Northwest Fisheries Science Center

National Marine Fisheries Service

NOAA Fisheries

Agency Report to the Technical Subcommittee

of the Canada-U.S. Groundfish Committee

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I. Agency Overview

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

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

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

During 2017, FRAMD continued to: implement a West Coast observer program; conduct a coast wide survey program that includes West Coast groundfish acoustic, hook and line, and trawl surveys; develop new technologies for surveying fish populations; and expand its stock assessment, economics, and habitat research. Significant progress continues in all programs.

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

Other Divisions at the NWFSC are:

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

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

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

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

II. Surveys

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

The NWFSC conducted its twentyith annual bottom trawl resource survey for groundfish off the coasts of Washington, Oregon, and California. The objective of the 2017 survey was to provide information on the distribution and relative abundance of demersal species within this region at depths from 30 to 700 fathoms. Other biological information necessary to assess the status of groundfish stocks (e.g. length, weight, sex and age structures) was collected throughout the survey period.

The NWFSC chartered commercial fishing vessels to conduct independent, replicate surveys using standardized trawl gear. Fishing vessels *Last Straw, Noah's Ark, Ms. Julie,* and *Excalibur* were contracted to survey the area from Cape Flattery, WA to the Mexican border in Southern California, beginning in the later part of May and continuing through October. Each charter was for a period of 11-12 weeks with the *Last Straw* and *Excalibur* surveying the coast during the initial survey period from May to July. The *Noah's Ark* and *Ms. Julie* operating in tandem, surveyed the coast during a second pass from mid-August to late October. The survey area was partitioned into ~12,000 adjacent cells of equal area (1.5 nm long. by 2.0 nm lat., Albers Equal Area projection) with each vessel assigned a primary subset of 188 randomly selected cells to sample. An Aberdeen-style net with a small mesh (1 1/2" stretch) liner in the codend was used for sampling. The survey followed a stratified random sampling scheme with 15-minute tows within 2 geographic strata (80% N of Pt. Conception, CA and 20% S) and 3 depth strata. The depth strata were: shallow (30-100 fms), middle (100-300 fms), and deep (300-700 fms). The sample design consisted of 752 sampling locations, with a minimum of 30 tows per strata.

In 2017, we continued to utilized an updated backdeck data collection system with improved software applications, and wireless networking. Programming used to gather data for the groundfish survey was rewritten so that the various components were fully integrated, updated to include multiple sensor streams, and enhanced to increase flexibility for data input from special projects and future undefined data sources. The changes in the back-deck programming, wheel house programming and data QA/QC process resulted in overall improvements to data collection efficiency and anticipated future decreases in time requirements for data to be made available to the Data Warehouse. Established NOAA national bottom trawl protocols were used throughout the survey. As in prior years, a series of special research projects were undertaken in cooperation with other NOAA groups and various Universities.

Additional data were collected during the trawl survey for collaborative research projects with several NMFS/academic colleagues:
1) Collection of voucher specimens for multiple fish species – Northwest Fisheries Science Center and University of Washington;
2) Lingcod aging study – collect otolith and fin ray from one lingcod in any tow where they are collected – NWFSC Aging Laboratory;
3) collection of DNA and/or whole specimens of rougheye rockfish (S*ebastes aleutianus*), blackspotted rockfish (S*ebastes melanostictus*), darkblotched rockfish (S*ebastes crameri*) and blackgill rockfish (S*ebastes melanostomus*) to reduce uncertainty in the assessment of morphologically-similar west coast rockfish – Northwest Fisheries Science Center;

4) Collect gill filaments from all lingcod with age samples for enhanced DNA analysis – Jameal Samhouri, Conservation Biology Division, NWFSC;
5) Collect fin clips from all Pacific sleeper sharks (*Somniosus pacificus*) to examine genetics – NOAA, NWFSC – Cindy Tribuzio
6) Collect all specimens of sharpnose sculpin (*Clinocottus acuticeps*) for species confirmation – Dan Kamikawa
7) Request for photographs of lamprey scars and specimens for Pacific lamprey (*Lampetra tridentata*) and river lamprey (*Lampetra ayresii* – NWFSC, Conservation Division, Newport;
8) Collect the first 6-8 caudal thorns from big skate – Tyler Johnson, Aging Laboratory, NWFSC
9) Collect and freeze all brown and filetail catsharks captured between San Francisco and Monterey Bay – Matt Jew, Moss Landing Marine Laboratories;
10) Collection of all biological data and specimens of deepsea skate (*Bathyraja abyssicola)* and broad skate ((*Amblyraja badia*) - Moss Landing Marine Laboratories;
11) Collect biological information on 20 – 30 brown, longnose and filetail catcharks from all hauls where they occur – Amber Reichert, Moss Landing Marine Laboratories;
12) Collection of all specimens of Pacific black dogfish (*Centroscyllium nigrum*)*,* velvet dog shark *(Zameus squamulosus) and* Cookiecutter Shark *(Isistius brasiliensis).* – Moss Landing Marine Laboratories;
13) Collection of all unusual or unidentifiable skates, Pacific white skate, *Bathyraja spinossisima*, fine-spined skate, *Bathyraja microtrachys*, and Aleutian skate, *Bathyraja aleutica* – Moss Landing Marine Laboratories;
14) Collection of all unusual or unidentifiable sharks including small sleeper sharks, *Somniosus pacificus* and velvet dog shark (*Zameus squamulosus*) – Moss Landing Marine Laboratories;
15) Collection of any chimaera that is not a spotted ratfish (*Hydrolagus colliei)*, including: *Harriotta raleighana*, *Hydrolagus* spp. and *Hydrolagus trolli* – Moss Landing Marine Laboratories;
18) Collection of voucher specimens for multiple fish species – Oregon State University;
19) Coral population genetics - Collect whole specimens of *Desmophyllum dianthus* - in 95% ETOH – Cheryl Morrison;
20) 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;
21) Growth of Pacific octopods – collect all vampire squid and incirrate octopods (*Japetelle*/*Bolitaena* complex – Henk-Jan Hoving and Richard Schwarz;
22) Rosy rockfish maturity – collect whole ovary and otoliths from any rosy rockfish – Sue Sogard
23) Pacific flatnose – Collect up to 30 fin clips per leg for DNA analysis, 25 random scale samples and 25 random fish – Alexei M. Orlov.

Several other research initiatives were undertaken by the Survey Team including: 1) Use of stable isotopes and feeding habits to examine the feeding ecology of rockfish (genus *Sebastes*) and other species; 2) Fin clip collection for various shelf rockfish species; 3) Collection of stomachs for various rockfish species (darkblotched rockfish, canary rockfish, blackgill rockfish, blackspotted/rougheye rockfish, yelloweye rockfish, and cowcod; 4) Collection and identification of cold water corals; 5) Fish distribution in relation to near-bottom dissolved oxygen concentration; 6) Composition and abundance of benthic marine debris collected during the 2017 West Coast Groundfish Trawl Survey; and 8) Collection of ovaries and finclips from copper rockfish, cowcod, yelloweye rockfish, and Pacific hake; 9) Collection of ovaries from aurora rockfish, yellowtail rockfish, shortspine thornyheads, lingcod and petrale sole to assess maturity; 10) Collection of whole ovary from petrale sole to assess fecundity; 10) Collection of stomachs for non-rockfish species (arrowtooth flounder, Pacific sanddab, petrale sole, sablefish, and lingcod; 11) Collection of voucher specimens for teaching purpose; 12) Photograph, tag, bag and freeze deep water species such as arbiter snailfish (*Careproctus kamikawi*) and other rare or unidentified deep water species; 13) collection of ovaries from Dover sole, longspine thornyhead, lingcod, petrale sole, widow rockfish and arrowtooth flounder; 14) macroscopic analysis of maturity of spiny dogfish.

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

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

In early Fall 2017, FRAM personnel conducted the 14th hook and line survey for shelf rockfish in the Southern California Bight (SCB). This project is a cooperative effort with Pacific States Marine Fisheries Commission (PSMFC) and the southern California sportfishing industry aimed at developing an annual index of relative abundance and time series of other biological information for structure-associated species of groundfish including bocaccio (*Sebastes paucispinis*), greenspotted rockfish (*S. chlorostictus*), cowcod (*S. levis*) blue rockfish (*S. mystinus*), the vermilion rockfish complex (e.g., *S. miniatus* and *S. crocotulus*) and lingcod (*Ophiodon elongatus*) within the SCB.

The F/V *Aggressor* (Newport Beach, CA), F/V *Mirage* (Port Hueneme, CA), and F/V *Toronado* (Long Beach, CA) were each chartered for 14 days of at-sea research, with 13 biologists participating during the course of the survey. The three vessels sampled a total of 198 sites ranging from Point Arguello in the north to the US-Mexico EEZ boundary in the south. For the first nine field seasons, sampling was conducted aboard two chartered vessels, however a third vessel was added to the survey in 2013 in response to internal and external peer reviews recommending additional research into the role the vessel platform plays in abundance modeling. In response to research needs identified by the PFMC and stock assessment scientists, the survey began adding sites within the Cowcod Conservation Areas (CCAs). During the period 2014-16, the survey added 79 sites within the CCAs bringing the total number of sites in the sampling frame to 200. It is anticipated that monitoring at these sites will continue during subsequent surveys.

Final data are not yet available for the 2017 survey, but given the increase in number of sites sampled, should be slightly more productive relative to the 2016 survey where approximately 5,942 sexed lengths and weights, 4,872 fin clips, and 4,738 otolith pairs were taken during the course of the entire survey representing approximately 40 different species of fish. Several ancillary projects were also conducted during the course of the survey. Approximately 486 ovaries were collected from 9 different species to support the development of maturity curves and fecundity analysis. Several dozen individual fish were retained for use in species identification training for west coast groundfish observers and for a genetic voucher program conducted by the University of Washington. For the second consecutive year, the survey caught a whitespeckled rockfish (*S. moseri*) - a species rarely captured with fishing gear. There are fewer than 10 documented captures of *S. moseri*, and the two individuals caught on the hook and line survey were submitted to the University of Washington's Burke Museum. Researchers also deployed an underwater video sled to capture visual observations for habitat analysis, species composition, and fish behavior studies. The survey continued to descend or release and tag all individuals captured at 6 sites located inside federal marine reserves. To date, approximately 350 individuals have been tagged. During the 2017 stock assessment cycle, data and specimens were incorporated into the assessments for bocaccio, blue rockfish, yelloweye rockfish, yellowtail rockfish, and lingcod.

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

C. 2017 joint U.S.-Canada integrated ecosystem and Pacific hake acoustic-trawl summer survey

The joint U.S.–Canada integrated ecosystem and Pacific hake acoustic-trawl summer survey was conducted in U.S. and Canadian waters by a U.S. team (NWFSC/FRAM) on the NOAA Ship *Bell M. Shimada* from 22 June 2017 to 13 September 2017, and by a Canadian team (DFO/Pacific region) on the Canadian chartered F/V *Nordic Pearl* from 16 August 2017 to 6 September 2017. Data collected during the survey were processed to provide an estimate of the abundance and spatial distribution of the coastal Pacific hake stock shared by both countries. The survey covered the slope and shelf of the U.S. and Canada West Coast with acoustic transects from roughly 34.5°N (Point Conception, California) to 54.8°N (Southeast Alaska and Dixon Entrance). Transects were oriented east-west (except for transects in Dixon Entrance that were oriented north-south) and were spaced 10 nm apart. Acoustic data were collected on the *Shimada* with a Simrad EK60 scientific echosounder system operating at frequencies of 18, 38, and 120 kHz, as well as with a Simrad EK80 broadband scientific echosounder operating at frequencies of 70 and 200 kHz. On the *Nordic Pearl*, acoustic data were collected with a Simrad EK60 echosounder operating at frequencies of 38 and 120 kHz. The *Shimada* collected acoustic data from 102 transects and the *Nordic Pearl* from 35, resulting in a total survey-wide linear distance of 5,246 nautical miles of acoustical transect that were used for the hake biomass estimate. Aggregations of adult (age 2+) Pacific hake were detected on 91 transects from just north of Morro Bay (35.5°N), along the U.S. West Coast and west side of Vancouver Island, in Queen Charlotte Sound and Hecate Strait (up to 53.3°N), and along the southwest portion of Haida Gwaii. Highest concentrations of Pacific hake were observed from San Francisco to Newport, near the entrance to the Strait of Juan de Fuca, along the northwest side of Vancouver Island, and in Hecate Strait. Hake sign was relatively light off southern California and in Queen Charlotte Sound. Hake were absent in Dixon Entrance, southeast Alaska, and along most of the West Coast of Haida Gwaii. Midwater trawls equipped with a camera system were conducted to verify species composition of observed backscatter layers and to obtain biological information (e.g., size and sex distribution, age composition, sexual maturity). A total of 68 successful midwater trawls (51 by the *Shimada* and 17 by the *Northern Pearl*) resulted in a combined total hake catch of 31,904 kg (14,008 kg from the *Shimada* and 17,896 kg from the *Northern Pearl*). Hake accounted for 75% of the catch in U.S. waters and 89% of the catch in Canadian waters. The estimated total biomass of adult Pacific hake in 2017 was 1.418 million metric tons. Although the 2017 estimate represented a decrease of 34% from the 2015 biomass estimate (1.418 vs. 2.156), it was very close to an historical average as observed since 1995. Approximately 73% of the 2017 estimate was from U.S. waters. Age-3 hake (2014 year class) were dominant in 2017, accounting for over 60% of the total survey-wide observed adult biomass.

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

D. 2017 Integrated Ecosystem and Pacific Hake Acoustic-Trawl Winter Research Cruise

We conducted our second Integrated Ecosystem and Pacific Hake Acoustic-Trawl Winter Research Cruise from January 11, 2017 to February 12, 2017. The purpose of this research cruise is to learn more about Pacific Hake spawning, distribution in winter and migration. The survey range was 45 30.58N and down to 30 47.02N and a total of 11 trawls using our standard AWT were conducted. This research cruise was impacted by weather and vessel issues so the number of transects and trawls were reduced from our research plan. EK60 and EK80 systems were used as described above.

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

III. Reserves

A. Cowcod Conservation Area Research

1. Potential reserve effects of Cowcod Conservation Areas on shelf rockfish in the Southern California Bight

Investigators: C. Jones, J.H. Harms, J. Benante, A. Chappell, J.R. Wallace and A.A. Keller

The Northwest Fisheries Science Center (NWFSC) annually conducts a fishery-independent hook and line survey to monitor groundfish associated with hard bottom habitats within the Southern California Bight (SCB). The survey was developed in 2003 and is a collaborative effort among Pacific States Marine Fisheries Commission, NWFSC, and southern California's sportfishing industry. The survey's historical sampling frame (2003-2013) consisted of 121 fixed sites and excluded two large Cowcod Conservation Areas (CCAs). The CCAs were implemented in 2001 to protect shelf habitat and fishery resources in areas where cowcod (Sebastes levis) are most abundant by prohibiting bottom fishing in depths greater than 37 meters. In 2014, at the request of the Pacific Fishery Management Council, the hook and line survey initiated sampling inside the CCAs, and currently monitors approximately 80 sites inside the two closures. Survey data results from 2014-2016, show a significantly higher total catch inside the CCAs versus outside. In addition, the mean number of species observed per site visit is greater inside the CCAs. With only four years of data inside the CCAs, the hook and line survey will continue to monitor these sites into the future and document other potential effects on shelf rockfish related to the CCAs. Sampling inside the CCAs will also allow for a more robust estimation of relative abundance for several important rockfish species in the SCB.

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

2. Variation in size and catch of demersal fish species within the Southern California Bight in relation to the Cowcod Conservation Areas (2014 - 2016)

Investigators: A.A. Keller, J.H. Harms, J.R. Wallace, J. Benante, C. Jones and A. Chappell

Since 2001, fishing was prohibited at depths greater than 36 m in two large (10878 km^2 and 260 km^2) Southern California Bight marine reserves known as the Cowcod Conservation Areas (CCAs). The Pacific Fishery Management Council established the CCAs in response to declining abundance of west coast rockfishes, particularly overfished cowcod. We investigated variations in catch rate, size, length frequency and percent of positive sites for 12 abundant groundfish (bank, bocaccio, chilipepper, copper, cowcod, greenspotted, lingcod, olive, speckled, squarespot, starry and the vermilion-sunset complex) inside and outside the CCAs using data from the Southern California Hook and Line Survey, an annual fishery independent survey. From 2014 to 2016, the Hook and Line Survey sampled up to 75 fixed sites within the CCAs and 121 sites outside the restricted areas using rod and reel gear. Generalized Linear Models (GLMs) that included area, year, depth and distance from port revealed significantly greater catch rates for 8 of 12 species and total catch of all species within the CCAs related to the area main effect ($P< 0.03$)). Significantly elevated catch occurred for cowcod within the CCAs ($P < 0.0001$) but related to depth not area. Significantly lower catch occurred for copper, lingcod, and the vermilion complex inside the CCAs. We also observed significant differences ($P<0.05$) in length frequency distribution and mean size for nine species and the vermilion-sunset complex with larger fish present inside the CCAs. Length frequency and mean size of bank and starry rockfishes were not significantly different by area. The proportion of sites positive for individual species tended to be greater inside the CCAs for nine species, although significant differences occurred only for bank, bocaccio and starry rockfishes.

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

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

A. Hagfish: No research or assessments in 2017

B. Dogfish and other sharks: No assessments in 2017

1. Research

a) If the tag fits.....finding the glass slipper of tags for spiny dogfish (*Squalus suckleyi*).

Investigators: C. Tribuzio and K.S. Andrews

There are a multitude of technologies available for tagging and tracking fish species, however, not all tags are appropriate for all species or situations. The spiny dogfish (Squalus suckleyi) is a small species of shark, common in coastal waters of the eastern North Pacific Ocean. Fishery dependent tags, those requiring recapture of the fish to recover data, are less appropriate for this species because of the likely biased response rate. The purpose of this study was to examine fishery independent tag technology for spiny dogfish. There are two main types of fishery independent tags: satellite transmitting (relatively high resolution archived data) and acoustic transmitting (low resolution data, only when tags are in range of receiver). The satellite tags have historically been too large to apply to small species, but miniaturization of the technology has dramatically reduced tag size. These tags are limited to a short battery life and greater potential for failure. Acoustic tags have a longer battery life and less of a potential for failure, but data is limited to the spatial extent of the receivers. In this study we double tagged six spiny dogfish in Puget Sound, Washington with both satellite and acoustic tags. Results suggest that either tag type would work well for the species, but both have benefits and drawbacks. In general, the satellite tags perform better for large scale movements, and provide high resolution depth and temperature (i.e., habitat) data, while the acoustic tags provide better fine scale movement information with lower resolution depth data.

Citation: Tribuzio, C.A. and K.S. Andrews. 2016. If the tag fits.....finding the glass slipper of tags for spiny dogfish (*Squalus suckleyi*). Western Groundfish Conference, Newport, OR. February 2016.

For more information please contact Kelly Andrews at Kelly.Andrews@noaa.gov.

b) Sibling rivalry: do sixgill sharks (*Hexanchus griseus*) co-occur in kin-structured pairs within nursery habitat of an inland estuary?

Investigators: K.S. Andrews and S. Larson

The association of individuals in the animal kingdom is based on several life-history, reproductive and behavioral processes. Some taxa, such as mammals, have relatively small litters, care for their young and form close-knit family units that remain together for several years and in some instances for their entire lives. However, many fishes broadcast spawn millions of eggs or release thousands of larvae into the water column, provide no subsequent parental care and never come in contact with offspring or siblings. In order to determine whether sixgill sharks move in kin-structured groups, we monitored the movement of 24 individuals from 2006 to 2009 in Puget Sound, WA. Using tissue samples from each shark, we were able to calculate the relatedness of all sharks collected. Using kinship coefficient values, pairs of sharks that were more closely related to each other were more likely to be detected at the same location during the same week than pairs of sharks that were not closely related to each other.

For more information please contact Kelly Andrews at Kelly.Andrews@noaa.gov.

c) Shark Interactions with Directed and Incidental Fisheries in the Northeast Pacific Ocean: Historic and Current Encounters, and Challenges for Shark Conservation.

