Northwest Fisheries Science Center

National Marine Fisheries Service

NOAA Fisheries

Agency Report to the Technical Subcommittee

of the Canada-U.S. Groundfish Committee

April 2022

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, 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 2021, FRAMD continued to implement a West Coast observer program and expand its stock assessment, economics, and habitat research. Following the interruption of annual surveys in 2020 due to the global COVID19 pandemic the Pacific hake acoustic survey, southern California hook and line survey, and the coast wide groundfish trawl survey took place in 2021.

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

Due to the uncertainties created by the COVID-19 pandemic and the unique challenges those created for NOAA Fisheries, we cancelled the 2020 *West Coast Groundfish Bottom Trawl Survey*. This was a difficult decision for the agency as we strived to meet our core mission responsibilities while balancing the realities and impacts of the 2020 health crisis.

The NWFSC conducted its twenty-third annual bottom trawl resource survey for groundfish off the coasts of Washington, Oregon, and California in 2021. The annual survey was canceled in 2020 due to the COVID-19 global pandemic. The objective of the 2021 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 four commercial fishing vessels to conduct the survey in 2021 using standardized trawl gear. Fishing vessels Last Straw, Ms. Julie, Noah's Ark 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 F/V Last Straw and F/V Ms. Julie surveying the coast during the initial survey period from May to July (Pass 1). Pas 1 was subdivided into 3 legs to decrease the number of port calls and reduce the exposure to COVID-19. The F/V Excalibur and F/V Noah's Ark 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 2021, we continued to utilize an updated back deck 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) Collect whole specimens of Pacific lamprey (*Entosphenus tridentatus*) and take photographs of groundfishes with visible lamprey scars – Laurie Weitkamp, NWFSC, Conservation Division, Newport, OR

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

3) Collection whole specimens of all unusual skates, Pacific white skate *(Bathyraja spinossisima)*, fine-spined skate (*Bathyraja microtrachys)* and broad skate (*Amblyraja badia*) – Moss Landing Marine Laboratories;

4) Collect all biological data and specimens of deepsea skate (*Bathyraja abyssicola*) and broad skate (*Amblyraja badia*) – Moss Landing Marine Laboratories;

5) Collect and freeze whole specimens of Pacific black dogfish (*Centroscyllium nigrum*) – Moss Landing Marine Laboratories;

6) Collect whole specimens of any uncommon chimaeras such as *Harriotta raleighana*, *Hydrolagus melanophasma* and *Hydrolagus trolli* (pointy-nosed blue chimaera) – Moss Landing Marine Laboratories;

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

8) Collect fin clips and other tissues from all Pacific sleeper sharks (*Somniosus pacificus*) to examine genetics – NOAA, NWFSC – Cindy Tribuzio, Auke Bay Laboratories, AFSC;

9) Collect DNA and 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 – CB Division, Northwest Fisheries Science Center;

10) Collection of voucher specimens for multiple fish species – Northwest Fisheries Science Center and University of Washington;

11) Collect voucher specimens for multiple fish species – Oregon State University;

12) 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, Institute of Marine Sciences and Fisheries Ecology Division, University of California, Santa Cruz and Southwest Fisheries Science Center;

13) 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, Institute of Marine Sciences and Fisheries Ecology Division, University of California, Santa Cruz and Southwest Fisheries Science Center;

14) Collect specimens for multiple fish species for teaching purposes for the West Coast Observer Program;

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

1) Collect up to five stomachs per tow from blackgill rockfish (*Sebastes melanostomus*), canary rockfish (*Sebastes pinniger*), widow rockfish (*Sebastes entomelas*) and yellowtail rockfish (*Sebastes flavidus*)

2) Collect all stomachs per tow from blackspotted/rougheye rockfish (*Sebastes aleutianus / S. melanostictus*), cowcod rockfish (*Sebates levis*) and yelloweye rockfish (*Sebastes ruberrimus*).

3) Collect up to two stomachs per tow and one per size-bin from sablefish (*Anplopoma fimbria*), lingcod (*Ophiodon elongatus*), petrale sole (*Eopsetta jordani*), shortspine thornyhead (*Sebastolobus alascanus*) and longspine thornyhead (*Sebastolobus altivelis*).

4) Collect a tissue sample for stable isotope analysis to examine the feeding ecology of rockfish (darkblotched, canary, blackgill, blackspotted/rougheye, yelloweye, yellowtail rockfishes, widow rockfishes and cowcod) and other species (sablefish, petrale sole, lingcod, longspine thornyhead and shortspine thornyhead);

5) Collect photographs and photographic quality specimens of arbiter snailfish (*Careproctus kamikawai*);

6) Collect photographs and all specimens of sharpnose sculpin (*Clinocottus acuticeps*) for species confirmation;

7) Collect numerous photos and whole specimens of small disk snailfish (*Careproctus gilberti*) and longjaw bigscale (*Scopeloberyx robustus*);

8) Record composition and abundance of benthic marine debris collected during the 2021 West Coast Groundfish Trawl Survey;

9) Continue fin clip collection for DNA analysis of various shelf rockfish species;

10) Collect and/or photograph cold water corals;

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

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

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

14) Collect whole ovary, finclips (and gonads for males) from selected species;

15) Collect specimens for maturity analysis from selected species.

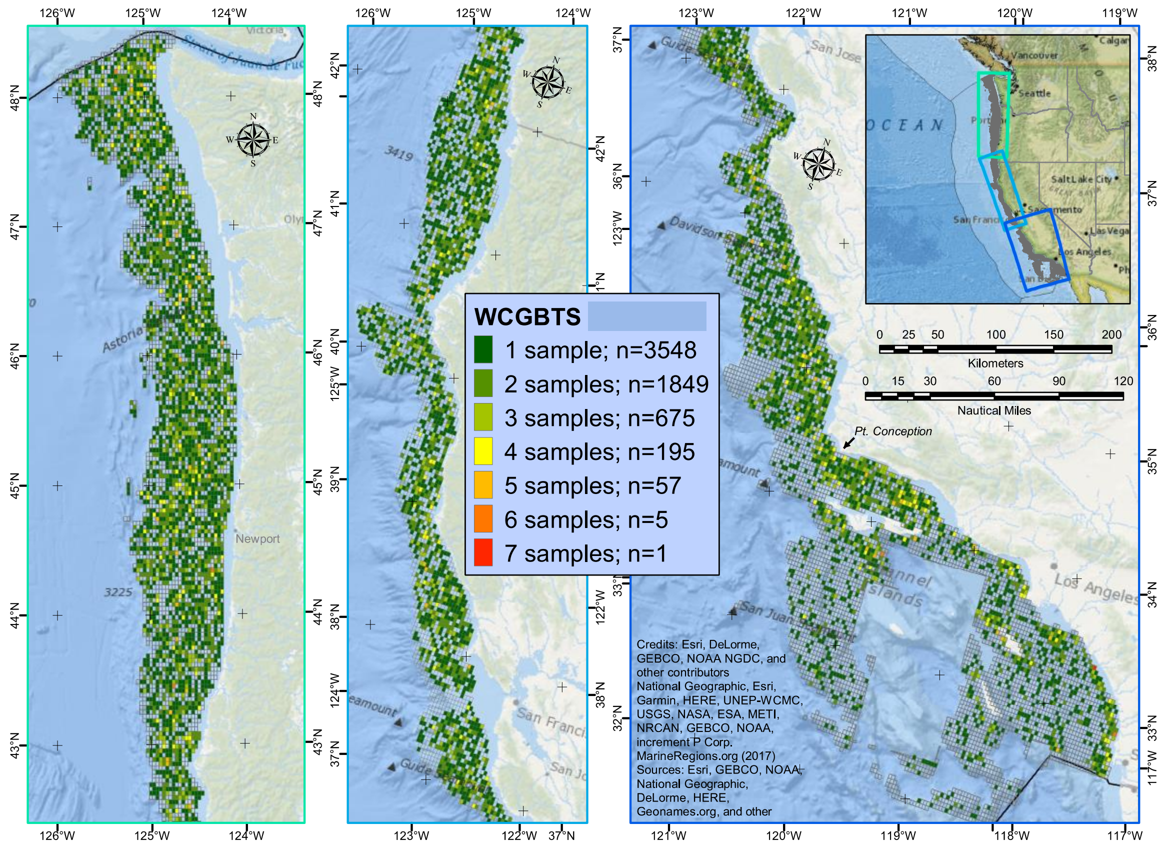

Figure 1. Summary of station locations and frequency for the West Coast Groundfish Bottom Trawl Survey 2003 to 2018.

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

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

Due to the uncertainties created by the COVID-19 pandemic and the unique challenges those created for NOAA Fisheries, we cancelled the Northwest Fisheries Science Centers' 2020 *Southern California Shelf Rockfish Hook and Line (H&L) Survey*.

In Fall 2021, NWFSC/FRAM conducted the 18th hook and line survey for shelf rockfish in the Southern California Bight (SCB). The survey was not conducted in 2020 due to the COVID-19 pandemic. This survey is a cooperative effort with Pacific States Marine Fisheries Commission (PSMFC) and the southern California sportfishing industry and is aimed at developing a time series of abundance and biological data for structure-associated groundfish species 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 17 biologists participating during the course of the survey. During the 2021 survey, the three vessels sampled 198 of the survey's 201 fixed sites which range from Point Arguello in the north to the US-Mexico EEZ boundary in the south and in a depth range of 20 – 125 fth (37 – 229 m) (Figure 2). Sites are located inside and outside the two Cowcod Conservation Areas – two large spatial closures implemented in 2000 to help recover overfished rockfish species including cowcod (*S. levis*). Some experimental re-sampling was conducted at 5 sites.

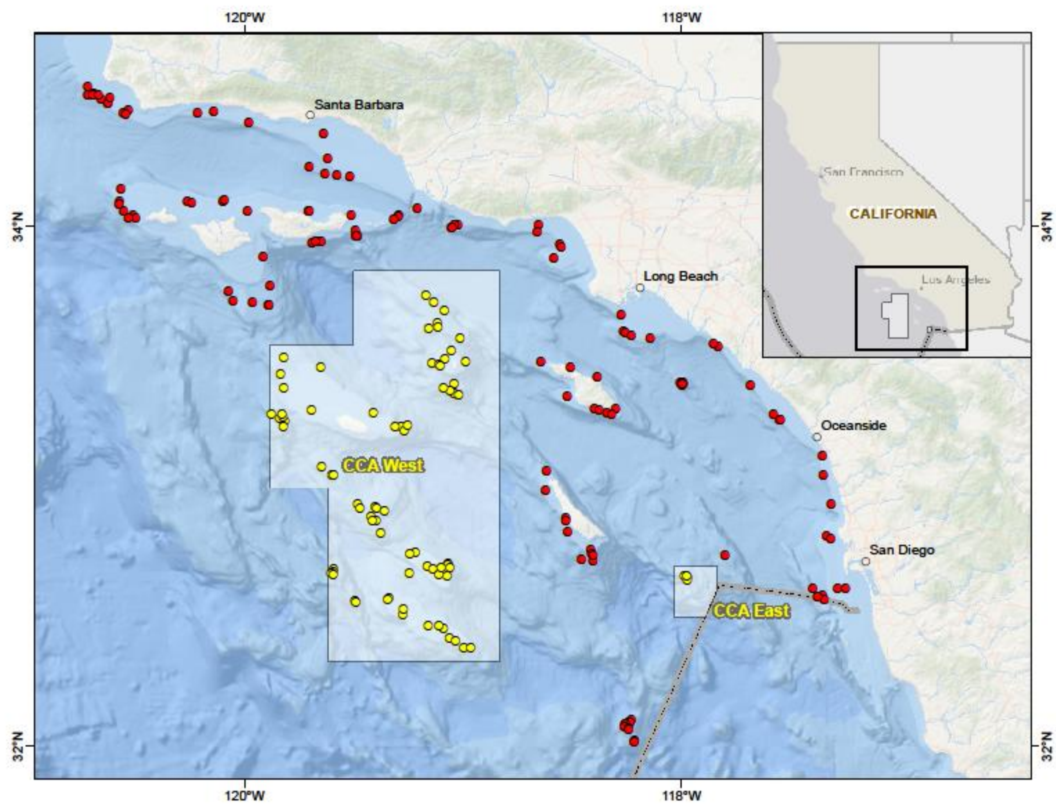

Figure 2. Sampling frame for the NWFSC Shelf Rockfish Hook and Line Survey

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

C) 2021 Joint U.S./Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey

Scientists from the Fishery Resource Analysis and Monitoring (FRAM) Division at the NWFSC and the Institute of Ocean Sciences at DFO led the 2021 joint U.S./Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey (IAT). The survey was conducted aboard the NOAA Ship *Bell M. Shimada*—a 209-foot acoustically quieted Fisheries Survey Vessel—and the *Nordic Pearl*, a chartered 115-foot Canadian fishing vessel. Both vessels are stern trawlers equipped for fisheries research, while the *Shimada* is also equipped for oceanographic research. The survey began at Point Conception, California (the current southern extent of the survey area) and proceeded north along the west coast of the U.S. and Canada, surveying Queen Charlotte Sound, Hecate Strait, Dixon Entrance (the northern extent of the survey area), and the west side of Haida Gwaii, which was surveyed from north to south (Figure 3). The *Shimada* surveyed between 1 July and 21 September and the *Nordic Pearl* surveyed between 21 August and 11 September. Acoustic transects were oriented east-west (except for transects in Dixon Entrance, which had a north-south orientation), extended from the 50-m isobath (or as close to shore as was safely navigable) to the 1,500-m isobath, and were spaced 10 nmi apart through Transect 100 (just north of Vancouver Island), after which spacing increased to 20 nmi. Transects were traversed sequentially, usually in alternating directions. If hake were observed on the first transect, the survey area was extended to the south; similarly, if hake were observed on the most northerly transect, the survey area was extended further north. If hake were detected at the offshore end of a transect, the vessel proceeded west to the end of the hake sign and then beyond for an additional 0.5 nmi to ensure that the end of the aggregation was located. This protocol was in place to ensure not only that the full extent of the hake coastal population was accounted for in the survey area, but also that the interpolation algorithm used for calculating hake biomass performed correctly at the offshore ends of transects.

Five Simrad split-beam transducers, operating at 18, 38, 70, 120, and 200 kHz, were mounted on the bottom of the *Shimada*'s retractable centerboard. To reduce interference from bubbles, the centerboard was extended to its maximum depth during the survey, thereby positioning the transducers at a depth of 9.15 m below the water surface. Acoustic data from all five transducers were collected with a Simrad EK80 wideband transceiver (WBT) scientific echosounder system that operated with an EK80 software system (version 2.0.0) in either a CW (continuous wave or narrowband) or FM (broadband or wideband) pulse transmission mode. The *Nordic Pearl* also collected acoustic data with a Simrad EK80 system (version 2.0.1); two Simrad split-beam transducers, operating at 38 and 120 kHz, were mounted on a transducer pod located roughly 1.5 m starboard of the keel. The *Shimada* was equipped with a Teledyne RD Instruments Ocean Surveyor 75-kHz Acoustic Doppler Current Profiler (ADCP) system and a Simrad ME70 scientific multibeam echosounder system, but the ME70 system was not used because of interference with the other acoustic systems. A Simrad K-Sync unit was used to synchronize pulse sequences from the EK80 and ADCP acoustic instruments.

Adult hake were observed on 61 transects, ranging from Transect 14, off Monterey, California (which was the northernmost start of observed adult hake sign since 2011), to the eastern side of Transect 104, off Price Island, British Columbia (Figure 3). The 2021 biomass estimate of adult hake off the west coast of the U.S. and Canada totaled 1.525 million metric tons, with approximately 95.7% (1.459 Mt) of observed biomass located in U.S. waters. Although the 2021 estimate was slightly smaller than the 2019 biomass estimate (a decrease of 0.198 Mt or approximately 11.5%), it was close (4.9% larger) to the average biomass estimate for all surveys conducted since 1995 (1.525 vs. 1.453 Mt). Age-5 and age-7 hake contributed most to the 2021 adult biomass estimate—combining for just under 50%—followed by age-4 (14.6%) and age-11 (10.9%) hake.

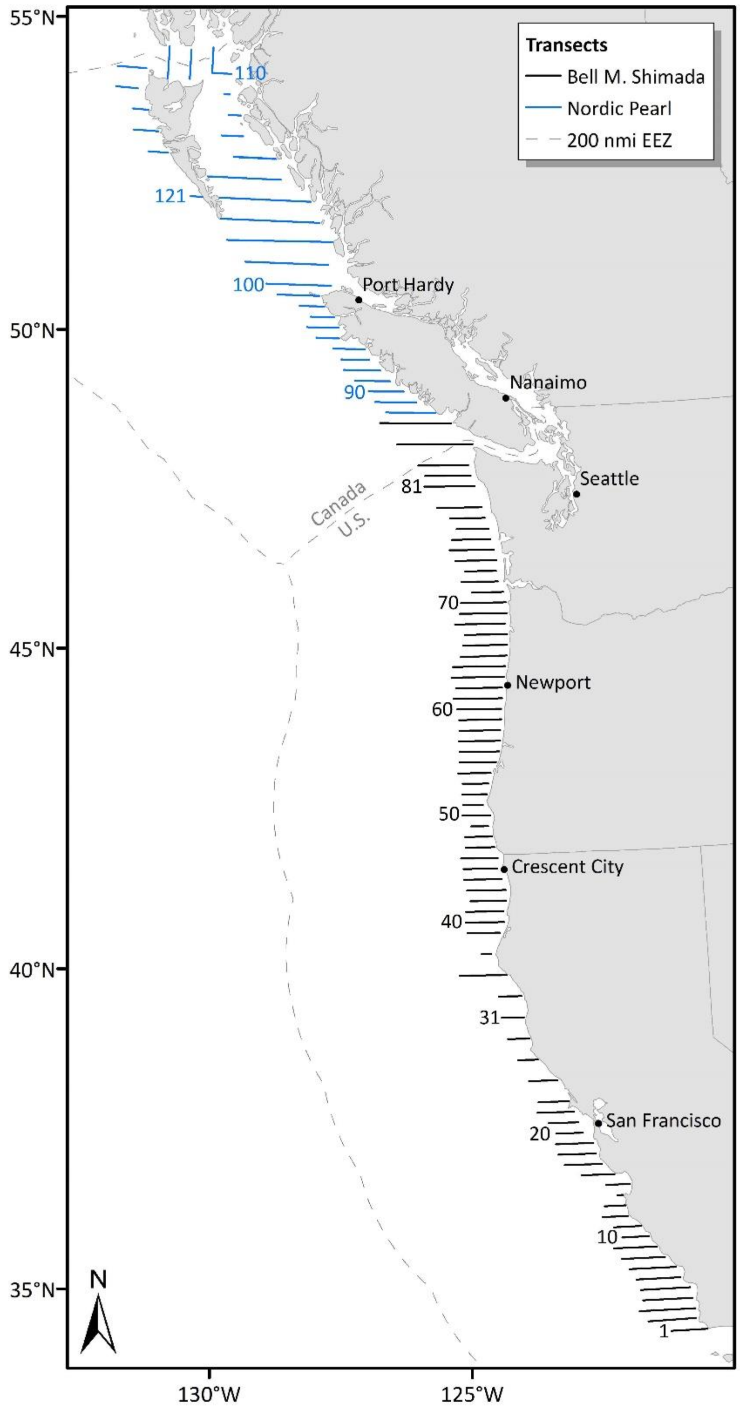

Figure 3. Survey track design used during the 2021 Joint U.S./Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey.

For more information, please contact Julia Clemons at julia.clemons@noaa.gov

III. Reserves

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

A. Hagfish

B. Dogfish and other sharks

1. Research

a) Elasmobranch bycatch in US West Coast groundfish fisheries

Investigators: Jannot J.E., Bjorkland R., Somers K.A., Mitchell T., Tuttle V.J., McVeigh J.

ABSTRACT: Effective management of multispecies fisheries in large marine ecosystems is challenging. To deal with these challenges, fisheries managers are moving toward ecosystem-based fishery management (EBFM). Despite this shift, many species remain outside protective legislation or fishery management plans. How do species that fall outside of formal management structures respond to changes in fisheries management strategies? In 2011, the US West Coast Groundfish Fishery (WCGF) shifted management to an Individual Fishing Quota (IFQ) program. We used data collected by fisheries observers to examine the impact of this shift on elasmobranch catch (sharks, skates, rays). Historically, not all elasmobranchs were included in the WCGF Management Plan, making them vulnerable to fishing mortality. We grouped elasmobranchs into 8 groups based on 14 ecomorphotypes to examine relative catch within groundfish fishing sectors during the period 2002-2014. Of the 22 sharks and 18 skates and rays that these fisheries capture, 9 are listed as Near Threatened or greater on the IUCN Red List and 10 species are listed as Data Deficient by IUCN. The bycatch of 4 non-managed elasmobranch species was reduced under the IFQ program; IFQ management had no significant impact on the remaining 27 species caught by the IFQ fleet. Overall, catch of non-managed elasmobranchs was relatively low. We show that groups of ecomorphotypes co-occur within fisheries, suggesting natural management units for use in EBFM. This work helps identify gaps in monitoring and assessing the impact of management and policy on elasmobranch populations.

