual animals that affect fitness or ecological function (termed "functional traits"). Here, we review the history of trait-based methods in fish and other taxa, and argue that fisheries science could see benefits by integrating trait-based approaches within existing fisheries analyses. We argue that measuring and modelling functional traits can improve estimates of population and community dynamics, and rapidly detect responses to fishing and environmental drivers. We support this claim using three concrete examples: how trait-based approaches could account for time-varying parameters in population models; improve fisheries management and harvest control rules; and inform size-based models of marine communities. We then present a step-by-step primer for how trait-based methods could be adapted to complement existing models and analyses in fisheries science. Finally, we call for the creation and expansion of publicly available trait databases to facilitate adapting trait-based methods in fisheries science, to complement existing public databases of life-history parameters for marine organisms.

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h) Testing methods of determining relative stock abundance priors when setting catch recommendations using data-limited approaches.

Investigators: A. Chrysafi, J.M. Cope

Data-limited methods for managing stocks have expanded greatly over the last decade due to the necessity of quantitatively assessing exploited populations with limited information. A special category of such approaches is based on stock reduction analysis. These "catch-only" methods provide a way to handle low data availability, but also require as an input relative stock status (e.g., current biomass/initial biomass), a difficult to determine value that leads to large sensitivity in method output and performance. Published methods have been developed to devise informative priors for this quantity, but have not been evaluated together with the assessment methods. Here, relative stock abundance priors derived from elicited expert knowledge, vulnerability analysis and catch trends are compared to the common assumption of a stock being at B40% (40% of the initial biomass). The performance of each prior source is evaluated both in the degree of bias in estimating stock status and in the estimation procedure of catches for ten data-rich stocks with six stock assessment models that require stock abundance input. The results from both performance metrics show that these alternative sources can provide more accurate priors than assuming current biomass equals B40%, with priors elicited from stock assessment experts performing best.

Finally, based on the findings of this work and the data requirements to construct a stock abundance prior, we make recommendations on how to navigate the options for devising a relative stock status prior.

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i) Performance evaluation of data-limited length-based stock assessment methods

Investigators: L. Chong, T. Mildenberger, M.B. Rudd, M.H. Taylor, J.M. Cope, T.A. Branch, M. Wolff, M. Stabler.

Performance evaluation of data-limited, length-based methods is instrumental in determining and quantifying their accuracy under various scenarios and in providing guidance about model applicability and limitations. We conducted a simulation–estimation analysis to compare the performance of four length-based stock assessment methods: length-based Thompson and Bell (TB), length-based spawning potential ratio (LBSPR), length-based integrated mixed effects (LIME), and length-based risk analysis (LBRA), under varying life history, exploitation status, and recruitment error scenarios. Across all scenarios, TB and LBSPR were the most consistent and accurate assessment methods. LBRA is highly biased, but precautionary, and LIME is more suitable for assessments with time-series longer than a year. All methods have difficulties when assessing short-lived species. The methods are less accurate in estimating the degree of recruitment overfishing when the stocks are severely overexploited, and inconsistent in determining growth overfishing when the stocks are underexploited. Increased recruitment error reduces precision but can decrease bias in estimations. This study highlights the importance of quantifying the accuracy of stock assessment methods and testing methods under different scenarios to determine their strengths and weaknesses and provides guidance on which methods to employ in various situations

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j) Performance of catch-based and length-based methods in data-limited fisheries

Investigators: M. Pons, J.M. Cope, L. Kell

The quantity of data from many small-scale fisheries is insufficient to allow for the application of conventional assessment methods. Even though in many countries they are moving to close-loop simulations to assess the performance of different management procedures in data limited situations, managers in most developing countries are still demanding information on stock status. In this study we use the common metric of harvest rate to evaluate and compare the performance of the following catch-only and length-only assessment models: Catch-Maximum Sustainable Yield (Catch-MSY), Depletion Based Stock Reduction Analysis (DBSRA), Simple Stock Synthesis (SSS), an extension of Catch-MSY (CMSY), Length Based Spawning Potential Ratio (LBSPR), Length-Based Integrated Mixed Effects (LIME), and Length-Based Bayesian (LBB). In general, results were more biased for slightly depleted than for highly depleted stocks, and for long-lived than for short-lived species. Length-based models, such as LIME, performed as well as catch-based methods in many scenarios and, among the catch-base models the one with the best performance was SSS.

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k) When are model-based stock assessments rejected for use in management and what happens then?

Investigators: A.E. Punt, G. Tuck, J. Day, C. Canales, J. Cope, C. De Moor, M. Dickey Collas, B. Elvarsson, M. Haltuch, O. Hamel, A. Hicks, C. M. Legault, P. D. Lynch, M. Wilberg

Model-based stock assessments form a key component of the management advice for fish and invertebrate stocks worldwide. It is important for such assessments to be peer-reviewed and to pass scientific scrutiny before they can be used to inform management decision making. While it is desirable for management decisions to be based on quantitative assessments that use as much of the available data as possible, this is not always the case. A proposed assessment may be found to be unsatisfactory during the peer-review process (even if it utilizes all of the available data), leading to decisions being made using simpler approaches. This paper provides a synthesis across seven jurisdictions of the types of diagnostic statistics and plots that can be used to evaluate whether a proposed assessment is 'best available science', summarizes several cases where a proposed assessment was not accepted for use in management, and how jurisdictions are able to provide management advice when a stock assessment is 'rejected.' The paper concludes with recommended general practices for reducing subjectivity when deciding whether to accept an assessment and how to provide advice when a proposed assessment is rejected.

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l) Investigating the value of including depth during spatiotemporal index standardization

Investigators: Kelli F. Johnson, James T. Thorson, André E. Punt

There are many methods available for estimating the current abundance of fish species. Design-based estimators, which assume random sampling within the sampling domain, have conventionally been used to provide relative indices of abundance. More recently, the use of spatiotemporal models has increased because of their ability to explicitly account for spatial heterogeneity and higher precision relative to design-based estimators. In theory, the inclusion of covariates (e.g., depth) should also improve precision by explaining a portion of the variability in fish abundance. We used a simulation experiment to evaluate the bias and precision of results from spatio-temporal index-standardization models when the true process was and was not governed by depth. The simulation was conditioned on fits to data for darkblotched rockfish (*Sebastes crameri*) because of the known preference of older individuals for deeper water, coupled with their limited migration after recruiting to the fishery. Trends in the simulated indices of abundance were estimated without bias, although individual parameters were not necessarily unbiased. Incorrectly including depth when it did not govern the true process was less problematic than not including it when it should have been included. Akaike Information Criterion correctly identified overfitting when the true dynamics were not governed by depth. Results illustrate how spatiotemporal models can include covariates, but additional testing is needed with respect to the utility of including dynamic covariates that vary in space and time or covariates that do not covary with latitude or longitude.

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m) Operationalizing model ensembles to provide scientific advice for fisheries management

Investigators: Ernesto Jardim, Jon Brodziak, Manuela Azevedo, Elizabeth Brooks, Kelli F. Johnson, Nikolai Klibansky, Coilin Minto, Colin Millar, Iago Mosqueira, Richard Nash, Paris Vasilakopoulus, Brian Wells

Providing scientific advice to fisheries managers can be a risky activity! It's not uncommon that a model which was working perfectly fails to properly fit an additional year of data, or to find that projections made in the past did not materialize when new information was made available. Scientists deal with very complex systems, with many unknown or poorly understood processes and limited information, which make advisory tools sensitive to alternative system representations, model assumptions or new data. Our approach to mitigate the potential lack of robustness and instability of fisheries advice is to expand its basis to integrate structural uncertainty using model ensembles. Two main reasons to use model ensembles are: to include structural uncertainty captured by differences across models of the same system, and to integrate across initial conditions and process errors in projections. This paper discusses and speculates about the utility and implementation of model ensembles for scientific advice to fisheries management. We discuss ensemble utilization, ensemble types, weighting metrics, model space and model expansion. We make the case for using ensembles in three main situations: to estimate stock status, to set future fishing opportunities, and to build operating models for management strategy evaluation.

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n) Visualizing and reporting model uncertainty in stock assessments

Investigators: Jason Cope, Vladlena Gertseva

We developed a visual representation of fisheries stock assessment model outputs to rapidly examine and effectively communicate results of sensitivity tests and model comparisons. This approach allows rapid identification of which stock assessment model configurations deserve further attention when quantifying uncertainty in model outputs important to management decisions. A detailed table aids identification as to what caused the major changes in those models identified as significantly different. The method can be used within a stock assessment of any stock around the world, and it was successfully applied in several groundfish stock assessments on the U.S. west coast.

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o) Right on target: Using data from targeted stocks to inform stock assessment of bycatch species.