Investigators: J. King, G. McFarlane, V. Gertseva, J. Gasper, S.Matson and C. Tribuzio

For over 100 years, sharks have been encountered, as either directed catch or incidental catch, in commercial fisheries throughout the Northeast Pacific Ocean. A long-standing directed fishery for North Pacific Spiny Dogfish (*Squalus suckleyi*) has occurred and dominated shark landings and discards. Other fisheries, mainly for shark livers, have historically targeted species including Bluntnose Sixgill Shark (*Hexanchus griseus*) and Tope Shark (*Galeorhinus galeus*). While incidental catches of numerous species have occurred historically, only recently have these encounters been reliably enumerated in commercial and recreational fisheries. In this chapter we present shark catch statistics (directed and incidental) for commercial and recreational fisheries from Canadian waters (off British Columbia), southern US waters (off California, Oregon, and

Washington), and northern US waters (off Alaska). In total, 17 species of sharks have collectively been encountered in these waters. Fishery encounters present conservation challenges for shark management, namely, the need for accurate catch statistics, stock delineation, life history parameter estimates, and improved assessments methods for population status and trends. Improvements in management and conservation of shark populations will only come with the further development of sound science-based fishery management practices for both targeted and incidental shark fisheries.

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

C. Skates: No assessments in 2017

1. Research
a) Standardizing the age reading protocol for longnose skate (*Raja rhina*).

Investigators: M. Arrington, T. Essington, T. Helser, B. Matta, C. Gburski, V. Gertseva, O.Ormseth and J.King

Longnose skate (*Raja rhina*) occur along most of the North American Pacific coast. While there is not currently a directed fishery for skates, they are commonly caught and retained as bycatch in the groundfish fishery. The ability to accurately estimate their abundance is important because their long life span and low fecundity make skates more vulnerable to overfishing. Despite this species' continuous range, it is managed in three separate regions: U.S. West Coast, British Columbia, and Gulf of Alaska. Each region currently has different age determination protocols which may lead to biases in age estimates. With collaboration between these three federal agencies, this study aims to standardize aging protocols based on validated age reading criteria. In doing so, spatial and temporal variability in growth may be also be explored. The results from this study will increase available age data and improve the understanding of longnose skate life history parameters as well as potentially improve the precision of abundance estimates.

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

D. Pacific cod: No research or assessments in 2017

E. Walleye Pollock: No assessments in 2017

1. Research

a) The relative influence of temperature and size-structure on fish distribution shifts: A case-study on Walleye pollock in the Bering Sea

Investigators: J. Thorson, S. Kotwicki and J. Ianelli

Research has estimated associations between water temperature and the spatial distribution of marine fishes based upon correlations between temperature and the centroid of fish distribution (centre of gravity, COG). Analysts have then projected future water temperatures to forecast shifts in COG, but often neglected to demonstrate that temperature explains a substantial portion of historical distribution shifts. We argue that estimating the proportion of observed distributional shifts that can be attributed to temperature vs. other factors is a critical first step in forecasting future changes. We illustrate this approach using Gadus chalcogrammus (Walleye pollock) in the Eastern Bering Sea, and use a vector-autoregressive spatiotemporal model to attribute variation in COG from 1982 to 2015 to three factors: local or regional changes in surface and bottom temperature ("temperature effects"), fluctuations in size-structure that cause COG to be skewed towards juvenile or adult habitats ("size-structured effects") or otherwise unexplained spatiotemporal variation in distribution ("unexplained effects"). We find that the majority of variation in COG (including the north-west trend since 1982) is largely unexplained by temperature or size-structured effects. Temperature alone generates a small portion of primarily north–south variation in COG, while size-structured effects generate a small portion of east–west variation. We therefore conclude that projections of future distribution based on temperature alone are likely to miss a substantial portion of both the interannual variation and interdecadal trends in COG for this species. More generally, we suggest that decomposing variation in COG into multiple causal factors is a vital first step for projecting likely impacts of temperature change.

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

F. Pacific whiting (hake)

1. Research

a) Spatio-temporal reproductive patterns in Pacific Hake, *Merluccius productus,* using a flexible model to estimate functional maturity

Investigators: M.A. Head, I.G. Taylor and J.M. Cope

Over the last decade, fisheries managers increasingly identified a need for up-to-date, coast wide reproductive information on groundfishes along the west coast. Many management models used out of date maturity studies that were localized and often from unreliable macroscopic maturity estimates. In response to this, the NWFSC FRAM's division instituted a reproductive biology program in 2009 using two sampling platforms. We sampled Pacific hake ovaries from the West Coast Groundfish Trawl Survey in 2009 and 2012 - 2017. In 2012, we expanded the sampling platform to capture better spatio-temporal patterns. This included sampling from the Fisheries Engineering Acoustics and Technology (FEAT) summer survey, the at-sea hake observer program in the spring and fall months, and finally the FEAT winter survey in 2016 – 2017. From 2009 – 2016, we histologically assessed 2544 hake maturity samples. These coast wide collections allowed us to explore biogeographic relationships North and South of Pt. Conception, CA (34.44°N) within varying temporal patterns. Overall length and age at 50% (L_{50}, A_{50}) maturity were estimated at 33.4 cm and 2.3 years. However, L_{50} results north and south of Pt. Conception varied substantially, with corresponding L_{50} estimates of 35.0 and 26.2 cm. In addition, to the varying spatial relationships, we found temporal trends in their reproductive cycle; including time of spawning, shift in spawning locality, and interannual variability in the rate of skipped spawning. To account for skip spawning we estimated length at maturity using a spline model that incorporates the fraction of adult sexually mature skip spawners into a flexible asymptote.

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

2. Assessment

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

Investigators: A. Edwards, I. Taylor, C. Grandin and A. Berger

This stock assessment reported the collaborative efforts of the official U.S. and Canadian JTC members in accordance with the Agreement between the government of the United States and the government of Canada on Pacific hake/whiting. The assessment reported the status of the coastal Pacific Hake (or Pacific whiting, 1*Merluccius productus*) resource off the west coast of the United States and Canada for 2018. Coast-wide fishery landings of Pacific hake averaged 230 thousand mt from 1966 to 2017, 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 2008–2017 have been above the long term average, at 276 thousand mt. Landings between 2013 and 2015 were predominantly comprised of fish from the very large 2010-year class, comprising around 70% of the total removals. Landings in 2016 and 2017 had high proportions for the 2010 and 2014-year classes. In 2017, U.S. fisheries caught mostly 3- and 7-year old fish from the 2010 and 2014 year classes, while the Canadian fisheries encountered mostly 7-year old fish from the 2010 year-class. The Agreement between the United States and Canada establishes U.S. and Canadian shares of the coast-wide TAC at 73.88% and 26.12%.

Data were updated for the 2018 assessment with the addition of fishery catch and age compositions from 2017, the acoustic survey biomass estimate and age composition for 2017, and other minor refinements such as catch estimates from earlier years. The assessment used Bayesian methods to incorporate prior information on two key parameters (natural mortality, M, and steepness of the stock-recruit relationship, h) and integrated over parameter uncertainty to provide results that can be probabilistically interpreted. The exploration of uncertainty was not limited to parameter uncertainty as structural uncertainty was investigated through sensitivity analyses. Pacific Hake displays the highest degree of recruitment variability of any west coast groundfish stock, resulting in large and rapid changes in stock biomass. This volatility, coupled with a dynamic fishery, which potentially targets strong cohorts resulting in time-varying selectivity, and little data to inform incoming recruitment until the cohort is age-2 or greater, will, in most circumstances, continue to result in highly uncertain estimates of current stock status and even less-certain projections of future stock trajectory. Uncertainty in this assessment is largely a function of the potentially large 2014 year-class, the potentially above average 2016 year-class, uncertain selectivity, and uncertainty about historical weight-at-age of fish (i.e., that associated with equilibrium conditions prior to or in the absence of fishing). However, with recruitment being a main source of uncertainty in the projections, short term forecasts are very uncertain.

The base model estimates indicate that since the 1960s, Pacific hake female spawning biomass has ranged from well below to near unfished equilibrium biomass. The model estimates that the stock was below the unfished equilibrium in the 1960s and 1970s, increased toward the unfished equilibrium after two or more large recruitments occurred in the early 1980s, and then declined steadily through the 1990s to a low in 2000. This long period of decline was followed by a brief peak in 2003 as the large 1999-year class matured and subsequently supported the fishery for several years. Estimated female spawning biomass declined to an all-time low of 0.568 million mt in 2010 because of low recruitment between 2000 and 2007, along with a declining 1999-year class. Spawning biomass estimates have increased since 2009 on the strength of large 2010 and 2014 cohorts and an above average 2008 cohort. The 2018 female spawning biomass is estimated to be 66.7% of the unfished equilibrium level (B_0) with a 95% posterior credibility interval ranging from 33% to 136%. The median estimated 2018 female spawning biomass is 1.36 million mt.

Estimates of historical Pacific hake recruitment indicate very large year classes in 1980, 1984, 1999, and 2010. The U.S. fishery and the coastwide acoustic survey show that the 2014 year-class comprised a very large proportion of the observations in 2017. Uncertainty in estimated recruitments is substantial, especially for 2014 and 2016, as indicated by broad posterior intervals. 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 (99.4% of the target). Fishing intensity has been substantially below the $F_{40\%}$ target since 2012, but has been rising since 2015. The official coastwide total catch target adopted by the U.S. and Canada has not been exceeded since 2002. Fishing intensity is estimated to have not exceeded the target rate. Recent catch and levels of depletion are presented in Figure 1.

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

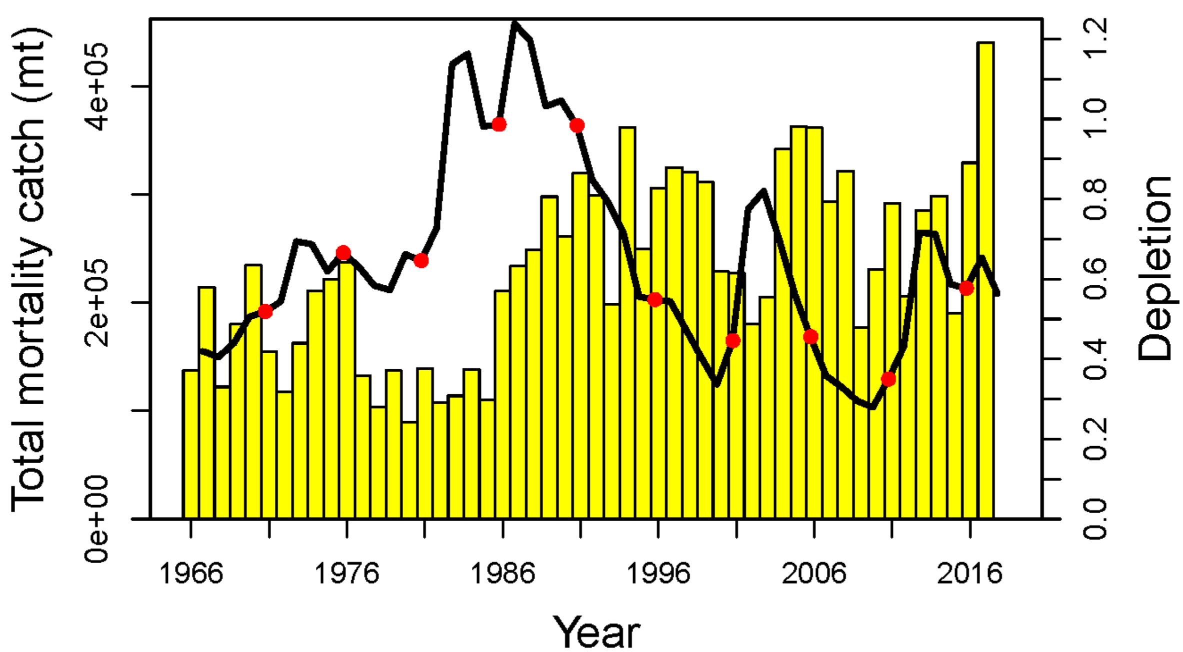

Figure 1. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Pacific hake, 1966-2017.

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

G. Grenadiers: No research or assessments in 2017

H. Rockfish

1. Research

a) Canary rockfishes (*Sebastes pinniger*) return from the brink: catch, distribution and life history along the U.S. west coast (Washington to California)

Investigators: A.A. Keller, P.H. Frey, J.R. Wallace, M.A. Head, C.R. Wetzel, J.M. Cope and J.H. Harms

We examined catch, distribution, and life history parameters for canary rockfishes *Sebastes pinniger*, an important groundfish that severely limited other U.S. west coast fisheries from 2000 to 2015 due to their overfished status. Average catch varied among years but catch-per-unit-effort, tows with positive catch, and biomass significantly increased since 2007. Weight-length and size-at-age relationships varied by regions separated at key biogeographic breakpoints. Weight increased more rapidly as a function of length north of Pt. Conception, CA, regardless of gender. Growth rates of females and maximum size of males increased with latitude with the greatest increases north of Pt. Conception. Mature females most commonly occurred north of Cape Mendocino, CA and at depths >115 m. Observed variations in spatial patterns (catch and distribution) and life history characteristics combined with reduced occurrence of large/old canary south of Cape Mendocino suggest coast-wide differences that indirectly imply existence of distinct biological stocks. However, since growth and condition appear related to basin-wide (Pacific Decadal Oscillation) and regional (based on *in situ* data) climatic effects, environmental variation may also contribute to the differences observed here.

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

b) Cooperative research sheds light on population structure and listing status of threatened and endangered rockfish species

Investigators: K.S. Andrews, K.M. Nichols, A. Elz, N. Tolimieri, C.J. Harvey, D. Tonnes, D. Lowry, R. Pacunski and K.L. Yamanaka

In 2010, the National Marine Fisheries Service listed yelloweye (*Sebastes ruberrimus)* and canary rockfish (*S. pinniger*) as threatened and bocaccio (*S. paucispinis*) as endangered in Puget Sound (PS), WA, USA under the federal Endangered Species Act (ESA). However, this decision was made despite a lack of data to directly answer the first criterion of an ESA listing – Is the population segment "discrete" and "significant" from the remainder of the taxon? Indirect evidence from other species or *Sebastes* spp. in other geographic regions was the primary basis of the listing decision. To answer the first criterion directly, we collaborated with recreational fishing communities to collect tissue samples from these rare species in PS. We used population genetics analyses to determine whether samples from PS were genetically "discrete" from samples collected from the outer coast. Thousands of genetic markers for each species were surveyed using restriction-site associated DNA sequencing (RAD-seq). Multiple analyses showed that yelloweye rockfish collected in inland waters of PS and British Columbia, Canada were genetically different from coastal populations, whereas we found no evidence of population structure for canary rockfish. The sample size for bocaccio was insufficient to test the hypothesis. These data support the ESA designation status for yelloweye rockfish, but suggest canary rockfish in PS are not a "discrete" population and do not meet the first criterion of the ESA. Collaboration among agencies and fishing communities and technological advances in genetic sequencing provided the framework for the first de-listing of a marine fish species under the ESA.

For more information please contact Kelly Andrews at Kelly.Andrews@noaa.gov.

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

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

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

For more information please contact Kelly Andrews at Kelly.andrews@noaa.gov.

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

Investigators: K.S. Andrews and D. Tonnes

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

For more information please contact Kelly Andrews at Kelly.Andrews@noaa.gov.

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

Investigators: B. Bartos, K.S. Andrews, C.J. Harvey P. MacReady and D. Tonnes

Genetic evidence has shown that yelloweye rockfish in Puget Sound/Georgia Basin (PSGB) are distinct from populations on the outer coast of the United States and Canada, while canary rockfish show no broad-scale population structure among these regions. Adult canary rockfish have been characterized as transient with wide-ranging spatial movements that may cover hundreds of kilometers over the span of multiple years. Adult yelloweye rockfish are characterized by low rates of migration with little month-to-month variability in horizontal and vertical movements. The genetic information is consistent with these characteristics and suggest adult movement is a likely mechanism for population connectivity in canary rockfish and for population differentiation in yelloweye rockfish. However, numerous marine populations are connected via the dispersal of individuals at very young ages (e.g., larvae and pelagic juveniles). This project will begin to investigate whether differences in the timing of release and location of release of larvae may provide a second mechanism for the connectivity of canary rockfish and the population differentiation observed in yelloweye rockfish. Canary rockfish have peaks in larvae release in February-March, while yelloweye rockfish peak in May-June. Horizontal and vertical volume transport varies seasonally in the PSGB region. Horizontal advection is greatest in summer and early autumn, while vertical advection is more negative (waters moving from surface to deep) in May/June as compared to relatively no net vertical advection in February/March. We are using ocean circulation models to simulate larval dispersal of canary and yelloweye rockfish throughout this region. "Larvae" will be released at different times of year, respective of each species, from different locations and tracked for a period of 4 months, which is an approximate period that they spend in the plankton. We will then calculate the proportion of larvae that are transported into or out of PSGB and coastal locations and the proportion retained within each region. This should provide preliminary information to test whether interactions between larval release timing, larval behavior and swimming ability, and oceanographic conditions provide a mechanism for differential larval dispersal that might explain the observed genetic differences for these species in the PSGB region.

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

2. Assessments

a) The Combined Status of Blue and Deacon Rockfishes in U.S. Waters off California and Oregon in 2017

Investigators: E.J. Dick, A. Berger, J. Bizzarro, K.M. Bosley, J. Cope, J. Field, L. Gilbert-Horvath, N. Grunloh, M. Ivens-Duran, R. Miller, K. Privitera-Johnson and B.T. Rodomsky

This assessment reports the status of the Blue Rockfish (*Sebastes mystinus*) and the recently described Deacon Rockfish (*Sebastes diaconus*) as a stock complex in U.S. waters off the coast of California and Oregon. The complex is modeled with two independent stock assessments to approximate spatial variation in species composition, exploitation history, and other factors affecting stock dynamics. The California model represents the stock complex in U.S. waters from Point Conception (34˚ 27´ North latitude) to the California-Oregon border (42˚ N. lat.), and the Oregon model includes all U.S. waters off the coast of Oregon. Recent genetic analyses suggest that Blue Rockfish may be the dominant species south of Monterey Bay, CA, with an increasing fraction of Deacon Rockfish north of Monterey and into Oregon. Historical data streams did not separate the two species or estimate removals at a spatial scale small enough to evaluate assessment boundaries near Monterey Bay.

Harvest of Blue and Deacon Rockfishes (BDR) is primarily from recreational fisheries, with a smaller commercial component coming from longline and hook and line gear types. Total removals in California north of Point Conception increased steadily following World War II, peaking in the late 1970s and early 1980s with annual removals exceeding 600 mt per year (Figure 1). This was followed by a decline in catch until about 2010. Recent years have seen a steady increase in landings, but total removals remain low relative to historical levels. Total landings in Oregon have generally increased through time up until the late-1990s when landings returned to levels in the 2000s that more consistent with those observed in the 1980s (Figure 2). Since the implementation of management limits on the Oregon commercial fishery in 2004 (fleet size limit, annual landing caps, and daily and period landing limits) and on the recreational fishery since 2001 (bag limit reductions), landings have reduced and have been generally stable.

California

The California assessment is structured as a single, sex-disaggregated, unit population, spanning U.S. waters from Point Conception to the California-Oregon border, and operates on an annual time step covering the period 1900 to 2017. The model is conditioned on catch from two sectors (commercial and recreational) divided among eight fleets, and is informed by five abundance indices. Size composition data include lengths from multiple fleets, and a limited number of age structures from the recreational fishery and two research programs.