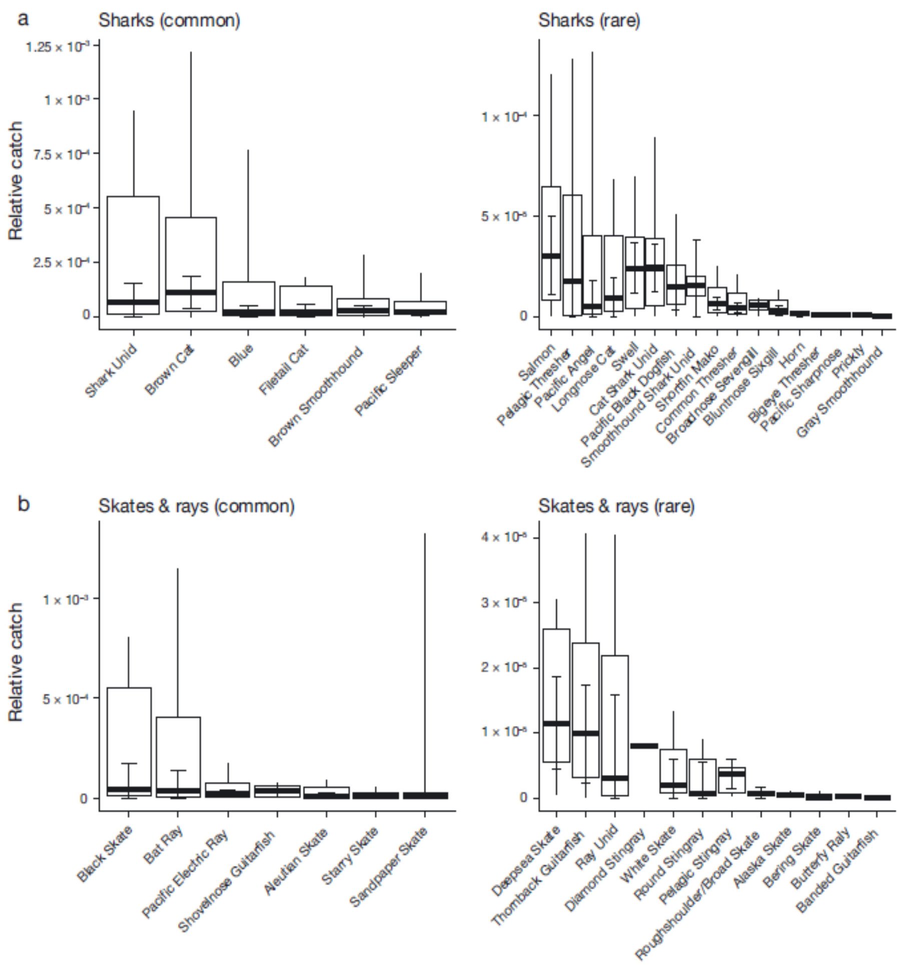

Figure 4. Relative catch (bar: median; box: ±25%; top whisker: 90%; error bar: 95% CI of median) of (a) sharks and (b) skates, rays, and guitarfish in US West Coast groundfish fisheries. Relative catch was calculated as the total catch of the elasmobranchs divided by the total landed catch. For clarity, elasmobranchs are divided into sharks and skates, and within each group, commonly caught species are plotted separately from rarely caught species. Unidentified skates are not shown.

Jannot J.E., Bjorkland R., Somers K.A., Mitchell T., Tuttle V.J., McVeigh J. 2021. Elasmobranch bycatch in US West Coast groundfish fisheries. Endang Species Res 45:109-126.

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

2. Assessment

a) Status of the Pacific Spiny Dogfish shark resource off the continental U.S. Pacific Coast in 2021.

Investigators: Gertseva, V. Taylor, I.G., Wallace, J.R., Matson, S.E.

Pacific spiny dogfish (*Squalus suckleyi*) in the Northeast Pacific Ocean occur from the Gulf of Alaska, with isolated individuals found in the Bering Sea, southward to San Martin Island, in southern Baja California. They are extremely abundant in waters off British Columbia and

Washington, but decline in abundance southward along the Oregon and California coasts. This assessment focuses on a portion of a population that occurs in coastal waters of the western United States, off Washington, Oregon and California, the area bounded by the U.S.-Canada border on the north and U.S.-Mexico border on the south. The assessment area does not include Puget Sound or any other inland waters.

In the coastal waters of the U.S. west coast, spiny dogfish has been utilized since early 20th century, and are caught by both trawl and non-trawl gears. The history of dogfish utilization included a brief but intense fishery in the 1940s, which started soon after it was discovered that livers of spiny dogfish contain high level of vitamin A. During the vitamin A fishery, removals averaged around 6,821mt per year reaching their peak of 16,876 mt in 1944. The fishery ended in 1950 with the advent of synthetic vitamins. In the mid-1970s, a food fish market developed for dogfish when the species was harvested and exported to other counties, primarily Great Britain. For the last 10 years landings ranged between 482 and 1,908 mt. The landings of spiny dogfish were reconstructed back to 1916 from variety of published sources and databases. Even though spiny dogfish was heavily harvested in the 1940s, this species is not highly prized and is mostly taken as bycatch in other commercially important fisheries.

This assessment, conducted in 2021, estimates that the stock of spiny dogfish off the continental U.S. Pacific Coast is currently at 42 percent of its unexploited level. This is above the overfished threshold of $SB_{25\%}$ and the management target of $SB_{40\%}$ of unfished spawning biomass. The assessment described that the spawning output of spiny dogfish showed a relatively sharp decline in the 1940s, during the time of the intense dogfish fishery for vitamin A. During a 10-year period (between 1940 and 1950), the spawning output dropped from 99% to under 75% of its unfished level. Between 1950 and 1974 the catches of spiny dogfish were minimal, but given the low productivity of the stock, the spawning output continued to slowly decline. Since late 1970s decrease became a bit more pronounced due to fishery removals (an export food fish fishery developed in the mid-1970s) and low productivity of the stock, but in the last decade catches decreased and the stock trajectory flattened.

The time series of total mortality catch (landings plus discards) and estimated depletion for spiny dogfish are presented in Figure 5.

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 fixed at the value of 0.43, which reasonably represent latitudinal, depth and vertical availably of spiny dogfish 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.

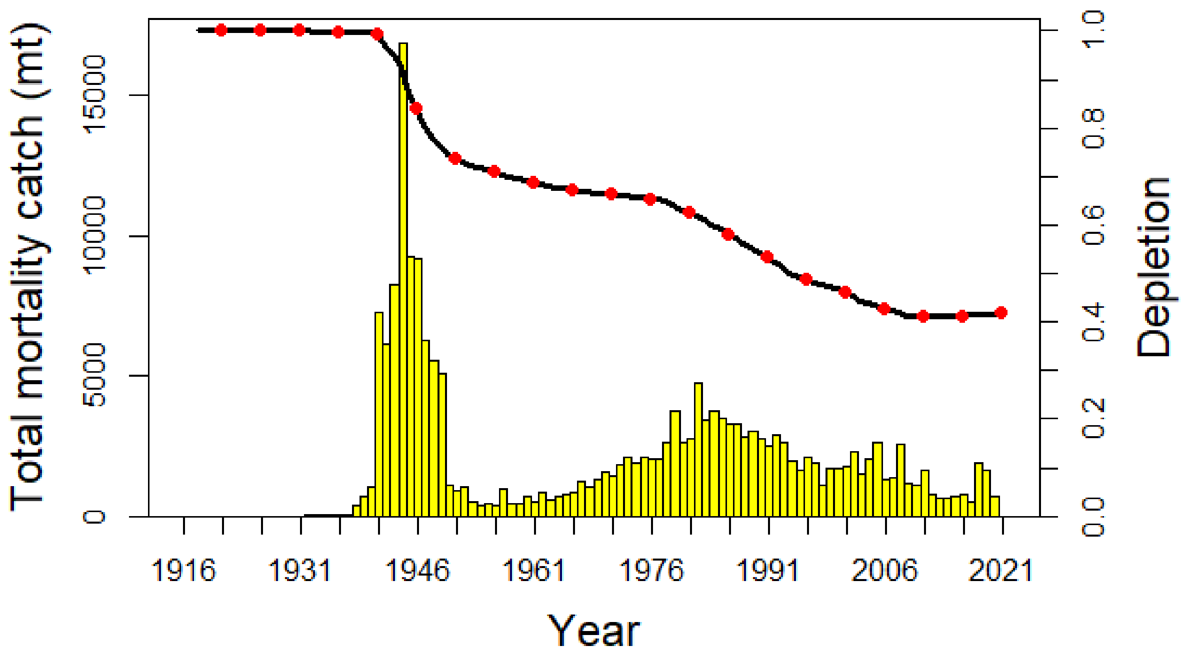

Figure 5. The time series of total mortality catch (bars) and estimated depletion (line) for Pacific spiny dogfish shark.

Gertseva, V. Taylor, I.G., Wallace, J.R., Matson, S.E. 2021. Status of the Pacific Spiny Dogfish shark resource off the continental U.S. Pacific Coast in 2021. Pacific Fishery Management Council, Portland, OR. Available from http://www.pcouncil.org/groundfish/stock-assessments

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

C. Skates

D. Pacific cod

E. Walleye Pollock

F. Pacific whiting (hake)

1. Research

a) eDNA research during Joint U.S./Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey

In support of environmental DNA (eDNA) work, Niskin bottle water collections were taken at conductivity-temperature-depth (CTD) stations during the 2021 Joint U.S./Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey and the water extracted from the Niskin bottles was filtered. During Leg 1 of the survey on the *Shimada*, an eDNA autonomous sampler, "SADIE", developed in conjunction with the University of Washington Applied Physics Lab (APL), was attached to the CTD rosette and tested.

For more information, please contact Julia Clemons (julia.clemons@noaa.gov)

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

In 2021, to investigate local movement of hake and the presence/absence of offshore hake, two Saildrones surveyed in tandem with the 2021 Joint U.S./Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey along parallel, extended transects by Cape Mendocino, California. Saildrone 1063 completed 22 lengths of Transect 37 (40.445°N) between 28 August and 2 October (~35 survey days). Saildrone 1064 completed 27 lengths of Transect 38 (40.6117°N) between 27 August and 2 October (~36 days). Length of both transects was 67.5 nmi.

For more information, please contact Julia Clemons at julia.clemons@noaa.gov

Figure 6. Saildrone operating at sea off San Francisco, CA

For more information, please contact Julia Clemons at julia.clemons@noaa.gov

c) Environmentally driven seasonal forecasts of Pacific hake distribution

Investigators: Michael J. Malick1, Samantha A. Siedlecki, Emily L. Norton, Isaac C. Kaplan, Melissa A. Haltuch, Mary E. Hunsicker, Sandra L. Parker-Stetter, Kristin N. Marshall5, Aaron M. Berger, Albert J. Hermann, Nicholas A. Bond and Stéphane Gauthier

Changing ecosystem conditions present a challenge for the monitoring and management of living marine resources, where decisions often require lead-times of weeks to months. Consistent improvement in the skill of regional ocean models to predict physical ocean states at seasonal time scales provides opportunities to forecast biological responses to changing ecosystem conditions that impact fishery management practices. In this study, we used 8-month lead-time predictions of temperature at 250 m depth from the J-SCOPE regional ocean model, along with stationary habitat conditions (e.g., distance to shelf break), to forecast Pacific hake (*Merluccius productus*) distribution in the northern California Current Ecosystem (CCE). Using retrospective skill assessments, we found strong agreement between hake distribution forecasts and historical observations. The top performing models [based on out-of-sample skill assessments using the area-under-the-curve (AUC) skill metric] were a generalized additive model (GAM) that included shelf-break distance (i.e., distance to the 200 m isobath) (AUC = 0.813) and a boosted regression tree (BRT) that included temperature at 250 m depth and shelf-break distance (AUC = 0.830). An ensemble forecast of the top performing GAM and BRT models only improved out-of-sample forecast skill slightly(AUC = 0.838) due to strongly correlated forecast errors between models (r = 0.88). Collectively, our results demonstrate that seasonal lead-time ocean predictions have predictive skill for important ecological processes in the northern CCE and can be used to provide early detection of impending distribution shifts of ecologically and economically important marine species.

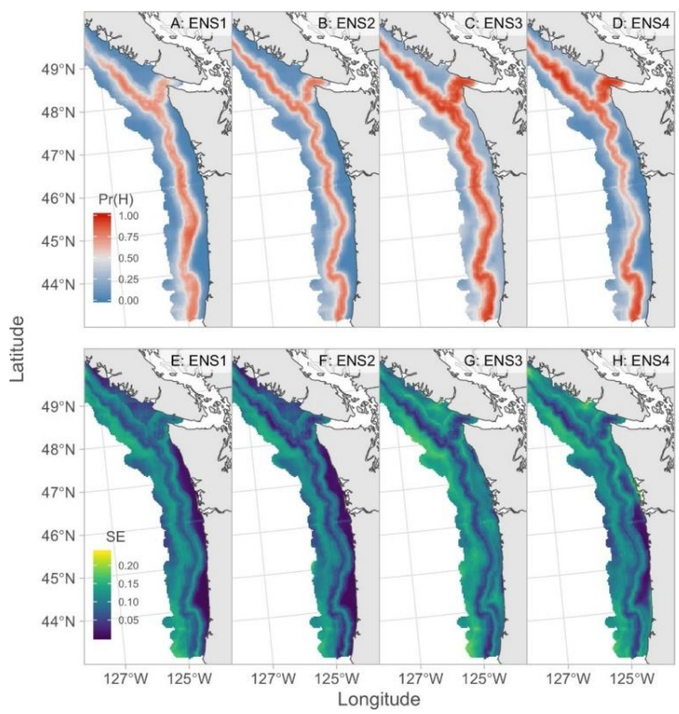

Figure 7. | August 2019 forecasts of hake occurrence from ensemble forecast models. Top row (A–D) shows the probability of hake occurrence where red indicates probabilities greater than 0.5 and blue indicates probabilities less than 0.5. Bottom row (E–H) shows the associated standard errors for each model where brighter colors indicate higher forecast uncertainty.

For more information, please contact Michael Malick michael.malick@noaa.gov)

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

Investigators: Michael J. Malick, Mary Hunsicker, Melissa Haltuch, 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. 2021 and 2022 forecasts are available via NANOOS: http://www.nanoos.org/products/j-scope/forecasts.php

For more information, please contact Mike Malick (Michael.Malick@noaa.gov), Melissa Haltuch (Melissa.Haltuch@noaa.gov), or Mary Hunsicker (Mary.Hunsicker@noaa.gov).

e) Relationships between temperature and Pacific hake distribution vary across latitude and life-history stage

Investigators: Malick M.J., Hunsicker M.E., Haltuch M.A., Parker-Stetter S., Berger A., Marshall K.N.

Environmental conditions can have spatially complex effects on the dynamics of marine fish stocks that change across life-history stages. Yet the potential for non-stationary environmental effects across multiple dimensions, e.g. space and ontogeny, are rarely considered. In this study, we examined the evidence for spatial and ontogenetic non-stationary temperature effects on Pacific hake *Merluccius productus* biomass along the west coast of North America. Specifically, we used Bayesian additive models to estimate the effects of temperature on Pacific hake biomass distribution and whether the effects change across space or life-history stage. We found latitudinal differences in the effects of temperature on mature Pacific hake distribution (i.e. age 3 and older); warmer than average subsurface temperatures were associated with higher biomass north of Vancouver Island, but lower biomass offshore of Washington and southern Vancouver Island. In contrast, immature Pacific hake distribution (i.e. age 2) was better explained by a nonlinear temperature effect; cooler than average temperatures were associated with higher biomass coastwide. Together, our results suggest that Pacific hake distribution is driven by interactions between age composition and environmental conditions and highlight the importance of accounting for varying environmental effects across multiple dimensions.

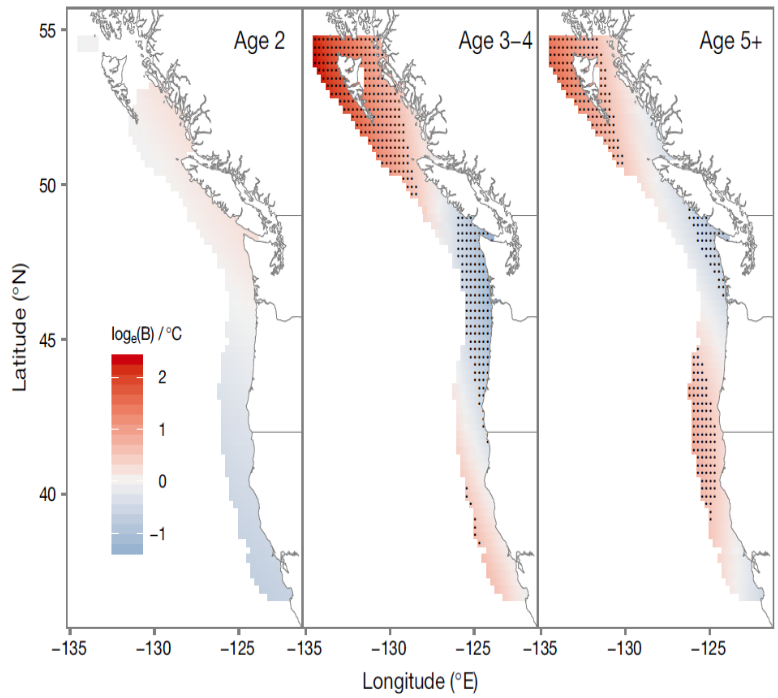

Figure 8. Spatially dependent temperature effect estimated using age-group-specific biomass (B). Shading represents the poste- rior median value for the non-stationary temperature effect on Pacific hake biomass given a 1 unit increase in temperature at a location. Red (blue) shading indicates the linear temperature effect was positive (negative). Black dots indicate locations where the 95% credibility interval for the temperature effect did not include 0. Effects are only shown for locations within 50 km of an age-specific hake biomass observation

Malick M.J., Hunsicker M.E., Haltuch M.A., Parker-Stetter S.L., Berger A.M., Marshall K.N. 2020. Relationships between temperature and Pacific hake distribution vary across latitude and life-history stage. Mar Ecol Prog Ser 639:185-197. https://doi.org/10.3354/meps13286

For more information, please contact Michael Malick michael.malick@noaa.gov)

f) The 2021 Joint U.S.–Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey - NWFSC PROCESSED REPORT, CRUISE NO. SH-21-06

Investigators: Stephen K. de Blois, Ethan M. Beyer,1 Alicia A. Billings, Dezhang Chu, Julia E. Clemons, Stéphane Gauthier, Elizabeth M. Phillips, John E. Pohl, Chelsea P. Stanley, Rebecca E. Thomas

The results presented in the 2021 report are from the 2021 Joint U.S.–Canada Integrated Ecosystem and Pacific Hake Acoustic 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 and secondary survey objectives.

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

g) Can spatio-temporal models provide the composition data necessary to estimate fish biomass-at-age with acoustic data collected from autonomous vehicles?

Investigators: D. Bolser, A.M Berger, D. Chu, J. Hastie, J. Clemons, L. Ciannelli

A key limitation of using autonomous vehicles in fishery resource surveys is their inability to collect biological samples. In particular, the lack of size or age composition data makes precise estimation of biomass-at-age difficult, limiting the use of acoustic data collected by autonomous vehicles in stock assessments. To overcome this barrier, we developed an approach that combines age composition information from existing data sources (e.g., fishing fleets, fishery-independent sampling not paired with acoustics) using geostatistics to create spatially and temporally resolved estimates of age compositions across the population domain that then are assigned to autonomous vehicle acoustic data. We examined the validity of this approach using a case study with Pacific Hake (*Merluccius productu*s; 'hake'). Specifically, we generated compositional data with a vector-autoregressive spatio-temporal (VAST) model, then estimated biomass-at-age by pairing those estimates with acoustic data from a U.S. West Coast-wide autonomous Saildrone survey. The performance of the VAST model was assessed with simulation testing and comparisons between VAST estimates of age composition and those from midwater trawls in the hake acoustic trawl (AT) survey. VAST-Saildrone biomass-at-age estimates were then compared with those derived from the hake AT survey. The challenges we encountered when fitting the VAST model to a relatively rich dataset (e.g., limited age class resolution, model instability) indicated that this approach may not be suitable in all situations, but our model produced estimates of age composition that were comparable to midwater trawls (~ +/-10%). Ultimately, the difference in acoustic backscatter recorded by the AT and Saildrone surveys influenced biomass-at-age estimates more than the source of compositional data. Leveraging existing compositional data and autonomous vehicle technologies can result in synergies that benefit stock assessment and fisheries management. *Ocean Sciences.*

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

h) Climate-mediated stock redistribution causes increased risk and challenges for fisheries management

Investigators: N.S. Jacobsen, K.N. Marshall, A.M. Berger, C. Grandin, and I.G. Taylor

The environmental conditions that marine populations experience are being altered because of climate change. In particular, changes in temperature and increased variability can cause shifts in spatial distribution, leading to changes in local physiological rates and recruitment success. Yet, management of fish stocks rarely accounts for variable spatial dynamics or changes in movement rates when estimating management quantities such as stock abundance or maximum sustainable yield. To address this concern, a management strategy evaluation (MSE) was developed to evaluate the robustness of the international management system for Pacific hake, an economically important migratory stock, by incorporating spatio-temporal population dynamics. Alternative hypotheses about climate-induced changes in age-specific movement rates, in combination with three different harvest control rules (HCR), were evaluated using a set of simulations that coupled single-area estimation models with alternative operating models representing spatial stock complexity. Movement rates intensified by climate change caused a median decline in catches, increased annual catch variability, and lower average spawning biomass. Impacts varied by area and HCR, underscoring the importance of spatial management. Incorporating spatial dynamics and climate change effects into management procedures for fish stocks with spatial complexity is warranted to mitigate risk and uncertainty for exploited marine populations. *ICES Journal of Marine Science*.