Investigators: Vladlena Gertseva, Sean Matson

Fisheries stock assessments heavily rely on historical catch information, to understand how a stock responds to exploitation and make meaningful forecast into the future under alterative management and environmental scenarios. However, for many bycatch species historical removals are virtually unknown as large portion of the catch is discarded at sea. For example, historical discard of elasmobranch species, such as skates and sharks, have been reported to be over 95% of the total catch based on available data. The longnose skate is one the most abundant groundfishes on the outer continental slope and upper continental slope of the U.S. Pacific Coast by biomass and the most abundant skate species in the Northeast Pacific Ocean. We developed a method to estimate catch of longnose skate on the U.S. west coast from catch of Dover sole, a targeted species that longnose skate co-occurs with and is often caught together. This method allowed us to reconstruct historical longnose skate catches back to the beginning of the bottom trawl fisheries and improve stock assessment for this species. Our method is not limited to specific case of longnose skate and can be easily adopted for other species and areas.

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

p) Unraveling the recruitment problem: A review of environmentally-informed forecasting and management strategy evaluation

Investigators: M.A. Haltuch, J. Brodziak, L. Brooks, J. Devine, A. Frank, K. Johnson, N. Klibansky, R. Nash, M. Payne, K. Shertzer, S. Subbey, B. Wells

Studies describing and hypothesizing the impact of climate change and environmental processes on vital rates of fish stocks are increasing in frequency, and concomitant with that is interest in incorporating these processes in fish stock assessments and forecasting models. Previous research suggests that including environmental drivers of fish recruitment in forecasting is of limited value, concluding that forecasting improvements are minimal while potential spurious relationships were sufficient to advise against inclusion. This review evaluates progress in implementing environmental factors in stock-recruitment projections and Management Strategy Evaluations (MSEs), from the year 2000 through 2017, by reviewing studies that incorporate environmental processes into recruitment forecasting, full-cycle MSEs, or simulations investigating harvest control rules. The only successes identified were for species with a short pre-recruit survival window (e.g., opportunistic life-history strategy), where the abbreviated life-span made it easier to identify one or a limited set of key drivers that directly impact dynamics. Autoregressive methods appeared to perform as well, if not better, for species with a longer pre-recruit survival window (e.g., seasonal, inter-annual) during which the environment could potentially exert influence. This review suggests that the inclusion of environmental drivers into assessments and forecasting is most likely to be successful for species with short pre-recruit survival windows (e.g., squid, sardine) and for those that have bottlenecks in their life history during which the environment can exert a well-defined pressure (e.g., anadromous fishes, those reliant on nursery areas). The effects of environment may be more complicated and variable for species with a longer pre-recruit survival window, reducing the ability to quantify environment-recruitment relationships. Species with more complex early life histories and longer pre-recruit survival windows would benefit from future research that focuses on relevant species-specific spatio-temporal scales to improve mechanistic understanding of abiotic-biotic interactions.

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

q) How does growth misspecification affect management advice derived from an integrated fisheries stock assessment model?

Investigators: C.C. Stawitz, M.A. Haltuch, K. Johnson

Analysts must make many decisions regarding model specification when fitting integrated fishery stock assessment models. While variation in vital rates (i.e., recruitment, somatic growth, and natural mortality) is common, capturing this variation in models fit to available data is often infeasible or impractical. Failing to account for this variation can result in underestimates of uncertainty and even biased estimates of stock status used for management advice. Here, we seek to determine how growth misspecification affects management advice derived from integrated stock assessment models that use the Stock Synthesis platform. We conduct a simulation-based case study on California Current petrale sole (Eopsetta jordani) to test whether and how the inclusion or omission of somatic-growth variation introduces bias into management reference points when estimation models misspecify growth. Scenarios we explored included inter-annual and regime-like changes in two key parameters (k, the initial slope of the growth curve, and L2, the asymptotic maximum length) used to model somatic growth in Stock Synthesis. We find misspecification of growth can overestimate management quantities, particularly the estimate of current biomass relative to the unfished biomass (stock depletion). This results in an overly optimistic view of stock status. This bias may be mitigated or eliminated if the assessment model includes growth variation. Including growth variation in the estimation model can also reduce the uncertainty in estimated management quantities by correctly attributing process error to somatic growth. However, the magnitude of detected biases is exceeded by the uncertainty when data are limited, suggesting that estimating growth variation is helpful only in relatively data-rich stock assessment models. We suggest investigators of data-rich assessments consider incorporating time-varying growth parameters into assessment models or decision tables more frequently to account for potential biases and reduce uncertainty caused by temporal growth variation.

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r) A review of methods for quantifying spatial predator–prey overlap

Investigators: G. Carroll, Holsman, K., Brodie, S., Thorson, J., Hazen, E., Bograd, S., Haltuch, M.A., Kotwicki, S., Samhouri, J., Spencer, P., Willis-Norton, E., Selden, R.

Background: Studies that attempt to measure shifts in species distributions often consider a single species in isolation. However, understanding changes in spatial overlap between predators and their prey might provide deeper insight into how species redistribution affects food web dynamics.

Predator–prey overlap metrics: Here, we review a suite of 10 metrics [range overlap, area overlap, the local index of collocation (Pianka's O), Hurlbert's index, biomass weighted overlap, asymmetrical alpha, Schoener's D, Bhattacharyya's coefficient, the global index of collocation and the AB ratio] that describe how two species overlap in space, using concepts such as binary co-occurrence, encounter rates, spatial niche similarity, spatial independence, geographical similarity and trophic transfer. We describe the specific ecological insights that can be gained using each overlap metric, in order to determine which is most appropriate for describing spatial predator–prey interactions for different applications.

Simulation and case study: We use simulated predator and prey distributions to demonstrate how the 10 metrics respond to variation in three types of predator–prey interactions: changing spatial overlap between predator and prey, changing predator population size and changing patterns of predator aggregation in response to prey density. We also apply these overlap metrics to a case study of a predatory fish (arrowtooth flounder, *Atheresthes stomias*) and its prey (juvenile walleye pollock, *Gadus chalcogrammus*) in the Eastern Bering Sea, AK, USA. We show how the metrics can be applied to understand spatial and temporal variation in the overlap of species distributions in this rapidly changing Arctic ecosystem.

Conclusions: Using both simulated and empirical data, we provide a roadmap for ecologists and other practitioners to select overlap metrics to describe particular aspects of spatial predator–prey interactions. We outline a range of research and management applications for which each metric may be suited.

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s) Trade-offs in covariate selection for species distribution models: a methodological comparison

Investigators: Stephanie Brodie, Gemma Carroll, James T. Thorson, Elliott L. Hazen, Steven Bograd, Melissa Haltuch, Kirstin Holsman, Stan Kotwicki, Ellen Willis-Norton, Jameal Samhouri, Rebecca Selden

Species distribution models (SDMs) are a common approach to describing species' space-use and spatially-explicit abundance. With a myriad of model types, methods and parameterization options available, it is challenging to make informed decisions about how to build robust SDMs appropriate for a given purpose. One key component of SDM development is the appropriate parameterization of covariates, such as the inclusion of covariates that reflect underlying processes (e.g. abiotic and biotic covariates) and covariates that act as proxies for unobserved processes (e.g. space and time covariates). It is unclear how different SDMs apportion variance among a suite of covariates, and how parameterization decisions influence model accuracy and performance. To examine trade-offs in covariation parameterization in SDMs, we explore the attribution of spatiotemporal and environmental variation across a suite of SDMs. We first used simulated species distributions with known environmental preferences to compare three types of SDM: a machine learning model (boosted regression tree), a semi-parametric model (generalized additive model) and a spatiotemporal mixed effects model (vector autoregressive spatiotemporal model, VAST). We then applied the same comparative framework to a case study with three fish species (arrowtooth flounder, pacific cod and walleye pollock) in the eastern Bering Sea, USA. Model type and covariate parameterization both had significant effects on model accuracy and performance. We found that including either spatiotemporal or environmental covariates typically reproduced patterns of species distribution and abundance across the three models tested, but model accuracy and performance was maximized when including both spatiotemporal and environmental covariates in the same model framework. Our results reveal trade-offs in the current generation of SDM tools between accurately estimating species abundance, accurately estimating spatial patterns, and accurately quantifying underlying species–environment relationships. These comparisons between model types and parameterization options can help SDM users better understand sources of model bias and estimate error.

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C. Survey Science

1. Research

a) Accounting for seasonal and composition-related variability in acoustic material properties in estimating copepod and krill target strength

Investigators: Serdar Sakinan, Gareth Lawson, Peter Wiebe, Dezhang Chu, Nancy Copley

Estimation of abundance or biomass, using acoustic techniques requires knowledge of the frequency dependent acoustic backscatter characteristics, or target strength, of organisms. Target strength of zooplankton is typically estimated from physics-based models that involve multiple parameters, notably including the acoustic material properties (i.e., the contrasts in density and sound speed between the animal and surrounding seawater). In this work, variability in the acoustic material properties of two zooplankton species in the Gulf of Maine, the copepod (*Calanus finmarchicus*) and krill (*Meganyctiphanes norvegica*), was investigated relative to changing season as well as, for the copepod, temperature and depth. Increases in the density and sound speed contrasts of these species from fall to spring were observed. Target strength predictions based on these measurements varied between fall and spring by 2-3 dB in krill. Measurements were also conducted on *C. finmarchicus* lipid extract at changing temperature and pressure. The density contrast of the extract varied negatively with temperature, while the sound speed contrast changed by more than 10 % over the temperature and pressure ranges that the organism expected to occupy. *C. finmarchicus* target strength predictions showed that the combined effect of temperature and pressure can be significant (more than 10 dB) due to the varying response of lipids. The large vertical migration ranges and lipid accumulation characteristics of these species (e.g., the diapause behaviour of *Calanus* copepods) suggest that it is necessary for seasonal and environmental variability in material properties to be taken into account to achieve reliable measurements.