Spawning output of BDR in California was estimated to be 812 million eggs in 2017 (~95% asymptotic intervals: 0-1,661 million eggs), or 37% of unfished spawning output ("depletion," ~95% asymptotic intervals: 0-78.5%; Figure 1). In California, spawning output declined rapidly in the 1970s and early 1980s, falling below the minimum stock size threshold in the early 1980s, followed by a steady recovery since the late 2000s. The trend in spawning output in 2017 is approaching the management target (40% of unfished spawning output), but the precision of that estimate is low relative to other management reference points (e.g. the $SPR_{50\%}$ proxies for target spawning output and maximum yield). A recent, strong recruitment in 2013 has contributed to the recent increase in BDR biomass in California. Above-average recruitments in 2008 and 2009 are largely driven by recent age data covering the years 2010-2011, but the 2007 recruitment appears to be supported by multiple data sources, as well. Overall, variability in recruitment is average (to low) relative to other rockfish species. The annual (equilibrium) SPR harvest rate for BDR in California has been below target since 2008. Prior to 2008, the harvest rate exceeded the target for over 30 years, regularly reaching levels 50% above target in the 1980s and 1990s. As with current estimates of spawning output, recent estimates of exploitation status are highly uncertain, ranging from 13% to 120% of target in 2016.

The 2017 BDR assessment for California is generally consistent with the results of the 2007 assessment. However, estimates of recent stock size based on the 2017 assessment are imprecise, which results in imprecise forecasts of yield. Uncertainty associated with natural mortality, steepness of the stock-recruitment relationship, the lack of available age data, and gender-specific population dynamics were the main drivers of model imprecision.

Oregon

The Oregon assessment is structured as a single, sex-disaggregated, unit population, spanning Oregon coastal waters, and operates on an annual time step covering the period 1892 to 2017. The model is conditioned on catch from two sectors (commercial and recreational) divided among 5 fleets, and is informed by four abundance indices, length compositions for each fleet, and age compositions from the recreational fishery, the commercial fishery, and from research surveys.

BDR spawning output in Oregon was estimated to be 296 million eggs in 2017 (~95% asymptotic intervals: 64-527 million eggs), which when compared to unfished spawning output equates to a depletion level of 69% (~95% asymptotic intervals: 0.52-0.85; Figure 2) in 2017. In general, spawning output has been trending slightly downwards, with the exception of an increase in the 1990s due to several high recruitment years. Stock size is estimated to be at the lowest level throughout the historic time series in 2017, but the stock is estimated to be well above the management target of $B_{40\%}$. Recruitment variability was dynamic for BDR in Oregon and indicated well above average recruitment in 2013. Other years with relatively high estimates of recruitment were 1993, 1994, and 1995. The BDR stock in Oregon has not been depleted to levels that would provide information on how recruitment changes with spawning output at low spawning output levels. Harvest rates in Oregon have generally increased through time until the mid-1990s when harvest was reduced to a relatively stable level beginning in the 2000s. The maximum relative harvest rate was 0.92 in 1993 (or 92% of the target level) before declining again to around 0.40 in recent years. In 2016, Oregon BDR biomass is estimated to have been 1.73 times higher than the target biomass level, and fishing intensity remains lower than the SPR fishing intensity target.

Major sources of uncertainty associated with the 2017 BDR assessment for Oregon were the size of population scale, natural mortality, gender-specific population dynamics (selectivity), and catch history for certain time periods. Significant uncertainty about recruitment in recent years leads to uncertainty in short term forecasts of yield.

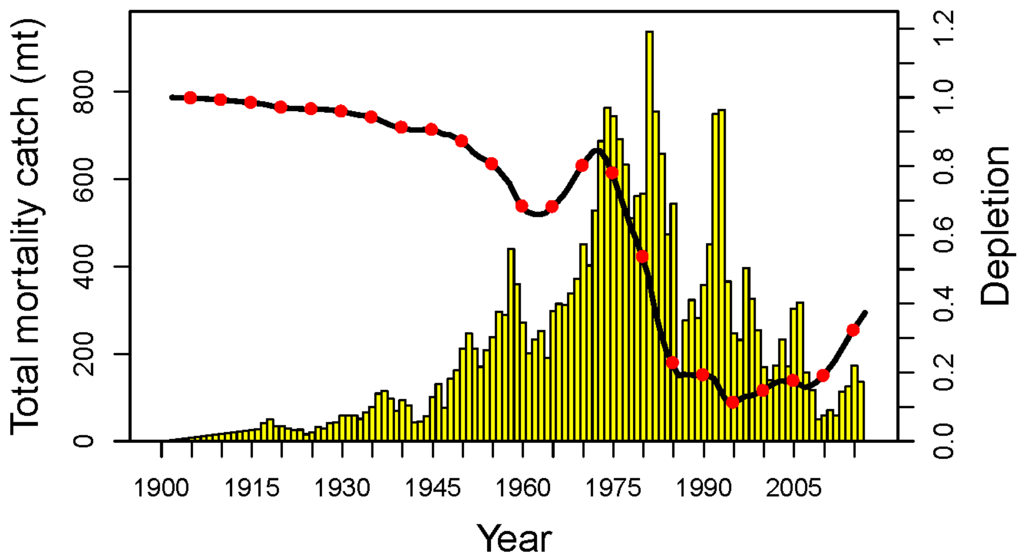

Figure 2. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Blue and Deacon Rockfishes in California, 1900-2016.

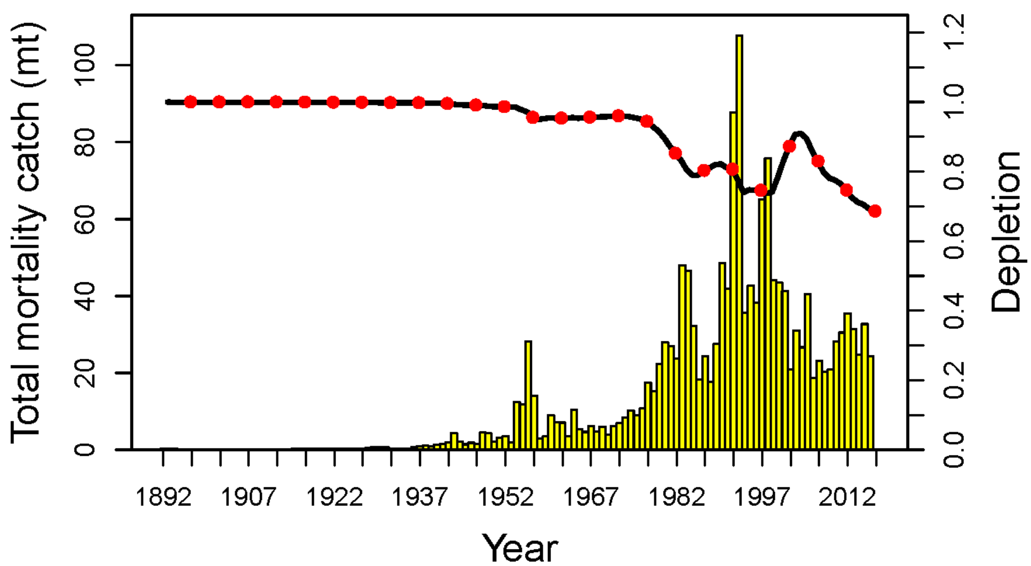

Figure 3. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Blue and Deacon Rockfishes in Oregon, 1892-2016.

For more information, please contact E.J. Dick at Edward.Dick@noaa.gov (California assessment) or Aaron Berger at Aaron.Berger@noaa.gov (Oregon assessment).

b) Darkblotched rockfish

Investigators: J.R. Wallace and V. Gertseva

Darkblotched rockfish (*Sebastes crameri*) in the Northeast Pacific Ocean occur from the southeastern Bering Sea and Aleutian Islands to near Santa Catalina Island in southern California. This species is most abundant from off British Columbia to Central California. Commercially important concentrations are found from the Canadian border through Northern California. This assessment focuses on the portion of the 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 population within this area is treated as a single coastwide stock, due to the lack of biological and genetic data supporting the presence of multiple stocks.

Darkblotched rockfish has always been caught primarily with commercial trawl gear, as part of a complex of slope rockfish, which includes Pacific ocean perch (*Sebastes alutus*), splitnose rockfish (*Sebastes diploproa*), yellowmouth rockfish (*Sebastes reedi*), and sharpchin rockfish (*Sebastes zacentrus*). Catches taken with non-trawl gear over the years comprised less than 2% of the total coastwide domestic catch. This species has not been taken recreationally.

Catch of darkblotched rockfish first became significant in the mid-1940s when balloon trawl nets (efficient in taking rockfish) were introduced, and due to increased demand during World War II. The largest removals of the species occurred in the 1960s, when foreign trawl fleets from the former Soviet Union, Japan, Poland, Bulgaria and East Germany came to the Northeast Pacific Ocean to target large aggregations of Pacific ocean perch, a species that co-occurs with darkblotched rockfish. In 1966 the removals of darkblotched rockfish reached 4,220 metric tons. By the late-1960s, the foreign fleet had more or less abandoned the fishery. Shoreside landings of darkblotched rockfish rose again between the late-1970s and the late-1980s, peaking in 1987 with landings of 2,415 metric tons. In 2000, the species was declared overfished, and landings substantially decreased due to management regulations. During the last decade the average landings of darkblotched rockfish made by the shoreside fishery was around 120 metric tons. Since the mid-1970s, a small amount of darkblotched rockfish has been also taken as bycatch in the at-sea Pacific hake fishery, with a maximum annual removal of 49 metric tons that occurred in 1995. In 2000, the species was declared overfished, and landings substantially decreased due to management regulations. During the last decade the average landings of darkblotched rockfish made by the domestic trawl fishery was around 120 metric tons.

The first stock assessment of darkblotched rockfish was done in 1993 and stock assessments have been conducted frequently since then. This current update assessment, conducted in 2017, shows that the stock of darkblotched rockfish off the continental U.S. Pacific Coast is currently at 40.03% of its unexploited level. This is just above the management target of 40% of unfished spawning output ($SB_{40\%}$). The time series of total mortality catch (landings plus discards) and estimated depletion for darkblotched rockfish are presented in Figure 1.

The spawning output of darkblotched rockfish started to decline in the 1940s, during World War II, but exhibited a sharp decline in the 1960s during the time of the intense foreign fishery targeting Pacific ocean perch. Between 1965 and 1976, spawning output dropped from 90% to

64% of its unfished level. Spawning output continued to decline throughout the 1980s and 1990s and in 2000 reached its lowest estimated level of 17% of its unfished state. Since 2000, the spawning output has been slowly increasing, which corresponds to decreased removals due to management regulations.

The assessment model captures some 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 natural mortality, which was found to have a relatively large influence on the perception of current stock size. Female natural mortality in the assessment is fixed at the value estimated outside the model, based on other life history characteristics of the species, while male natural mortality is estimated within the model. Uncertainty from natural mortality is reported via alternate states of nature in the decision table, bracketing the base model results.

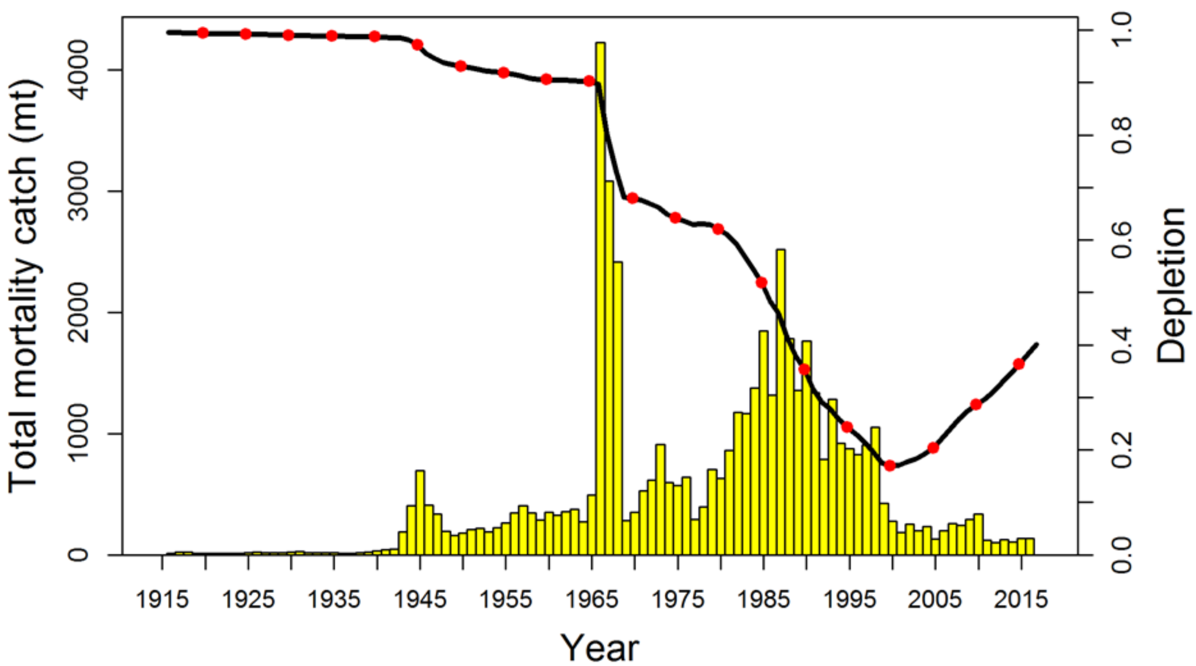

Figure 4. The time series of total mortality catch (bars) and estimated depletion (line) for darkblotched rockfish.

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

c) Status of Pacific ocean perch (*Sebastes alutus*) along the US west coast in 2017

Investigators: C. Wetzel, L. Cronin-Fine and K. Johnson

Pacific ocean perch (POP) were the target of distant-water foreign fishing fleets operating off the west coasts of U.S. and Canada during the mid-1960s to mid-1970s. This species also occurs off northern Japan but in the eastern Pacific the species is most abundant in the Gulf of Alaska and occurs as far south as Baja California. The portion of population off the U.S. West Coast, which has generally been treated as a single separate stock for assessment and management purposes, was declared overfished in 1999. The current assessment, as in the most recent previous assessment (Hamel et al. 2011), assumes that POP off the U.S. West Coast are a single, unit stock whose dynamics are independent of POP populations off Canada and in the Gulf of Alaska.

The stock assessment was conducted with Stock Synthesis. Data were compiled into three fishing fleets and several indices of relative abundance. The three fishing fleets were a commercial fleet (combining three gear-types: bottom trawl, midwater trawl and fixed gear), a historical foreign fleet, and the at-sea hake fleet. These fishing fleet definitions were based on discard practices, with unreported discards only assumed to occur in the commercial fleet. For this fleet the model included a retention curve and was informed by observer data on discard rates and length-compositions. Several indices of relative abundance were considered during development of the model, including fishery dependent CPUE indices and fishery independent surveys (POP survey, the Triennial survey, the AFSC slope survey, the NWFSC slope survey and the NWFSC shelf-slope survey). The NWFSC shelf-slope survey provides the longest the time series and is considered the most reliable information on population abundance and data. Selectivity was estimated for each modeled fleet using observations of age and/or length composition data, except for the historical foreign fleet, which assumed the same selectivity as the commercial fleet because no data were available for the foreign fleet to inform its own selection curve. The NWFSC shelf-slope survey age data were included as conditional age-at-length observations (CAAL). For some fleets both the age and length composition data were included. All fleets and surveys were modeled with double normal selectivity parameterizations except for the POP survey, which was forced to estimate an asymptotic selectivity pattern. The assessment model was structured to have two sexes and it started from an unfished non-equilibrium state in 1918 with annual recruitment deviations estimated to 2015.

The model estimates that the spawning output of POP at the start of 2017 was 5,280 million eggs and was at 72% of its unfished level. The trajectory of spawning output has been increasing steadily since about 1990 and underwent a rapid increase during the last three years, largely due to exceptionally large recruitment in 2008 and strong recruitment in 2013. The assessment estimates that the stock's spawning output hovered at or slightly below the Council's target level (40% of unfished) for a period extending from approximately the mid-1970s to the late-1990s with the stock never dropping below the below the Council's minimum stock size threshold (MSST, 25% of unfished, i.e., the stock was never overfished). The estimated dynamics from this stock assessment are considerably different from the prior assessment, which indicated the stock was in a depleted state below the MSST for a period extending from 1980 to 2011, reaching a low point of 14% depletion in 1998. The differing views of the stock from the two assessments was partly due to the inclusion of new data, but primarily driven by changes in key assumed life-history parameters (natural mortality and steepness).

The current data for Pacific ocean perch weighted according to the Francis weighting approach do not contain information regarding steepness or natural mortality and hence both were fixed within the final model. Natural mortality was fixed at the median of the prior, 0.054 yr^{-1}. The estimated final status was highly dependent upon the assumed steepness value, as is typical for most US west coast groundfish assessments. The data available and the modeling approach applied in 2011 supported a steepness value of 0.40. However, the current data no longer support this value. Models that used the mean to the 2017 steepness prior (0.72) resulted in stock size estimates near unfished conditions leading to low survey catchability for the NWFSC shelf-slope survey that the Scientific and Statistical Committee (SSC) deemed implausible. A steepness value for the final model was determined by a form of model averaging. Spawning output was calculated across a range of steepness values (0.25-0.95) which were considered equally likely. The expected (i.e. arithmetic mean) ending spawning output was calculated and the steepness value most closely associated with the expected value was identified, a value of 0.50. Additional research for alternative approaches for determining steepness values when traditional approaches do not seem appropriate should be identified.

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

d) Stock assessment of the yelloweye rockfish (*Sebastes ruberrimus*) in state and Federal waters off California, Oregon and Washington in 2017

Investigators: V. Gertseva and J.M. Cope

Yelloweye rockfish (*Sebastes ruberrimus*) are distributed in the northeastern Pacific Ocean from the western Gulf of Alaska to northern Baja California. The species is most abundant from southeast Alaska to central California. This assessment reports the status of the yelloweye rockfish resource off the coast of the United States from southern California to the U.S. - Canadian border. The species is modeled as a single stock, but with two explicit spatial areas: waters off California (area 1) and waters off Oregon and Washington (area 2). Each area has its own unique catch history and fishing fleets (commercial and recreational), but the areas are linked by a common stock-recruit relationship.

Yelloweye rockfish have historically been a prized catch in both commercial and recreational fisheries. Commercially, they have been caught by trawl and hook-and-line gear types. They have generally yielded a higher price than other rockfish and have largely been retained when encountered. Catches of yelloweye rockfish increased gradually throughout the first half of the 20th century, with a brief peak around World War II due to increased demand. The largest removals of the species occurred in the 1980s and 1990s and reached 552 mt in 1982.
After 2002 (when yelloweye were declared overfished), total catches have been maintained at much lower levels. Currently, yelloweye are caught only incidentally in commercial and sport fisheries targeting other species that are found in association with yelloweye. The recent fishery encounters a very patchy yelloweye rockfish distribution, and extensive effort is made to avoid all but a small amount of bycatch.

This current assessment, conducted in 2017, estimates that the stock of yelloweye rockfish off the continental U.S. Pacific Coast is currently at 28.4% of its unexploited level. This is above the overfished threshold of SB25%, but below the management target of SB40% of unfished spawning output. Both areas are above the overfished level of 25% (Figure ES-7). This is 7.4 percent higher than the estimated relative spawning output of 21.0% from the previous assessment, conducted in 2011.

This assessment estimates that historically, the coastwide spawning output of yelloweye rockfish dropped below the SB40% target for the first time in 1986, and below the SB25% overfished threshold in 1993 as a result of intense fishing by commercial and recreational fleets. It continued to decline, and dipped to 14.2% of its unfished output in 2000. In 2002, the stock was declared overfished. Since then, the spawning output is slowly increasing due to management regulations implemented for this and other overfished rockfish species.

The time series of total mortality catch (landings plus discards) and estimated depletion for darkblotched rockfish are presented in Figure 1.

The assessment model captures some 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 natural mortality, which was found to have a relatively large influence on the perception of current stock size. Natural mortality in the assessment is fixed at the value estimated outside the model, based on other life history characteristics of the species, while male natural mortality is estimated within the model. Uncertainty from natural mortality is reported via alternate states of nature in the decision table, bracketing the base model results.