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 2022

Investigators: A. Edwards, A. Berger, C. Grandin, K. Johnson

This stock assessment reported the collaborative efforts of the official U.S. and Canadian Joint Technical Committee members in accordance with the Agreement between the government of the U.S. and the government of Canada to assess the status of the coastal Pacific Hake (or Pacific whiting, *Merluccius productus*) resource off the west coast of the U.S. and Canada for 2022. Coast-wide fishery landings of Pacific hake averaged 241 thousand mt from 1966 to 2021, with a low of 90 thousand mt in 1980 and a peak of 441 thousand mt in 2017. Prior to 1966 the total removals were negligible relative to the modern fishery. Recent coast-wide landings from 2017–2021 have been above the long term average, at 394 thousand mt, with U.S. and Canadian catches averaging 309 thousand mt and 85 thousand mt, respectively. In the 2021 catch, the 2016 cohort was the largest (36%), followed by the 2014 cohort (24%), then the 2017 (14%) and 2010 (10%) cohorts. The Agreement between the U.S. and Canada establishes U.S. and Canadian shares of the coast-wide TAC at 73.88% and 26.12%, respectively.

Data were updated for the 2022 assessment with the addition of the 2021acoustic survey biomass estimate and age-composition data, fishery catch and age-composition data from 2021, weight-at-age data for 2021, the addition of an age-1 index time series (1995–2021), and minor changes to pre-2021 data. The assessment used Bayesian methods to incorporate prior information on two key parameters (natural mortality, M, and steepness of the stock-recruitment relationship, h) and integrate 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 recent recruitment, 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 the results of this assessment is largely a function of the potentially above-average 2020 year class, the lack of data informing recruitment in 2021, uncertain selectivity, and uncertainty about historical equilibrium conditions prior to or in the absence of fishing. Short-term forecasts are very uncertain because recruitment is a main source of uncertainty in the projections.

Estimates from the 2022 base model indicate that since the 1960s, Pacific Hake female spawning biomass has ranged from well below to near unfished equilibrium biomass. The stock is estimated to have been below the unfished equilibrium in the 1960s before increasing rapidly to near unfished equilibrium after two or more large recruitments occurred in the early 1980s, followed by steady decline through the 1990s to a low in 1999. This long period of decline was followed by a brief peak in 2002 as the large 1999 year class matured and subsequently supported the fishery for several years. Estimated female spawning biomass declined to a time-series low of 0.625 million mt in 2010 because of low recruitment between 2000 and 2007, along with a declining 1999 year class. Spawning biomass esimates peaked again in 2013 and 2014 due to a very large 2010 year class and an above-average 2008 year class. The subsequent decline from 2014 to 2016 is primarily from the 2010 year class surpassing the age at which gains in weight from growth are greater than the loss in weight from mortality (growth-mortality transition). The 2014 year class is estimated to be large, though not as large as the 1999 and 2010 year classes, increasing the biomass in 2017. The estimated biomass was relatively steady from 2017 to 2019, and then declined in 2020 and 2021 due to the 2014 and 2016 year classes moving through the growth-mortality transition during a period of high catches. The 2022 female spawning biomass is estimated to be 65% of the unfished equilibrium level (B_0) with a 95% posterior credibility interval ranging from 31% to 135%. The median estimated 2022 female spawning biomass is 1.17 million mt. Uncertainty in current stock status is considerable, largely due to the lack of information about recent recruitment.

The fishing intensity on the Pacific Hake stock is estimated to have been below the $F_{40\%}$ target in all years, with the median estimate for 1999 being only slightly below (95% of the target). Fishing intensity has been considerably below the $F_{40\%}$ target since 2012 and has been decreasing over the last 5 years (from 74% in 2017 to 53% in 2021). The official coastwide total catch target adopted by the U.S. and Canada has not been exceeded since 2002. Recent catch and levels of depletion are presented in Figure 9.

Management strategy evaluation tools continue to be developed and tested 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. Alternative spatially explicit representations of Pacific Hake population dynamics (i.e., operating models) have been developed, and continued research will focus on how best to model spatial dynamics and include ecosystem information into operation management procedures.

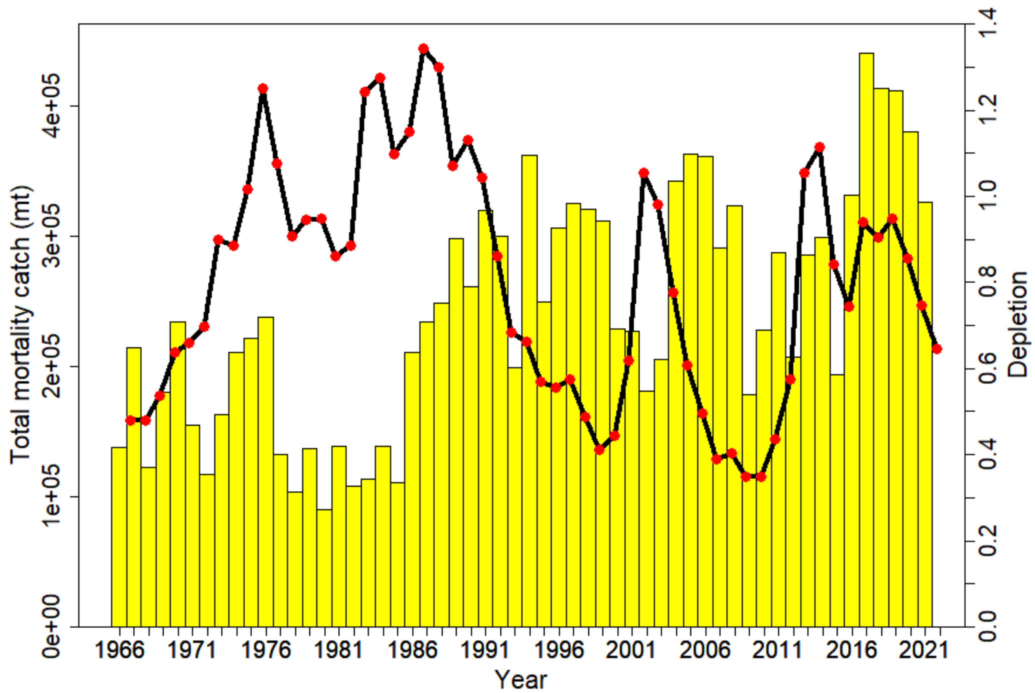

Figure 9. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Pacific hake, 1966-2021.

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

3. Management

a) Management strategy evaluation of Pacific Hake: exploring the robustness of the current harvest policy to spatial stock structure, shifts in fishery selectivity, and climate-driven distribution shifts

Investigators: N.S. Jacobsen, K.N. Marshall, A.M. Berger, C. Grandin, and I.G. Taylor

The Pacific hake (*Merluccius productus*) management strategy evaluation (MSE) entered a new iteration in mid-2017. This report documents the MSE process and provides technical documentation for a new closed-loop simulation model and scenarios developed to explore key uncertainties. The goals of this iteration of the MSE were to: evaluate the performance of current hake harvest policy under alternative hypotheses about current and future environmental conditions; better understand the effects of hake distribution and movement on the ability of both countries (the United States and Canada) to catch fish; and better understand how fishing in each country affects the availability of fish to the other country in future years. We worked with the Joint Management Committee (JMC) and the MSE Working Group (MSEWG) 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. A spatially explicit (two-area) operating model was developed, with age-based movement of fish between areas. Other aspects of the operating model closely resemble the current stock assessment model for Pacific hake. The model was conditioned to the coastwide stock assessment and available country-specific data (i.e., survey biomass, survey age compositions, and fishery age compositions). We evaluated the performance of alternative management procedures (MPs) that explored: 1) the implementation of the default harvest policy defined in the Pacific Hake/Whiting Treaty and 2) the consequences of changing the frequency of conducting the Joint U.S.–Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey. We also developed scenarios to begin to explore how key uncertainties might influence future performance of the current management procedure for hake. These scenarios explored the potential implications of: 1) climate change-driven increases in northward fish movement rates and decreases in southward movement rates; and 2) shifts in selectivity in the United States fishery resulting in changes to the age composition of catch in each country. While each MP and scenario revealed different sensitivities and tradeoffs, the alternative implementations of the harvest policy 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 and MPs. Assessment error was influenced most by the selectivity scenarios and survey frequency MPs. The technical documentation and model output shown here demonstrate the utility of the closed-loop simulation model framework we developed 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 with MPs may be necessary to more fully explore the model dynamics and to address future questions of interest to the Pacific Hake/Whiting Treaty parties. *NOAA Technical Memorandum NMFS-NWFSC-168.*

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

b) Management of Pacific Hake

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) Applying a flexible spline model to estimate functional maturity and spatio-temporal variability in aurora rockfish (*Sebastes aurora*)

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

The authors outlined a new flexible method for estimating maturity that incorporates skip spawning, which can lead to non-asymptotic behavior in the population maturity schedule. This new approach aids fisheries managers who seek to understand marine species' responses to changing oceans. In an effort to assess shifts in maturity and spawning behavior of west coast groundfish, a new method was used to evaluate spatio-temporal trends in length at maturity, the annual reproductive cycle, and spawning behavior of aurora rockfish (*Sebastes aurora*). 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 lengths at 50% maturity (biological and functional) slightly varied between the two methods (23.66–23.93 and 25.34–25.57 cm). They also investigated spatial trends in maturity and found ~ 2 cm difference in functional maturity between fish sampled north and south of Cape Mendocino, CA (26.22–26.48 and 24.38–24.74 cm). The authors demonstrated model sensitivity by updating the maturity estimates in the 2013 aurora rockfish stock assessment. Absolute, but not relative, spawning output, was sensitive to model choice, spatial resolution, and the updated data. This new flexible spline model can account for skip spawning, capturing potential spawners in a given year, and thus provides accurate measurements for spawning output models.

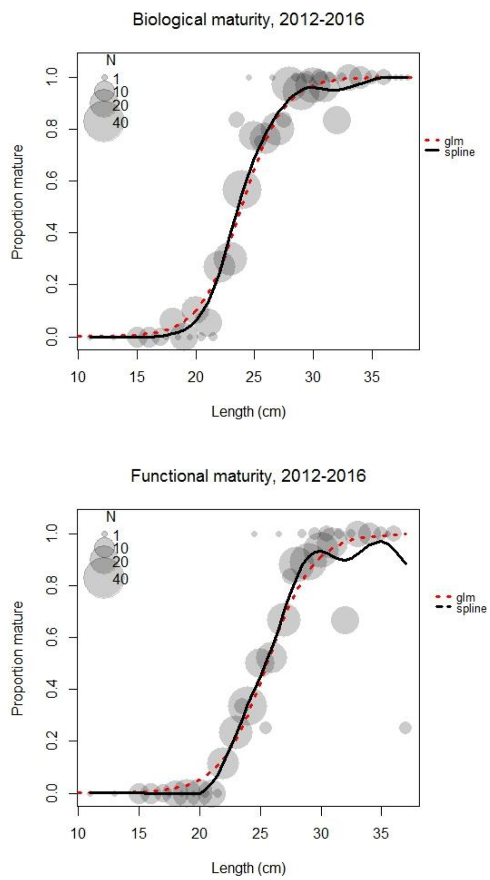

Figure 10. Length (cm) at maturity estimates for Biological maturity coast-wide showing the GLM (red dashed line) and spline (solid black line) fit (upper figure) and Functional maturity coast-wide showing the GLM (red dashed line) and spline (black solid line) (lower figure).

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

b) Genome-wide markers reveal differentiation between and within the cryptic sister species, sunset and vermilion rockfish

Investigators: Longo, G.C., Harms, J., Hyde, J.R., Craig, M.T., Ramon-Laca, A. Nichols, K.

The vermilion rockfish complex, which consists of the cryptic sister species vermilion and sunset rockfish, is one of themost valuable recreational fisheries on the U.S. West Coast. These species are currently managed as a single complex, and because of uncertainty surrounding the relative contribution of each species within existing data sources, the stock status of each species is not fully known. A reliable and cost-effective method is needed to disentangle these species that will allow for the development of abundance indices, life history profiles, and catch histories that may potentially support species-specific stock assessments. Using restriction-site associated DNA sequence (RADseq) markers we generated 10,003 polymorphic loci to characterize the vermilion rockfish complex. PCA and Bayesian clustering approaches based on these loci clearly distinguished between sunset and vermilion rockfishes and identified hybrid individuals. These loci included 203 highly differentiated ($FST \geq 0.99$) single nucleotide polymorphisms, which we consider candidates in the planned development of a diagnostic assay capable of distinguishing between these cryptic species. In addition to clearly delineating to species, subsets of the interspecific markers allowed for insight into intraspecific differentiation in both species. Population genetic analyses for sunset rockfish identified two weakly divergent genetic groups with similar levels of genetic diversity. Vermilion rockfish, however, were characterized by three distinct genetic groups with much stronger signals of differentiation and significantly different genetic diversities. Collectively, these data will contribute to well informed, species-specific management strategies to protect this valuable species complex.

Longo, G.C., Harms, J., Hyde, J.R., Craig, M.T., Ramon-Laca, A. Nichols, K. 2022. Genome-wide markers reveal differentiation between and within the cryptic sister species, sunset and vermilion rockfish. Conserv Genet 23, 75–89.

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

c) Spatiotemporal patterns of variability in the abundance and distribution of winter-spawned pelagic juvenile rockfish in the California Current

Investigators: Field J.C., Miller R.R., Santora J.A., Tolimieri N., Haltuch M.A., Brodeur R.D., Auth T.D., Dick E.J, Monk M.H, Sakuma K.M., Wells, B.K

Rockfish are an important component of West Coast fisheries and California Current food webs, and recruitment (cohort strength) for rockfish populations has long been characterized as highly variable for most studied populations. Research efforts and fisheries surveys have long sought to provide greater insights on both the environmental drivers, and the fisheries and ecosystem consequences, of this variability. Here, variability in the temporal and spatial abundance and distribution patterns of young-of-the-year (YOY) rockfishes are described based on midwater trawl surveys conducted throughout the coastal waters of California Current between 2001 and 2019. Results confirm that the abundance of winter spawning rockfish taxa in particular is highly variable over space and time. Although there is considerable spatial coherence in these relative abundance patterns, there are many years in which abundance patterns are very heterogeneous over the scale of the California Current. Results also confirm that the high abundance levels of YOY rockfish observed during the 2014–2016 large marine heatwave were largely coast wide events. Species association patterns of pelagic YOY for over 20 rockfish taxa in space and time are also described. The overall results will help inform future fisheries-independent surveys, and will improve future indices of recruitment strength used to inform stock assessment models and marine ecosystem status reports.

Field J.C., Miller R.R., Santora J.A., Tolimieri N., Haltuch M.A., Brodeur R.D., Auth T.D., Dick E.J, Monk M.H, Sakuma K.M., Wells, B.K. 2021. Spatiotemporal patterns of variability in the abundance and distribution of winter-spawned pelagic juvenile rockfish in the California Current. PLoS ONE 16(5): e0251638. https://doi.org/ 10.1371/journal.pone.0251638

For more information, please contact Nick Tolimieri at nick.tolimieri@noaa.gov.

d) Diel vertical movement of yelloweye rockfish in Hood Canal, WA
Investigator: Kelly Andrews

Preliminary analyses using data from fifteen Yelloweye Rockfish collected and tagged with acoustic transmitters in Hood Canal, WA showed patterns of diel vertical movement and activity level. Individuals were generally slightly shallower, and more active during the night compared to daylight hours. However, during periods when dissolved oxygen (DO) concentrations were lowest, activity levels at night were reduced compared to periods with higher DO concentrations. If the increased activity level at night is related to increased foraging activity, periods of low DO could significantly reduce foraging and bioenergetic capabilities during these periods.

e) Cross-shelf variability of Deacon Rockfish *Sebastes diaconus* age, growth, and maturity in Oregon waters and their effect on stock status

Investigators: L. Rasmuson, P.S. Rankin, L.A. Kautzi, **A. Berger**, M.T.O. Blume, K.A. Lawrence, and K. Bosley

Understanding the basic biology of exploited fish populations, and how it changes across the waterscape, is essential to sustainable management. Biological features (age, growth, reproductive investment, and fish condition) for the newly described Deacon Rockfish *Sebastes diaconus* were evaluated between two different population segments, an exploited nearshore population and an unexploited offshore population, and were used to parameterize population dynamics models to evaluate how area-specific biological features influence measures of stock status. Monthly hook-and-line sampling was conducted for 1 year, with~50fish collected per area per sampling period. Despite the relatively small (<50 km) distance between the two sampling areas, there were discernible differences in the biology of Deacon Rockfish. When fish of the same size-class were compared between offshore and nearshore segments, the unexploited offshore fish were older, suggesting that fishing may have decreased the overall age structure of the exploited nearshore population segment. Parameters of the von Bertalanffy growth model differed the most between the sexes and secondarily between the nearshore and offshore population segments. Length at 50% maturity was 28cm and age at 50% maturity was 4.1 years for females, which is smaller and younger than previously reported in the literature. Deacon Rockfish were captured in both the nearshore and offshore areas throughout the year, which suggests that at least some component(s) of the population is present in both areas throughout the year. These differences had a nontrivial influence on measures of stock status and will be important to consider during future stock assessments and as management considers the effect of the recent reopening of the offshore population segment to fishing. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*.

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

2. Assessments

a) Stock Assessment of the copper rockfish (*Sebastes caurinus*) along the U.S. West Coast in 2021 using catch, length, and fishery-independent abundance data

Investigators: C.R. Wetzel, B.J. Langseth, J.M. Cope, J.E. Budrick, A.D. Whitman, T.S. Tsou, K.E. Hinton

This assessment reports the status of copper rockfish (*Sebastes caurinus*) off the U.S. West Coast using data through 2020. Copper rockfish is a rockfish that is commonly found of the west coast in nearshore waters with a core distribution off of California. This species was assessed using four separate area-based assessments: south of Point Conception in California, north of Point Conception in California, Oregon, and Washington. This was the second data-moderate assessment of this species and was the first assessment to use length-data.

Relative spawning output declined sharply in both California areas, reaching low biomass levels in the late 1980s. The stock south of Point Conception had an increase in biomass following low biomass levels in the 1980s until recent years (2015) with declines in biomass in recent years. The stock south of Point Conception estimated stock status in 2021 was 18 percent of unfished spawning biomass, below the management threshold (25 percent) due to recent increases in total mortality (Figure 11). The estimated stock status for the portion of the population in California north of Point Conception was estimated to be 39 percent of unfished spawning biomass, just below the management target of 40 percent (Figure 12), with recent above average recruitment driving up the stock at the end of the time series. Overall status determination was summed across both California assessments with a combined stock status of 32 percent.

The overall population size off of Oregon and Washington were relatively low, relative to the California stocks. Both assessment models assumed deterministic stock-recruitment relationship due to limited data. The estimated stock status in Oregon was estimated to be well above the management target at 72 percent of unfished spawning biomass (Figure 13). The estimated stock status off the coast of Washington was near the management target at 42 percent of unfished spawning biomass (Figure 14).

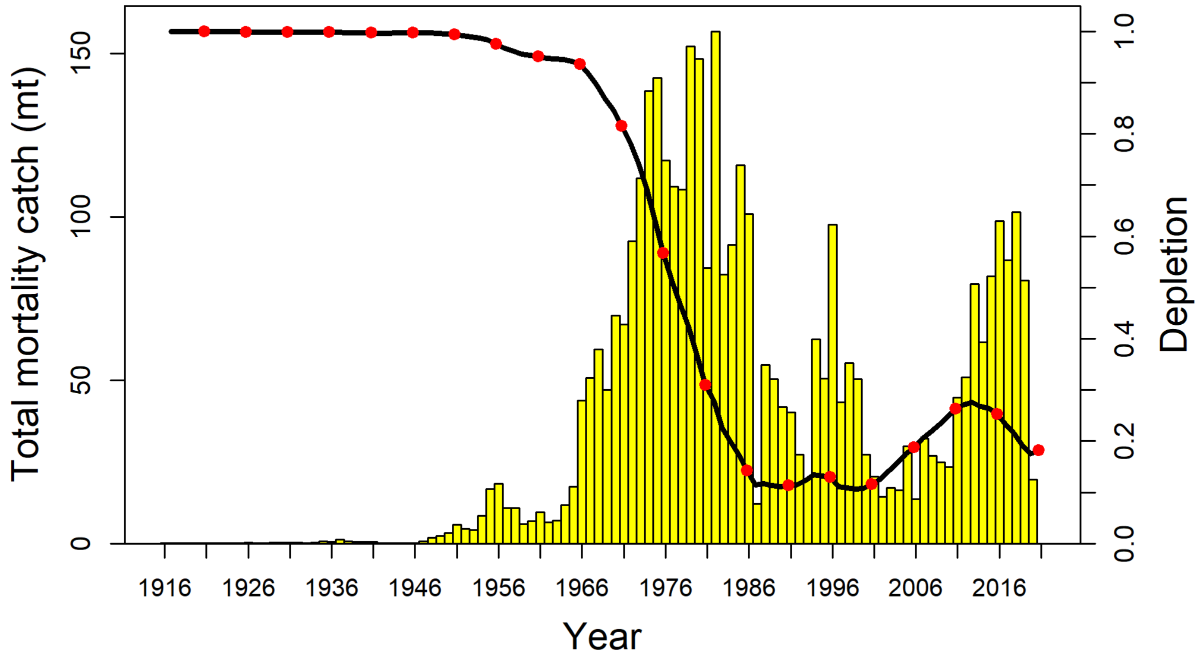

Figure 11. Copper South of Point Conception. Total catch (bars) and depletion (line: relative to average unexploited equilibrium spawning output) of copper rockfish south of Point Conception for years modeled.