For more information, please contact Dezhang Chu at Dezhang.Chu@noaa.gov

c) ZooScatR—An R package for modelling the scattering properties of weak scattering targets using the distorted wave Born approximation

Investigators: Sven Gastauer, Dezhang Chu, Martin Cox

A thorough understanding of the scattering characteristics of marine organisms is a prerequisite for robust quantitative fisheries acoustic data processing or interpretation. Target strength models, such as the distorted wave Born approximation (DWBA) can be used to improve the understanding of field recordings of weakly scattering targets. With acoustic methods now being used by a wide audience, allowing access to such models becomes a necessity. To ease access to the DWBA model, an r package (zooscatr) which includes a web application and the ability to parameterise the model either through the web application, text files, or pure scripting has been developed and is now freely available on Github.

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d) The Joint U.S.-Canada integrated ecosystem and Pacific hake acoustic-trawl survey: Growing beyond a single-species focus

Investigators: Sandra Parker-Stetter, Stéphane Gauthier, Julia Clemons, Michael Malick, Elizabeth Phillips, Alicia Billings, Dezhang Chu, Steve de Blois, Jackie Detering, John Pohl, Ben Snow, Chelsea Stanley, Rebecca Thomas

The Integrated Ecosystem and Pacific Hake Acoustic-Trawl Survey has been conducted along the coasts of California, Oregon, Washington, and British Columbia since 1992. Beginning in 2003, the Survey has been a biennial partnership between the Northwest Fisheries Science Center (NWFSC) and Fisheries and Oceans Canada (DFO), including a 3-year shared effort with Southwest Fisheries Science Center (2012, 2013, 2015). The joint NWFSC-DFO survey supports the Pacific Hake (*Merluccius productus*) stock assessment under the U.S.-Canada Pacific Hake/Whiting Treaty. The original survey goal was simple: use acoustic data and midwater trawling to estimate age-2+ Hake biomass and provide biological information for the age-based stock assessment. Over time, survey sampling and data products have expanded in response to changing capabilities and needs. Acoustic analyses now include age-1 Hake and euphausiids/krill (a key prey item for Hake), with anticipated future inclusions of pelagic rockfish and mesopelagic fish. Oceanographic data, once limited to temperature-depth measurements during midwater trawls, now include continuous day/night Acoustic Doppler Current Profiler (ADCP) data, nighttime Conductivity-Temperature-Depth (CTD) rosette casts, and daytime Underway CTD casts. Many of these data have been processed and are becoming publicly available. Environmental data are being used to groundtruth forecasts of Hake horizontal distribution, integrated into models of Hake and euphausiid habitat use, and as inputs to bioenergetics models of Hake growth. Upcoming projects will evaluate the potential role of dissolved oxygen in Hake and euphausiid vertical distributions. From a biological standpoint, the Survey supports a host of regular and on-demand joint and partner projects, including studies of maturity, physiology, tagging, stable isotopes, and genetic studies. With its large spatial coverage, the Survey is the platform for the coast-wide Harmful Algal Bloom (HAB) sampling and also completes 5-6 sampling lines for zooplankton between CA and BC. In 2019, the Survey's CTD rosettes provided water samples for the eDNA Strategic Initiative, and the NOAA Ship Bell M. Shimada's flow-through system was used to evaluate potential utility of a continuous phytoplankton sampler (CytoBot). While the Survey maintains its strong ties to fisheries management, it continues to evolve to efficiently meet broader acoustic, biological, oceanographic, and ecosystem data and sampling needs.

For more information, please contact Sandra Parker-Stetter at Sandra Parker-Stetter@noaa.gov.

e) Small scale acoustic surveys, mapping prey fields and sizing fish – Portable and on a budget

Investigators: Sven Gastauer, Lachlan Philipps, Adam Wilkins, Robert Harcourt, Ian Jonsen, Gemma Carroll, Ben Pitcher, Dezhang Chu, Martin Cox

The use of acoustics as a non-invasive sampling technique to monitor marine resources has largely been accepted. A main limitation of the technology is that it generally requires large, expensive research vessels. Besides the economic limitations, this also limits surveys to the open ocean. Yet inshore coastal systems are ecologically and economically important. We examined a portable system that can be easily transported and mounted on small (>5m) boats to enable acoustic surveys to be run without the need for a dedicated, scientific survey vessel. The usefulness of small-scale surveys was illustrated based on an acoustic prey-field survey for foraging penguins. Further the variability of high- and low-density single targets on broadband data were illustrated and methods on how to determine fish size based on acoustic data only demonstrated.

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f) How much more informative are broadband compared to narrowband echoes for biological interpretation?

Investigators: Wu-Jung Lee, Dezhang Chu, Stan Dosso

The recent availability of commercial broadband echosounders has elicited wide interests in their potentials for enhancing the effectiveness, efficiency, and accuracy of acoustic sensing capability for monitoring mid-trophic level marine organisms. However, despite the significantly improved temporal and spatial resolutions, it remains unclear how the additional spectral information provided by broadband echosounders contribute to achieving these goals. In this study, we use a Bayesian inversion framework to compare the estimation uncertainty between broadband and narrowband echo data for biological model parameters, such as organism length, tile angle, numerical density and aggregation composition. We employ the Markov Chain Monte-Carlo (MCMC) sampling technique to construct the posterior probability density (PPD) of biological parameters given simulated zooplankton and calibrated fish echo data in the form of volume backscattering strength (Sv). The data are simulated for frequency ranges commonly employed in marine ecological and fisheries surveys. We investigate the changes in PPD in response to variations in echo spectral information, with specific emphasis on the correlation structure among model parameters and whether and how broadband information reduces the uncertainty in inferring biological information from acoustic quantities available from field surveys. [Work supported by NMFS Office of Science and Technology Advanced Sampling Technology Working Group].

For more information, please contact Dezhang Chu at Dezhang.Chu@noaa.gov

g) Spatio-temporal trends in west coast groundfish reproduction: A case study of ecologically important species with varying life history strategies

Investigators: Melissa A. Head, Jason M. Cope, Aimee Keller

Ecosystem-based fisheries management (EBFM) aims to support strong fisheries and communities by considering variables that affect a species' health and productivity, i.e. spatio-temporal trends, environmental changes, and fishing pressure. Fisheries managers use life history data to inform stock assessment models. A critical component to this is estimating spawning stock biomass. Reproduction is a fundamental process of population dynamics and changes in its success contribute to a large portion of variability in marine populations. Understanding the timing of maturity, and factors that influence spawning capability are important to measure reproductive potential. Stock assessments conducted at the Northwest Fisheries Science Center (NWFSC) aim to implement EBFM practices by incorporating spatio-temporal varying life history parameters. To accomplish this, the NWFSC implemented a reproductive program in 2011. Since its creation, we have collected ~21,000 gonad samples from 39 groundfish species using seven sampling platforms. We have histologically assessed ~15,000 of these, evaluating biological (physiological) and functional maturity (potential spawners in a given year). This data set now spans multiple years across a large geographical range, and has provided a unique opportunity to explore EBFM concepts, i.e. spatio-temporal changes in maturity, timing of spawning, and reproductive development. We have evaluated this for multiple groundfish species that span the entire U.S. west coast. We found differences in maturity and skip spawning between important biogeographical regions of the coast (Cape Mendocino and Pt. Conception, CA) for several of the species. In addition to the spatial trends, we found temporal differences in the reproductive cycle.

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

2. Habitat

a) Relating groundfish diversity and biomass to deep-sea corals and sponges in the northeast Pacific Ocean

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

Deep-sea corals and sponges (DSCS) inhabit the world's oceans and are often associated with high fish abundance; however the precise nature and extent of any association is difficult to quantify and remains poorly understood. We investigated the associations between DSCS and demersal fish using data from the Northwest Fisheries Science Center's bottom trawl survey (2003-2015). General linear models (GLMs) showed that average species density of groundfish was slightly higher and groundfish biomass slightly lower in hauls with DSCS. Multivariate analyses were used to examine relationships among fish community structure, DSCS densities, and environmental parameters (depth, latitude and bottom temperature). No strong correlations occurred between the community structure of groundfish and DSCS densities, but bottom temperature and depth were the primary drivers of community composition. Indicator species analysis also showed various species-specific associations with DSCS. Specifically, some flatfish species exhibited relationships with coral and sea pen densities, whereas some rockfishes were associated with high sponge densities. Our results provide information on the broad-scale associations among DSCS and demersal fishes that may be useful for developing studies focused on the functional value of DSCS as essential fish habitat and the role they play in groundfish life-history and ecology.