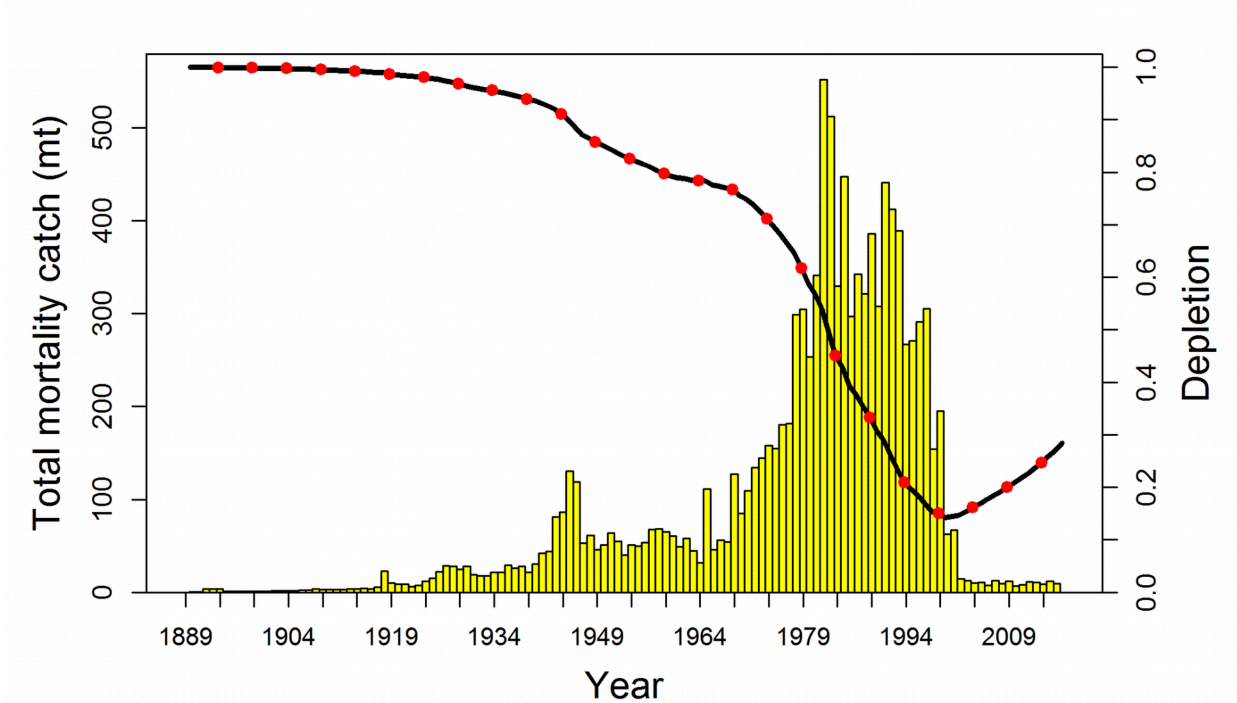

Figure 5. The time series of total mortality catch (bars) and estimated depletion (line) for yelloweye rockfish.

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

e) Rebuilding analysis for yelloweye rockfish (*Sebastes ruberrimus*) based on the 2017 stock assessment

Investigators: V.V. Gertseva and J.M. Cope

This rebuilding analysis for the stock of yelloweye rockfish (*Sebastes ruberrimus*) in waters off California, Oregon and Washington is based on the 2017 stock assessment. The 2017 assessment model estimated the yelloweye rockfish resource to be at 28.4% of the unexploited equilibrium spawning output at the beginning of 2017. This rebuilding analysis compares the results of applying a suite of potential management actions to the stock for 2019 and beyond, assuming Annual Catch Limits (ACLs) of 20 mt (adopted by the Pacific Fishery Management Council) being removed in 2017 and 2018 and assuming 65% of the ACL (13 mt) being removed in 2017 and 2018.

The results of the analysis show that the value for T_{MIN}, the median year for rebuilding to the target level in the absence of fishing since the year of declaration (2002), is 2025 (revised downward from 2037 in the 2011 rebuilding analysis). The estimated generation time has decreased by one year to 45 years compared to the 2011 analysis. In conjunction with T_{MIN}, the mean generation time dictates the revised estimate of T_{MAX} to be 2070 (decreased from 2083 in the 2011 analysis). The harvest rate in the current rebuilding plan (SPR_{TARGET}) is 76% and T_{TARGET} = 2074. The SPR = 76% harvest rate generates a P_{MAX} (probability of recovery by T_{MAX}) of 100% in the current model, (in the 2011 analysis it was 72.9%).

Fishing at the current SPR target (SPR = 76%) results in an increase from the 20 mt ACL in 2018 to 29 mt in 2019. This harvest rate has a 100% probability of recovery by the year 2027, a 100% probability of recovery by T_{TARGET} = 2074 (the current rebuilding target), and a 100% probability of recovery by T_{MAX} = 2070.

In general, the faster rebuilding times in the 2017 analysis compared to the 2011 analysis are associated with the higher estimates of recruitment compensation (i.e., steepness) and stock status in the 2017 assessment compared to the 2011 assessment.

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

I. Thornyheads: No research or assessments in 2017

J. Sablefish: No assessments in 2017

1. Research

a) Oceanographic drivers of sablefish recruitment in the California Current

Investigators: N. Tolimieri, M.A. Haltuch, Q. Lee, M.G. Jacox and S.J. Bograd

Oceanographic processes and ecological interactions can strongly influence recruitment success in marine fishes. Here, we develop an environmental index of sablefish recruitment with the goal of elucidating recruitment-environment relationships and informing stock assessment. We start with a conceptual life-history model for sablefish *Anoplopoma fimbria* on the US west coast to generate stage- and spatio-temporally-specific hypotheses regarding the oceanographic and biological variables likely influencing sablefish recruitment. Our model includes seven stages from pre-spawn female condition through benthic recruitment (age-0 fish) for the northern portion of the U.S. sablefish stock (40-50 °N). We then fit linear models and use model comparison to select predictors. We use residuals from the asserted sablefish stock-recruitment relationship in the 2015 assessment as the dependent variable (thus removing the effect of spawning stock biomass). Predictor variables were drawn primarily from ROMS model outputs for the California Current Ecosystem. We also include indices of prey and predator abundance and freshwater input. Five variables explained 57% of the variation in recruitment not accounted for by the stock-recruitment relationship asserted in the sablefish assessment. Recruitment deviations were positively correlated with (1) colder conditions during the spawner preconditioning period, (2) warmer water temperatures during the egg stage, (3) stronger cross shelf transport to near-shore nursery habitats during the egg stage, (4) stronger long-shore transport to the north during early development, and (5) cold surface water temperatures during the larval stage. This result suggests that multiple mechanisms likely affect sablefish recruitment at different points in their life-history.

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

K. Lingcod:

1. Research

a) Landscape genomics & life history diversity in lingcod on the US West Coast

Investigators: J.F. Samhouri, K.S. Andrews, B. Brown, J. Cope, S. Hamilton, L. Lam, G. Longo, K. Nichols and G. Williams

Demographic rates, life history traits, and genetic structure are the foundations of stock assessment models. Mounting evidence suggests that genetic stock structure and geographic variation in demographic rates and life history traits (hereafter, regional stock structure) may be much more common than previously assumed, in some cases due to natural gradients in environmental factors such as temperature, habitat, prey availability, and predation pressure. More recently, the field of landscape genomics has begun to reveal the extent to which such gradients in environmental factors lead to predictable genotypic variation. This possibility is especially likely for reef-associated nearshore stocks, as they occupy spatially-fractured habitats likely to produce localized demographic, life history, and genetic differences.

Despite universal recognition of the potential for regional stock structure, most stock assessment models currently in use along the US West Coast have assumed (often due to data limitations) homogeneous stock structure across broad regions. Thus, most commercial and recreational fisheries are managed with a single set of regulations (e.g., catch limits) tuned to biological parameters that are fixed over large spatial scales. Inappropriate assumptions of spatial homogeneity can produce inefficiencies in fisheries yields and revenues, and thus there is a great need to use information on spatial heterogeneity in demographic, life history, and genetic variability to guide future stock assessment efforts.

Using lingcod, Ophiodon elongatus, as a focal stock, this project aims to develop a general approach for determining if there are regional differences in degraphic rates, life history traits, and genetic composition along the US West Coast. Lingcod are one of the stocks determined to be a high priority for habitat science following regional Habitat Assessment Prioritization, and they are listed under the Fish Stock Sustainability Index. On the US West Coast, the lingcod stock has been rebuilt recently from a depleted state, and in some places is now considered underutilized (e.g., Central and Northern CA Coast). These large, piscivorous, temperate fish occur from Baja California to Alaska in relatively shallow (common to 200 m), rocky habitats, and can show substantial spatial variability in life history-related traits (e.g., lingcod body length can be two-fold greater in WA than in CA). Combined with the fact that lingcod have relatively small home ranges, geographic variability in body size creates huge potential for regional differences in demographic rates and life history traits. Previous work examining lingcod genetic structure using allozymes, mtDNA, and microsatellites has proven equivocal, and no analyses have been conducted on lingcod collected after 2000, since the stock rebuilt. The most recent stock assessment considered separate Northern (WA and OR) and Southern (CA) stocks, but stressed major uncertainty with respect to (i) the proper break points for stocks and sub-stocks and (ii) stock-specific length-at-age data.

We have collected lingcod from all regions of the U.S. West Coast and, in 2017, are sampling Puget Sound, WA, and southeast Alaska. In addition, the FRAM trawl survey team has collected lingcod for us as part of a Special Project in 2015-2016, and plans to sample gill tissues for us in 2017. When collections from all regions are complete, we will evaluate the extent to which demographic rates and life history traits vary spatially, and whether there is a genetic basis for such variation using cost-effective sampling techniques and state-of-the-art approaches in genetics.

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

b) Spatial demographic and life-history variation in Lingcod (Ophiodon elongatus) along the U.S. West Coast

Investigators: L. Lam, S. Hamilton, J. Samhouri, J.M. Cope and B. Brown

Fish populations are known to exhibit spatial variability in life history demography due to factors such as temperature, productivity, habitat, and fishing pressure. However, most stock assessment methods neglect to account for these differences and assume that life history traits are constant and unchanging across space and time. As a result, stocks are managed across broad geographic areas with catch quotas, size limits and other regulations applying equally in all places, running the risk of over-harvesting in one area while underharvesting in another. In this study, Lingcod were collected throughout their U.S. range from 7 geographically distinct regions (Alaska to Southern California) in collaboration with volunteer anglers. We evaluated regional differences in Lingcod sizes and age structure, growth parameters, the timing at 50% maturity, and total mortality rates. Size structure, growth, and maturity rates were found to exhibit a latitudinal cline, where Lingcod in northern waters grew faster, larger, and matured at larger sizes than Lingcod in southern waters. Between sexes, females were found to grow slower, larger, and matured at larger sizes than males. There was no trend in total mortality. Overall, these findings demonstrate significant latitudinal and sex-based variability of life history traits and demography in Lingcod stocks. Implications for applying these findings to other groundfish species and stock assessment models will be discussed.

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

2. Assessments

a) 2017 Lingcod Stock Assessment

Investigators: M.A. Haltuch, J.R. Wallace, C.A. Akselrud, J. Nowlis, L.A.K. Barnett, J.L. Valero, T.S. Tsou and L. Lam

This assessment applies to lingcod (*Ophiodon elongatus*) off the West Coast of the United States, and is conducted as two separate single stock assessment models, Washington and Oregon in the north, and California in the south. Four fisheries are modeled in the north: commercial trawl (including limited landings in other net gears), commercial fixed gears, and WA and OR recreational fisheries. Three fisheries are modeled in the south: commercial trawl (including limited landings in other net gears), commercial fixed gears, and CA recreational fisheries. Both models start in1889, at the onset of landings.

This assessment uses the Stock Synthesis (SS) fisheries stock assessment model, version 3.30.03.07. Lingcod has been modeled using various age-structured forward-projection models since the mid-1990s, with the most recent assessments conducted during 2005 (Jagielo et al. 2005) and 2009 (Hamel et al. 2009). Base model data sets include: landings data from each fleet; commercial discard data from the West Coast Groundfish Observer Program (WCGOP), NMFS Triennial bottom trawl survey, NWFSC bottom trawl survey, the NWFSC Hook and Line survey, PacFIN commercial logbook CPUE, OR nearshore commercial CPUE, both WA and OR recreational CPUE (North Only), commercial, recreational, and research length composition data, and survey age composition data (including CAAL data from the NWFSC bottom trawl survey).

The north base model indicates that the lingcod female spawning biomass off of Washington and Oregon declined rapidly in the 1980s and 1990s, hitting a low during the mid-1990s, and has subsequently recovered to levels above the target reference point. The south base model indicates that the lingcod female spawning biomass off of California declined rapidly in the 1970s and early 1980s, reaching a low point during the 1990s, but that the southern stock has recovered above the minimum stock size threshold and remains in the precautionary zone (i.e. below the target reference point).

Stock status is currently estimated to be above the target reference point (40% of the estimated unfished spawning biomass) at 57.9% (47.9–67.8, 95% asymptotic interval) in the north and in the precautionary zone at 32.1% (11.1–53.1, 95% asymptotic interval) in the south. Unfished spawning biomass was measured at 37,947 mt (25,776–50,172 mt, 95% asymptotic interval) in the north and 20,260 mt (15,304–25,215 mt, 95% asymptotic interval) in the south. Spawning biomass at the beginning of 2017 was estimated to be 21,976 mt (12,517-31,434 mt, 95% asymptotic interval) in the north and 6,509 mt (1,624–11,394 mt, 95% asymptotic interval) in the south. The north stock is estimated to have been below the target reference point from approximately the

1980s through the early 2000s, while the south stock is currently estimated to be in the precautionary zone.

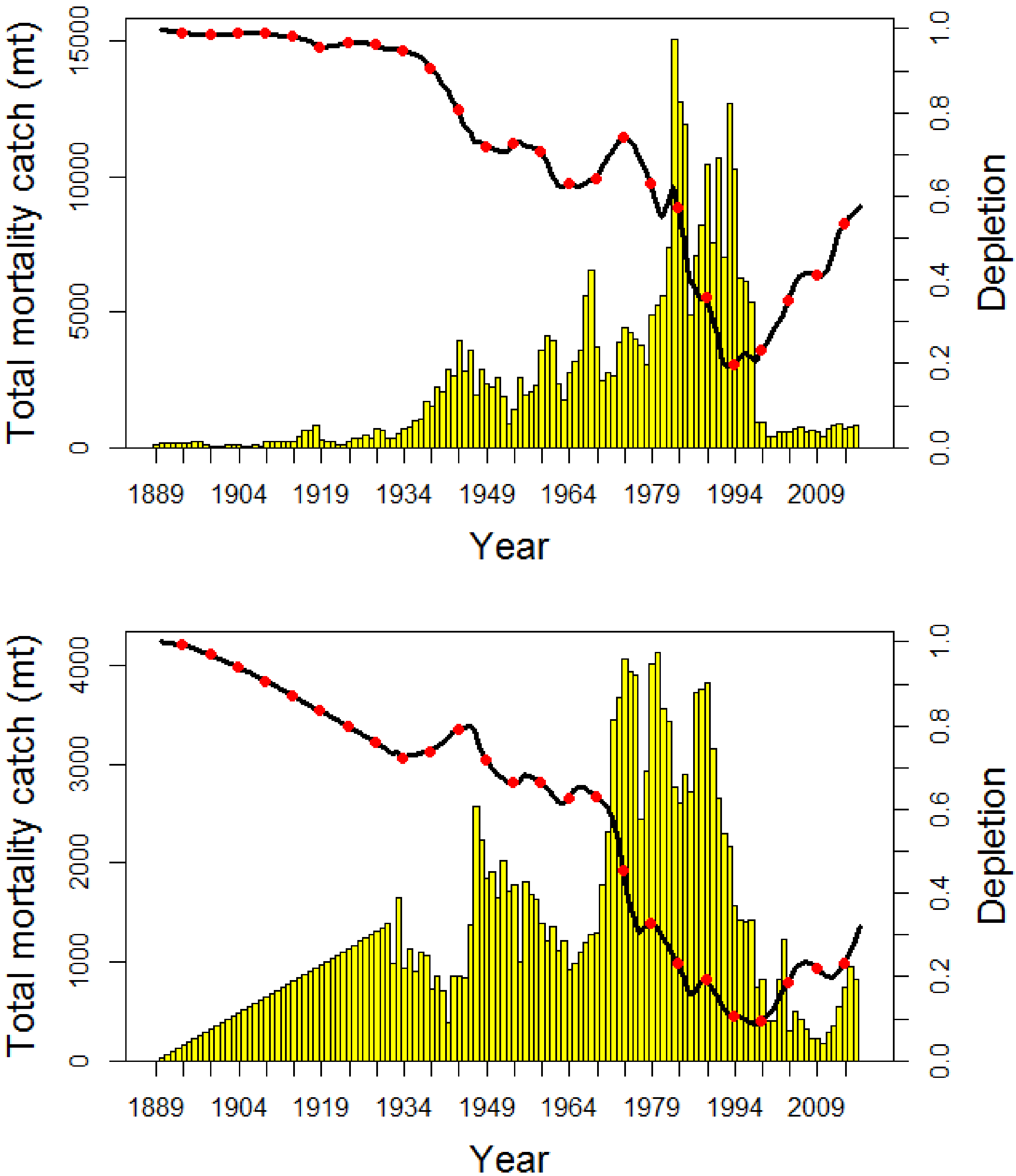

Figure 6. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for the Lincod north (upper panel) and south (lower panel) stocks.

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

L. Atka mackerel: No research or assessments in 2017

M. Flatfish: No research or assessments in 2017

N. Pacific halibut & IPHC activities: No research or assessments in 2017

O. Other groundfish species: No assessments in 2017

1. Research

a) Dynamic population trends observed in the deep-living Pacific flatnose, *Antimora microlepis*, on the U.S. West Coast

Investigators: P.H. Frey, A.A. Keller and V. Simon
As fisheries managers attempt to incorporate ecosystem-based considerations into decision making, it is important to understand the role that non-target species play in the ecosystems that support commercial fisheries. For some deep-water groundfishes, basic information on biology and population dynamics is extremely limited. This study presents findings on the spatial distribution, growth trends, and relative abundance of the Pacific flatnose, *Antimora microlepis*, using data collected from 2003 to 2015 by the Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl Survey (WCGBTS). We observed a 67% increase in mean fork-length over the study period reflecting the advancement of strong year-classes from the early 2000s that currently dominate the population as a whole. Catch-weighted depth increased significantly as these cohorts migrated to deeper waters of the continental slope. Although catch per unit effort remained relatively constant, this demographic shift suggests that episodic recruitment may affect the resilience of this stock to fishing mortality over time. A notable decrease in the percentage of females observed after 2012 seemed to indicate the movement of large, older females to depths beyond the 1280 m limit of the survey. Otolith weight provided a useful proxy for age in growth models for this species.

For more information, please contact Peter Frey at Peter.Frey@noaa.gov.

VII. Ecosystem Studies

A. Assessment Science

1. Modeling

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

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

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

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

b) Closing the Loop: On Stakeholder Participation in Management Strategy Evaluation

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

Management strategy evaluation (MSE) is a simulation-based analytical approach used to examine the efficacy of various management options to achieve fishery- and ecosystem-related objectives while integrating over system uncertainties. As a form of structured decision analysis, MSE is amenable to stakeholder involvement which can be used to reduce implementation barriers associated with non-transparent decision-making procedures. In this paper, we outline the basic components that define MSE with focus on stakeholder engagement and provide suggestions to improve ownership of MSE results by all user groups involved in the fishery and broader ecosystem. Specifications that go into an MSE are often case-specific, including the aspirations of stakeholders involved, which can dictate the need for customized analytical, visual, and educational tools. No matter the context, communication and education are critical components to implementing a successful MSE. Communication breakdown can be avoided by clearly defining roles, responsibilities and terms of engagement for all involved, clearly laying out the goals and objectives of the MSE before modeling has begun, and providing opportunities to revisit the goals throughout the MSE process.