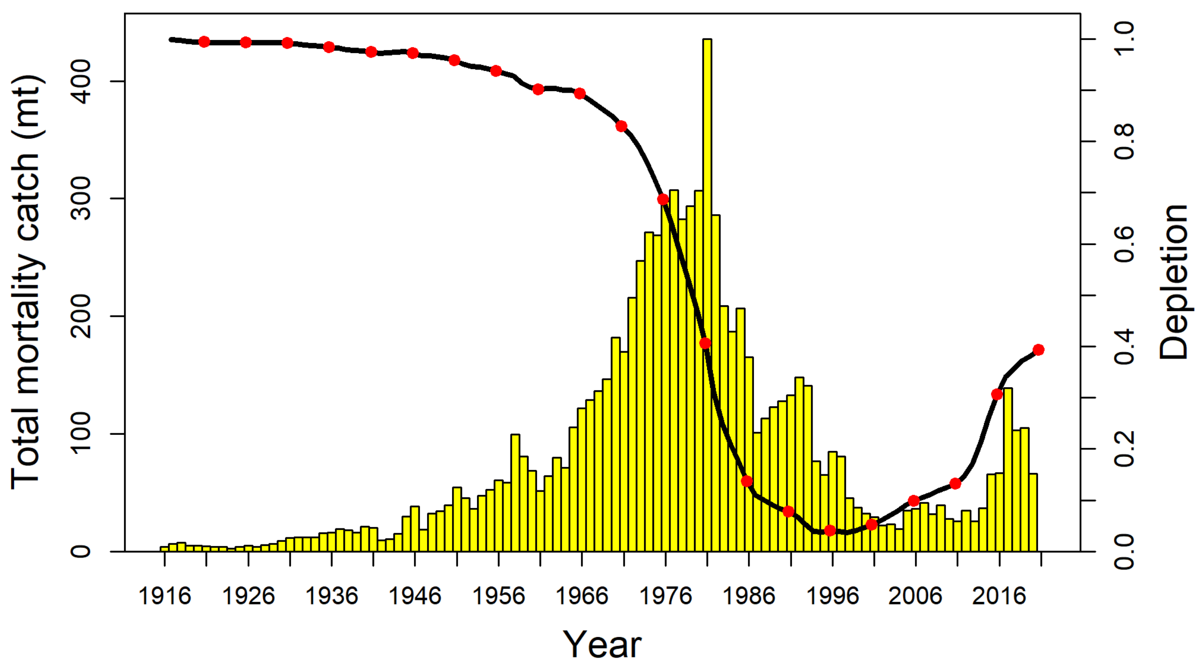

Figure 12. Copper North of Point Conception. Total catch (bars) and depletion (line: relative to average unexploited equilibrium spawning output) of copper rockfish in California north of Point Conception for years modeled.

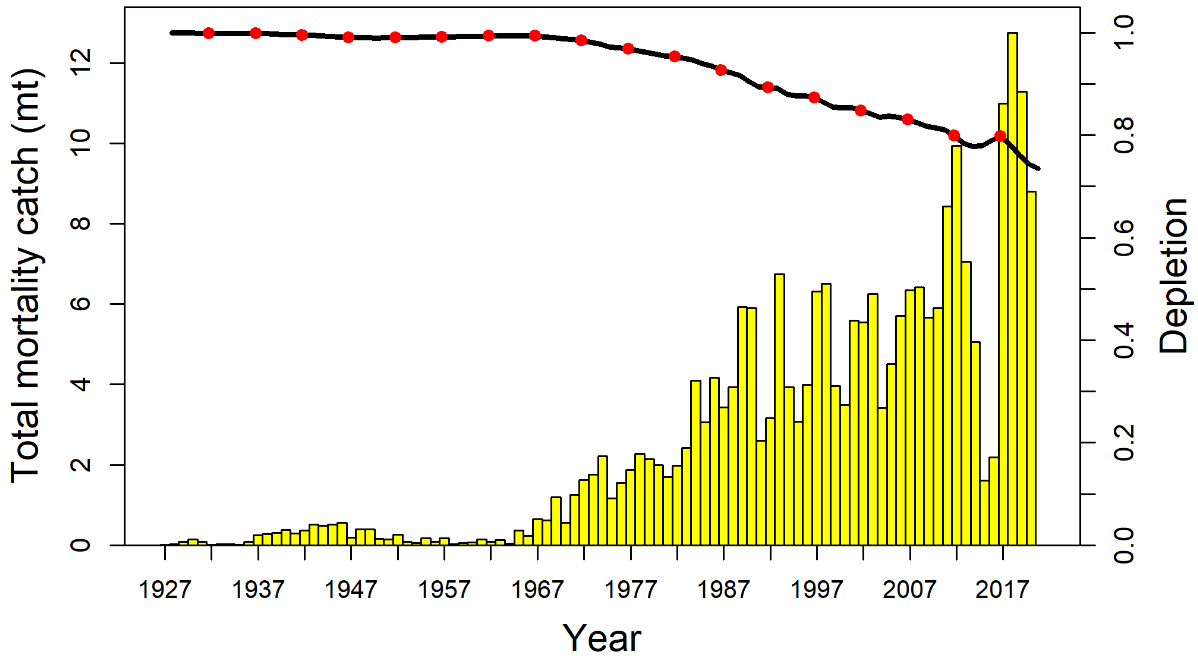

Figure 13. Copper Oregon. Total catch (bars) and depletion (line: relative to average unexploited equilibrium spawning output) of copper rockfish in Oregon waters for years modeled.

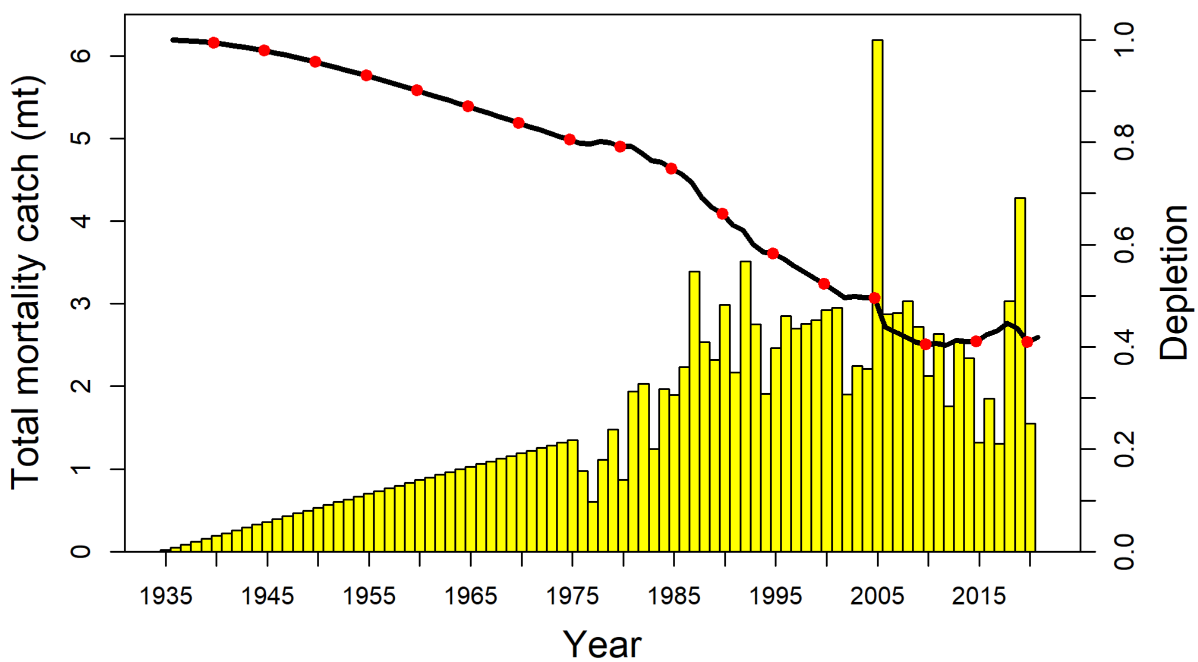

Figure 14. Copper Washington. Total catch (bars) and depletion (line: relative to average unexploited equilibrium spawning output) of copper rockfish in Washington waters for years modeled.

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

b) Stock Assessment of the Squarespot Rockfish (*Sebastes hopkinsi*) along the California U.S. West Coast in 2021 using catch, length, and fishery-independent abundance data

Investigators: J.M. Cope, C.R. Wetzel, B.J. Langseth, and J.E. Budrick

This assessment reports the status of squarespot rockfish (*Sebastes hopkinsi*) off the U.S. West Coast using data through 2020. Squarespot rockfish is a relatively small rockfish found from Mexico to southern Oregon, with a core distribution in southern California. This species is treated as one stock, as there is no evidence of population structure. This is the first full assessment for squarespot rockfish.

Squarespot rockfish are generally undesirable in the recreational and commercial fishery due to their small size (Figure A- bars). Females grow larger than males, and only nearing their maximum length do they reach a size that is marginally acceptable to anglers, thus the landings are primarily composed of older females. The commercial removals for squarespot rockfish are extremely sparse throughout the time series. The small size of squarespot rockfish individuals makes squarespot rockfish an undesirable fish to market and to capture by trawl or commercial hook and line gears. The input catches in the model represent total removals: landings plus discards. Discard totals for the commercial fleet from 2002-2019 were determined based on West Coast Groundfish Observer Program (WCGOP) data provided in the Groundfish Expanded Mortality Multiyear (GEMM) product. The historical commercial discard mortality was calculated based on the average discard rates from WCGOP of 28 percent and used to adjust the landings data from 1916 to 2001 to account for total removals. Given the extremely small commercial landings and minimal sampling of lengths (see below), the recreational and commercial catches were combined into a single fleet by aggregating across gear types.

Relative spawning output declined below the management target in the early 1980s and again fell below the target starting in 2019 (Figure 15). The relative stock status at the start of 2021 is estimated to be below the rockfish relative biomass target of 40 percent (37%) but above the management threshold of 25 percent. The very low catches in 2020 (likely attributable to the COVID-19 pandemic) allowed the population to rebound under the assumption of deterministic recruitment,

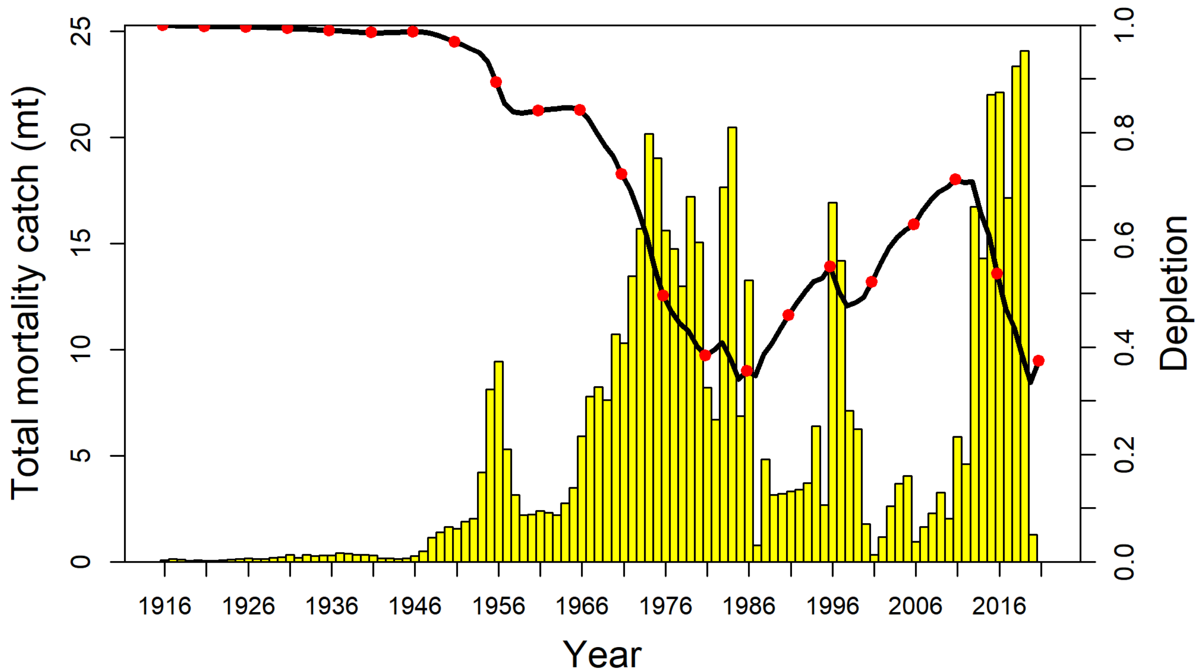

Figure 15. Total catch (bars) and depletion (line: relative to average unexploited equilibrium spawning output) of Squarespot Rockfish for years.

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

c) Status of Vermilion rockfish (*Sebastes miniatus*) along the US West - Oregon coast in 2021

Investigators: J.M. Cope and A.D. Whitman

This assessment reports the status of vermilion rockfish (*Sebastes miniatus*) off Oregon state using data through 2020. Vermilion rockfish are also found in California (their core range) and Washington waters of the U.S. West Coast, and those are treated in separate stock assessments given different management considerations and exploitation histories. There is substantial biogeographic separation in the populations off Oregon and Washington, thus justifying separation of those populations into different management units and stock assessments.

Vermilion rockfish have been caught mainly by hook and line gear in commercial and recreational fisheries (Figure 16). Commercial catches ramped up in the late 1960s followed by decreasing catches since the mid-1980s. Recreational catches started to increase in the 1980s, fluctuating over time, with high catches over the last several years.

Relative spawning output declined with the onset of increasing commercial removals in the 1960s and continued to decline with the increase in recreational catches through the 1990s, even dropping below the target relative stock size.

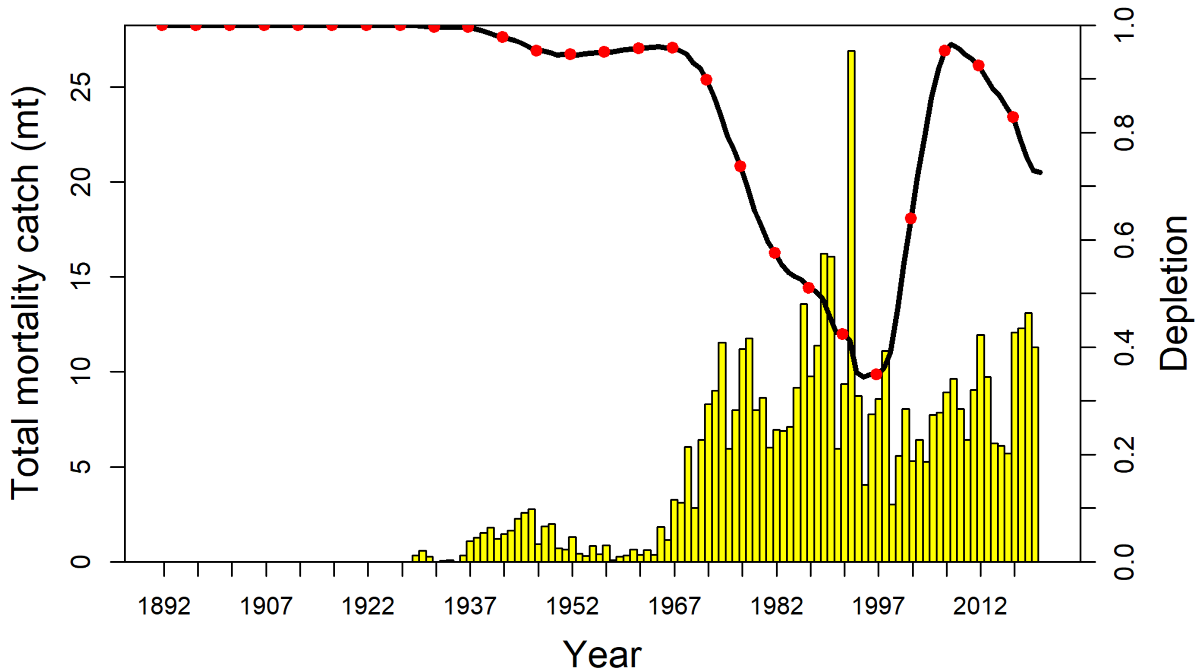

Figure 16. Total catch (bars) and depletion (line: relative to average unexploited equilibrium spawning output) of Vermilion Rockfish in Oregon.

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

d) Status of Vermilion rockfish (*Sebastes miniatus*) along the US West - Washington State coast in 2021

Investigators: J.M. Cope, T-S. Tsou, K. Hinton, and C. Niles

This assessment reports the status of vermilion rockfish (*Sebastes miniatus*) off Washington state using data through 2020. Vermilion rockfish are also found in California and Oregon waters, but those are treated separately in other stock assessments. The core range of vermilion rockfish are in California, thus outside Washington waters; this assessment thus considers a very small population at the limit of the species range under different management considerations and exploitation histories than vermilion rockfish stocks in either California or Oregon. There is substantial biogeographic separation in the populations off Oregon and Washington, thus justifying separation of those populations into different management units and stock assessments. Vermilion in Canadian waters are also rare and not included in this assessment.

Vermilion rockfish are mainly caught in recreational fisheries by hook and line gear. Recreational catches are generally low, but in relative terms increased in mid-1980s and have fluctuated since to a peak catch in 2019. Vermilion rockfish are not targets in the Washington recreational fishery and are considered rare.

The relative spawning output at the beginning of 2021 56 percent of unfished (Figure 17). Overall, spawning output declined with the onset of increasing recreational removals in the mid-1980s and continued to decline with the increase in recreational catches through the 1990s.

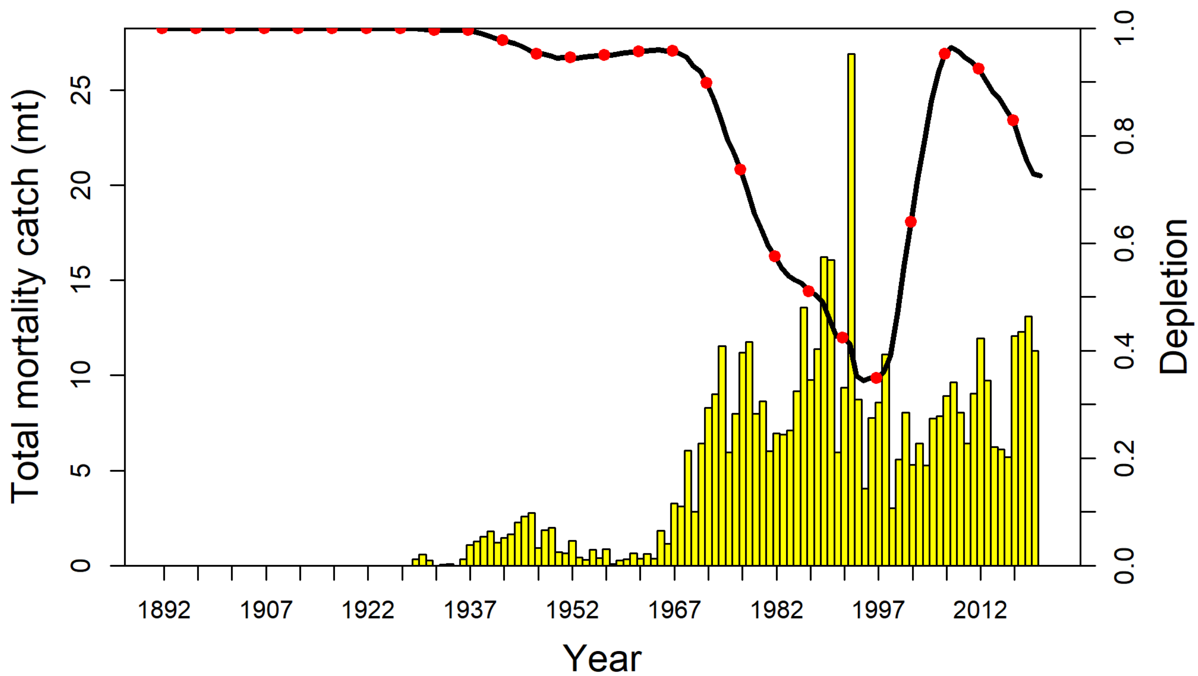

Figure 17. Total catch (bars) and depletion (line: relative to average unexploited equilibrium spawning output) of Vermilion Rockfish in Washington State.

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

e) Status of quillback rockfish (*Sebastes maliger*) in U.S. waters off the coast of Washington in 2021 using catch and length data

Investigators: B.J. Langseth, C.R. Wetzel, J.M. Cope, T.S. Tsou, and L.K. Hillier

This assessment reports the status of quillback rockfish (*Sebastes maliger*) off the Washington coast using data through 2020. Quillback rockfish are a medium- to large-sized nearshore rockfish found from southern California to the Gulf of Alaska. The stock off the Washington coast was assessed as a separate stock from other populations off the U.S. West Coast because of the fairly sedentary nature of quillback rockfish, and different exploitation history and magnitude of removals off the Washington coast. Populations off Oregon and California are assessed in separate stock assessments. This is the first stock assessment of quillback rockfish using catch and length composition data. Quillback rockfish was last assessed in 2010, coastwide, using Depletion-Based Stock Reduction Analysis.