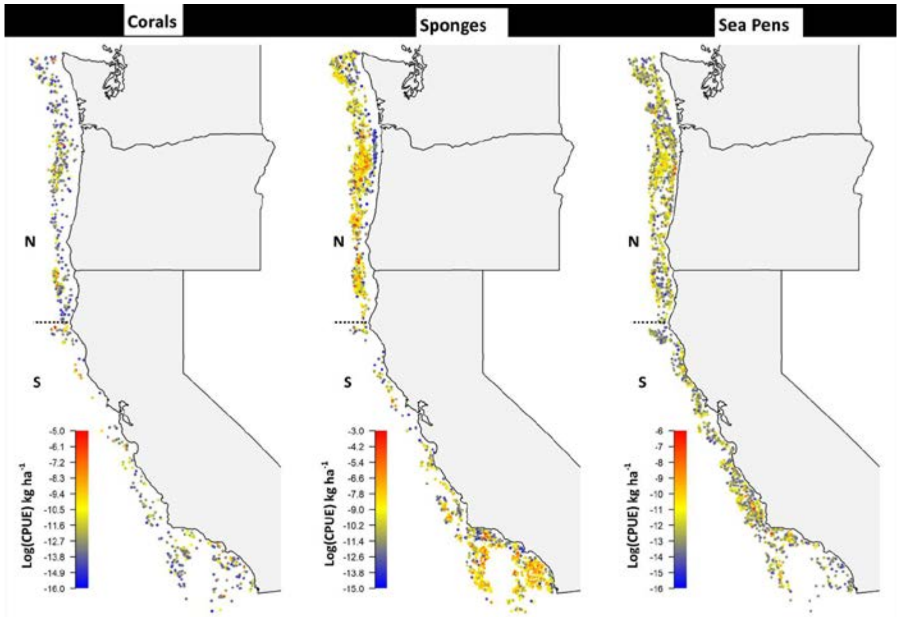

Figure 20. Location of trawls containing corals, sponges and sea pens during the bottom trawl survey 2003 to 2015. Density is on a log scale to better represent low CPUE (ka ha^{-1}). Dashed line shows delineation between the northern and southern geographic groups at Cape Mendocino, CA (40°26'18" N).

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

b) The abundance and habitat use of demersal fishes on a rocky offshore bank using the ROPOS remotely operated vehicle

Investigators: N. Tolimieri, M.E. Clarke, J. Clemons, W. Wakefield, A. Powell

Offshore rocky banks are ecologically important refuge habitats for a number of U.S. commercial groundfish species. However, they are challenging to survey, and data on the abundance and ecology of fish populations at deep banks are limited. We used the remotely operated vehicle ROPOS to carry out visual surveys at two sites on Cherry Bank in the Southern California Bight, eastern Pacific Ocean. We observed differences in fish assemblages related to depth and habitat type and found that rockfishes (*Sebastes* spp.) made up 65% of fishes recorded. Rockfishes and combfish (*Zaniolepis* spp.) were associated with relatively shallow areas with hard substrate whereas flatfishes (Pleuronectiformes) and poachers (Agonidae) were found on unconsolidated sediments. Thornyheads (*Sebastolobus* spp.) and hagfishes (Myxinidae) mainly occurred in areas of patchy habitat. Habitat and depth explained 52% of the variation in fish assemblages between transects with habitat explaining a greater proportion of the variation than depth. We observed large differences in the number of juvenile rockfishes and *Sebastomus* rockfishes between study sites with hard substrates and also had higher abundances of juvenile rockfishes versus sites characterized by mixed substrates. With the exception of unidentified *Sebastomus*, the current design had relatively low power to reliably detect observed differences for most taxa, so we report the number of additional transects that would be required to detect a 50% increase in densities. These data provide a baseline on groundfish densities and habitat associations at Cherry Bank and key information for the design of future work including Bayesian approaches to estimating coast-wide abundance.

For more information please contact Dr. Nick Tolimieri at NOAA's Northwest Fisheries Science Center, nick.tolimieri@noaa.gov.

c) Fish condition and implications for recruitment in the Northeast Pacific

Investigators: Jennifer L. Boldt[1], Christopher N. Rooper[2] , Gerald Hoff[2] , Robyn Forrest[1], Keith Bosley[3]

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[2] National Marine Fisheries Service, Alaska Fisheries Science Center, Seattle, WA, USA

[3] National Marine Fisheries Service, Northwest Fisheries Science Center, Newport, OR, USA

Ecosystem responses to climate change vary across space and time in the North Pacific. Increasing water temperatures and changes in lower trophic level productivity have implications for fish growth on both regional and basin scales. Responses of fish growth to environmental drivers can be examined by comparing fish condition over time and space. Fish condition, measured as length-weight residuals, is an indicator of somatic growth and ecosystem productivity, and a fish's condition has implications for its survival and recruitment. Condition was compared among fish species and ecosystems in the Northeast Pacific - from the Bering Sea to the northern California Current. For example, in the Eastern Bering Sea, there has been a negative trend in Pacific cod condition since 2003, and age 2+ walleye Pollock condition in 2017 was the second lowest on record. For most species, condition metrics varied over space and time. Fish were generally in better condition on the outer shelf, compared to shallower regions. There is an absence of consistent trends within species among different areas, but within an area, condition often is observed to change in synchrony among species, suggesting that local conditions might be driving observed patterns for multiple species.

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d) Sub-regional differences in groundfish distributional responses to anomalous ocean temperatures in the northeast Pacific

Investigators: Lingbo Li, Anne Hollowed, Edward Cokelet, Steve Barbeaux, Nicholas Bond, Aimee Keller, Jackie King, Michelle McClure, Wayne Palsson, Phyllis Stabeno, Qiong Yang

Although climate-induced shifts in fish distribution have been widely reported at the population level, studies that account for ontogenetic shifts and sub-regional differences when assessing responses are rare. In this study, groundfish distributional changes were assessed at different size classes by species within nine sub-regions using indicators of shifts in depth, latitude, and longitude. We examined large, quality-controlled datasets of depth-stratified, random bottom trawl surveys conducted during summer in three large regions – the Gulf of Alaska and the west coast of Canada and the U.S. – over the period 1996-2015, a time period punctuated by a marine “heat wave”. Temporal biases in bottom temperature were minimized by subdividing each region into three sub-regions, each with short-duration surveys. Near-bottom temperatures, weighted by stratum area, were unsynchronized across sub-regions and exhibited varying sub-regional interannual variability. The weighted-mean bottom depths in the sub-regions also vary largely among sub-regions. The centroids (centers of gravity) of groundfish distribution were weighted with catch per unit effort (CPUE) and stratum area for ten commercially important groundfish species by size class and sub-region. Our multivariate analyses showed that there were significant differences in aggregate fish movements of temperature responses across sub-regions but not among species or sizes. Groundfish demonstrated poleward responses to warming temperatures only in a few sub-regions and moved shallower or deeper to seek colder waters depending on the sub-region. They likely form geographically distinct thermal ecoregions, instead of continuously moving northward along northeast Pacific shelf under global warming. Shallow-depth species exhibited greatly different distributional responses to temperature changes across sub-regions while deep-depth species of different sub-regions tend to have relatively similar temperature responses. Future climate studies would benefit by considering fish distributions on small sub-regional scales.