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c) Shifts in stock productivity: recruitment potential and static/dynamic reference points

Investigator: Aaron Berger

Reference points guide rational fishery management systems worldwide, and often form the basis for defining sustainable fishing levels and population sizes, population states that result in preferred fishery performance, and population states that trigger management action. Many reference points used for determining stock status are pre-supposed by equilibrium population assumptions, which may be inappropriate when stock productivity differs in space or through time as a result of persistent environmental change, variable management and fishing practices, predator-prey dynamics, and many other factors. Static reference points may not be robust to new equilibrium states (e.g., due to regime shifts), leading to a mismatch between the productive capacity of the population and the benchmarks used to guide management. Dynamic reference points, e.g. dynamic B_0, could be used to take into account shifts in the underlying productivity of the population, but careful consideration of the recruitment dynamics is warranted to ensure that management benchmarks are informed by current productivity potential, not cyclical, white noise, or other process-based errors in recruitment estimation. Static and dynamic reference points were calculated for 18 recent west coast groundfish stock assessments to first evaluate if differences in depletion-based stock status indicators were apparent between the two approaches. Second, a set of simulations were conducted to further compare differences between static and dynamic reference points under alternative states of nature driven by recruitment dynamics (productivity regime), fishing dynamics (mortality regime), and species biology and longevity. The use of dynamic B_0 often implies a different state of the stock under directional productivity regime shifts, but is more similar to static (equilibrium) B_0 under cyclic or white noise productivity scenarios. Despite the approach used to define reference points for current stock status and management, it remains unclear how best to forecast recruitment when developing stock rebuilding plans and is an area of future research.

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

d) Fisheries management of spatially structured populations: addressing the quandary of allocating harvest quotas

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

Ignoring spatial population structure in the development of fisheries management advice can affect population resilience and yield. However, the resources required to develop spatial stock assessment models that match the scale of spatial management are often unavailable. As a result, quota recommendations from spatially aggregated assessment models are commonly divided among management areas based on empirical or *ad hoc* methods. We applied a spatially explicit simulation model to two case studies (Pacific hake and sablefish) to explore how population structure and connectivity influence spatial distribution of harvest and to evaluate several empirical quota allocation methods for approximating maximum system yield. Although using spatially resolved data to inform catch allocation provided a reasonable approximation for maximizing system-level yield, area-specific harvest rates were often biased, which led to depletion within management units. When connectivity existed through post-recruitment movement of individuals, results demonstrated that multiple combinations of fishing mortality rate applied across management units produced the same maximum system yield, suggesting that socioeconomic factors could be important in determining which harvest scheme is truly 'optimal' with desired conservation outcomes.

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e) Estimating recruitment in spatially-explicit stock assessment models: the impacts of population structure assumptions on recruitment bias

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

Recruitment estimation within stock assessment models can be difficult when limited data on year class strength exist, and estimation difficulties may be exacerbated as demographic data become sparser (i.e., when data are disaggregated to perform a spatially explicit stock assessment). However, spatially explicit modeling techniques may improve estimates of population productivity by simultaneously assessing individual spawning components (along with the connectivity among them) instead of aggregating data and parameter estimates across multiple reproductive units, which commonly occurs with closed population models. Although spatial models can more accurately represent the underlying population dynamics, there has been little research into the potential risk associated with incorrect assumptions regarding population structure and how it might impact resulting productivity estimates. We develop a spatially explicit, tag-integrated assessment model that directly estimates movement and is able to account for a variety of population structure assumptions (e.g., panmictic, single population with spatial heterogeneity, metapopulation, and natal homing). A simulation framework is applied to compare bias in recruitment estimates when population structure is correctly or incorrectly specified for both spatially explicit and spatially aggregated assessment methods. We also investigate how recruitment and movement assumptions interact within spatially explicit models to determine whether certain parameterizations may act to reduce parameter correlation. When the underlying population structure is correctly specified, recruitment and movement are often well estimated. However, misspecification of spatial structure can lead to biases equivalent to or worse than assuming a panmictic population. Even when incorrectly specified, spatial models may be more useful than aggregated models, because outputs are provided on scales more likely to represent real-world biology and may better inform fine-scale spatial management.

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f) When to use spatially-explicit fishery stock assessments: Are good data good enough?

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

Spatially-explicit stock assessment models can provide information on spatiotemporal variation in population parameters, which are necessary to inform fine-scale fishery management decisions. However, spatial models often require spatially-explicit data that may be sparse or unavailable. While an increasing number of assessment methods employ spatially explicit techniques, simulation studies have yet to evaluate the potential biases associated with both the quality and quantity of data and the effect of mis-diagnosing spatial population structure. We develop a generalized spatially explicit, tag-integrated assessment model that directly estimates movement and is able to account for common spatial population structures (e.g., panmictic, single population with spatial heterogeneity, metapopulation, and natal homing). A simulation framework is then applied, which generates both tagging and population data, to determine the robustness of various parametrizations of the assessment model to a variety of data quality, quantity, and collection scenarios. Results indicate that incorporating tagging data can greatly improve estimation of movement rates and management quantities, but is not strictly required for robust management depending on the underlying population structure, connectivity and assessment parametrization. Based on these simulations, we provide general guidelines on the data needed to assess spatially structured populations, and provide recommendations about tag-recapture experimental design that can be used to better inform tag-integrated assessment frameworks. Appropriate data can allow informed decisions about population structure and connectivity that then make spatially explicit models valid, potentially achieving greater accuracy in parameter estimates than traditional spatially aggregated assessment models.

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

g) Spatial growth variability in marine fish: example from northeast Pacific groundfish

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

Life history parameters of marine fishes vary in space and time, often in response to multiple factors. Understanding this variability is vital to resource management and ecological knowledge. We examined spatial variability in growth of eight groundfish species in the northeast Pacific Ocean to identify shared spatial patterns and hypothesize about common mechanisms behind them. Growth parameters were estimated in different areas over the latitudinal range of the species and multiple hypotheses were tested as to whether growth parameters differ in all the areas, at specific area breaks or exhibit a latitudinal cline. Clear differences emerged among the species examined. Shelf species exhibited the highest growth rate between Cape Blanco and Cape Mendocino, which may in part be attributed to area-specific upwelling patterns in the California Current ecosystem, when nutrient rich deep water is brought to the surface southward of Cape Blanco and is uniquely distributed throughout this area, providing favorable conditions for primary productivity. Slope species showed a cline in asymptotic size (L_∞), with L_∞ increasing from south to north. This cline, previously attributed to fishery removals, also fits a specific case of the widely described Bergmann's rule, and we explore specific potential ecological mechanisms behind this relationship.

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

h) Novel Catch Projection Model for a Commercial Groundfish Catch Shares Fishery

Investigators: S. Matson, I. Taylor, V.V. Gertseva and M. Dorn

Fishery catch projection models play a central role in fishery management, yet are underrepresented in the literature. A wide range of statistical approaches are employed for the task, including multiple regression models, autoregressive methods, different classes of generalized linear models, mixed model approaches and many others. However, the applicability of these statistical approaches can be limited in specific cases of complex fisheries. We developed a new catch projection model for quota-based fisheries on the West Coast of the U.S. to forecast annual catch and landings for a variety of groundfish species in the Northeast Pacific Ocean. The model projects total and landed catch of each species by individual vessel and for the entire fishing fleet, using a combination of weighted mean vessel attainment rates and historical catch rates, and generates uncertainty intervals. It demonstrated an ability to produce highly accurate predictions at both fleet (R^2=0.9847) and vessel levels (R^2=0.8447). The model framework contains much built-in versatility, is generalizable enough to serve a variety of quota based applications, and the approach can be tailored to other fisheries around the world. With the proliferation of quota based management of commercial fisheries, tools such as this one are increasingly useful for sustainable management of fishery resources.

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

i) Incorporating Climate Driven Growth Variability into Stock Assessment Models: a Simulation-based Decision Table Approach

Investigators: Q. Lee, J. Thorson, V.V. Gertseva and A. Punt

Indices of annual growth variation are not routinely incorporated into fisheries stock assessment models, due to a lack of a general framework for deciding when to include these indices, and of a mechanistic understanding about growth drivers. Such incorporation may also not necessarily lead to improved estimation or management performance. We develop a way to incorporate such an index into an assessment model (Stock Synthesis), and use risk analysis to evaluate its management-related advantages and shortcomings. We applied this method to splitnose rockfish (*Sebastes diploproa*), where a previously-developed growth index is highly correlated with decadal-scale climate indices. We find that including a similar index in the simulated assessment increases precision and reduces bias of parameter estimates. However, not including an index or including a completely erroneous index led to highly imprecise estimates when growth was strongly climate-driven. Including this growth index when individual growth was actually constant did not lead to poorer estimation performance. The risk analysis approach can be applied to other stocks to evaluate the consequences of including time-varying growth indices.Indices of annual growth variation are not routinely incorporated into fisheries stock assessment models, due to a lack of a general framework for deciding when to include these indices, and of a mechanistic understanding about growth drivers. Such incorporation may also not necessarily lead to improved estimation or management performance. We develop a way to incorporate such an index into an assessment model (Stock Synthesis), and use risk analysis to evaluate its management-related advantages and shortcomings. We applied this method to splitnose rockfish (*Sebastes diploproa*), where a previously-developed growth index is highly correlated with decadal-scale climate indices. We find that including a similar index in the simulated assessment increases precision and reduces bias of parameter estimates. However, not including an index or including a completely erroneous index led to highly imprecise estimates when growth was strongly climate-driven. Including this growth index when individual growth was actually constant did not lead to poorer estimation performance. The risk analysis approach can be applied to other stocks to evaluate the consequences of including time-varying growth indices.

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

j) Improving stock assessments of a wide-ranging species: Estimation of spatial and temporal variability in life history parameters of longnose skate (*Raja rhina*).

Investigators: T. Helser, T. Essington, V.V. Gertseva, O. Ormseth, J. King, B. Matta, C. Gburski

Skates are commonly taken as bycatch in Pacific groundfish fisheries, yet most species are managed as data-poor stocks because relatively little is known regarding their life history parameters. Increasing exploitation of this group is of concern because their biological traits (e.g., long life span, slow growth, low fecundity, and late age at maturity) make them vulnerable to overfishing and prone to slow recovery. The longnose skate (*Raja rhina*), a common large-bodied species ranging from the eastern Bering Sea to Baja California, is managed under U.S. and Canadian federal jurisdiction. Despite the regular occurrence of this species in fisheries catches throughout its range, stock assessments for longnose skate in its three main management regions (U.S. West Coast, British Columbia, and Gulf of Alaska) are considered data poor and/or highly uncertain. Key data limitations are the paucity of age estimates across all three regions and potential biases owing to inconsistency in age determination procedures among laboratories. However, due to recent cooperative efforts between the Alaska Fisheries Science Center (AFSC), Northwest Fisheries Science Center (NWFSC), and Canadian Department of Fisheries and Oceans (DFO), longnose skate age estimation at AFSC was found to be accurate based on bomb-derived radiocarbon (^{14}C) validation. Further, over 2,000 age structures have been collected from longnose skate across all three management regions since 2008 and are awaiting age determination. The goals of this international collaborative project are to: 1) standardize the age determination protocol across the three federal agencies responsible for skate management in the U.S. West Coast (NWFSC), British Columbia, Canada (DFO), and the Gulf of Alaska (AFSC) based on validated age determination criteria (King et al. 2015), 2) estimate ages for a backlog of longnose skate vertebrae and reexamine historically aged specimens based on the standardized protocol, and 3) estimate life history parameters and examine spatial and temporal variability in those vital rates for sensitivity analysis in stock assessments.

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

k) Accounting for spatial complexities in the calculation of biological reference points: effects of misdiagnosing population structure for stock status indicators

Investigators: D. Goethel and A. Berger

Misidentifying spatial population structure may result in harvest levels that are unable to achieve management goals. We developed a spatially explicit simulation model to determine how biological reference points differ among common population structures and to investigate the performance of management quantities that were calculated assuming incorrect spatial population dynamics. Simulated reference points were compared across a range of population structures and connectivity scenarios demonstrating the influence of spatial assumptions on management benchmarks. Simulations also illustrated that applying a harvest level based on misdiagnosed spatial structure leads to biased stock status indicators, overharvesting, or foregone yield. Across the scenarios examined, incorrectly specifying the connectivity dynamics (particularly misdiagnosing source–sink dynamics) was often more detrimental than ignoring spatial structure altogether. However, when the true dynamics exhibited spatial structure, incorrectly assuming panmictic structure resulted in severe depletion if harvesting concentrated on more productive population units (instead of being homogeneously distributed). Incorporating spatially generalized operating models, such as the one developed here, into management strategy evaluations will help develop management procedures that are more robust to spatial complexities.

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l) Space oddity: The mission for spatial integration

Investigators: A. Berger, D. Goethel, P. Lynch, T. Quinn, S. Mormede, J. McKenzie and A. Dunn

Fishery management decisions are commonly guided by stock assessment models that aggregate outputs across the spatial domain of the species. With refined understanding of spatial population structures, scientists have begun to address how spatiotemporal mismatches among the scale of ecological processes, data collection programs, and stock assessment methods (or assumptions) influence the reliability and, ultimately, appropriateness of regional fishery management (e.g., assigning regional quotas). Development and evaluation of spatial modeling techniques to improve fisheries assessment and management have increased rapidly in recent years. We overview the historical context of spatial models in fisheries science, highlight recent advances in spatial modeling, and discuss how spatial models have been incorporated into the management process. Despite limited examples where spatial assessment models are used as the basis for management advice, continued investment in fine-scale data collection and associated spatial analyses will improve integration of spatial dynamics and ecosystem-level interactions in stock assessment. In the near future, spatiotemporal fisheries management advice will increasingly rely on fine-scale outputs from spatial analyses.

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m) The performance and trade-offs of alternative harvest control rules to meet management goals for U.S. west coast flatfish fish stocks

Investigators: C. Wetzel and A. Punt

U.S. federal fisheries managers are mandated to obtain optimum yield while preventing overfishing. However, optimum yield is not well defined and the concept of maximum sustainable yield (MSY) has often been applied to provide an upper bound for the optimum yield value, but determining the MSY, identifying the relative biomass that produces MSY and the associated fishing rate required (F_{MSY}) is difficult. The Pacific Fishery Management Council, which manages groundfish stocks off the U.S. west coast, has employed proxy targets in lieu of species-specific estimates of MSY, B_{MSY}, and F_{MSY}. The proxy targets are life history specific, with flatfish stocks managed using a target B_{PROXY} of 0.25 of unfished biomass and a harvest control rule that applies an exploitation rate equal to a spawner-per-recruit harvest rate of $F_{0.30}$, with a linear reduction of catch to zero if the stock falls below 5% of unfished biomass (B_{LIMIT}). A management strategy evaluation was performed to explore the performance of the current harvest control rule applied to flatfish stocks to meet management goals, along with alternative harvest control rules that explore varying the values for B_{PROXY}, B_{LIMIT}, and F_{SPR}. Each of the harvest control rules explored maintained stocks at or near B_{PROXY} when stock-recruit steepness was 0.85 or greater, with very low probabilities of reducing relative biomass below a minimum stock size threshold (set at 0.50 B_{PROXY} of each harvest control rule). The most aggressive harvest control rule, which applied a B_{PROXY} of 0.20 and a target harvest rate of $F_{0.25}$, led to fishing rates that exceeded the operating model F_{MSY} values for low steepness (0.75), reducing the stock below B_{PROXY} with catches exceeding MSY. Trade-offs exist among alternative harvest control rules where the more aggressive harvest control rules resulted in higher average catches, but with an increase in the average annual variation in catches and a decrease probability of the relative biomass being with 10% of the B_{PROXY}. The trade-offs among the performance metrics and alternative harvest control rules coupled with the risk to the resource across a range of life histories should be carefully considered by fishery managers when selecting a harvest control rule that will meet the goals of management.

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n) Extending integrated stock assessment models to use non-depensatory three-parameter stock-recruitment relationships

Investigators: A. Punt and J.M. Cope

Stock assessments based on the integrated paradigm often include an underlying stock-recruitment relationship. This, along with estimates of fishery selectivity and biological parameters, allows the biomass and fishing mortality associated with Maximum Sustainable Yield (BMSY and FMSY respectively) to be calculated. However, the estimates of these quantities may differ from the proxies assumed in the harvest control rules that are used to provide management advice. Moreover, the estimated values for BMSY and FMSY are related functionally in population dynamics models based on 2-parameter stock-recruitment relationships such as the commonly used Beverton-Holt or Ricker relationships. Use of 2-parameter stock-recruitment relationships (SRRs) consequently restricts the ability to fully quantify the uncertainty associated with estimating BMSY and FMSY because 2-parameter SRRs restrict the potential range of values for BMSY/B0. In principle, BMSY/B0 and FMSY can be more independent if the stock-recruitment relationship is more general than these 2-parameter SRRs. This paper outlines eleven potential 3-parameter stock-recruitment relationships and evaluates them in terms of whether they are able to match a wide range of specifications for BMSY (expressed relative to unfished spawning stock biomass, B0) and FMSY (expressed relative to natural mortality, M). Of the eleven 3-parameter stock-recruitment relationships considered, the Ricker-Power stock-recruitment relationship is found to best satisfy the characteristics of (a) being able to mimic a wide range of BMSY/B0 and FMSY/M values, (b) not to lead to negative recruitment for biomasses between 0 and B0, and (c) not to lead to increasing recruitment while approaching the limit of zero population size. Bayesian assessments of three example groundfish species off the US west coast (aurora rockfish, petrale sole, and cabezon) are conducted using Simple Stock Synthesis based on the Beverton-Holt and Ricker-Power stock-recruitment relationships to illustrate some of the impacts of allowing for a 3-parameter stock-recruitment relationship.

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o) Eliciting expert knowledge to inform stock status for data-limited stock assessments

Investigators: A. Chrysafi, J.M.Cope and A. Kuparinenc

Data-limited fisheries are a major challenge for stock assessment analysts, as many traditional data-rich models cannot be implemented. Approaches based on stock reduction analysis offer simple ways to handle low data availability, but are particularly sensitive to assumptions on relative stock status (i.e., current biomass compared to unperturbed biomass). For the vast majority of data-limited stocks, stock status is unmeasured. The present study presents a method to elicit expert knowledge to inform stock status and a novel, user-friendly on-line application for expert elicitation. Expert opinions are compared to stock status derived from data-rich models. Here, it is evaluated how experts with different levels of experience in stock assessment performed relative to each other and with different qualities of data. Both "true" stock status and expert experience level were identified as significant factors accounting for the error in stock status elicitation. Relative stock status was the main driver of imprecision in the stock status prior (e.g., lower stock status had more imprecision in elicited stock status). Data availability and life-history information were not identified to be significant variables explaining imprecision in elicited stock status. All experts, regardless of their experience level, appeared to be risk neutral in the central tendency of stock status. Given the sensitivity to stock status misspecification for some popular data-limited methods, stock status can be usefully elicited from experts, but expert subjectivity and experience should be taken under consideration when applying those values.

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p) Depletion-Based Stock Reduction Analysis estimates of sustainable yield for cabezon (*Scorpaenichthys marmoratus*) in waters off Washington State.

Investigators: J.M. Cope, E.J. Dick and J. Hastie

This report estimates yield for cabezon (*Scorpaenichthys marmoratus*) in waters off Washington State, using Depletion-Based Stock Reduction Analysis (DB-SRA) (Dick and MacCall 2011). This method requires annual removals, estimates of relative stock status for a given year y (SBy/SB0), natural mortality (M), the ratio of the fishing rate at maximum sustainable yield to M (FMSY/M) and age at maturity.

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q) Three problems with the conventional delta-model for biomass sampling data, and a computationally efficient alternative.

Investigator: J. Thorson

Ecologists often analyse biomass sampling data that result in many zeros, where remaining samples can take any positive real number. Samples are often analysed using a "delta model" that combines two separate generalized linear models, GLMs (for encounter probability and positive catch rates), or less often using a compound Poisson-gamma (CPG) distribution that is computationally expensive. I discuss three theoretical problems with the conventional delta-model: difficulty interpreting covariates for encounter-probability; the assumed independence of the two GLMs; and the biologically implausible form when eliminating covariates for either GLM. I then derive an alternative "Poisson-link model" that solves these problems. To illustrate, I use biomass samples for 113 fish populations to show that the Poisson-link model improves fit (and decreases residual spatial variation) for >80% of populations relative to the conventional delta-model. A simulation experiment illustrates that CPG and Poisson-link models estimate covariate effects that are similar and biologically interpretable. I therefore recommend the Poisson-link model as useful alternative to the conventional delta-model with similar properties to the CPG distribution.