Quillback rockfish have historically been part of both commercial and recreational fisheries throughout their range. Off the Washington coast, quillback rockfish are primarily caught in the recreational fishery, and in general, are not targeted by either commercial or recreational fleets

(Figure 18 - bars). Recreational removals were specified in numbers of fish (1,000s) but were converted to metric tons internally to the model. The recreational removals generally increased over-time in the early years, spiked in 1990, declined through 2010, and remained level through 2020, with the exception of high removals in 2019. The commercial removals for quillback rockfish are sparse throughout the time series. Washington state waters were closed to commercial fixed gears in 1995 and to trawling in 1999. There are four treaty tribes along the Washington coast that continue to fish under separate commercial rules and are not subject to the state water closure.

Relative spawning output showed a steady decline over the early part of the time series, stabilizing around 2010, and increasing in recent years (Figure 18 – line). The 2021 relative spawning output was just under (39%) the target of 40 percent of unfished spawning output. Recruitment was assumed to be deterministic.

The primary uncertainty for the Washington quillback rockfish model was in the scale of the population. The trajectory of the population was generally consistent across model explorations however there was limited information in the data to inform population scale scale. The ability to estimate additional process and biological parameters for quillback rockfish was also limited by data. Collecting more length and otolith samples from the recreational and commercial fleets would be beneficial to future assessments.

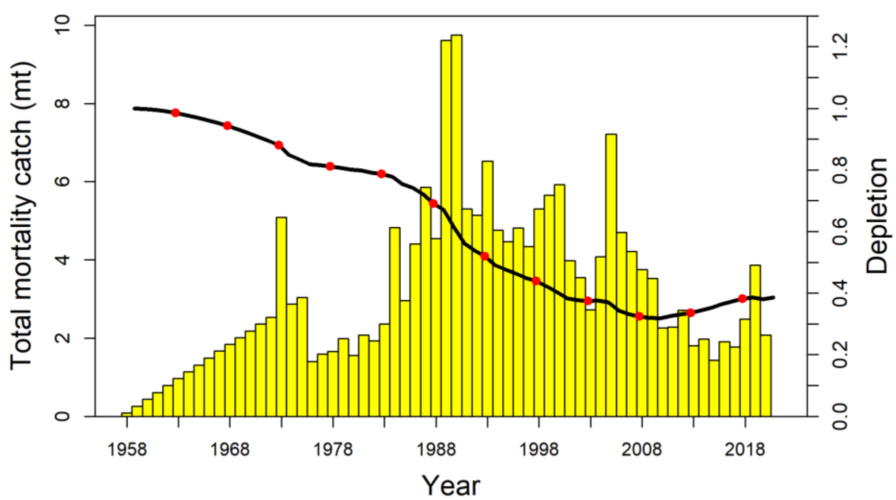

Figure 18. Total catch (bars) and depletion (line: relative to average unexploited equilibrium spawning output) of quillback rockfish off Washington for years 1958 - 2020.

For more information, please contact Brian Langseth at brian.langseth@noaa.gov

e) Status of quillback rockfish (*Sebastes maliger*) in U.S. waters off the coast of Oregon in 2021 using catch and length data

Investigators: B.J. Langseth, C.R. Wetzel, J.M. Cope, and A.D. Whitman

This assessment reports the status of quillback rockfish (*Sebastes maliger*) off the Oregon coast using data through 2020. Quillback rockfish are a medium- to large-sized nearshore rockfish found from southern California to the Gulf of Alaska. The stock off the Oregon coast was assessed as a separate stock from other populations off the U.S. West Coast because of the fairly sedentary nature of quillback rockfish and different exploitation history and magnitude of removals off the Oregon coast. Populations off Washington and California are assessed in separate stock assessments. This is the first stock assessment of quillback rockfish using catch and length composition data. Quillback rockfish was last assessed in 2010, coastwide, using Depletion-Based Stock Reduction Analysis.

Quillback rockfish off the coast of Oregon are caught in both the commercial and recreational fisheries (Figure 19 - bars). The reported landings from the commercial fishery extend back to 1892 and, other than a small peak in the late 1930s through the 1940s, were minimal until the late-1960s. Commercial landings for quillback rockfish increased from the mid-1960s to 1974 and have since fluctuated between approximately 0.4 and 4.5 mt annually. From 2003 to 2020, landings averaged 1.6 mt annually, and represent approximately one third of the total removals. Landings from the recreational fishery off the coast of Oregon were assumed to begin in 1970 and have generally increased across time and now represent the majority of landings for quillback rockfish off the coast of Oregon. Annual fluctuations in recreational landings were high, ranging from 0.5 to 9.5 mt, and landings since 2017 were some of the highest across the time series.

Relative spawning output declined until 1995, where it steadied due to several above average recruitment events that occurred in the early- to mid-1990s, and then increased dramatically in the early 2000s due to the very large recruitment event in 1995 (Figure 19 – line). The increase slowed in the late 2000s, and then declined in the 2010s due to below average recruitment through the 2000s. The 2021 relative spawning output was above (47%) the target of 40 percent of unfished spawning output.

The important uncertainties for the Oregon quillback rockfish model included selectivity assumptions, the magnitude of recruitment variations, and estimates of growth. The ability to estimate additional process and biological parameters for quillback rockfish was limited by data. Future assessments would benefit from collecting more length and otolith samples from the recreational and commercial fleets, which would also help address the uncertainties described above.

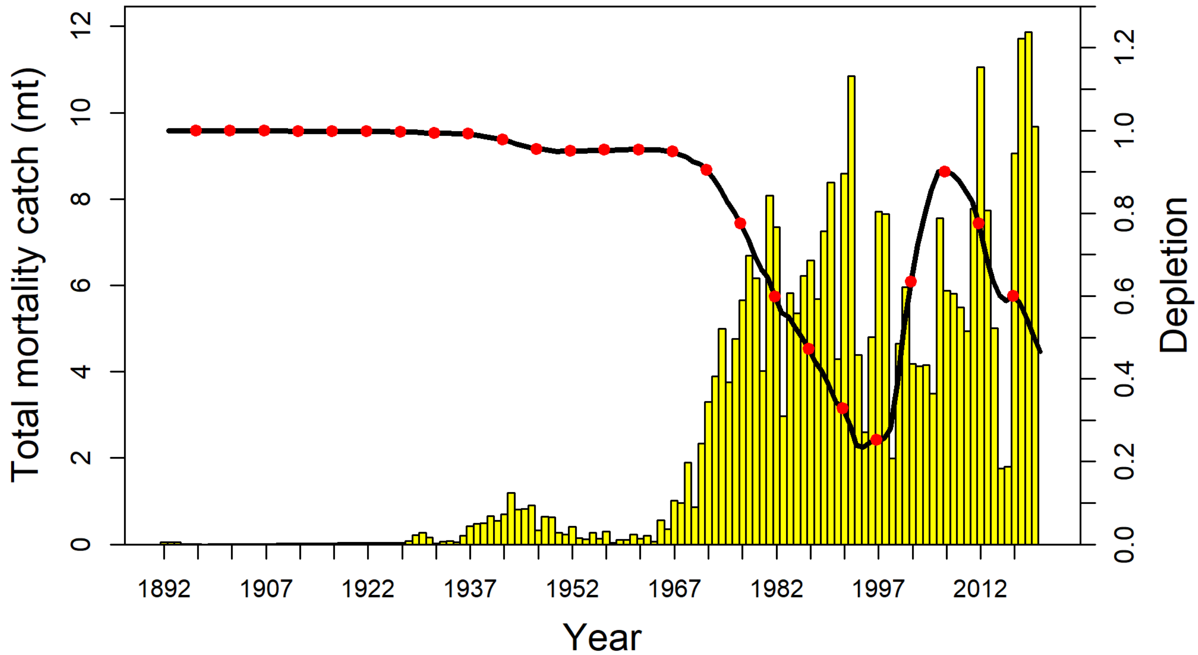

Figure 19. Total catch (bars) and depletion (line: relative to average unexploited equilibrium spawning output) of quillback rockfish off Oregon for years 1892 - 2020.

For more information, please contact Brian Langseth at brian.langseth@noaa.gov

f) Status of quillback rockfish (*Sebastes maliger*) in U.S. waters off the coast of California in 2021 using catch and length data

Investigators: B.J. Langseth, C.R. Wetzel, J.M. Cope, and J.E. Budrick

This assessment reports the status of quillback rockfish (*Sebastes maliger*) off the California coast using data through 2020. Quillback rockfish are a medium- to large-sized nearshore rockfish found from southern California to the Gulf of Alaska. Off the U.S. West Coast quillback rockfish are primarily located north of central California, with few observations south of Point Conception. The stock off the California coast was assessed as a separate stock from other populations off the U.S. West Coast because of the fairly sedentary nature of quillback rockfish, and different exploitation history and magnitude of removals off the California coast. Populations off Oregon and Washington are assessed in separate stock assessments. This is the first stock assessment of quillback rockfish using catch and length composition data. Quillback rockfish was last assessed in 2010, coastwide, using Depletion-Based Stock Reduction Analysis.

Quillback rockfish off the coast of California are caught in both the recreational and commercial fisheries (Figure 20 – bars). Recreational removals are the largest source of fishing mortality and represent approximately 70 percent of the total removals of quillback rockfish across all years. Recreational removals peaked in the late 1970s and early 1980s, with two years of exceptionally large catches in 1984 and 1993. Removals declined sharply in 1994, but increased to levels similar to the late 1970s and early 1980s in the mid-2000s and again in recent years. The majority of the commercial landings for quillback rockfish occurred between 1990 and 2008, and outside these years, apart from 1945-1946, 1984, and the last four years, commercial landings for quillback rockfish have been less than 2 mt per year.

Relative spawning output declined steadily from the first modeled year until 1999, with the exception of a slight increase around 1990, and then increased due to several above average recruitment events that occurred in the mid- to late-1990s. Relative spawning output increased until 2007 and remained level until 2016, after which it declined through 2020. The 2021 relative spawning output was 14%, and below the threshold of 25 percent of unfished spawning output.

The primary uncertainty for the California quillback rockfish model was in estimates of growth, particularly whether growth differed from Oregon and Washington populations, which had growth data available. The ability to estimate additional process and biological parameters for quillback rockfish was limited by data as few California fish were aged. Future assessments would benefit from collecting more length and otolith samples from the recreational and commercial fleets, particularly otolith samples from very small and very large individuals, to best inform growth parameters.

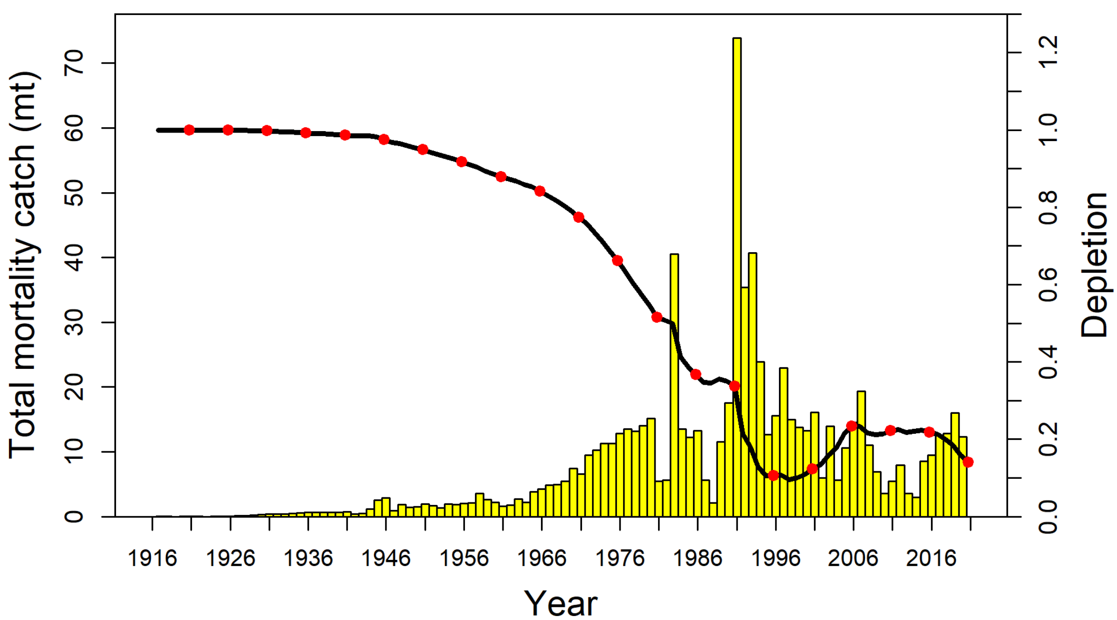

Figure 20. Total catch (bars) and depletion (line: relative to average unexploited equilibrium spawning output) of quillback rockfish off California for years 1916 - 2020.

For more information, please contact Brian Langseth at brian.langseth@noaa.gov

3. Management

I. Thornyheads

J. Sablefish

1. Research

a) 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 and S. Flores

Accurate maturity schedules are critical to ensure that stock assessment models can track changes in spawning stock biomass. To generate updated maturity estimates, the Northwest Fisheries Science Center's Fishery Resource Analysis and Monitoring Division instituted a reproductive biology program in 2009. This program uses histological analysis of ovaries to determine maturity, a technique that is more reliable than the traditional macroscopic method but is also time-consuming and expensive. As macroscopic maturity data are still being collected by multiple agencies on the US west coast, most prominently the Oregon Department of Fish and Wildlife (ODFW), we evaluated the usefulness of these macroscopic maturity recordings by verifying their accuracy using histological methods. Two species in this study, arrowtooth flounder (*Atheresthes stomias*) and canary rockfish (*Sebastes pinniger*), representative of west coast flatfishes and rockfishes (*Sebastes* spp.), had high correspondence between length at 50% biological (physiological) maturity (L50) evaluated histologically and macroscopically. Estimates of L50 for sablefish (*Anoplopoma fimbria*), a representative west coast roundfish, varied significantly between macroscopic and histological methods. Functional maturity (potential spawners in a given year) determined via histology did not correlate with macroscopic maturity for any studied species. In its current form, macroscopic maturity collections are insufficient for assessments of species with significant reproductive complexities but have limited application in assessing changes in maturity schedules over time. However, a lack of standardization among different state departments of fish and wildlife severely hinders any attempt at using macroscopic maturity data to analyze spatial trends in maturity.

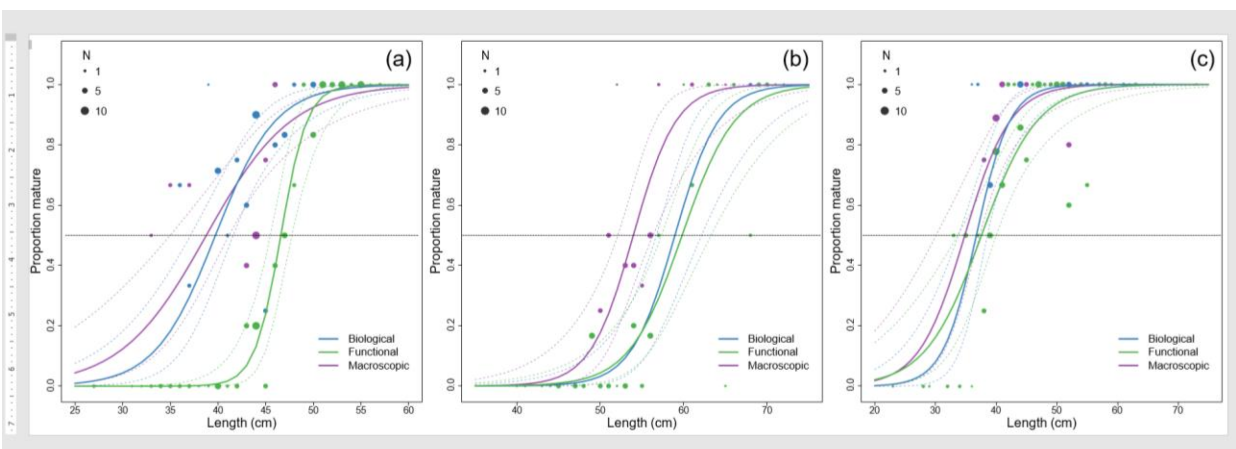

Figure 21. Comparison of maturity ogives fit to maturity data for the three different types of maturity data (biological, functional, and macroscopic) for (**a)** canary rockfish (*Sebastes pinniger*), (**b)** sablefish (*Anoplopoma fimbria*), and (**c)** arrowtooth flounder (*Atheresthes stomias*). Confidence intervals are for the proportion mature at each length

Min, M., Head, M.A., Cope, J., Hastie, J. and Flores, S. 2021. Limitations and applications of macroscopic maturity analyses: A comparison of histological and visual maturity staging in multiple west coast groundfish species. Environmental Biology of Fishes. 105. 10.1007/s10641-021-01208-2.

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

b) The shadow model: how and why small choices in spatially explicit species distribution models affect predictions

Investigators: Commander C.J.C., Barnett L.A.K., Ward E.J., Anderson S.C., Essington T.E.

The use of species distribution models (SDMs) has rapidly increased over the last decade, driven largely by increasing observational evidence of distributional shifts of terrestrial and aquatic populations. These models permit, for example, the quantification of range shifts, the estimation of species co-occurrence, and the association of habitat to species distribution and abundance. The increasing complexity of contemporary SDMs presents new challenges—as the choices among modeling options increase, it is essential to understand how these choices affect model outcomes. Using a combination of original analysis and literature review, we synthesize the effects of three common model choices in semi-parametric predictive process species distribution modeling: model structure, spatial extent of the data, and spatial scale of predictions. To illustrate the effects of these choices, we develop a case study centered around sablefish (*Anoplopoma fimbria*) distribution on the west coast of the USA. The three modeling choices represent decisions necessary in virtually all ecological applications of these methods, and are important because the consequences of these choices impact derived quantities of interest (*e.g*., estimates of population size and their management implications). Truncating the spatial extent of data near the observed range edge, or using a model that is misspecified in terms of covariates and spatial and spatiotemporal fields, led to bias in population biomass trends and mean distribution compared to estimates from models using the full dataset and appropriate model structure. In some cases, these suboptimal modeling decisions may be unavoidable, but understanding the tradeoffs of these choices and impacts on predictions is critical. We illustrate how seemingly small model choices, often made out of necessity or simplicity, can affect scientific advice informing management decisions—potentially leading to erroneous conclusions about changes in abundance or distribution and the precision of such estimates. For example, we show how incorrect decisions could cause overestimation of abundance, which could result in management advice resulting in overfishing. Based on these findings and literature gaps, we outline important frontiers in SDM development**.**

Commander CJC, Barnett LAK, Ward EJ, Anderson SC, Essington TE. 2022. The shadow model: how and why small choices in spatially explicit species distribution models affect predictions. PeerJ 10:e12783 https://doi.org/10.7717/peerj.12783

For more information, contact Eric Ward at Eric.Ward@noaa.gov

c) PSTAT Oceanographic features delineate growth zonation in Northeast Pacific sablefish

Investigators: Haltuch, M.A., Connors, B., Kapur, M., Rogers, L., Berger, A., Echave, K., Williams, B., Lundsford, C., Marshall, K., Punt A.E.

The Pacific Sablefish Transboundary Assessment Team (PSTAT), in collaboration with the NWFSC, AFSC, DFO, ADF&G, PFMC, and NPFMC, held a public workshop to solicit feedback on the ongoing range-wide sablefish Management Strategy Evaluation (MSE) during spring 2021. The MSE explores the consequences of spatial stock structure and movement for regional management. The workshop engaged fishery stakeholders, Alaska Natives and Tribal governments, First Nations, scientists, managers, and Non-governmental organization staff from each region on discussions about sablefish science and management. The workshop introduced the basic premise, goals, and utility of a MSE and participants' roles in the process. The successful sablefish MSE experience from British Columbia was introduced, along with the range of time horizons for incorporating stakeholder input into this NE Pacific MSE. Then the Operating Model (OM) structure and justification for focusing on the NE Pacific, rather than the traditional regional approach to scientific analyses was discussed. Breakout groups focused on identifying fishery objectives, performance metrics, and proposed near term MSE management procedures to evaluate.

Since the spring 2021 workshop, the Operating Model (OM) development has been completed and is currently being tuned to observed data. The study reanalyzing all available sablefish tagging data used to specify movement in the OM is in preparation for publication. The team anticipates initial results during 2023.

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

2. Assessment

a) 2021 Update Sablefish Stock Assessment: Status of Sablefish (*Anoplopoma fimbria*) along the US West coast in 2021.

Investigators: Kapur, M. S., Lee, Q., Correa, G. M., Haltuch, M., Gertseva, V., and Hamel, O. S. 2021

This update assessment reports the status of sablefish (Anoplopoma fimbria) off the US West coast using data through 2020. The resource is modeled as a single stock; however, sablefish disperse to and from offshore seamounts, along the coastal waters of the US West Coast, 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. 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 generally been 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 about 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 2021 spawning biomass from the base model is 97,802 mt, however, the 95% interval ranges broadly from 40,802-154,801 mt. The point estimate of 2021 spawning biomass relative to an unfished state (i.e., depletion) from the base model is 57.9% of unexploited levels (95% interval: 38.4%-77.5%).

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.

Unfished spawning biomass was estimated to be 168,875 mt (107,749-230,001 ~95% interval). The abundance of sablefish was estimated to have declined to near the target during the period 1980-2000. The estimate of the target spawning biomass was 67,550 (43,099-92,001, ~95% interval). The stock was estimated to be above the target stock size in the beginning of 2021 at 97,802 mt (40,801-154,802, ~95% interval). The stock was estimated to be above the depletion level that would lead to maximum yield (0.4) (Figure 22). The estimate of the stock's current 2021 level of depletion was 0.579.