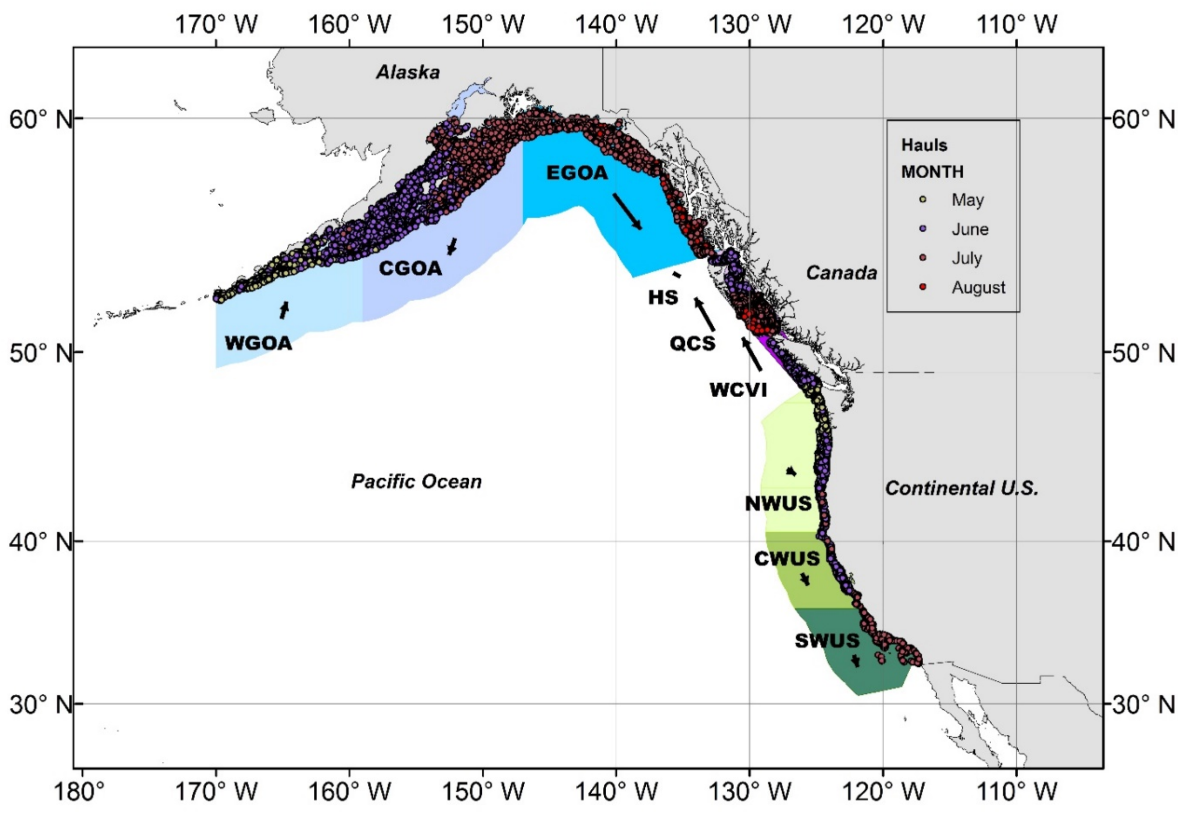

Figure 21. The study area (Mercator Projection) of northeast Pacific including bottom trawl hauls (filled circles) in three surveys, which were divided into nine sub-regions. Polygons of sub-regions in the GOA and U.S. west coast are consistent with fishery management areas. Arrows are scaled to average standardized temperature responses in latitude and longitude for each sub-region, indicating that these groundfish tended to form three thermal ecoregions, W-CGOA, EGOA-HS-QCS-WCVI, and U.S. west coast, under global warming.

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

e) Effects of warming ocean conditions on feeding ecology of small pelagic fishes in a coastal upwelling ecosystem: a shift to gelatinous food sources.

Investigators: R.D Brodeur, M.E. Hunsicker, A. Hann, T.W. Miller

Forage fish play a central role in the transfer of energy from lower to higher trophic levels. Ocean conditions may influence this energy pathway in the Northern California Current (NCC) ecosystem, and we may expect it to differ between warm and cold periods in the northeast Pacific Ocean. The recent unprecedented warming in the NCC provides a unique opportunity to better understand the connection between ocean conditions and forage fish feeding habits and the potential consequences for predators that depend on them for sustenance. Here we present findings from gut content analysis to examine food sources of multiple forage fishes (northern anchovy *Engraulis mordax*, Pacific sardine *Sardinops sagax*, jack mackerel *Trachurus symmetricus*, Pacific herring *Clupea pallasii*, surf smelt *Hypomesus pretiosus*, and whitebait smelt *Allosmerus elongatus*) off the Washington and Oregon coasts. Analyses were applied to fish collected in May and June during recent warm years (2015 and 2016) and compared to previous collections made during cool (2011, 2012) and average (2000, 2002) years. Results of the diet analysis indicate that fish feeding habits varied significantly between cold and both average and warm periods. Euphausiids, decapods, and copepods were the main prey items of the forage fishes for most years examined; however, gelatinous zooplankton were consumed in much higher quantities in warm years compared to cold years. This shift in prey availability was also seen in plankton and trawl surveys in recent years and suggests that changing ocean conditions are likely to affect the type and quality of prey available to forage fish. Although gelatinous zooplankton are generally not believed to be suitable prey for most fishes due to their low energy content, some forage fishes may utilize this prey in the absence of more preferred prey resources during anomalously warm ocean conditions.

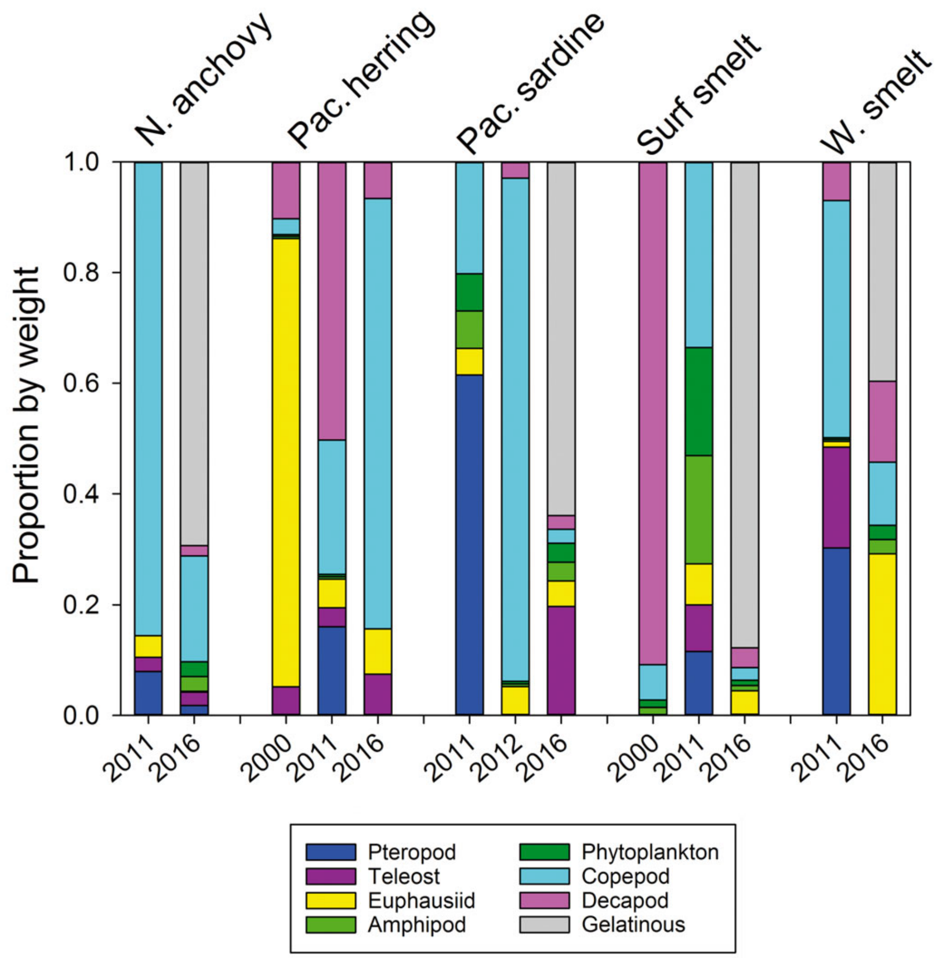

Figure 22. May diet composition by proportion wet weight of dominant forage fishes by year for the major taxonomic categories.

For more information, please contact Rick Brodeur at Rick.Brodeur@noaa.gov

f) Unclear associations between pelagic fish and jellyfish in several major marine ecosystems.

Investigators: A.F. Opdal, R.D. Brodeur, K. Cieciel, G.M. Daskalov, V. Mihneva, J.J. Ruzicka, H.M. Verheye, D.L. Aksnes.

During the last 20 years, a series of studies has suggested trends of increasing jellyfish (Cnidaria and Ctenophora) biomass in several major ecosystems worldwide. Some of these systems have been heavily fished, causing a decline among their historically dominant small pelagic fish stocks, or have experienced environmental shifts favouring jellyfish proliferation. Apparent reduction in fish abundance alongside increasing jellyfish abundance has led to hypotheses suggesting that jellyfish in these areas could be replacing small planktivorous fish through resource competition and/or through predation on early life stages of fish. In this study, we test these hypotheses using extended and published data of jellyfish, small pelagic fish and crustacean zooplankton biomass from four major ecosystems within the period of 1960 to 2014: the Southeastern Bering Sea, the Black Sea, the Northern California Current and the Northern Benguela. Except for a negative association between jellyfish and crustacean zooplankton in the Black Sea, we found no evidence of jellyfish biomass being related to the biomass of small pelagic fish nor to a common crustacean zooplankton resource. Calculations of the energy requirements of small pelagic fish and jellyfish stocks in the most recent years suggest that fish predation on crustacean zooplankton is 2–30 times higher than jellyfish predation, depending on ecosystem. However, compared with available historical data in the Southeastern Bering Sea and the Black Sea, it is evident that jellyfish have increased their share of the common resource, and that jellyfish can account for up to 30% of the combined fish-jellyfish energy consumption. We conclude that the best available time-series data do not suggest that jellyfish are outcompeting, or have replaced, small pelagic fish on a regional scale in any of the four investigated ecosystems. However, further clarification of the role of jellyfish requires higher-resolution spatial, temporal and taxonomic sampling of the pelagic community.