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r) Predicting life history traits for all fishes worldwide.

Investigator: J. Thorson, S. Munch, J.M. Cope and J. Gao

Scientists and resource managers need to know life history parameters (e.g., average mortality rate, individual growth rate, maximum length or mass, and timing of maturity) to understand and respond to risks to natural populations and ecosystems. For over 100 years, scientists have identified "life history invariants" (LHI) representing pairs of parameters whose ratio is theorized to be constant across species. LHI then promise to allow prediction of many parameters from field measurements of a few important traits. Using LHI in this way, however, neglects any residual patterns in parameters when making predictions. We therefore apply a multivariate model for eight variables (seven parameters and temperature) in over 32,000 fishes, and include taxonomic structure for residuals (with levels for class, order, family, genus, and species). We illustrate that this approach predicts variables probabilistically for taxa with many or few data. We then use this model to resolve three questions regarding life history parameters in fishes. Specifically we show that (1) on average there is a 1.24% decrease in the Brody growth coefficient for every 1% increase in maximum size; (2) the ratio of natural mortality rate and growth coefficient is not an LHI but instead varies systematically based on the timing of maturation, where movement along this life history axis is predictably correlated with species taxonomy; and (3) three variables must be known per species to precisely predict remaining life history variables. We distribute our predictive model as an R package, FishLife, to allow future life history predictions for fishes to be conditioned on taxonomy and life history data for fishes worldwide. This package also contains predictions (and predictive intervals) for mortality, maturity, size, and growth parameters for all described fishes.

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s) Applying a new ensemble approach to estimating stock status of marine fisheries around the world

Investigators: A. Rosenberg, K. Kleisner, J. Afflerbach, S. Anderson, M. Dickey-Collas, A. Cooper, M. Fogarty, E. Fulton, N. Gutierrez, K. Hyde, E. Jardim, O. Jensen, T. Kristiansen, C. Longo, C. Minte-Vera, C. Minto, I. Mosqueira, C. Osio, D. Ovando, E. Selig, J. Thorson, J. Walsh and Y. Ye

The exploitation status of marine fisheries stocks worldwide is of critical importance for food security, ecosystem conservation, and fishery sustainability. Applying a suite of data-limited methods to global catch data, combined through an ensemble modeling approach, we provide quantitative estimates of exploitation status for 785 fish stocks. Fifty-three percent (414 stocks) are below BMSY and of these, 265 are estimated to be below 80% of the BMSY level. While the 149 stocks above 80% of BMSY are conventionally considered “fully exploited,” stocks staying at this level for many years, forego substantial yield. Our results enable managers to consider more detailed information than simply a categorization of stocks as “fully” or “over” exploited. Our approach is reproducible, allows consistent application to a broad range of stocks, and can be easily updated as new data become available. Applied on an ongoing basis, this approach can provide critical, more detailed information for resource management for more exploited fish stocks than currently available.

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t) Producing distribution maps for informing ecosystem-based fisheries management using a comprehensive survey database and spatio-temporal models

Investigators: A. Grüss, J. Thorson, E. Babcock and J. Tarnecki,

Ecosystem-based fisheries-management (EBFM) is increasingly used in the United States (U.S.), including in the Gulf of Mexico (GOM). Producing distribution maps for marine organisms is a critical step in the implementation of EBFM. In particular, distribution maps are important inputs for many spatially-explicit ecosystem models, such as OSMOSE models, as well as for biophysical models used to predict annual recruitment anomalies due to oceanographic factors. In this study, we applied a recently proposed statistical modelling framework to produce distribution maps for: (i) younger juveniles (ages 0–1) of red snapper (Lutjanus campechanus), red grouper (Epinephelus morio), and gag (Mycteroperca microlepis), so as to be able to define the potential larval settlement areas of the three species in a biophysical model; and (ii) the functional groups and life stages represented in the OSMOSE model of the West Florida Shelf (“OSMOSE-WFS”). This statistical modelling framework consists of: (i) compiling a large database blending all of the encounter/non-encounter data of the GOM collected by the fisheries-independent and fisheries-dependent surveys using random sampling schemes, referred to as the "comprehensive survey database;" (ii) employing the comprehensive survey database to fit spatio-temporal binomial generalized linear mixed models (GLMMs) that integrate the confounding effects of survey and year; and (iii) using the predictions of the fitted spatio-temporal binomial GLMMs to generate distribution maps. This large endeavour allowed us to produce distribution maps for younger juveniles of red snapper, red grouper and gag and nearly all of the other functional groups and life stages represented in OSMOSE-WFS, at different seasons. Using Pearson residuals, the probabilities of encounter predicted by all spatio-temporal binomial GLMMs were demonstrated to be reasonable. Moreover, the results obtained for younger juvenile fish concur with the literature, provide additional insights into the spatial distribution patterns of these life stages, and highlight important future research avenues.

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u) Confronting preferential sampling in count and occupancy surveys: diagnosis and triage

Investigators: P.B. Conn, J. Thorson and D.S. Johnson

Population surveys are often used to estimate the density, abundance, or distribution of natural populations. Recently, model-based approaches to analyzing survey data have become popular because one can more readily accommodate departures from pre-planned survey routes and construct more detailed maps than one can with design-based procedures.

Spatial models for population distributions (SMPDs) often make the implicit assumption that locations chosen for sampling and animal abundance at those locations are conditionally independent given modelled covariates. However, this assumption may be violated when survey effort is non-randomized, leading to preferential sampling.

We develop a hierarchical statistical modelling framework for detecting and alleviating the biasing effects of preferential sampling in spatial distribution models fitted to count data. The approach works by specifying a joint model for population density and the locations selected for sampling, and specifying a dependent correlation structure between the two processes.

Using simulation, we show that moderate levels of preferential sampling can lead to large (e.g. 40%) bias in estimates of animal density and that our modelling approach can considerably reduce this bias. In contrast, preferential sampling did not appear to bias inferences about parameters informing species–habitat relationships (i.e. slope parameters).

We apply our approach to aerial survey counts of bearded seals (Erignathus barbatus) in the eastern Bering Sea. As expected, models with a preferential sampling effect led to lower abundance than those without. However, several lines of reasoning (better predictive performance, higher biological realism) led us to prefer models without a preferential sampling effect for this dataset.

When population surveys break from traditional scientific survey design principles, ecologists should recognize the potentially biasing effects of preferential sampling when estimating population density or occurrence. Joint models, such as those described in this paper, can be used to test and correct for such biases. However, such models can be unstable; ultimately the best way to avoid preferential sampling bias is to incorporate design-based principles such as randomization and/or systematic sampling into survey design.

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v) Global fishery dynamics are poorly predicted by classical models

Investigators: C. Szuwalski and J. Thorson

Fisheries dynamics can be thought of as the reciprocal relationship between an exploited population and the fishers and/or managers determining the exploitation patterns. Sustainable production of protein of these coupled human-natural systems requires an understanding of their dynamics. Here, we characterized the fishery dynamics for 173 fisheries from around the globe by applying general additive models to estimated fishing mortality and spawning biomass from the RAM Legacy Database. GAMs specified to mimic production models and more flexible GAMs were applied. We show observed dynamics do not always match assumptions made in management using "classical" fisheries models, and the suitability of these assumptions varies significantly according to large marine ecosystem, habitat, variability in recruitment, maximum weight of a species and minimum observed stock biomass. These results identify circumstances in which simple models may be useful for management. However, adding flexibility to classical models often did not substantially improve performance, which suggests in many cases considering only biomass and removals will not be sufficient to model fishery dynamics. Knowledge of the suitability of common assumptions in management should be used in selecting modelling frameworks, setting management targets, testing management strategies and developing tools to manage data-limited fisheries. Effectively balancing expectations of future protein production from capture fisheries and risk of undesirable outcomes (e.g., "fisheries collapse") depends on understanding how well we can expect to predict future dynamics of a fishery using current management paradigms.

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w) Uniform, uninformed or misinformed?: The lingering challenge of minimally informative priors in data-limited Bayesian stock assessments

Investigators: J. Thorson and J.M. Cope

A Bayesian approach to parameter estimation in fisheries stock assessment is often preferred over maximum likelihood estimates, and fisheries management guidelines also sometimes specify that one or the other paradigm be used. However, important issues remain unresolved for the Bayesian approach to stock assessment despite over 25 years of research, development, and application. Here, we explore the consequence of a common practice in Bayesian assessment models: assigning a uniform prior to the logarithm of the parameter representing population scale (log-carrying capacity for biomass-dynamics models, or log-unfished recruits for age-structured models). First, we explain why the value chosen for the upper bound of this prior will affect parameter estimates and fisheries management advice given two properties that are met for many data-poor stock assessment models. Next, we use three case studies and a simulation experiment to show a substantial impact of this decision for data-limited assessments off the US West Coast. We end by discussing four methods for generating an informative prior on the population scale parameter, but conclude that these will not be suitable for many assessments. In these cases, we advocate that maximum likelihood estimation is a simple way to avoid the use of Bayesian priors that are excessively informative.

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x) Inclusion of ecological, economic, social, and institutional considerations when setting targets and limits for multispecies fisheries

Investigators: A. Rindorf, C.M. Dichmont, J. Thorson, A. Charles, L.W. Clausen, P. Degnbol, D. Garcia, N.T. Hintzen, A. Kempf, P. Levin, P. Mace, C. Maravelias, C. Minto, J. Mumford, A. Pascoe, R. Prellezo, A.E. Punt, D. Reid, C. Röckmann, R.L. Stephenson, O. Thebaud, G. Tserpes and R. Voss

Targets and limits for long-term management are used in fisheries advice to operationalize the way management reflects societal priorities on ecological, economic, social and institutional aspects. This study reflects on the available published literature as well as new research presented at the international ICES/Myfish symposium on targets and limits for long term fisheries management. We examine the inclusion of ecological, economic, social and institutional objectives in fisheries management, with the aim of progressing towards including all four objectives when setting management targets or limits, or both, for multispecies fisheries. The topics covered include ecological, economic, social and governance objectives in fisheries management, consistent approaches to management, uncertainty and variability, and fisheries governance. We end by identifying ten ways to more effectively include multiple objectives in setting targets and limits in ecosystem based fisheries management.

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y) Integrating count and detection–nondetection data to model population dynamics.

Investigators: E. Zipkin, S. Rossman, C. Yackulic, J.D. Wiens, J. Thorson, R.J. Davis and E.H.C. Grant

There is increasing need for methods that integrate multiple data types into a single analytical framework as the spatial and temporal scale of ecological research expands. Current work on this topic primarily focuses on combining capture–recapture data from marked individuals with other data types into integrated population models. Yet, studies of species distributions and trends often rely on data from unmarked individuals across broad scales where local abundance and environmental variables may vary. We present a modeling framework for integrating detection–nondetection and count data into a single analysis to estimate population dynamics, abundance, and individual detection probabilities during sampling. Our dynamic population model assumes that site-specific abundance can change over time according to survival of individuals and gains through reproduction and immigration. The observation process for each data type is modeled by assuming that every individual present at a site has an equal probability of being detected during sampling processes. We examine our modeling approach through a series of simulations illustrating the relative value of count vs. detection–nondetection data under a variety of parameter values and survey configurations. We also provide an empirical example of the model by combining long-term detection–nondetection data (1995–2014) with newly collected count data (2015–2016) from a growing population of Barred Owl (Strix varia) in the Pacific Northwest to examine the factors influencing population abundance over time. Our model provides a foundation for incorporating unmarked data within a single framework, even in cases where sampling processes yield different detection probabilities. This approach will be useful for survey design and to researchers interested in incorporating historical or citizen science data into analyses focused on understanding how demographic rates drive population abundance.

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z) Improving estimates of population status and trajectory with superensemble models.

Investigators: S. Anderson, A. Cooper, O. Jensen, C. Minto, J. Thorson, J. Walsh, J. Afflerbach, M. Dickey-Collas, K. Kleisner, C. Longo, G. Osio, D. Ovando, A. Rosenberg, and E. Selig

Fishery managers must often reconcile conflicting estimates of population status and trend. Superensemble models, commonly used in climate and weather forecasting, may provide an effective solution. This approach uses predictions from multiple models as covariates in an additional "superensemble" model fitted to known data. We evaluated the potential for ensemble averages and superensemble models (ensemble methods) to improve estimates of population status and trend for fisheries. We fit four widely applicable data-limited models that estimate stock biomass relative to equilibrium biomass at maximum sustainable yield (B/BMSY). We combined these estimates of recent fishery status and trends in B/BMSY with four ensemble methods: an ensemble average and three superensembles (a linear model, a random forest and a boosted regression tree). We trained our superensembles on 5,760 simulated stocks and tested them with cross-validation and against a global database of 249 stock assessments. Ensemble methods substantially improved estimates of population status and trend. Random forest and boosted regression trees performed the best at estimating population status: inaccuracy (median absolute proportional error) decreased from 0.42 – 0.56 to 0.32 – 0.33, rank-order correlation between predicted and true status improved from 0.02 – 0.32 to 0.44 – 0.48 and bias (median proportional error) declined from −0.22 – 0.31 to −0.12 – 0.03. We found similar improvements when predicting trend and when applying the simulation-trained superensembles to catch data for global fish stocks. Superensembles can optimally leverage multiple model predictions; however, they must be tested, formed from a diverse set of accurate models and built on a data set representative of the populations to which they are applied.

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aa) Comparing estimates of abundance trends and distribution shifts using single- and multispecies models of fishes and biogenic habitat.

Investigators: J. Thorson and L. Barnett

Several approaches have been developed over the last decade to simultaneously estimate distribution or density for multiple species (e.g. "joint species distribution" or "multispecies occupancy" models). However, there has been little research comparing estimates of abundance trends or distribution shifts from these multispecies models with similar single-species estimates. We seek to determine whether a model including correlations among species (and particularly species that may affect habitat quality, termed "biogenic habitat") improves predictive performance or decreases standard errors for estimates of total biomass and distribution shift relative to similar single-species models. To accomplish this objective, we apply a vector-autoregressive spatio-temporal (VAST) model that simultaneously estimates spatio-temporal variation in density for multiple species, and present an application of this model using data for eight US Pacific Coast rockfishes (Sebastes spp.), thornyheads (Sebastolobus spp.), and structure-forming invertebrates (SFIs). We identified three fish groups having similar spatial distribution (northern Sebastes, coastwide Sebastes, and Sebastolobus species), and estimated differences among groups in their association with SFI. The multispecies model was more parsimonious and had better predictive performance than fitting a single-species model to each taxon individually, and estimated fine-scale variation in density even for species with relatively few encounters (which the single-species model was unable to do). However, the single-species models showed similar abundance trends and distribution shifts to those of the multispecies model, with slightly smaller standard errors. Therefore, we conclude that spatial variation in density (and annual variation in these patterns) is correlated among fishes and SFI, with congeneric fishes more correlated than species from different genera. However, explicitly modelling correlations among fishes and biogenic habitat does not seem to improve precision for estimates of abundance trends or distribution shifts for these fishes.

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bb) Faster estimation of Bayesian models in ecology using Hamiltonian Monte Carlo.

Investigators: C.C. Monnahan, J. Thorson and T.A. Branch

Bayesian inference is a powerful tool to better understand ecological processes across varied subfields in ecology, and is often implemented in generic and flexible software packages such as the widely used BUGS family (BUGS, WinBUGS, OpenBUGS and JAGS). However, some models have prohibitively long run times when implemented in BUGS. A relatively new software platform called Stan uses Hamiltonian Monte Carlo (HMC), a family of Markov chain Monte Carlo (MCMC) algorithms which promise improved efficiency and faster inference relative to those used by BUGS. Stan is gaining traction in many fields as an alternative to BUGS, but adoption has been slow in ecology, likely due in part to the complex nature of HMC.

Here, we provide an intuitive illustration of the principles of HMC on a set of simple models. We then compared the relative efficiency of BUGS and Stan using population ecology models that vary in size and complexity. For hierarchical models, we also investigated the effect of an alternative parameterization of random effects, known as non-centering.

For small, simple models there is little practical difference between the two platforms, but Stan outperforms BUGS as model size and complexity grows. Stan also performs well for hierarchical models, but is more sensitive to model parameterization than BUGS. Stan may also be more robust to biased inference caused by pathologies, because it produces diagnostic warnings where BUGS provides none. Disadvantages of Stan include an inability to use discrete parameters, more complex diagnostics and a greater requirement for hands-on tuning.

Given these results, Stan is a valuable tool for many ecologists utilizing Bayesian inference, particularly for problems where BUGS is prohibitively slow. As such, Stan can extend the boundaries of feasible models for applied problems, leading to better understanding of ecological processes. Fields that would likely benefit include estimation of individual and population growth rates, meta-analyses and cross-system comparisons and spatiotemporal models.

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cc) Model-based estimates of effective sample size in Stock Synthesis using the Dirichlet-multinomial distribution.

Investigators: J. Thorson, K. Johnson, R. Methot and I. Taylor

Theoretical considerations and applied examples suggest that stock assessments are highly sensitive to the weighting of different data sources whenever data sources conflict regarding parameter estimates. Previous iterative reweighting approaches to weighting compositional data are generally ad hoc, do not propagate uncertainty about data-weighting when calculating uncertainty intervals, and often are not re-adjusted when conducting sensitivity or retrospective analyses. We therefore incorporate the Dirichlet-multinomial distribution into Stock Synthesis, and propose it as a model-based method for estimating effective sample size. This distribution incorporates one additional parameter per fleet (with the option of mirroring its value among fleets), and we show that this parameter governs the ratio of nominal ("input") and effective ("output") sample size. We demonstrate this approach using data for Pacific hake, where the Dirichlet-multinomial distribution and an iterative reweighting approach previously developed by McAllister and Ianelli (1997) give similar results. We also use simulation testing to explore the estimation properties of this new estimator, and show that it provides approximately unbiased estimates of variance inflation when compositional samples capture clusters of individuals with similar ages/lengths. We conclude by recommending further research to develop computationally efficient estimators of effective sample size that are based on alternative, a priori consideration of sampling theory and population biology.

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dd) Accounting for spatiotemporal variation and fisher targeting when estimating abundance from multispecies fishery data.

Investigators: J. Thorson, R. Fonner, M. Haltuch, K. Ono and H. Winker

Estimating trends in abundance from fishery catch rates is one of the oldest endeavors in fisheries science. However, many jurisdictions do not analyze fishery catch rates due to concerns that these data confound changes in fishing behavior (adjustments in fishing location or gear operation) with trends in abundance. In response, we developed a spatial dynamic factor analysis (SDFA) model that decomposes covariation in multispecies catch rates into components representing spatial variation and fishing behavior. SDFA estimates spatiotemporal variation in fish density for multiple species and accounts for fisher behavior at large spatial scales (i.e., choice of fishing location) while controlling for fisher behavior at fine spatial scales (e.g., daily timing of fishing activity). We first use a multispecies simulation experiment to show that SDFA decreases bias in abundance indices relative to ignoring spatial adjustments and fishing tactics. We then present results for a case study involving petrale sole (Eopsetta jordani) in the California Current, for which SDFA estimates initially stable and then increasing abundance for the period 1986–2003, in accordance with fishery-independent survey and stock assessment estimates.

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ee) Using spatio-temporal models of population growth and movement to monitor overlap between human impacts and fish populations.

Investigators: J. Thorson, J. Jannot and K. Somers

Protected and managed species, including harvested fishes, exhibit spatial and temporal variation in their distribution and productivity. Spatio-temporal variation can arise from differences in habitat quality, human impacts (including harvest), density-dependent changes in per capita productivity, as well as individual movement. Human impacts (e.g. direct harvest) also vary spatially and over time, and monitoring the overlap between impacts and population distribution is necessary to ensure that human impacts are sustainable and to prioritize research and management for populations that are heavily impacted. However, estimating spatio-temporal variation in human impacts and population dynamics while accounting for individual movement has remained computationally challenging for decades.