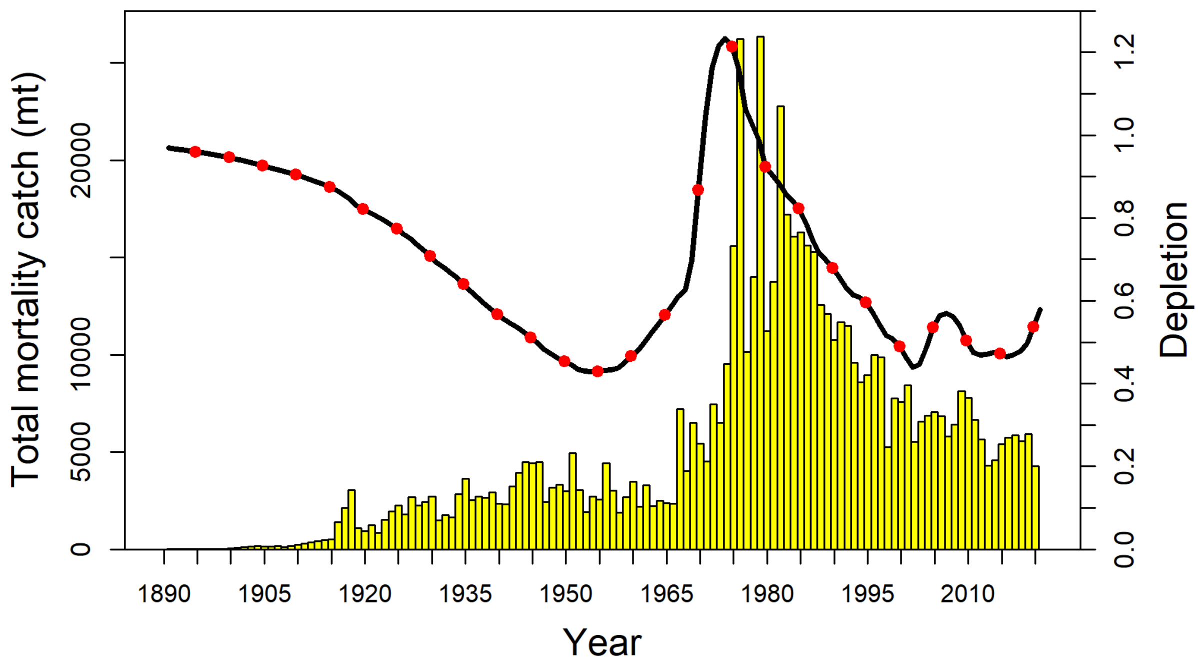

Figure 22. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for sablefish.

1. Research

2. Assessment

3. Management

K. Lingcod

1. Research

a) Geographic variability in lingcod (*Ophiodon elongatus*) life-history and demography along the U.S. West Coast

Investigators: Lam L.S., Basnett, B.L., Haltuch, M.A., Cope J., Andrews K., Nichols K.M,Longo G.C., Samhouri, J.F., Hamilton S.L.

Understanding the spatial patterns as well as environmental and anthropogenic drivers of life-history variation for exploited fish populations is important when making management decisions and designating stock boundaries. These considerations are especially germane for stocks that are overfished or recently rebuilt, such as lingcod (*Ophiodon elongatus*), a commercially and recreationally valuable species of groundfish along the West Coast of North America. Between 2015 and 2017, 2,189 lingcod were collected from 24 port locations, spanning 28° of latitude from southeast Alaska (60°N) to southern California (32°N), to investigate latitudinal patterns in size and age structure, growth, timing of maturity, condition, and mortality, as well as to identify biologically relevant population breakpoints along the coast. The authors found strong latitudinal patterns in these life history and demographic traits consistent with Bergmann's Rule: lingcod from colder, northern waters were larger at age, lived longer, matured at larger sizes, and had lower natural mortality rates than lingcod from lower latitudes. Female lingcod were larger at age, lived longer, and matured at larger sizes compared to males within each examined region. In addition, authors found evidence for strong associations between lingcod life-history traits and oceanographic variables. Cluster analysis using life history traits indicated that central Oregon is a biologically-relevant breakpoint for lingcod along the U.S. West Coast. This newfound breakpoint, in conjunction with a recently identified genetics breakpoint in central California discovered by Longo et al. (2020), highlights the need for future lingcod stock assessments to consider population dynamics and genetic connectivity when managing complex, trans-boundary stocks.

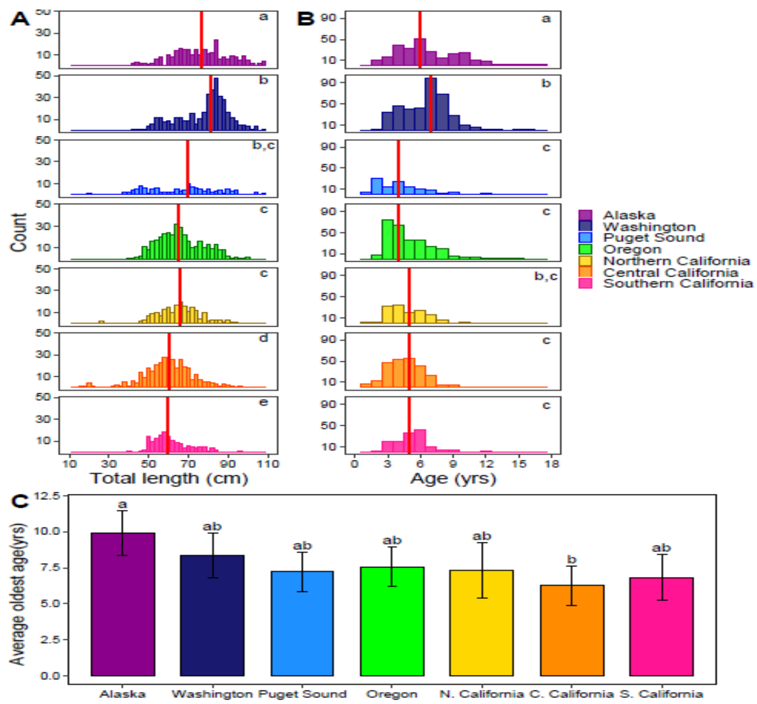

Figure 23. A) Size- and B) age-frequency of lingcod by region (sexes pooled) in order of decreasing latitude. The red vertical line indicates median size and age per region, respectively. Regions were compared using the nonparametric Kruskal-Wallis test; nonparametric pairwise comparisons were conducted using Steel-Dwass All Pairs where non-overlapping letters indicate significant difference (α=0.05). Note that nonparametric analysis was performed on extracted residuals from the linear regression between length and depth. C) average oldest age (yrs) was calculated using the mean of the upper quartile of ages. Error bars were calculated using ±2 SE. Statistical significance is noted by the lack of overlapping letters above error bars.

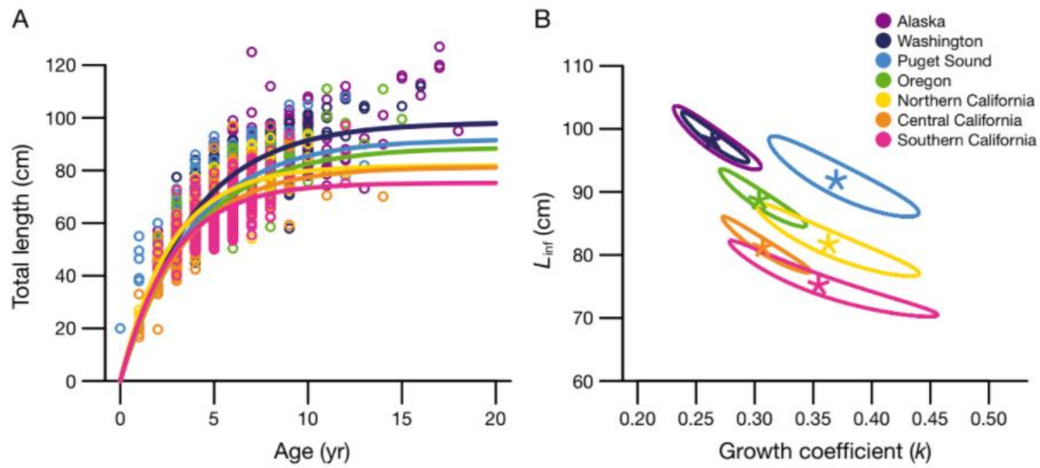

Fig. 24. A) Spatial variation in lingcod von Bertalanffy growth curves across 7 sampled regions; B) 95% confidence intervals for predicted maximum asymptotic length (L_∞) and growth coefficients (k) for each region. Overlapping intervals indicate no differences in growth. Note growth curves for lingcod from Alaska and Washington overlap

Lam L.S., Basnett, B.L., Haltuch, M.A., Cope J., Andrews K., Nichols K.M, Longo G.C., Samhouri, J.F., Hamilton S.L. 2021. Geographic variability in lingcod (*Ophiodon elongatus*) life-history and demography along the U.S. West Coast: Oceanographic drivers and management implications. Mar. Ecol. Prog. Ser. 670:263-222

For more information, contact Laurel Lam at laurel.lam@noaa.gov

b) Male lingcod (*Ophiodon elongatus*) with blue color polymorphism

Investigators: Wood, C.L., Leslie, K.L., Greene, A., Lam, L.S., Basnett, B., Hamilton, S.L., Samhouri, J. F.

The unusual blue color polymorphism of lingcod (*Ophiodon elongatus*) is the subject of much speculation but little empirical research; ~20% of lingcod individuals exhibit this striking blue color morph, which is discrete from and found within the same populations as the more common brown morph. In other species, color polymorphisms are intimately linked with host–parasite interactions, which led us to ask whether blue coloration in lingcod might be associated with parasitism, either as cause or effect. To test how color and parasitism are related in this host species, we performed parasitological dissection of 89 lingcod individuals collected across more than 26 degrees of latitude from Alaska, Washington, and California, USA. We found that male lingcod carried 1.89 times more parasites if they were blue than if they were brown, whereas there was no difference in parasite burden between blue and brown female lingcod. Blue individuals of both sexes had lower hepatosomatic index (i.e., relative liver weight) values than did brown individuals, indicating that blueness is associated with poor body condition. The immune systems of male vertebrates are typically less effective than those of females, due to the immunocompromising properties of male sex hormones; this might explain why blueness is associated with elevated parasite burdens in males but not in females. What remains to be determined is whether parasites induce physiological damage that produces blueness or if both blue coloration and parasite burden are driven by some unmeasured variable, such as starvation. Although our study cannot discriminate between these possibilities, our data suggest that the immune system could be involved in the blue color polymorphism–an exciting jumping-off point for future research to definitively identify the cause of lingcod blueness and a hint that immunocompetence and parasitism may play a role in lingcod population dynamics.

Figure 25. (a) Lingcod (*Ophiodon elongatus*) of two color morphs: blue (topmost and fourth-from-top) and brown (second-from-top, third-from-top and bottommost. (b) Blue coloration affects both external and internal tissues (photo: Laurel Lam).

Wood, C. L., Leslie, K. L., Greene, A., Lam, L. S., Basnett, B., Hamilton, S. L., Samhouri, J. F. 2021. The weaker sex: Male lingcod (*Ophiodon elongatus*) with blue color polymorphism are more burdened by parasites than are other sex–color combinations. PloS one, 16(12), e0261202.

For more information, contact Laurel Lam at laurel.lam@noaa.gov

c) Why so blue? Assessing prevalence and correlates of blue-colored flesh in lingcod (*Ophiodon elongatus*) across their geographic range.

Investigators: Galloway, A.W., Beaudreau, A.H., Thomas, M.D., Basnett B.L., Lam L.S., Hamilton S.L., Andrews K.S., Schram J.B., Watson J.,

Abstract Intraspecific variation in external and internal pigmentation is common among fishes and explained by a variety of biological and ecological factors. Blue-colored flesh in fishes is relatively rare but has been documented in some species of the sculpin, greenling, and perch families. Diet, starvation, photoprotection, and camouflage have all been suggested as proximate mechanisms driving blue flesh, but causal factors are poorly understood. We evaluated the

relative importance of biological and spatial factors that could explain variation in blue coloration in 2021 lingcod (*Ophiodon elongatus*) captured across their range in the northeastern Pacific, from southeast Alaska to southern California. The probability of having blue flesh was highest for fish that were female, caught in shallower water, and smaller in body size. The incidence of blueness varied by region (4–25% of all fish) but was also confounded by differences in sex ratios of fish caught among regions. We analyzed the multivariate fatty acid composition of a subset of 175 fish from across the sampling range to test for differences in trophic biomarkers in blue lingcod. Lingcod fatty acid composition differed between regions and flesh colors but not between sexes. Blue-fleshed fish had lower concentrations of total fatty acids, 18:1ω-9, 16:1ω-7, 18:1ω-7, and ω-6 fatty acids, suggesting differences in energetics and energy storage in blue fish. While our data indicate potential links between diet and blue flesh in lingcod, important questions remain about the physiological mechanisms governing blueness and its biological consequences.

Figure 26.

Fig. 1 Examples of blue-fleshed fish and serum. **a** Blue-fleshed rock greenling (*Hexagrammos lagocephalus*; Aleutian Islands, AK; Photo by Scott Gabara). **b**, **c** Blue flesh and mouth tissues of a lingcod (Port Orford, OR; Photos by Aaron Galloway); **d** Blue serum from lingcod (San Juan Islands, WA; Photo by Aaron Dufault); **e** Representative range of color variants—from the left, individuals 1, 3, and 4 were designated 'brown' and individuals 2 and 5 were designated 'blue' (Photo by Laurel Lam)

Galloway A.W., Beaudreau A.H., Thomas M.D., Basnett B.L., Lam L.S., Hamilton S.L., Andrews K.S., Schram J.B., Watson J., Samhouri J.F. 2021. Assessing prevalence and

correlates of blue-colored flesh in lingcod (*Ophiodon elongatus*) across their geographic range. *Marine Biology*, *168*(9), 1-15.

For more information, contact Laurel Lam at laurel.lam@noaa.gov

2. Assessment

a) Status of lingcod (*Ophiodon elongatus*) along the northern U.S. west coast in 2021

Investigators: Ian G. Taylor, Kelli F. Johnson, Brian J. Langseth, Andi Stephens, Laurel S. Lam, Melissa H. Monk, Alison D. Whitman, Melissa A. Haltuch

This assessment reports the status of lingcod (*Ophiodon elongatus*) north of 40°10'N along the U.S. west coast using data through 2020. Lingcod were modeled as two stocks split at 40°10'N. This choice is informed by a consideration of genetic differences (Longo et al. 2020) as well as differences in growth and management. Models for lingcod do not include catches or dynamics from the Alaskan, Canadian, or Mexican populations.

Data included information on landings for each commercial and recreational fleet; commercial discards, available from the West Coast Groundfish Observer Program; relative abundance as informed by the Triennial Survey, West Coast Groundfish Bottom Trawl Survey, commercial trawl fishery, and each recreational fishery; and length and age compositions, available from the previous sources as well as research by L. Lam.

The stock biomass is currently trending downwards, though the rate of the decline is highly uncertain (Figure 27). Although the biomass is currently estimated to be declining, no estimate is below the minimum stock size threshold and all estimates since the late 1990s are above the management target (Figure 27).

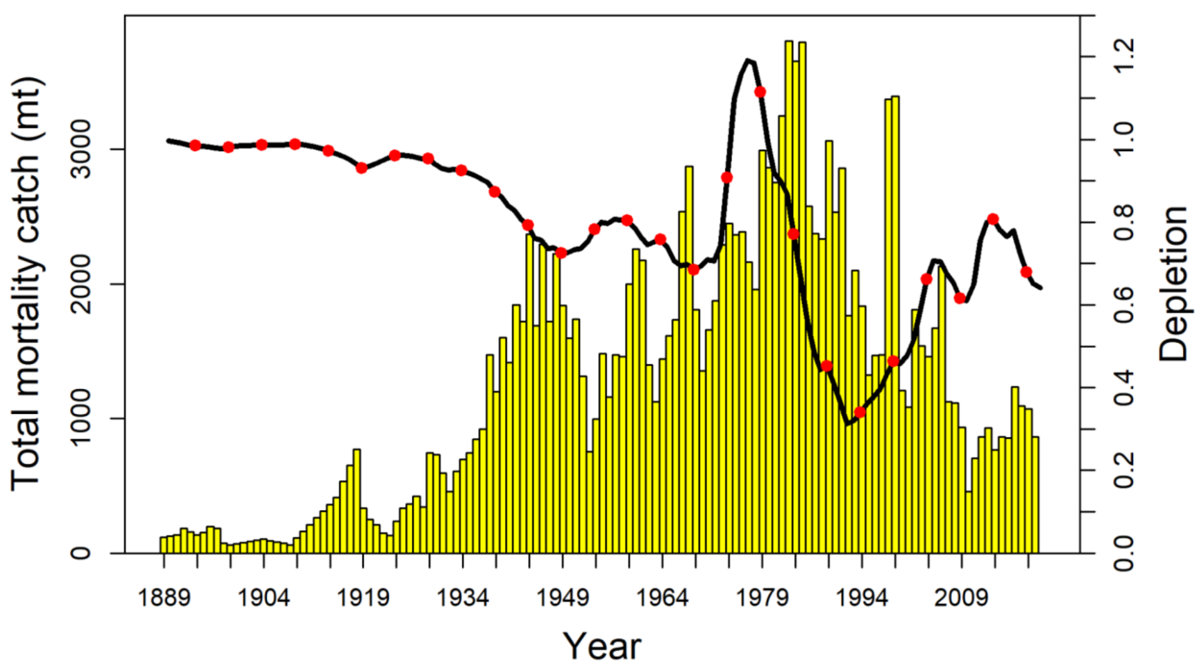

Figure 27. Total catch (bars) and depletion (line: relative to average unexploited equilibrium spawning output) of lingcod north of 40°10'.

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

b) Status of lingcod (*Ophiodon elongatus*) along the southern U.S. west coast in 2021

Investigators: Kelli F. Johnson, Ian G. Taylor, Brian J. Langseth, Andi Stephens, Laurel S. Lam, Melissa H. Monk, John E. Budrick, Melissa A. Haltuch

This assessment reports the status of lingcod (*Ophiodon elongatus*) south of 40°10'N along the U.S. west coast using data through 2020. Lingcod were modeled as two stocks split at 40°10'N. This choice is informed by a consideration of genetic differences (Longo et al. 2020) as well as differences in growth and management. Models for lingcod do not include catches or dynamics from the Alaskan, Canadian, or Mexican populations.

Data included information on landings for each commercial and recreational fleet; commercial discards, available from the West Coast Groundfish Observer Program; relative abundance as informed by the Triennial Survey, West Coast Groundfish Bottom Trawl Survey, commercial trawl fishery, and each recreational fishery; and length and age compositions, available from the previous sources as well as research by L. Lam. Information on relative abundance, length, and age was also available from the NWFSC Hook and Line Survey (Hook and Line Survey). The final model included ages from only the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) because of conflicts between age- and length-composition data.

Over the last decade, the spawning biomass has been trending upward due to a period of above-average recruitment which ended in 2013, though the rate of the increase is highly uncertain (Figure 28). Uncertainty in the initial stock size is vast and this uncertainty is carried forward until approximately the early 1980s when more informative data are available. The current estimated biomass is below, but close to, the management target with the uncertainty in this estimate spanning well above and below the management target and the minimum stock size threshold (Figure 28).

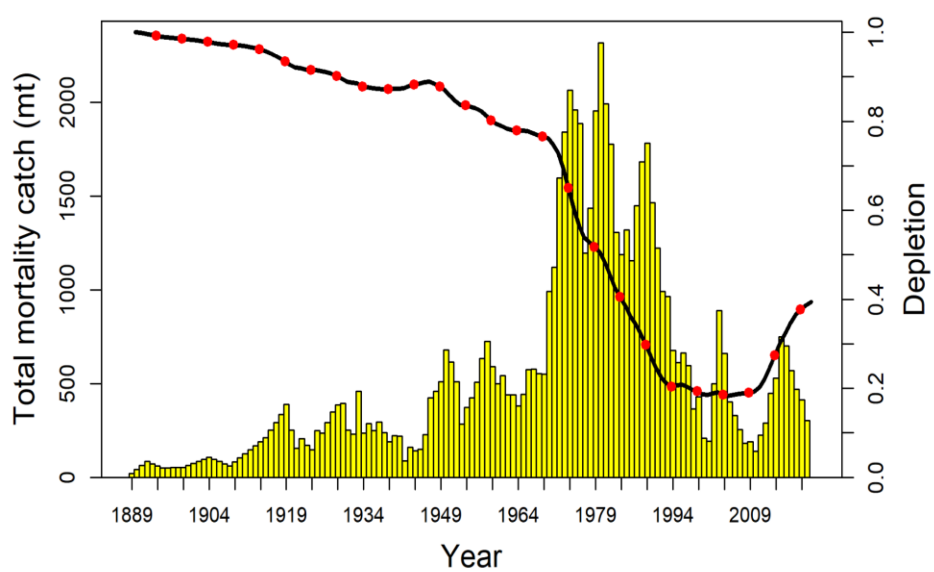

Figure 28. Total catch (bars) and depletion (line: relative to average unexploited equilibrium spawning output) of lingcod south of 40°10'.