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g) Major shifts in macroplankton and micronekton pelagic community structure in an upwelling ecosystem related to an unprecedented marine heatwave

Investigators: R.D. Brodeur, T.D. Auth, A.J. Phillips

The community structure of pelagic zooplankton and micronekton may be a sensitive indicator of changes in environmental conditions within the California Current ecosystem. Substantial oceanographic changes in 2015 and 2016, due to the anomalously warm ocean conditions associated with a large-scale marine heatwave perturbation, resulted in onshore and northward advection of warmer and more stratified surface waters resulting in reduced upwelling. Here we quantify changes in the macrozooplankton and micronekton community composition and structure based on five highly contrasting ocean conditions. Data from fine-mesh pelagic trawl surveys conducted off Oregon and Washington during early summer of 2011 and 2013–2016 were examined for interannual changes in spatial distribution and abundance of fish and invertebrate taxa. Overall species diversity was highest in 2015 and lowest in 2011, but 2016 was similar to the other years, although the evenness was somewhat lower. The community of taxa in both 2015 and 2016 was significantly different from the previously sampled years. Crustacean plankton densities (especially Euphausiidae) were extremely low in both of these years, and the invertebrate composition became dominated mostly by gelatinous zooplankton. Fishes and cephalopods showed mixed trends overall, but some species such as age-0 Pacific hake were found in relatively high abundances mainly along the shelf break in 2015 and 2016. These results suggest dramatically different pelagic communities were present during the recent warm years with a greater contribution from offshore taxa, especially gelatinous taxa, during 2015 and 2016. The substantial reorganization of the pelagic community has the potential to lead to major alterations in trophic functioning in this normally productive ecosystem.

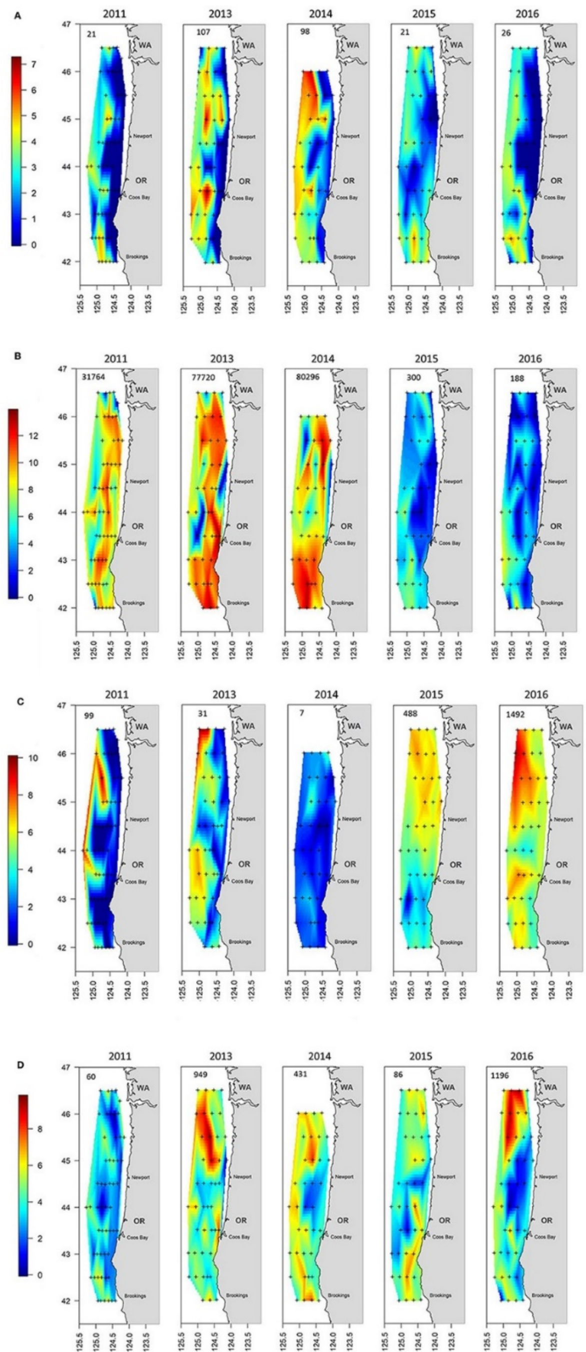

Figure 23. Distribution maps of the catch by year for the aggregated groupings of (A) Cephalopods, (B) Crustacea, (C) Gelatinous, and (D) Teleosts. The number in the upper left of each panel indicates the geometric mean catch of that grouping per haul by year. Note that the scale bar is logarithmic. The plus signs indicate locations where trawling was conducted.

For more information, please contact Rick Brodeur at Rick.Brodeur@noaa.gov

h) Distribution of pelagic thaliaceans, *Thetys vagina* and *Pyrosoma atlanticum*, during a period of mass occurrence within the California Current Large Marine Ecosystem

Investigators: R.R. Miller, J.A. Santora, T.D. Auth, K.M. Sakuma, B.K. Wells, J.C. Field, R.D. Brodeur

The spatial distribution, abundance, and size variability of two pelagic tunicate species, *Thetys vagina* and *Pyrosoma atlanticum*, were examined from midwater trawl surveys to assess the historical context and geographical aspects of a major mass occurrence event throughout the California Current Large Marine Ecosystem during 2012–19. Off central California, abundance of both species were significantly greater in 2012–19 compared to 1983–2001, and their recent persistent multiyear abundance peaks were unprecedented. Coastwide abundance and distribution of *T. vagina* during 2013–19 was patchy, with no discernible shifts in distribution or changes in mean length. From 2013–18, abundance and distribution of *P. atlanticum* demonstrated a temporal trend of increasing abundance from south to north, and in northern areas, average *P. atlanticum* colony length increased over time. In 2019, high abundances of *P. atlanticum* occurred south of Monterey Bay, but were not found in the northern California Current. We discuss how in situ and regional-scale environmental drivers may have contributed to this recent multiyear gelatinous mass occurrence, and potential consequences to forage community structure and ecosystem function.

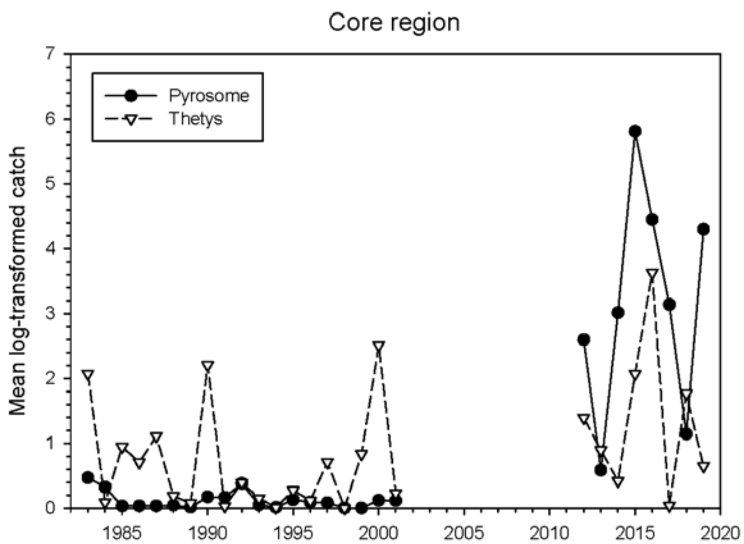

Figure 24. Time series of the annual mean log-transformed catch, ln(catch+1), for *Pyrosoma atlanticum* and *Thetys vagina* within the core region for the years 1983–2001 and 2012–19.

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i) Nekton.

Investigators: Rick Brodeur, E.A. Pakhomov

Marine nekton are the swimmers in the sea. They range in size from a few centimeters, e.g., euphausiids (krill), to the largest whales (tens of meters). Many are important in fisheries. Micronekton, the emphasis of this article, are small nekton, mainly fishes, squids, and shrimps. They inhabit all oceans and all depths. Many undertake diel vertical migrations into near-surface waters as light intensity decreases at dusk and then descend into deeper water before dawn. Some are bioluminescent, often with ventrally-oriented photophores. In addition to diel vertical migrations, we know that some micronekton also migrate horizontally over slope waters into shallow water at night. They comprise a key link between primary consumers and the higher trophic levels in all marine food webs.

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j) Spatio-temporal patterns in juvenile habitat for 13 groundfishes in the California Current Ecosystem

Investigators: Nick Tolimieri, John Wallace, Melissa Haltuch

A species' spatial distribution is one of the fundamental aspects of its ecology and is an important component of many conservation and management plans, including the designation of Essential Fish Habitat (EFH). Identifying juvenile habitats is critical for defining a species' EFH and for focusing spatial fishery management because recruitment events strongly affect population age structure and abundance. Here, we used vector autoregressive spatio-temporal models (VAST) to delineate spatial and temporal patterns in juvenile density for 13 commercially important species of groundfishes off the U.S. west coast. In particular, we identified hotspots with high juvenile density. Three qualitative patterns of distribution and abundance emerged. First, Dover sole *Microstomus pacificus*, Pacific grenadier *Coryphaenoides acrolepis*, shortspine thornyhead *Sebastolobus alascanus*, and splitnose rockfish *Sebastes diploproa* had distinct, spatially limited hotspots that were spatially consistent through time. Next, Pacific hake *Merluccius productus* and darkblotched rockfish *S. crameri* had distinct, spatially limited hotspots, but the location of these hotspots varied through time. Finally, arrowtooth flounder *Atheresthes stomias*, English sole *Parophrys vetulus*, sablefish *Anoplopoma fimbria*, Pacific grenadier *Coryphaenoides acrolepis*, lingcod *Ophiodon elongatus*, longspine thornyhead *S. altivelis*, petrale sole *Eopsetta jordani* , and Pacific sanddab *Citharichthys sordidus* had large hotspots that spanned a broad latitudinal range. These habitats represent potential, if not likely, nursery areas, the location of which will inform spatial management.