We developed a spatial population growth (also known as 'surplus production') model that is inspired by finite element analysis, which estimates spatio-temporal population dynamics given density-dependent population regulation, individual movement and spatially explicit harvest. We demonstrate the method using data for big skate Raja binoculata in the California Current from 2003 to 2013 and demonstrate that results can be processed to estimate an upper limit on sustainable harvest (an 'overfishing limit'). We also conduct a simulation experiment to explore the small-sample properties of parameter estimates.

A simulation experiment confirms that real-world sample sizes are sufficient to estimate the sustainable harvest level within 20% of its actual value. However, sample sizes are likely insufficient to reliably estimate movement rates.

The spatial population growth model estimates an overfishing limit of 740–890 metric tonnes for big skate from 2010 to 2013, compared with annual harvest <100 tonnes. This suggests that recent harvest of big skate is likely sustainable, and sensitivity analysis confirms that this conclusion is robust to different potential rates for individual movement.

We recommend that spatio-temporal population models be used across systems and taxa to monitor the spatial overlap between species distribution and human impacts. For big skate, we recommend management rules triggering additional data collection and assessment effort if harvest rates substantially increase. We also recommend future research regarding spatial management regulations for emerging fisheries.

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

ff) Assessing the effects of climate change on U.S. West Coast sablefish productivity and on the performance of alternative management strategies

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

U.S. west coast sablefish are commercially valuable, making assessing and understanding the impact of climate change on the California Current (CC) stock a priority for (1) forecasting future stock productivity, and (2) testing the robustness of management strategies to climate variability and change. The horizontal-advection bottom-up forcing paradigm describes large-scale climate forcing that drives regional changes in alongshore and cross-shelf ocean transport and directly impacts the transport of water masses, nutrients, and organisms. This concept describes a mechanistic framework through which climate variability and change alter sea level (SL), zooplankton community structure, and sablefish recruitment, all of which have been shown to be regionally correlated. This study forecasts potential future trends in sablefish productivity using SL from Global Climate Models (GCMs) as well as explores the robustness of harvest control rules (HCRs) to climate driven changes in recruitment by conducting a management strategy evaluation (MSE) of the currently implemented 40-10 HCR as well as an alternative Dynamic Unfished Biomass 40-10 HCR. A majority of the GCMs suggest that after about 2040 there will be a slight trend towards generally lower SLs relative to the global mean, with an increasing frequency of low SLs outside of the range of the historical observations, suggesting favorable conditions for sablefish in the northern CC by 2060. Projected SLs from the GCMs suggest that future sablefish recruitment is likely to fall within the range of past observations but may be less variable and is likely to exhibit decadal trends that result in recruitments that persist at lower levels (through about 2040) followed by somewhat higher levels (from about 2040 through 2060). Although this MSE suggests that spawning biomass and catches will decline, and then stabilize, into the future under both HCRs, the sablefish stock is not projected to fall below the stock size that would lead to a fishery closure during the period analyzed (through 2060). However, the 40-10 HCR triggers stock rebuilding plans more frequently than the alternative Dynamic Unfished Biomass 40-10 HCR (based on the concept of a dynamic, rather than static, baseline stock size), suggesting that the alternative HCR is more robust to potential future climate driven changes in sablefish productivity.

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

gg) Investigating California Current petrale sole spawning dynamics and oceanographic recruitment drivers

Investigators: M.A. Haltuch, J.R. Wallace, N. Tolimeri, Q. Lee, M.G. Jacox, C. Parada, E. Churchitser

The horizontal-advection bottom-up forcing paradigm, in which large-scale climate forcing drives regional changes in alongshore and cross-shelf ocean transport that directly impact ecosystem functions, provides a mechanistic framework for testing the hypothesis that cross-shelf and alongshore advection are drivers of petrale sole recruitment strength. Petrale sole is the most commercially valuable flatfish targeted in the California Current and form offshore, localized, winter spawning aggregations routinely targeted by trawl fisheries. This study takes a three-prong approach to investigating petrale sole spawning dynamics and oceanographic recruitment drivers. First, winter fishery log-book data provide the basis for investigating annual spatio-temporal changes in spawning aggregation locations and the proportion of the stock occupying each spawning ground. Next, a stage- and spatio-temporally specific conceptual life-history model for petrale sole provides the foundation to posit hypotheses regarding the oceanographic variables likely to influence survival at each life stage, with testing via statistical model fitting. Finally, which spawning grounds contribute the most to recruitment success and variability via on-shore transport through time are quantified by using the winter commercial spawning aggregation fishery data and the conceptual life history model, to parameterize a biophysical individual-based model driven by ROMS.

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

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

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

Otolith-derived ages provide an informative piece of data in fisheries stock assessment in regard to estimating recruitments, growth, and exploitation rates (e.g. Haltuch, Ono, Valero 2013). The research and data needs sections of NWFSC stock assessments routinely identify the need for age-determination and age-validation studies (e.g. Gertseva et al. 2011). 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 (e.g. Haltuch et al. 2013).

Rockfish are the focus of the proposed bomb radiocarbon analyses due to longevity, and thus the likelihood of large ageing bias and variability at older ages. Archived samples are available for splitnose, canary, black, copper, and brown rockfish. 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. Canary rockfish have a complimentary bomb radiocarbon age validation study in the north (Piner at al. 2005) but this age validation used the northeast Pacific halibut reference chronology, which came from a much different environment than the reference chronology developed for the west coast of the US (Haltuch et al, 2013). CC petrale sole radiocarbon data suggests that it may be necessary to revisit the canary rockfish age validation using a species specific CC reference chronology (Haltuch et al. 2013). If species specific reference chronologies are not able to be developed for the above rockfish species, the petrale sole reference chronology, which is more environmentally representative of the canary rockfish distribution, will be used for age validation. Most radiocarbon ages have been processed for canary and black rockfish, data analyses and manuscript preparation are underway.

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

ii) Spatial growth variability in marine fish: example from northeast Pacific

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

Groundfish Life history parameters of marine fishes vary in space and time, often in response to multiple factors. Understanding this variability is vital to ensure sustainability of marine resources and ecosystem services provided by the ocean. We examined spatial variability in growth for a number of groundfish species in the northeast Pacific Ocean to identify shared spatial patterns and hypothesize about common mechanisms behind them. Growth parameters were estimated in different areas over the latitudinal range of the species and multiple hypotheses were tested as to whether growth parameters differ in all the areas, at specific area breaks or exhibit a latitudinal cline. Clear differences in spatial growth variability emerged among the species examined. Shelf species exhibited the highest growth rate between Cape Blanco and Cape Mendocino, which may in part be attributed to area-specific upwelling patterns in the California Current ecosystem, when nutrient rich deep water are brought to the surface southward of Cape Blanco and are uniquely distributed throughout this area, providing favorable conditions for primary productivity. Slope species showed a cline in asymptotic size (Linf), with Linf increasing from south to north. This cline, previously attributed to fishery removals, also fits a specific case of the widely described Bergmann's rule, and we explore specific potential ecological mechanisms behind this relationship.

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

jj) Challenges in the dockside sampling of species composition in changing groundfish fisheries

Investigators: TS Tsou, J.M. Cope, K. Privitera-Johnson and J. Fuller

Groundfish species composition sampling is a key activity for collecting information to prorate multispecies market category landings into single species landings that ultimately inform catch estimates. The treatment of species compositions is difficult, though, because sampling designs, protocols, and data processing algorithms vary among the agencies and through time. This presentation will focus on current issues associated with sampling commercial groundfish landed in Washington State. We will discuss the mismatches between our current sampling design and fishing practices, and the impacts of these mismatches on single species catch estimates.

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

kk) Accounting for variable recruitment and fishing mortality in length-based stock assessments for data-limited fisheries

Investigators: M. Rudd and J. Thorson

In fisheries with limited capacity for monitoring, it is often easier to collect length measurements from fishery catch than quantify total catch. Conventional stock assessment tools that rely on length measurements without total catch do not directly account for variable fishing mortality and recruitment over time. However, this equilibrium assumption is likely violated in almost every fishery, degrading estimation performance. We developed an extension of length-only approaches to account for time-varying recruitment and fishing mortality. This Length-based Integrated Mixed

Effects (LIME) method at a minimum requires a single year of length data and basic biological information but can fit to multiple years of length data, catch, and an abundance index if available. We use simulation testing to demonstrate that LIME can estimate how much fishing has reduced spawning output in the most recent year across a variety of scenarios for recruitment and fishing mortality. LIME improves data-limited fisheries stock assessments by its flexibility to incorporate additional years or types of data if available and obviates the need for equilibrium assumptions.

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

2. Survey and Observer Science

a) Investigating bias associated with hook saturation, hook competition, and fixed-site design in the Southern California hook-and-line survey

Investigators: P.T. Kuriyama, T.A. Branch, A.C. Hicks, J.H. Harms and O.S. Hamel

The Southern California hook-and-line survey has been conducted by the Northwest Fisheries Science Center since 2004 to monitor the untrawlable habitat of the Southern California Bight. Data from the survey have been used in stock assessments and supporting research for 8 groundfish species, including bocaccio (*Sebastes paucispinis*), vermilion rockfish (*s. miniatus*), cowcod (*S. levis*), and lingcod (*Ophiodon elongatus*). However, an index of abundance estimated from hook-and-line data may be biased due to the fixed-site design of the survey, hook saturation, and hook competition. We are using empirical results from the hook-and-line data and to inform a simulation study exploring the biases associated with aspects of the survey. Bocaccio are the most sampled species in the survey, and sites with low catch rates of bocaccio may also have high catch rates of vermilion rockfish suggesting possible bias associated with interspecific competition for hooks. Preliminary results from the simulations indicate that hook saturation causes estimates of abundance to be negatively biased at large population sizes, hook competition leads to positively biased indices of abundance, and weighting catch rates by site leads to the least biased index of abundance. Results are aimed at identifying methods of incorporating hook-and-line data from untrawlable habitat into stock assessments and identify ways of correcting biases common to all hook-and-line surveys.

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

b) Development of a high-throughput approach for descending shelf rockfish

Investigators: J.H. Harms, J. Benante, C. Jones, A. Chappell, V. Simon, and J. Villareal

Since 2004, the Northwest Fisheries Science Center's (NWFSC) Hook and Line Survey has monitored a network of fixed sites throughout the Southern California Bight to provide data to support stock assessments for shelf rockfish populations in the region's untrawlable habitats. When no-take marine reserves within the Channel Islands National Marine Sanctuary (CINMS) were expanded in 2007-2008 to encompass existing survey sites, NWFSC and CINMS staff discussed ways to continue sampling these locations to maintain the data time series while minimizing impacts to the reserves' living resources. In 2016, survey protocols were modified so captured individuals are descended after expedited collection of biological data. To reduce potential mortality to captured specimens, we needed to minimize the amount of time fish spent out of the water by descending fish more rapidly than is feasible using traditional descending methods. We developed a downrigger approach using a recreational crab pot puller to lower a downline and cannonball weight most of the way to the seafloor. After basic data are collected, fish are attached to a SeaQualizer™ Recompression Device affixed to a customized bracket which is then clipped onto the downline and dropped into the water. Fish are released when the bracket assembly reaches the depth setting selected on the SeaQualizer. All descended fish are tagged prior to release to provide a secondary measure of abundance and to provide information about fish movement and potential post-release mortality. We discuss our approach in detail and share some of the lessons we learned in developing and implementing this approach.

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

c) *HookLogger*: An Integrated and interactive three-station, portable, rugged data collection platform

Investigators: V. Simon, T. Hay, J. Benante, C. Jones, A. Chappell and J.H. Harms

Since 2004, the Northwest Fisheries Science Center (NWFSC) has annually monitored an array of fixed sampling sites over high relief habitat using rod and reel gear in the Southern California Bight. Pencil and paper forms were used for capturing all back deck information such as catch, effort, and biological sampling details. These hard to read forms were transcribed into approximately 150,000 unique data fields and manually entered into a relational database in the offseason. In 2017 a portable, rugged, wireless, integrated and interactive data collection platform was deployed. The new three-station system is named *HookLogger* and it utilizes Windows tablets, barcode label printers, barcode scanners, and motion compensated digital scales to input data over TCP/IP using virtual comports. The tablets communicate with a centralized SQLite database located at the primary event logging *Galley-station*. The benefits of this digital data collection capability include faster and streamlined field data collection, on-entry data validations, and the elimination of approximately 320 hours of post-season data entry.

For more information, please contact Victor Simon at Victor.Simon@noaa.gov

d) The Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl Survey: Survey History, Design, and Description

Investigators: A. Keller, J.R. Wallace and R. Methot

Scientists from the Northwest Fisheries Science Center (NWFSC) Fisheries Resources Analysis and Monitoring (FRAM) division annually conduct a bottom trawl survey of groundfish resources. The purpose of the West Coast Groundfish Bottom Trawl Survey (WCGBTS) is to provide fisheries-independent indices of stock abundance to support stock assessment models for commercially and recreationally harvested groundfish species. The survey produces annual biomass estimates that are calculated using the area swept by the trawl to estimate fish density.

These estimates are expanded to the full survey area to produce species-specific biomass indices. The WCGBTS collects data on 90+ species contained in the Fisheries Management Plan (FMP) to fulfill the mandates of the Magnuson-Stevens Sustainable Fisheries Act. Fishery managers on the West Coast of the United States rely on fishery stock assessments to provide information on the status of groundfish stocks. Stock status determinations directly influence decisions regarding harvest levels. Here we provided a detailed description of the groundfish survey's history, design and current description.

Prior to 1998, surveys conducted by the Alaska Fisheries Science Center (AFSC) were the principal source for fishery-independent data about groundfish resources along the upper continental slope and shelf of the U.S. west coast. The AFSC triennial shelf surveys used chartered Alaska fishing vessels (19.8–52.1 m) while slope surveys were conducted with the NOAA R/V Miller Freeman during most years (1988 and 1990–2001). A review of the earlier surveys reveals that both the AFSC's west coast shelf and slope surveys varied considerably among years both in the timing of the surveys and the geographical extent (longitudinally and by depth). Survey timing varied between years as the focus of the surveys shifted among different groundfish species. Spatial coverage varied between years due to constraints imposed by annual budget levels and/or availability of NOAA ship time. The various configurations of these surveys are described since they provide insights into the design of the current NWFSC's annual groundfish survey. The NWFSC survey has utilized a consistent survey extent and design since 2003 except for the changes to geographic strata and station allocations in 2004.

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e) West Coast Observer Program

The FRAM West Coast Groundfish Observer Program (WCGOP) continued collecting fishery-dependent data during 2017 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.

Table 1. Number of observers deployed by the WCGOP in 2017

2016	
Number of catch share observers	54
Number of non-catch share observers	48
Number of A-SHOP Observers	45

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. Table 3 below provides information on observer activities in the catch share fishery.

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

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

Table 2. Summary of observer coverage and sea days in the catch share fisheries during 2017

DESCRIPTION	SS IFQ Trawl	SS IFQ Fixed Gear	SS Hake	MSCV	A-SHOP
Number of vessels	64	9	4	1	14
Number of trips	907	55	137	3	88
Number of Sea days	3,061		264	58	1902
Number of Observers	54				45

*Includes trips and/or sea days where no fishing activity occurred.

SS IFQ trawl: vessels targeting non-hake groundfish with trawl gear and landing at shore based processors.
SS IFQ Fixed Gear: vessels targeting non-hake groundfish using longlines or pots and landing at shore based processors.
SS Hake: vessels targeting hake using trawl gear and landing at shore based processors.
MSCV: mother ship catcher-vessel targeting hake with trawl gear
CPs and Motherships: mother ships and catcher-processors targeting hake using trawl gear

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 2,537 sea days in the non-catch share fisheries in 2017 aboard vessels ranging in size from skiffs to larger fixed gear vessels and depths ranging from less than 20 ft. to more than 300 ft.

Table 3. Non-Catch Share sea day summary by fisheries/sectors during 2017:

NCS Sea Days	
FISHERY DESCRIPTION	SEA DAYS
OR Blue/Black Rockfish Nearshore	136
OR Blue/Black Rockfish	72
OR Pink Shrimp	542
WC Open Access Fixed Gear	170
WA Pink Shrimp	244
Limited Entry Sablefish	447
CA Emley-Platt EFP	31
Electronic Monitoring EFP	170
PSMFC Discard Handling Research	16
Trawl Gear Modification EFP	141
CA Cucumber Trawl	22
IPHC Directed Commercial Halibut	28
Trawl Gear Modification EFP (EM)	3
Limited Entry Zero Tier	52
CA Halibut	186
CA Nearshore	152
CA Ridgeback Prawn	70
CA Pink Shrimp	55

*Includes sea days where no fishing activity occurred.

Due to its unique data collection circumstances in both the catch shares and non-catch shares fisheries, the program continues to stress safety and data quality.

Data and analytical reports

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

Summaries of data collected on observed trips are routinely published on the NWFSC web site.

All WCGOP reports can be obtained at: http://www.nwfsc.noaa.gov/research/divisions/fram/observer/datareport/index.cfm.

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

f) Community Participation in U.S. Catch Share Programs

Investigators: K. Norman, L.L. Colburn, M. Jepson, A. Himes-Cornell, S. Kasperski, C. Weng and P.M. Clay

A guiding principle of the NOAA Catch Share Policy is to track the performance of programs to monitor whether they are achieving their goals and objectives. This report focuses on assessing changes in fisheries participation for communities involved in each of the U.S. catch share programs, including the shore-based trawl-caught groundfish fishery on the U.S. West Coast. The indicators included in this communities research effort were chosen to better elucidate catch share performance by providing a comparison between pre and post implementation community participation in a particular catch share program. Trends in community participation in 13 of the 16 federally managed catch share programs in the U.S. were measured using a standard set of indicators. These indicators were calculated for each catch share program and reported by region. A community level pre-implementation Baseline was established and compared to each year post-implementation through 2013 for each indicator. Indicators of community-level social well-being are included to provide a context for understanding community involvement in catch share programs.

For more information please contact Dr. Karma Norman at Karma.norman@noaa.gov.

3. Age and Life History

a) 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 2017, CAP production aged 23,150 age structures, production double read 6,280 age structures. The lab also completed over 1,000 training and recalibration reads. The lab hosted age readers from Washington Department of Fisheries and Wildlife to define differences of ageing methodology for yelloweye rockfish. Production ages supported the 2017 assessments on arrowtooth flounder, California scorpionfish, darkblotched rockfish, lingcod, Pacific hake, Pacific Ocean perch, yelloweye rockfish and yellowtail rockfish. The lab cored 42 canary rockfish otoliths that were sent to NOSAMS for C14 analysis. A total of 600 canary rockfish otoliths were double read in order to make the coring selection. CAP continued the practice of recording otolith weights prior to breaking and burning most specimens when possible. Over 18,500 otolith weights were collected in 2017 to support of research into alternative methods of age determination. Five

CAP personnel attended the 2017 C.A.R.E conference (Committee of Age Reading Experts) in Seattle Washington.

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

b) Assessing reproductive strategies in marine fishes: applications to management

Investigator: M.A. Head

By incorporating accurate estimates of life history parameters into population models, we increase the reliability of biomass estimates used to manage fish stocks. In addition, understanding the reproductive biology and life history strategies of these fish provides support for sustainable management. However, data collections restricted by seasonal surveys create challenges for gaining a full understanding of their reproductive biology. Many groundfish species on the U.S. West Coast spawn between November – March, when opportunities to collect biological data on surveys or from fisheries landings are limited. Starting in 2009, the FRAM division instituted ovary collections on annual surveys, after fisheries managers identified a need for updated life history information for several groundfish species along the U.S. West Coast. Currently, the FRAM reproductive biology program has sampled from over 36 groundfish species along the coast, and collected over 15,000 ovaries using six sampling platforms: West Coast groundfish bottom trawl survey (WCGBT), Southern California Bight Hook and Line survey (H&L), At-sea hake observer program (ASHOP), Acoustics summer and winter survey, Oregon Department of Fish and Wildlife (ODFW), and Washington Department of Fish and Wildlife (WDFW).