For more information, please contact Kelli Johnson at Kelli.Johnson@noaa.gov

L. Atka Mackerel

M. Flatfish

1. Research

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

Investigator: Douglas Draper

A diet study of arrowtooth flounder (*Atheresthes stomias*) was undertaken to provide current information on their food habits and predator-prey relationships in the California Current Ecosystem. Arrowtooth flounder stomachs (n = 573) were collected between 2013 and 2018 from 397 trawls during the Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl Survey. A total of 357 stomachs (62.3%) contained prey, which revealed a highly piscivorous diet across all lengths examined (14 – 77 cm) and described a regionalized and opportunistic feeding behavior. Increased predator length correlated both with an increase in percentage of fish prey consumed and an increase in depth of capture. Smaller (< 43 cm) and shallower (≤ 183 m) arrowtooth flounder consumed a relatively high percentage of euphausiids and shrimp, while larger arrowtooth flounder (≥ 43 cm) captured at greater depths (> 183 m) consumed more fish and fewer shrimp and euphausiids. Arrowtooth flounder diet varied by geographic area, likely resulting from regional differences in prey availability. North of the mean latitude of capture (44.45◦N), Pacific hake (*Merluccius productus*) and Pacific herring (*Clupea pallasii*) were the predominant fish in arrowtooth flounder diets, while arrowtooth flounder caught south of the mean latitude consumed mostly Pacific hake and rockfishes (Scorpaenidae). Unidentified teleost fish contributed much to the diet across all size, depth, and latitude ranges.

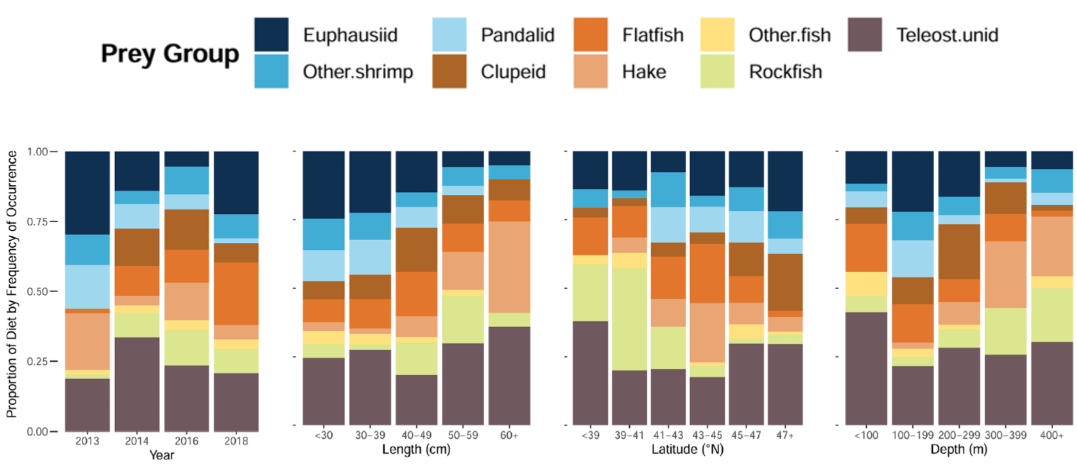

Figure 29. Stacked barplots of diet proportions by frequency of arrowtooth flounder prey groups for year, length, latitude, and depth bins.

2. Assessement

a) Stock Assessment of the Dover sole (*Microstomus pacificus*) along the U.S. West Coast in 2021

Investigators: C.R. Wetzel and A.M. Berger

This is an assessment of the Dover sole population off the U.S. west coast, including coastal waters of California, Oregon, and Washington from the U.S./Mexico border to the U.S./Canadian border. It does not include Canadian or Alaskan populations and assumes that these northern populations do not contribute to the stock being assessed here.

The longest time series of fishery-independent information off the U.S. west coast arises from the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) that has been conducted annually from 2003 - 2019. The length and age data from this survey were highly influential on the model estimates of stock size and status. Additionally, these data were used to externally estimate starting parameter values by sex for length-at-age and the fixed values by sex for length-weight relationship. Dover sole off the U.S. west coast appear to have complex movement patterns, moving across depths, likely driven by season, spawning, and by size. Additionally, observations indicate possible sex-specific aggregations where a higher proportion of female fish are found in shallower (less than 300 m) and deeper waters (greater than 900 m), with higher proportion of males observed at intermediate depths (300 - 700 m).

The estimated spawning biomass at the beginning of 2021 was 232,065 mt (~95 percent asymptotic intervals: 154,153 to 309,977 mt), which when compared to unfished spawning biomass (294,070 mt) equates to a relative stock status level of 79 percent (~95 percent asymptotic intervals: 71 to 87 percent). The estimated scale of the stock ($SB0$) from this assessment, 294,070 mt, is lower than the value estimated in the 2011 assessment of 469,866 mt but well within the 2011 ~95 percent asymptotic interval (182,741 - 756,991 mt). Fishing intensity (1 - SPR) over the past decade has been well below the target SPR30%, ranging between 0.11 and 0.2. The estimated target spawning biomass based on the 25 percent management target is 73,518. Sustainable total yield, landings plus discards, using SPR30% is estimated at 22,891 mt.

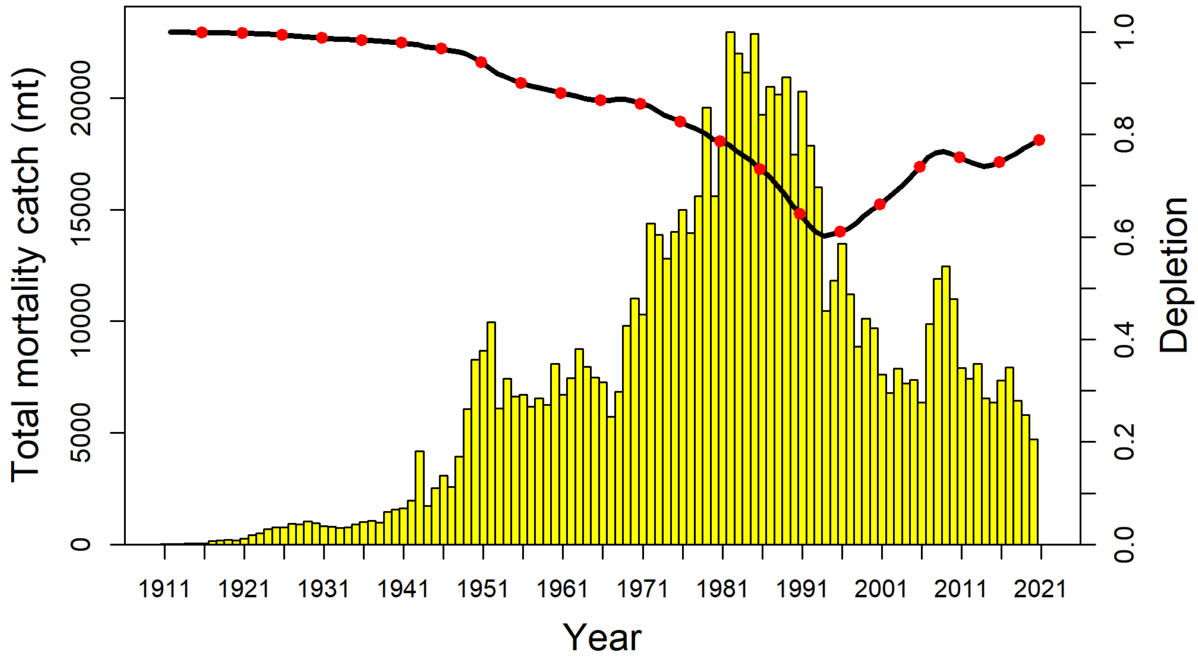

Figure 30. Total catch (bars) and depletion (line: relative to average unexploited equilibrium spawning output) of Dover sole for years modeled.

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

1. Research

N. Halibut

O. Other Groundfish

1. Research

a) U.S. California Current Climate Change Vulnerability Assessment

Investigators: Michelle McClure, Melissa Haltuch and others

In 2015 NOAA Fisheries released its Climate Science Strategy to address a growing need for information about how climate change may affect living marine resources, their habitats and the people who depend on them. The Climate Science Strategy identified seven key objectives and called for each region to develop a Regional Action Plan to cover them, including an assessment of the risk climate change poses to protected species and fisheries. Researchers from the NOAA Fisheries' Northwest and Southwest Fisheries Science Centers have developed a Climate Vulnerability Assessment (CVA) that examines the risk of anticipated climate change to species managed under the Magnuson-Stevens Act and ESA-listed salmon and steelhead in California, Oregon, Washington and Idaho. The general CVA publication that compasses groundfish, coastal pelagic species, highly migratory species, and protected species is in review.

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

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

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

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, please contact Melissa Haltuch at Melissa.Haltuch@noaa.gov

c) 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.

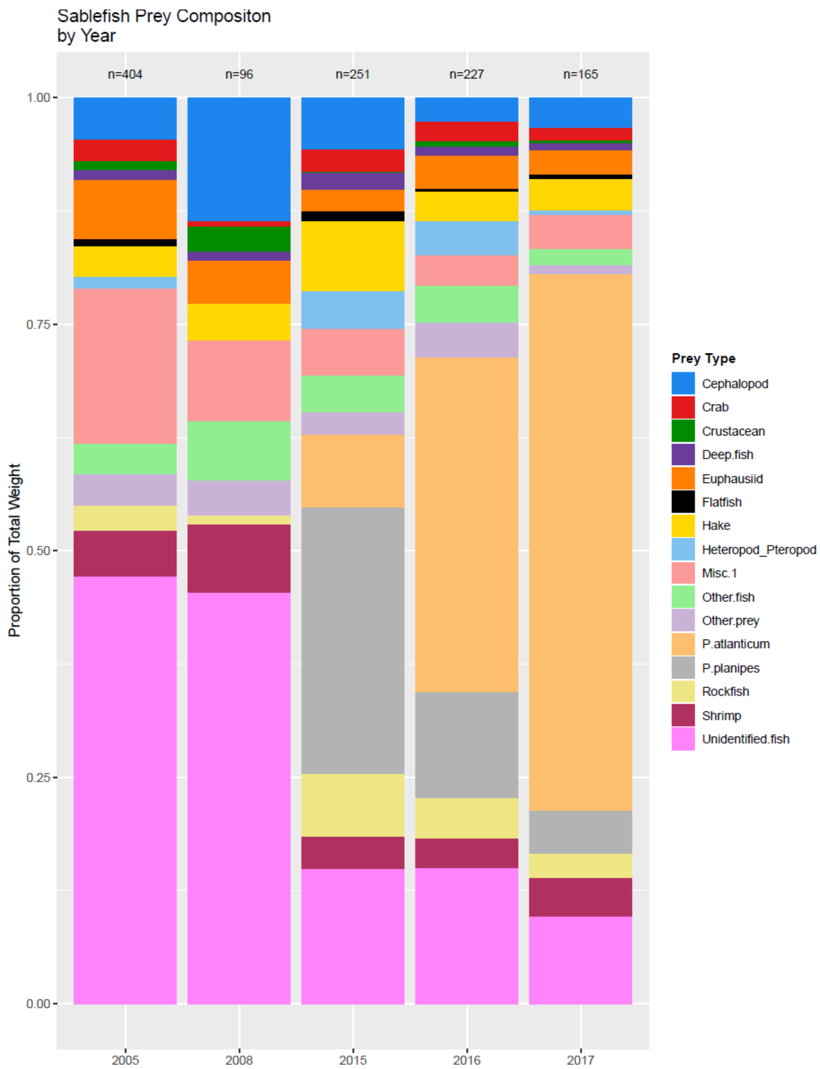

Figure 31. Stacked barplot of diet proportions by weight of sablefish prey groups for 2005, 2008, 2015-2017.

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

d) Climate shock effects and mediation in fisheries

Investigators: Fisher, M.C., S.K. Moore, S. Jardine, J. Watson, J.F. Samhouri

Climate shocks can reorganize the social-ecological linkages in food-producing communities, leading to a sudden loss of key products in food systems. The extent and persistence of this reorganization are difficult to observe and summarize, but are critical aspects of predicting and rapidly assessing community vulnerability to extreme events. We apply network analysis to evaluate the impact of a climate shock-an unprecedented marine heatwave-on patterns of resource use in California fishing communities, which were severely affected through closures of the Dungeness crab fishery. The climate shock significantly modified flows of users between fishery resources during the closures. These modifications were predicted by pre-shock patterns of resource use and were associated with three strategies used by fishing community member vessels to respond to the closures: temporary exit from the food system, spillover of effort from the Dungeness crab fishery into other fisheries, and spatial shifts in where crab were landed. Regional differences in resource use patterns and vessel-level responses highlighted the Dungeness crab fishery as a seasonal "gilded trap" for northern California fishing communities. We also detected disparities in climate shock response based on vessel size, with larger vessels more likely to display spatial mobility. Our study demonstrates the importance of highly connected and decentralized networks of resource use in reducing the vulnerability of human communities to climate shocks.

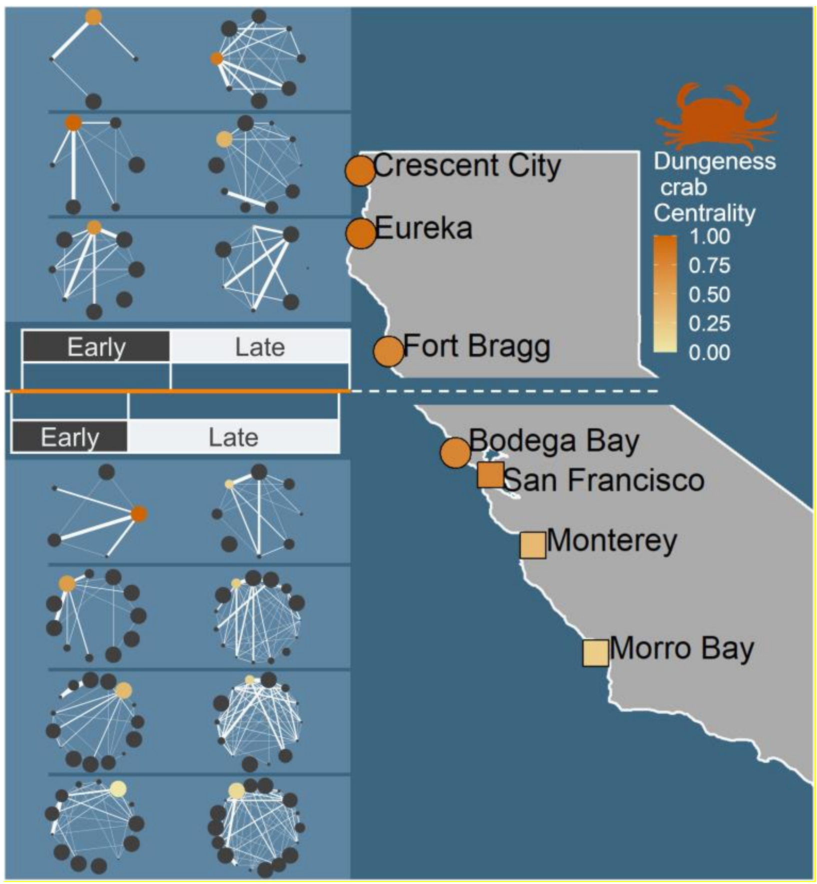

Figure 32. The seven California fishing communities included in this study and their pre-shock fisheries participation networks. Pre-shock early (*Left*) and late (*Right*) networks represent a 3-y average (crab years 2013 to 2015) of participation prior to the 2016 fishery closures. The Dungeness crab fishery node is shaded orange in each network according to its betweenness centrality, a measure of importance (note that nodes are not consistently positioned across networks). The timeline shows the relative duration of the early and late seasons for fishing communities in the two California management districts (above/below timeline). Point color on the map indicates average Dungeness crab betweenness centrality across the early and late seasons, and point shape indicates whether the fishing community was considered part of the northern region (circle) or the central region (square) for this study.

Fisher, M.C., S.K. Moore, S. Jardine, J. Watson, J.F. Samhouri. 2021. Climate shock effects and mediation in fisheries. Proceedings of the National Academy of Sciences USA 118 (2) e2014379117. https://doi.org/10.1073/pnas.2014379117

For more information, please contact Jameal Samhouri at jameal.samhouri@noaa.gov

e) Footprints of fixed gear fisheries in relation to rising whale entanglements on the U.S. West Coast

Investigators: Feist, B.E., J.F. Samhouri, K.A. Forney, L.A. Saez.

On the U.S. West Coast, reports of whales entangled in fishing gear increased dramatically in 2014. In this study, a time series of fishing activity maps was developed from 2009 to 2016 for the four fixed-gear fisheries most commonly implicated in entanglements. Maps were generated using vessel monitoring system (VMS) data linked to port-level landings databases, which were related to entangled whale reports over the same time period and with modelled distributions of humpback whales *Megaptera novaeangliae* Borowski. Over the full study period, neither marked increases in fishing activity nor changes in fisheries footprints within regions with high whale densities were detected. By contrast, a delayed fishery opening in California due to a harmful algal bloom in spring of 2016 led to ~5–7 times average levels of Dungeness crab *Metacarcinus magister* (Dana) fishing activity, which was consistent with a high rate of entanglement in that year. These results are consistent with current hypotheses that habitat compression caused by a marine heatwave increased the overlap of whales with fishing activity, despite minimal changes in the fisheries themselves. This study adds to literature on bycatch of protected species in otherwise sustainable fisheries, highlighting the value of using VMS data for reducing human–wildlife conflict in the ocean.

Feist, B.E., J.F. Samhouri, K.A. Forney, L.A. Saez. 2021. Footprints of fixed gear fisheries in relation to rising whale entanglements on the U.S. West Coast. Fisheries Management and Ecology 28(3): 283-294. DOI: 10.1111/fme.12478

For more information, please contact Blake Feist at blake.feist@noaa.gov

2. Assessments

3. Management

a) Incoherent dimensionality in fisheries management

Investigator: A.M Berger

Fisheries policy inherently relies on an explicit definition of management boundaries that delineate the spatial extent over which stocks are assessed and regulations are implemented. However, management boundaries tend to be static and determined by politically negotiated or historically identified population (or multi-species) units, which creates a potential disconnect

with underlying, dynamic population structure. The consequences of incoherent management and population or stock boundaries were explored through the application of a two-area spatial simulation-estimation framework. Results highlight the importance of aligning management assessment areas with underlying population structure and processes, especially when fishing mortality is disproportionate to vulnerable biomass among management areas, demographic parameters (e.g., growth and maturity) are not homogenous within management areas, and connectivity (via recruitment or movement) unknowingly exists among management areas. Bias and risk was greater for assessments that incorrectly span multiple population segments compared to assessments that cover a subset of a population segment, and these results were exacerbated when there was connectivity between population segments. Directed studies and due consideration of critical population segments, spatially-explicit models, and dynamic management options that help align management and population boundaries would likely reduce estimation biases and management risk, as would closely coordinated management that functions across population boundaries. *Oregon Chapter American Fisheries Society.*
For more information, please contact Aaron Berger at Aaron.Berger@noaa.gov

b) Incoherent dimensionality in fisheries management: consequences of misaligned stock assessment and ecological boundaries

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

Fisheries policy inherently relies on an explicit definition of management boundaries that delineate the spatial extent over which regulations are implemented. However, management boundaries tend to be static and determined by politically negotiated or historically identified population units, which creates a potential disconnect with underlying, dynamic population structure. Additionally, understanding spatial population structure and aligning the management boundaries with the population areas may improve management advice. We use a two-area (single stock-recruit relationship but differing demographic or fishery characteristics) spatial simulation-estimation framework to evaluate the consequences associated with misalignment among management and population boundaries (i.e., boundary incoherence). Results highlight the importance of aligning management areas with underlying population structure and processes, especially when fishing mortality is disproportionate to vulnerable biomass among management areas, demographic data (e.g., growth and maturity) is not homogenous within management areas, or connectivity (via recruitment or movement) exists among management areas. Spatially incoherent population and management unit boundaries created bias in population estimates, averaging a 12.2% median relative error (MRE; at 10% boundary incoherence) to 79.9% MRE (at 50% boundary incoherence) in terminal year spawning stock biomass. Bias was largest (>200% MRE) when spatial patterns in fishery selectivity, growth, and maturity were supplemented with disproportionate recruitment and directional movement. The risk of drastically misinformed management (arising from population estimates > 2 standard deviations from spatially coherent models) increased with the degree of boundary incoherence. *World Fisheries Congress.*

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

c) Space jam: evaluating assumptions and methods for conducting spatial stock assessments

Investigators: C. Barceló, A.M Berger, A. Dunn, D.R. Goethel, S. Hoyle, P. Lynch, J. McKenzie

Abstract: Climate change is affecting the distribution of target species, fisheries, and fish communities in ways that influence the productivity and population structure of harvested species. Stock assessments must therefore be able to include ecosystem information at a spatiotemporal scale relevant to the population. Nevertheless, there is no clear guidance on how best to integrate ecosystem information or spatial population structure into stock assessment models. Currently, there are several modeling platforms that can incorporate spatial structure (either explicitly or implicitly), each with unique features of methodology, modelling approach, or underlying assumptions. In this presentation, we review: 1) the current state of applying spatial structure in stock assessments used for management, 2) the spatial capabilities of contemporary spatial stock assessment modeling platforms, and 3) and a computer simulation-based participatory research experiment to elicit current successes, existing limitations, and future research needs. Based on a questionnaire surveying international platform developers (14 developer responses and 10 platforms/models), results highlight differences in the parametrization of movement, incorporation of tagging data, integration of fleets and surveys, modeling of productivity and population structure, and other key spatial or ecosystem-linkage features. Initial results from the participatory simulation experiment will also be discussed to identify the commonalities and key differences in the decisions made to build a spatial stock assessment and the related modeling assumptions. The results from this study will serve to inform best practices for applying spatial stock assessments and will help guide the development of 'next generation' stock assessment platforms. *American Fisheries Society.*

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

d) Strength and consistency of density dependence in marine fish productivity

Investigators: A. Rindorf, M. van Deurs, D. Howell, E. Andonegi, A. Berger, B. Bogstad, N. Cadigan, B. Elvarsson, N. Hintzen, M. Roland, M. Taylor, V. Trijoulet, T. van Kooten, F. Zhang, J. Collie

The correct prediction of the shape and strength of density dependence in productivity is key to predicting future stock development and providing the best possible long-term fisheries management advice. Here, we identify unbiased estimators of the relationship between somatic growth, recruitment and density, and apply these to 80 stocks in the Northeast Atlantic. The analyses revealed density-dependent recruitment in 68% of the stocks. Excluding pelagic stocks exhibiting significant trends in spawning stock biomass, the probability of significant density dependence was even higher at 78%. The relationships demonstrated that at the commonly used biomass limit of 0.2 times maximum spawning stock size, only 32% of the stocks attained three quarters of their maximum recruitment. This leaves 68% of the stocks with less than three quarters of their maximum recruitment at this biomass limit. Significantly lower recruitment at high stock size than at intermediate stock size was seen in 38% of the stocks. Density dependence in late growth occurred in 54% of the stocks, whereas early growth was generally density-independent. Pelagic stocks were less likely to exhibit density dependence in recruitment than demersal and benthic stocks. We recommend that both the degree to which productivity is related to density and the degree to which the relationship changes over time should be investigated. Both of these aspects should be considered in evaluations of whether sustainability and yield can be improved by including density dependence in forecasts of the effects of different management actions. *Fish and Fisheries*.