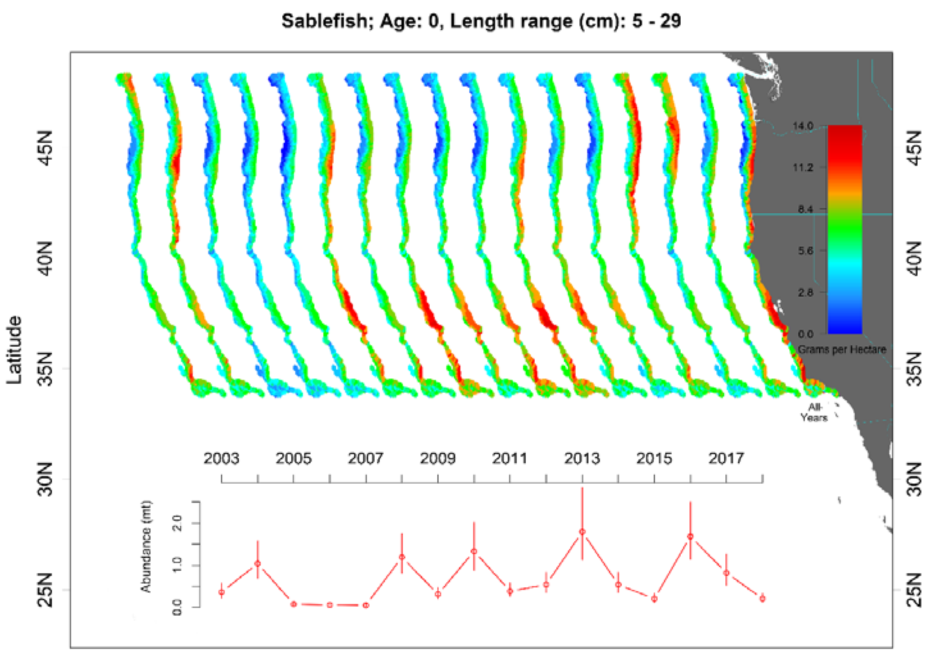

Figure 25. Spatial distribution and annual abundance index of juvenile sablefish off the west coast of the U.S.

For more information please contact Dr. Nick Tolimieri at NOAA's Northwest Fisheries Science Center, nick.tolimieri@noaa.gov.

D. Observer Program and Science

1. West Coast Observer Program

The FRAM West Coast Groundfish Observer Program (WCGOP) continued collecting fishery-dependent data during 2019 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 fishery can be further broken down into the shorebased fleet and the at sea fleet. The at sea fleet includes catcher-processors (CPs) and motherships. 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.

Catch Shares

There are three sectors in the catch share program: shorebased, motherships (includes motherships and mother ship catcher-vessels), and catcher-processors. All vessels participating in the shorebased sector or acting as mother ship 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 shore side processors. Catch shares regulations allow the shorebased sector to use trawl, longline, or pots to harvest IFQ species. The mother ship 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.

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 mother ship catcher-vessels participating in the at-sea hake fishery
- All catcher-processors participating in the at-sea hake fishery

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 vessels ranging in size from skiffs to larger fixed gear vessels and depths ranging from less than 20 ft. to more than 300 ft. 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.

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

2. Research

a) Comparing predictions of fisheries bycatch using multiple spatiotemporal species distribution model frameworks

Investigators: Stock, B.C., E.J. Ward, T. Eguchi, J.E. Jannot, J.T. Thorson, B.E. Feist, B.X. Semmens

Spatiotemporal predictions of bycatch (i.e., catch of nontargeted species) have shown promise as dynamic ocean management tools for reducing bycatch. However, which spatiotemporal model framework to use for generating these predictions is unclear. We evaluated a relatively new method, Gaussian Markov random fields (GMRFs), with two other frameworks, generalized additive models (GAMs) and random forests. We fit geostatistical delta-models to fisheries observer bycatch data for six species with a broad range of movement patterns (e.g., highly migratory sea turtles versus sedentary rockfish) and bycatch rates (percentage of observations with nonzero catch, 0.3%–96.2%). Random forests had better interpolation performance than the GMRF and GAM models for all six species, but random forests performance was more sensitive when predicting data at the edge of the fishery (i.e., spatial extrapolation). Using random forests to identify and remove the 5% highest bycatch risk fishing events reduced the bycatch-to-target species catch ratio by 34% on average. All models considerably reduced the bycatch-to-target ratio, demonstrating the clear potential of species distribution models to support spatial fishery management.

For more information please contact Dr. Eric Ward at NOAA's Northwest Fisheries Science Center, eric.ward@noaa.gov.

b) Bycatch quotas, risk pools, and cooperation in the Pacific whiting fishery (Bycatch Quotas and Risk Pools PGTF)

Investigators: D.S. Holland, C. Martin

The United States Pacific whiting fishery uses mid-water trawl gear to target Pacific whiting off the United States west coast. The fishery is subject to sector-specific bycatch caps for Chinook salmon (*Oncorhynchus tshawytscha*) and several rockfish species (widow rockfish–*Sebastes entomelas*, canary rockfish-*Sebastes pinniger*, darkblotched rockfish–*Sebastes crameri*, Pacific Ocean Perch (POP)-*Sebastes alutus*, and yelloweye rockfish-*Sebastes ruberrimus*). Chinook bycatch can include fish from endangered populations and rockfish stocks were recovering from severe depletion though most are now rebuilt. Catch of these species is rare and uncertain, making it difficult for vessels to meet strict individual performance standards. Consequently the industry has developed risk pools in which bycatch quota for a group of vessels is pooled, but vessels are required to follow practices that minimize bycatch risk including temporal and spatial fishing restrictions. The risk pools also require vessels to share information about bycatch hotspots enabling a cooperative approach to avoid bycatch based on real-time information. In this article we discuss the formation and structure of these risk pools, the bycatch reduction strategies they apply, and outcomes in the fishery in terms of observed bycatch avoidance behavior and utilization of target species. The analysis demonstrates the ability of these fishers to keep bycatch within aggregate limits and keep individual vessels from being tied up due to quota overages.

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

c) The utility of spatial model-based estimators of unobserved bycatch

Investigators: B.C. Stock, E.J. Ward, J.T. Thorson, J.E. Janot, B.X. Semmens

Quantifying effects of fishing on non-targeted (bycatch) species is an important management and conservation issue. Bycatch estimates are typically calculated using data collected by on-board observers, but observer programs are costly and therefore often only cover a small percentage of the fishery. The challenge is then to estimate bycatch for the unobserved fishing activity. The *status quo* for most fisheries is to assume the ratio of bycatch to effort is constant and multiply this ratio by the effort in the unobserved activity (ratio estimator). We used a dataset with 100% observer coverage, 35,440 hauls from the U.S. west coast groundfish trawl fishery, to evaluate the ratio estimator against methods that utilize fine-scale spatial information: generalized additive models (GAMs) and random forests. Applied to 15 species representing a range of bycatch rates, including spatial locations improved model predictive ability, whereas including effort-associated covariates generally did not. Random forests performed best for all species (lower root mean square error), but were slightly biased (overpredicting total bycatch). Thus, the choice of bycatch estimation method involves a tradeoff between bias and precision, and which method is optimal may depend on the species bycatch rate and how the estimates are to be used.

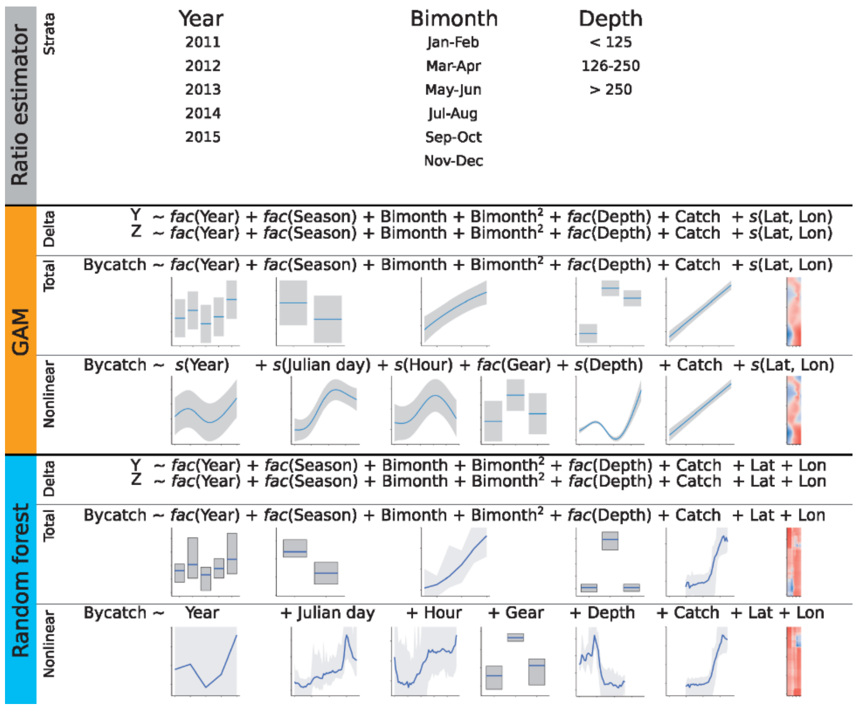

Figure 26. Summary of models fit to the West Coast Groundfish Observer Program bycatch dataset. The ratio estimator was stratified by year, bimonthly period, and depth (fathoms). The Delta and Total models were fit to the same covariates, meant to mimic the stratified ratio estimator. Covariates treated as factors are indicated by fac(). The Delta models split the bycatch data into presence/absence (Y) and positive catches (Z), then calculated bycatch as Y × Z. The Nonlinear models incorporate all available covariates using nonlinear terms, e.g. spline terms in GAMs, s(). Covariate effect plots are shown for models fit to Pacific hake. The following R packages were used in analyses: “mgcv” to fit GAMs, “visreg” to visualize GAM covariate effects, “randomForest” to fit RFs, and “forestFloor” to visualize RF covariate effects.