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

e) Finding the perfect mismatch: evaluating misspecification of population structure within spatially explicit integrated population models

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

Spatially stratified integrated population models (IPMs) can account for fine-scale demographic processes and support spatial management for complex, heterogeneous populations. Although spatial IPMs may provide a more realistic representation of true population dynamics, few studies have evaluated the consequences associated with incorrect assumptions regarding population structure and connectivity. We utilized a simulation-estimation framework to explore how mismatches between the true population structure (i.e. uniform, single population with spatial heterogeneity or metapopulation) and various parametrizations of an IPM (i.e. panmictic, fleets-as-areas or a spatially explicit, tag-integrated model) impacted resultant fish population estimates. When population structure was incorrectly specified in the IPM, parameter estimates were generally unbiased at the system level, but were often biased for sub-areas. Correctly specifying population structure in spatial IPMs led to strong performance, whereas incorrectly specified spatial IPMs performed adequately (and better than spatially aggregated counterparts). Allowing for flexible parametrization of movement rates (e.g. estimating age-varying values) was more important than correctly identifying the population structure, and incorporation of tag-recapture data helped movement estimation. Our results elucidate how incorrect population structure assumptions can influence the estimation of key parameters of spatial IPMs, while indicating that, even if incorrectly specified, spatial IPMs can adequately support spatial management decisions. *Fish and Fisheries*.

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

V. Ecosystem Studies

A. Socioeconomics

a) Understanding climate impacts on groundfish fisheries and fishing communities along the US West Coast

Investigators: Jameal Samhouri, Chris Harvey, Isaac Kaplan, Karma Norman, Owen Liu, and collaborators at NOAA NWFSC and SWFSC, universities, and beyond.

A group of collaborators at NOAA NWFSC, SWFSC, NMFS Western Regional Office, and multiple universities are working together to (a) improve understanding of how climate variability and change influence availability of groundfish to fisheries and fishing communities along the US West Coast, and (b) determine how existing fisheries management approaches perform under climate change and in an uncertain future. This group's work is divided into three major components: a Species Distribution Modeling (SDM) Module, an Atlantis Ecosystem Model Module, and a Communities Module. The SDM Module is focused on determining environmental affinities of groundfish based on ocean observations and regional ocean models, and using that information to project expected groundfish distribution shifts in relation to west coast communities. This Module leverages the recent development of the R package sdmTMB, a joint product of DFO and NOAA scientists and others. The Atlantis Module builds on the SDM Module by considering how future changes in local availability of individual groundfish stocks are affected by coast-wide threshold harvest control rules and spatial closures. The Communities Module serves as a foundation for both the SDM and Atlantis Modules by exploring definitions of fishing communities, assessing changes in the footprints of the groundfish trawl fishery over time in relation to environmental change and other factors, and evaluating the potential for indicators of ecosystem change to inform National Standard 8 under the Magnuson Stevens Act. Together, this work is intended to generate new products and insights to support the US Pacific Fisheries Management Council process, including but not limited to harvest policy and spatial allocation decisions; the Climate and Communities Initiative; and marine planning activities enriched by deep, community-level analyses.

For more information, please contact Jameal Samhouri (jameal.samhouri@noaa.gov)

B. Assessment Science

1. Research

a) 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.

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

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 2021, CAP production aged 27,740 age structures and production double read 5,551 age structures. Production ages supported the 2021 stock assessments on sablefish, Dover sole, vermilion/sunset rockfish complex, copper rockfish, quillback rockfish, lingcod and the 2022 Pacific hake. Resources were also allocated to produce age estimates on anticipated assessments for 2023. CAP continued the practice of recording otolith weights prior to breaking and burning most specimens when possible. Over 20,000 otolith weights were collected in 2021 to support research into alternative methods of age determination. For our participation in the NOAA Strategic Initiative investigating the use of Fourier Transform Near-Infrared Spectrometry for rapid age assessment, CAP sent to Seattle (AFSC) 2 years of sablefish and canary rockfish surveys to be scanned by our infrared spectrometer.

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

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.

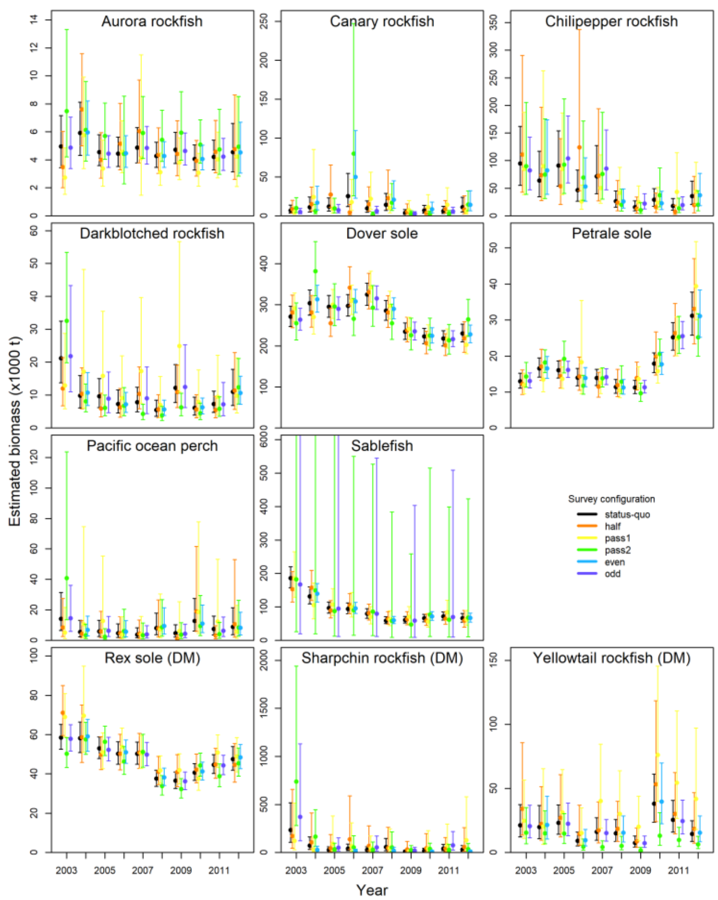

Figure 33. GLMM-derived indices of abundance and 75% lognormal confidence intervals for each survey configuration for each species. “DM” indicates species with Data Moderate stock assessments. The upper limit of the confidence intervals for sablefish that extend beyond the range of the figure are 1,451,000 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.

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

b) 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 2011 to ensure US west coast groundfish stock assessments could incorporate latitudinal variability in spawning capacity (Figure 34). 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 collected size and age at maturity estimates of over 40 groundfish species along the entire west coast. This extensive data set allows for evaluation of spatio-temporal trends in reproduction, and for understanding more about the drivers of observed variability 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 temporaldifferences in the reproductive cycle.

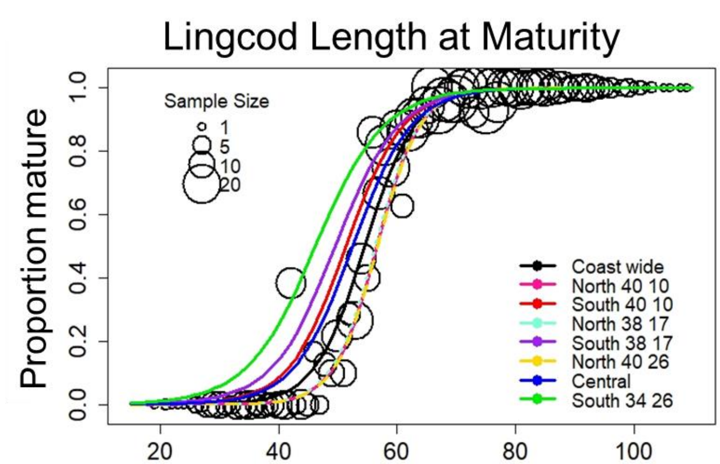

Figure 34. Latitudinal variability in spawning capacity for a representative groundfish species: lingcod.

For more information, please contact Melissa Head at Melissa.Head@noaa.gov**b) Evaluating**

C. Survey Science

1. Research

a) Three-dimensional ontogenetic shifts of groundfish in the northeast Pacific

Investigators: Lingbo Li, Anne Hollowed, Edward Cokelet, Michelle McClure, Aimee Keller, Wayne Palsson, Steve Barbeaux

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.

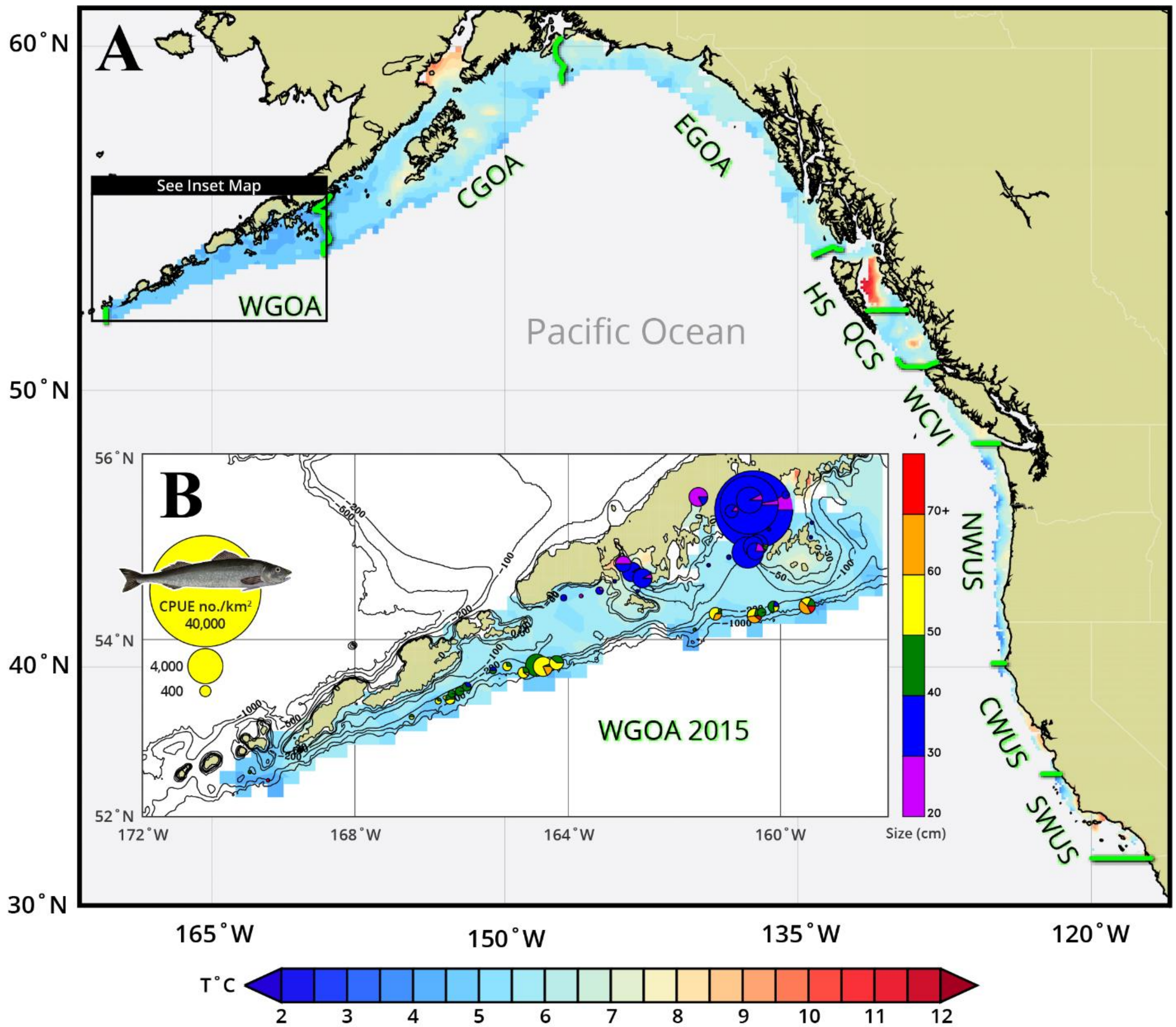

Figure 35. Mean bottom temperature map and western Gulf of Alaska (WGOA) sablefish distribution. (A) Bottom temperature was averaged 1996-2015 and interpolated to a 0.1104 X 0.0833 degree longitude-latitude grid (5 x 5 nmi at 41°N, Mercator projection) across the nine subregions in this study: western (WGOA), central (CGOA) and eastern (EGOA) Gulf of Alaska, Hecate Strait (HS), Queen Charlotte Sound (QCS), west coast Vancouver Island (WCVI), and northern (NWUS), central (CWUS) and southern (SWUS) west coast of U.S. (B) catch per unit effort (CPUE; number per km^2) of sablefish by size class (color bar on the right) in individual non-zero catch hauls during the bottom trawl survey over the WGOA in 2015. Bathymetric contours are at 50, 100, 200, 500, and 1,000 m depth.

For more information, please contact Aimee Keller at Aimee.Keller@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 2021 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.

a) 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

b) Non-catch shares

The observer program collects data in other west coast fisheries that are not part of the catch share program. The program had 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.

Table 1. The following tables summarize the West Coast Groundfish Observer Program (WCGOP), including catch shares, non-catch shares and at-sea-hake-observer program (A-SHOP), activity in 2020 and 2021 during the global COVID-19 pandemic. Most of the whiting catcher vessels still require 100% monitoring, but are carrying electronic monitoring (EM) not observers. Consequently, the number of vessels, trips, seadays and observers in table for shoreside

IFQ fixed gear, shoreside hake and MSCV are low. These values only represent the vessels still carrying observers, and do not represent the fleet.

DESCRIPTION	2020	2021
Number of catch share observers	**63**	**58**
Number of non-catch share observers	**38**	**41**
Number of A-SHOP Observers	**48**	**37**

DESCRIPTION	Shoreside IFQ Trawl		Shoreside IFQ Fixed Gear		Shoreside Hake		MSCV		A-SHOP	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Number of vessels	39	40	2	2	1	1	2	1	15	14
Number of trips	446	611	13	5	28	30	6	2	47	45
Number of Sea days (with fish ng activity)	1,274	1,736	65	23	73	80	85	59	1600	1440
Number of Observers	57	57	6	3	2	1	3	2	48	37

NonCatch Share - NCS Sea Days		
FISHERY DESCRIPTION	**2020**	**2021**
CA Cucumber Trawl	4	0
CA Emley-Platt SFCFA EFP	8	15
CA Halibut	71	105
CA Nearshore	113	119
CA Pink Shrimp	15	7
CA Real Good Fish Monterey Bay EFP	5	0
CA Ridgeback Prawn	23	6
Electronic Monitoring EFP	31	107
IPHC Directed Commercial Halibut	21	25
Limited Entry Sablefish	301	356
Limited Entry Zero Tier	28	21
OR Blue/Black Rockfish	39	89
OR Blue/Black Rockfish Nearshore	111	122
OR Cook Midwater H&L EFP	5	0
OR Pink Shrimp	169	195
Trawl Gear Modification EFP	365	147
WA Pink Shrimp	91	80
WC Open Access Fixed Gear	43	65

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

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

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

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

e) Joint and several liability in fishery cooperatives

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

3. Observer Program Reports

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DOI : https://doi.org/10.25923/8y03-z703

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E. By-catch Reduction Engineering

1. Research

a) Reducing seafloor and benthic macroinvertebrate impacts using semi-pelagic trawl technology to harvest U.S. West Coast demersal groundfishes

Investigator: Mark Lomelli

This research compared the catch efficiency and trawl-seafloor interactions between a conventional demersal trawl rigged with bottom tending doors and bottom sweeps and a semi-pelagic trawl outfitted with midwater doors and elevated sweeps (Fig. 36). Door spread sensors showed the semi-pelagic trawl had a 42 m greater door spread than the conventional demersal trawl. Further, bottom contact sensors showed the doors of the semi-pelagic trawl fished on average >63.5 cm above the seafloor. In terms of catch efficiency, the semi-pelagic trawl caught significantly more sablefish (*Anoplopoma fimbria*) than the conventional demersal trawl. For other target groundfishes such as lingcod (*Ophiodon elongatus*), Dover sole (*Microstomus pacificus*), and petrale sole (*Eopsetta jordani*), the semi-pelagic trawl on average caught more fish than the conventional demersal trawl, but not at a significant level. A sled outfitted with DIDSON sonar imagery and a video camera was towed across trawl paths of the two trawl designs to observe their interactions with the seafloor. The DIDSON sonar imagery and video footage data is currently being analyzed.

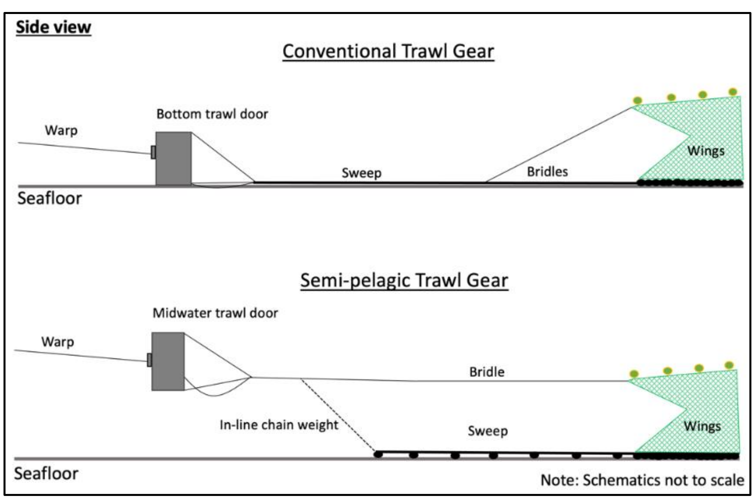

Figure 36. Schematic comparison between a conventional bottom trawl and a semi-pelagic trawl.

For more information, please contact Mark Lomelli at mark.lomelli@noaa.gov

b) Testing a dual sorting grid system to reduce juvenile sablefish catches in the West Coast groundfish bottom trawl fishery

Investigator: Mark Lomelli

This study tested a dual sorting grid system (Fig. 37) to reduce juvenile sablefish (*Anoplopoma fimbria*) catches (e.g., fish smaller than ~45 cm in total length) in the West Coast groundfish bottom trawl fishery. The unique characteristic of the dual grid system is that it consists of a double grid system to provide smaller-sized fished increased escapement opportunities In this research, we tested three different grid sizes: 6.9 x 6.9, 8.3 x 8.3, & 9.5 x 9.5 cm. Of the three grid sizes examined, the 8.3 x 8.3 cm grid size performed best at reducing catches of smaller-sized sablefish (a mean catch reduction of 45.8% for sablefish <45 cm in length was noted) while maintaining catches of preferred marketable-sized sablefish. While our study achieved positive results, fishers' input, our catch data and in situ video observations indicate that gear modifications could be made that could further enhance the performance of the grid system, and affect fishers voluntary use of the gear.

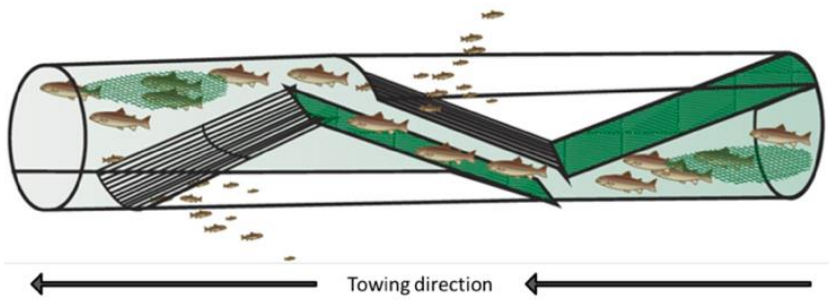

Figure 37. Schematic example of a dual grid system (From: Sistiaga et al., 2016; Fish. Res.)
For more information, please contact Mark Lomelli at mark.lomelli@noaa.gov

c) 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.

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