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

d) Fishing to live or living to fish: job satisfaction and identity of west coast fishermen

Investigators: D.S. Holland, K. Norman, J.E. Abbott

Fishing is a dangerous and financially risky way to make a living, but it attracts many participants that prefer it to higher paying and safer jobs. Based on a survey of over 1400 U.S. west coast fishing vessel owners we use factor analysis and structural equation modeling to quantify distinct latent variables representing job satisfaction related to non-monetary versus monetary aspects of fishing and measures of identity and social capital associated with being a fisher. We show that these latent variables have distinct effects on (stated) fishery participation behavior and that higher non-monetary job satisfaction, social capital, and identity, are associated with a willingness to forgo higher income to be a fisher. Understanding how these factors affect and are affected by participation in fisheries could be important to increase benefits from fisheries and to ensure sustainability of management regimes that rely on indirect controls on effort to limit catch.

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

e) Joint and several liability in fishery cooperatives

Investigators: M. Bellanger, D.S. Holland, C.M. Anderson, O. Guyader, C. Macher

Cooperative-based catch share systems can be implemented such that the members of the same fishery cooperative are jointly and severally liable for not exceeding collectively assigned fishing rights. In practice, this means that a regulator can take away catch privileges from an entire cooperative that overruns its collective quota, effectively creating a penalty much larger than what could be recovered with an individual fine. Fishery cooperatives then typically implement their own internal compliance regime that includes monitoring and penalties. This article first reviews compliance practice in cooperative-based catch share systems by examining the commonalities and differences in the way compliance regimes are structured (observation and reporting requirements, penalty scheme, internal enforcement authority and indemnification mechanisms) in a number of internal agreements from fishery cooperatives in North America and in Europe. Based on our review of cooperatives and the literature on compliance, we discuss how incentives to comply may be different for an individual fisherman operating in a fishery cooperative where joint and several liability applies as compared to an individual fishing quota baseline situation without fishery cooperative. Our review suggests that, from the regulators' point of view, joint and several liability can increase the level of compliance for a given enforcement expenditure. However, the regulator cannot rely solely on cooperatives to carry out controls and must ensure that the cooperatives themselves have an interest in setting up an effective monitoring system and will enforce sanctions within the cooperative.

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f) Catch shares drive fleet consolidation and increased targeting but not spatial effort concentration nor changes in location choice in a multispecies trawl fishery

Investigators: P.T. Kuriyama, D.S. Holland, T.A. Branch, L.A.K. Barnett, R.L. Hicks, K.E. Schnier

Catch share systems are generally expected to increase economic rents in fisheries by increasing harvest efficiency, reducing capital costs through consolidation, and increasing the value of landed catch. However, these benefits may have costs, as consolidation and the potential for associated change in spatial distribution in landings can hinder social objectives such as maintaining access for fishery-dependent communities and small owner-operators. Achievement of such fishery management objectives are determined by changes in fisher behavior, which may be complex and difficult to predict. Predicting fisher behavior is particularly challenging in multispecies fisheries, in which the mix of species is a determinant of where and when fishing effort and landings occur. We evaluate changes in overall fishing effort, species targeting, and determinants of fishing location choice in response to catch shares in the U.S. west coast Groundfish Trawl Fishery. We found reductions in total fishing effort, increased targeting of some species, and no evidence of spatial effort concentration. Key determinants of location choice (distance, expected revenue, and recently fished locations) were similar among time periods, but after catch shares there was more avoidance of areas that lacked recent fishing activity or associated information with which to develop expectations of catch and bycatch. Additionally, location choice remained constant with up to 100-fold financial penalties on bycatch species.

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

g) Observer Program Reports

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E. By-catch Reduction Engineering

1. Research

a) Use of artificial illumination to reduce Pacific halibut bycatch before trawl capture in a U.S. West Coast Groundfish Bottom Trawl

Investigator: Mark Lomeli

In the U.S. west coast groundfish bottom trawl fishery, Pacific halibut (*Hippoglossus stenolepis*) bycatch can impact some fishers ability to fully utilize their quota shares of target groundfishes. In this study, we compared the catch efficiency for Pacific halibut and four commercially important groundfish species between an unilluminated trawl and a trawl with illumination along its wing tips and upper bridles. Results show the illuminated trawl caught significantly fewer Pacific halibut than the unilluminated trawl. This result translates to significantly fewer Pacific halibut exposed to capture-escape processes within the trawl which can cause physiological stress, fatigue, injuries and lead to unobserved and unaccounted post-release mortality. For target groundfishes, results show no significant catch efficiency effect of changing from unilluminated to illuminated trawl for lingcod (*Ophiodon elongatus*), Dover sole (*Microstomus pacificus*), and petrale sole (*Eopsetta jordani*). A significant catch efficiency effect was noted for sablefish (*Anoplopoma fimbria*) with the illuminated trawl catching fewer fish on average. Our results contribute new data on how artificial illumination can affect catches of Pacific halibut and four commercially important groundfish species. In addition, physiological parameters of Pacific halibut caught between the illuminated and unilluminated trawl are presented. While our results have obvious implications to the west coast groundfish bottom trawl fishery, our findings could have potential applications in Alaska groundfish bottom trawl fisheries, such as the eastern Bering Sea directed flatfish fishery and Pacific cod (*Gadus macrocephalus*) fishery, where Pacific halibut bycatch also occurs.

Figure 27. Images of six LED clusters placed along the selective flatfish trawl port side upper bridle and wing tip(upper left image); image of selective flatfish trawl without LED along its upper bridles and wing tips (upper right image); image of the selective flatfish trawl being deployed with LEDs along its upper bridles and wing tips (bottom images).

b) Disentangling the web of factors influencing whale bycatch in fixed gear fisheries on the U.S. west coast

Investigators: B. Feist, J. Samhouri, and in collaboration with the SWFSC and WCRO

Protection of endangered and threatened cetaceans has resulted in population recoveries and the delisting of species across the globe. While this increase in population size is desirable from a conservation perspective, it can have unintended consequences for human activities such as shipping and fishing that operate in the same ocean waters. Anomalous ocean conditions can increase the probability of whale entanglement with fishing gear by altering spatio-temporal distributions of both fisheries and cetaceans in such a way that co-occurrence increases. Entangled whale reports on the U.S. west coast increased dramatically from historical norms, ca. 2014, especially among humpback whales. Gear type can only be determined in about half of the reports, which is predominantly fixed-gear (pot- and trap-based), the majority of which originating from the highly profitable Dungeness crab fisheries. In this paper we address the question of whether changes in the spatio-temporal distributions of these fixed-gear fleets occurred coincident with the increase in entanglement sightings, and if these changes placed the fisheries in closer proximity to cetaceans. We also examine two alternate and non-mutually exclusive scenarios, including (i) changes in the spatio-temporal distribution of whales that may have resulted in overlap with fisheries activities, and (ii) increases in human observation of whale activity. We find that fishing vessel activity for the dominant pot-based fishery, Dungeness crab, was somewhat declining from 2009 to mid-2016, rather than increasing, despite increases in whale entanglement reporting that began ca. mid-2014. However, unprecedented fishing activity in the months of May and June in California (but not Washington or Oregon) were evident during the domoic acid closures of the 2015-16 Dungeness crab season, which likely led to cooccurrence of humpbacks with Dungeness fishing activities. This result is consistent with the hypothesis that increased entanglement of humpback whales that began ca. 2014 was likely a result of changes in whale spatial distributions, exacerbated by a delay in fishing effort during the 2015-16 season. Future efforts to incorporate forecasts of cetacean and fishing distributions, and oceanographic conditions, will provide information to anticipate the potential for conflicts rather than after they have already occurred.

For more information please contact Dr. Blake Feist at NOAA's Northwest Fisheries Science Center, Blake.Feist@noaa.gov.

VI. Publications

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