We have examined the reproductive biology of multiple groundfish species using ovaries collected from fishery independent surveys and fishery dependent sources (port sampling of offloads and on board observer samples). These collections allowed for comparisons of length and age at maturity estimates based on the histological examination of ovaries collected within and outside the spawning season. We identified several key factors essential for understanding reproductive biology of west coast groundfishes: (1) spatial and temporal patterns, (2) the effects of oceanographic conditions on reproductive patterns related to skip spawning and abortive maturation, and (3) the estimation of biological (physiological) versus functional (potential spawner) maturity for fisheries management models. Ecosystem variables, such as habitat, food availability, upwelling, and oceanographic patterns may also have an outsized influence on the reproductive behavior of groundfish stocks. Understanding how these variables influence reproduction can provide useful information for predicting the influence of shifting oceanographic conditions on the spawning output of groundfish stocks.

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e) Re-evaluation of the single genetic stock hypothesis for Pacific Hake (*Merluccius productus*)

Investigator: M.A. Head, S. Parker-Stetter, K. Nichols, I. Taylor and M. McClure

Pacific Hake (*Merluccius productus,* hereafter "hake") are the most abundant groundfish in the California Current Ecosystem off the West Coast of the U.S. and Canada. The coastal stock supports a large commercial fishery that has had an average annual catch of over 250,000 mt over the past 30 years and was valued at US$59 million in 2014[1]. Catch limits used in the management of hake are informed by an acoustic-trawl survey conducted jointly by the U.S. and Canada that estimates total biomass for the entire West Coast. Its spatial extent is adapted to cover the full latitudinal range of the species in any survey year under the assumption that all fish within this range are part of a single coastal stock. If the survey area either includes fish from multiple stocks or does not include areas that are part of the coastal stock, it could bias the stock assessments, causing either potential harvest to be foregone, or unnecessarily jeopardizing smaller stocks. Previous genetic work, done with limited spatial samples (see Fig. 1), identified that the coastal Northeast Pacific Ocean hake were genetically distinct from hake in the Strait of Georgia and Puget Sound, and no differences within the coastal samples were identified[2].

Recent observations, however, suggest the assumption of a single coastal hake stock requires validation. Hake collected south of 34.5º latitude (~Point Conception, CA) matured at a smaller size than those collected farther north[3]. Moreover, winter surveys in 2016 and 2017 observed hake much further north than suggested by the conventional hypothesis that hake spawn offshore of Mexico in the winter[4]. Environmental conditions, such as El Niño/La Niña, may influence latitudinal trends in maturation, timing of spawning, or winter distribution, or by genetic variation underlying different growth regimes among hake stocks[5]. Using a spatially and temporally comprehensive set of genetic samples, we propose to test the single stock assumption and evaluate associations of genetic variation with life history trends within hake.

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

B. Ecosystem Research

1. Habitat

a) Relating groundfish diversity and biomass to structure-forming invertebrates in the Northeast Pacific Ocean: an exploration of catch data from a fishery-independent trawl survey

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

We investigated the associations between structure-forming invertebrates (SFIs: corals, sea pens and sponges) and demersal fish using bottom trawl survey data from the Northwest Fisheries Science Center's bottom trawl survey (2003-2015). General linear models (GLMs) showed that average species richness was slightly lower and finfish biomass slightly higher in hauls with no SFIs. Generalized additive models (GAMs) indicated a weak, non-linear relationship between species richness and sponge density (<1% of deviance explained). Slightly higher finfish biomass occurred in hauls with few or no sea pens or sponges. We used multivariate analyses to examine relationships between fish community structure, SFI densities, and environmental parameters (depth, latitude and bottom temperature). No strong correlations occurred between community structure and SFI densities, but bottom temperature and depth were the primary drivers of community composition. However, indicator species analysis, based on three SFI levels (high, low and none), showed various species-specific associations. Depending on species, flatfishes exhibited relationships with high and low densities of corals and sea pens or the absence of sponges. Thornyheads and some rockfishes were associated with high sponge densities but low or zero coral and sea pen densities. Sablefish exhibited opposite trends. These results provide information about broad-scale associations between SFIs and demersal fish that may be useful for developing studies specifically focused on the function of SFIs as essential fish habitat and the role they may play in the life-histories of groundfishes.

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

b) National Marine Fisheries Service, Untrawlable Habitat Strategic Initiative (UHSI)

Investigator: W. Wakefield

The NMFS Untrawlable Habitat Strategic Initiative (UHSI) was started in 2013 to identify and quantify biases associated with mobile survey vehicles (i.e., remotely operated vehicle (ROV), autonomous underwater vehicle (AUV), human-occupied submersible (HOV), and towed camera) used to count fishes in complex habitats that preclude the use of bottom trawls. Following on a two-year Gulf of Mexico study focused on a snapper / grouper complex, the UHSI moved to the West Coast to address a critical need to quantify the response of West Coast rockfishes (genus *Sebastes*) to mobile survey vehicles. In 2016, a pilot testbed experiment was initiated on a deep-water rocky bank (100-150m) in the Southern California Bight – a site characterized by diverse and abundant assemblages of rockfishes and a long history of HOV, AUV, and ROV surveys. MOUSS stereo cameras and orthogonal DIDSON imaging sonars were integrated into two instrumented and novel autonomous fixed platforms, which were deployed and positioned daily by an HOV along a high-relief rocky section of the bank. These optical and acoustical imaging surveillance systems were used to quantify changes in fish density and behavior in response to two representative survey vehicles, a Seabed AUV and the DeepWorker HOV. A final field experiment was conducted in October 2017 at the Southern California Bight study site. Data analysis is underway.

For more information, contact Waldo Wakefield at Waldo.Wakefield@noaa.gov

c) Revising the Essential Fish Habitat Conservation Areas and Rockfish Conservation Area of the Pacific Coast Groundfish Fishery Management Plan

Investigators: G. Hanshew, J. Stadler, W. Wakefield and K. Griffin

The Pacific Fishery Management Council (PFMC) designated essential fish habitat (EFH) for 82 groundfish species in the Pacific Coast Groundfish Fishery Management Plan in 2005. At the same time, the PFMC designated a number EFH Conservation Areas (EFHCAs), covering 70% of the area designated as EFH. The EFHCA prohibit certain types of bottom-contact gear, primarily bottom trawls, to minimize the adverse effects of fishing on EFH. In 2010, NOAA Fisheries and the PFMC began an effort to review and revise the EFH components of the FMP. The review compiled and summarized new information on EFH for groundfishes (now with 91 FMP Species plus 26 Ecosystem Component Species), including information on seafloor habitats, bathymetry, groundfish fishing effort, distribution of deep-sea corals and sponges, prey species, and habitat associations. Subsequent to the review, the PFMC issued a request for proposals seeking public input on potential changes to the EFH components of the plan. The Council is now revising those components, with an emphasis on proposed modifications to Pacific Coast groundfish essential fish habitat conservation areas (EFHCAs), trawl rockfish conservation areas (RCAs), and proposed closure of waters deeper than 3,500 meters. The Council is analyzing a range of alternatives drawn from the public proposals or developed by the Council and NOAA Fisheries.

d) Fine-scale benthic habitat classification using a towed video camera-sled

Investigators: A. Chappell, C. Whitmire, J.H. Harms, J. Benante, A. Keller and C. Jones

The Northwest Fisheries Science Center's Southern California Shelf Rockfish Hook and Line Survey samples hard bottom habitats within the Southern California Bight via rod and reel gear to provide management information for multiple demersal rockfishes (*Sebastes* sp.). The survey, initiated in 2004, consists of 202 fixed stations sampled annually from Pt. Arguello (34.6° N) to the Mexican border (32.1° N) at depths of 37 – 229 m. We analyzed benthic habitat observations collected during 90 dives representing 70 unique sites via deployment of a towed video camera-sled. Benthic habitat observations were categorized both by major strata (primary, ≥ 50% of the field of view; secondary habitat ≥ 20% of the next most abundant habitat; and all other habitats in the field of view), and by eight previously-defined substrata categories: mud, sand, pebble, cobble, boulder, continuous flat rock, diagonal rock ridge and vertical rock-pinnacle top. When compared with existing NOAA's Essential Fish Habitat maps, we found significantly different habitat classification values, especially of hard substrates. Depending on method of collection and equipment type, the available Essential Fish Habitat maps contain varying degrees of resolution, or use algorithms to predict benthic habitat composition. Overall, our analysis of camera-sled tows showed 47% hard bottom habitats and 53% soft bottom habitats. Essential Fish Habitat designations in the same areas of our camera-sled tows were comprised of 27% hard bottom substrates, and 73% soft bottom substrates, both significantly different. Our findings indicate hard-bottom habitat features, especially smaller reefs, are not adequately resolved within available habitat maps.

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

2. Ecosystems

a) Integrated Ecosystem Assessment of the California Current

Investigators: C.J. Harvey, N. Garfield, E.L. Hazen and G.D. Williams, 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.

We are well into the Phase IV iteration of the California Current IEA, which builds on earlier reports by focusing on integrative products, particularly: 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 involve analyses related to groundfish and will be fleshed out further between now and 2018.

The project includes regular reporting of ecosystem status and trends to the Pacific Fishery Management Council. These reports and other California Current IEA documents can be found at https://www.integratedecosystemassessment.noaa.gov/regions/california-current-region/index.html.

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

b) Assessing sublethal effects of hypoxia on West Coast groundfish: do growth rates of greenstriped rockfish *Sebastes elongatus* vary with levels of dissolved oxygen?

Investigators: C.J. Harvey, K.S. Andrews, B.R. Beckman, V. Simon, P. Frey and D. Draper

In this project, we examine variation in the levels of insulin-like growth factor (IGF) in the blood plasma of greenstriped rockfish (*Sebastes elongatus*) in the northern portion of the U.S. West Coast as sampled by the FRAM groundfish trawl survey (legs 1, 2 and 3 to Cape Mendocino). We collected IGF samples on the first and second passes of the 2015 survey. IGF is an indicator of feeding and somatic growth in fishes. Our objective is to determine if IGF levels of greenstriped rockfish, a model groundfish species, are correlated with physical parameters of the environment, with an emphasis on temperature and dissolved oxygen (DO). We propose to collect samples from the smallest size-frequency bins of greenstripe rockfish on the first pass, i.e., likely before hypoxia has developed, and on the second pass, i.e., likely after hypoxia has become established. We also hope to collect these samples over a broad spatial range of the northern portion of the survey domain, so that there are individuals both inside and outside but adjacent to the region most affected by hypoxic conditions. In addition to collecting blood, scientists will be collecting and analyzing stomach contents for comparison with IGF levels. Additional samples collected during the 2016 FRAM groundfish trawl survey are now being processed.

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

c) Use of eelgrass and kelp habitats by post-settled juvenile rockfish in Washington state

Investigators: A.O. Shelton, N. Tolimieri, J.F. Samhouri, C.J. Harvey, G.D. Williams, K.S. Andrews, K.E. Frick and B.E. Feist.

Nearshore biogenic habitat is potentially valuable foraging or refuge habitat for recently settled age-0 rockfish (*Sebastes* spp.). We are conducting numerous scuba-based surveys in coastal waters of Washington state to explore spatiotemporal dynamics of juvenile rockfish occurrence, habitat characteristics, and overall community structure within these habitats. Inside Puget Sound, we conduct seasonal scuba surveys in nearshore beds of native eelgrass (*Zostera marina*) and also in treatment and reference sites near kelp mariculture projects. On the outer coast, we conduct annual scuba surveys in kelp forests along the Olympic Coast. We are establishing baselines of juvenile rockfish abundance and variability and also exploring correlations and mechanisms that may influence rockfish occurrence. This information may inform habitat conservation practices and also provide indicators of year class strengths for rockfish populations both in Puget Sound and along the outer coast.

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

d) Potential effects of ocean acidification on the California Current food web and fisheries: ecosystem model projections

Investigators: K.N. Marshall, I.C. Kaplan, E.E. Hodgson, A. Hermann, S. Busch, P. McElhany, T.E. Essington, C.J. Harvey and E.A. Fulton

Humans rely heavily on ocean ecosystems and the services they provide. Global climate change manifests in the ocean through a number of pathways, one of which is ocean acidification. In this project and associated manuscripts we describe the effects of ocean acidification on an upwelling system that is particularly prone to low pH conditions, the California Current. We used an end-to-end ecosystem model (Atlantis), forced by downscaled global climate models and informed by a meta-analysis of the pH sensitivities of local taxa, to investigate the direct and indirect effects of future pH on biomass and fisheries revenues. Our model projects wide ranging magnitudes of effects across guilds and functional groups, although with more "losers" than "winners". The most dramatic effects of future pH may be expected on demersal fish, sharks, and epibenthic invertebrates. State-managed fisheries such as those that harvest Dungeness crab were particularly vulnerable in our projections, with revenues declining by almost 30%. The model's pelagic species, marine mammals, and seabirds were much less influenced by future pH. Ongoing research

(E.E. Hodgson et al. *in review*) identifies northern ports as most economically impacted by the projected declines in groundfish and Dungeness crab. Our results provide a set of projections that generally support and build upon previous findings and set the stage for hypotheses to guide future modeling and experimental analysis on the effects of OA on marine ecosystems and fisheries.

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

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

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

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

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

f) Spatio-temporal changes in groundfish communities: patterns of diversity and responses to anthropogenic disturbances in the Gulf of Alaska

Investigators: A.O. Shelton, M.E. Hunsicker, E.J. Ward, B.E. Feist, R. Blake, C.L. Ward, B.C. Williams, J.T. Duffy-Anderson, A.B. Hollowed and A.C. Haynie

Toxic pollutants such as crude oil have direct negative effects for a wide array of marine life. While mortality from acute exposure to oil is obvious, sub-lethal consequences of exposure to petroleum derivatives for growth and reproduction are less evident and sub-lethal effects in fish populations are obscured by natural environmental variation, fishing, and measurement error. We use fisheries independent surveys in the Gulf of Alaska to examine the consequences of the 1989

Exxon Valdez oil spill (EVOS) for demersal fish. We delineate areas across a range of exposure to EVOS and use spatio-temporal models to quantify the abundance of 53 species-groups over 31 years. We compare multiple community metrics for demersal fish in EVOS and Control areas. We find that areas more exposed to EVOS have more negative trends in total groundfish biomass than non-EVOS areas, and that this change is driven primarily by reductions in the abundance of the apex predator guild. We show no signature of increased variability or increased levels of synchrony within EVOS areas. Our analysis supports mild consequences of EVOS for groundfish communities, but suggests that long time-series and assessments of changes at the community level may reveal sub-lethal effects in marine communities.

For more information please contact Dr. Ole Shelton at NOAA's Northwest Fisheries Science Center, ole.shelton@noaa.gov.

g) Patterns of diversity, stability and community composition in the groundfish community of the Gulf of Alaska

Investigators: R.E. Blake, C. Ward, M. Hunsicker, A.O. Shelton and A.B. Hollowed.

The mechanisms structuring patterns of diversity and community composition can be difficult to identify, and much of our knowledge stems from study of local ecological systems. It is important to understand these patterns and their drivers at larger scales, especially in the face of climate change and other perturbations. The Gulf of Alaska (GOA) has complex topography, climate-driven variability, and a well-studied groundfish community, making it an ideal study system. We examined patterns of diversity, stability, and community composition in the groundfish community across 10 sites in the GOA using geostatistically modeled groundfish abundance and biomass from the Alaska Fisheries Science Center trawl survey data (1984 – 2015). We found that species richness, and alpha, beta, and functional diversity varied little both within and between study areas, and were conserved across the central GOA. However, community composition varied significantly along a longitudinal gradient, with differences driven by lower-density species indicating functional redundancy among individual study areas. The regional community was also less variable, suggesting a spatial portfolio effect across this ecosystem. Overall, environmental heterogeneity and functional redundancy drive conserved community structure and patterns of groundfish diversity across the GOA large marine ecosystem.

For more information please contact Dr. Ole Shelton at NOAA's Northwest Fisheries Science Center, ole.shelton@noaa.gov.

h) Getting to the Bottom of Fishery Interactions with Living Habitats: Spatiotemporal Trends in Disturbance of Corals and Sponges on the US West Coast

Investigators: L. Barnett, S. Hennessey, T. Essington, A. Shelton, B Feist, T. Branch and M. McClure

Physical seafloor damage by mobile bottom fishing gear is a conservation concern because of potential direct impacts on habitat-forming organisms, and indirect effects on fishes supported by these habitats. Despite this concern, it has not been common practice to systematically quantify changes over time in the extent and intensity of fishery impacts on seafloor habitat, making it difficult to determine the effect of fisheries management actions on habitat. Here, we estimate spatiotemporal trends in bottom trawl activity in areas containing such biogenic habitat (sponges and corals) on the US west coast to evaluate the effect of policies such as spatial closures, catch shares and vessel buybacks. Biogenic habitat exposure to trawl gear was greatest at moderate to deep depths of the outer continental shelf and upper slope, primarily north of Cape Mendocino and off Southern California. However, given the location of commercial trawling, the interaction frequency between biogenic habitat and trawl gear is likely highest in deep waters off Oregon and Washington. Temporal trends in total biogenic habitat contacts tracked changes in fishing effort, but the relative frequency of contacts in areas open to fishing actually increased after spatial closures were implemented—likely due to effort displacement and shifts in the spatial distribution of fishing—and was only slightly reduced by implementation of catch shares. Thus although spatial closures may protect habitat within reserves, without complimentary policies, spatial closures may increase gear-habitat interactions in adjacent areas due to changes in fisher behavior and fishing effort displacement.

For more information please contact Dr. Lewis Barnett at NOAA's Northwest Fisheries Science Center, lewis.barnett@noaa.gov.

i) Why are whale entanglements with fishing gear increasing on the west coast of the US?

Investigators: B. Feist, J. Samhouri and E. Fuller

Over the past few years, cetacean entanglements with commercial fishing gear off the US west coast have increased dramatically. Trap and pot gear types account for much of the entanglement observed, affecting humpback and gray whale disproportionately, but many of the gear types associated with entanglements are unknown. Surprisingly, the 2015 Dungeness crab fishery saw unprecedented closures due to above standard domoic acid levels, suggesting effort was, in fact, much lower than average. To further complicate matters, recreational whale watching activity is difficult to quantify, so changes in observation intensity of cetaceans over time are largely unknown. Here, we use vessel monitoring system (VMS) data, linked to landings data to characterize spatio-temporal patterns of vessels fishing off the west coast of the US that use trap and pot gear to catch Dungeness crab, spiny lobster, sablefish or spot prawn. We then link these analyses spatially with gridded models of cetacean abundance. Finally, we use data from social media outlets and from state park beach attendance records to characterize patterns in entanglement observation effort over time.

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

j) The Pacific Coast Groundfish Fishery Social Study

Investigators: Suzanne Russell, Max Van Oostenburg, Ashley Vizek, Brian Carter

The Pacific Coast Groundfish Fishery Social Study is a multi-year study designed to measure social changes in affected fishing communities resulting from the implementation of a catch shares program in January 2011. Extensive data collection include efforts in 2010, 2012, and 2015/2016. Data was collected using a survey tool and semi-structured interviews, primarily in person.

Additional data collection will be pursued on a 5-year cycle. Study participants include anyone with a connection to the trawl fishery. Additional participation by others outside the trawl fishery were welcomed. Data is analyzed and compared across all study years. Common themes in the data include Graying of the Fleet, Changing Women's Roles, Impacts on Small Vessels, Changing Fishery Participation, New Entry, and other emerging themes. Data is provided to management entities to inform the 5-year review of the catch shares program, as well as other management needs. Results will be distributed through agency reports and other publications.

For more information please contact Suzanne Russell at NOAA's Northwest Fisheries Science Center, suzanne.russell@noaa.gov.

C. Bycatch Reduction Research

Overview: In 2017, the Pacific States Marine Fisheries Commission and project collaborators, including the Northwest Fisheries Science Center, conducted studies using artificial illumination to reduce bycatch in two US West Coast trawl fisheries; the Pacific hake (Merluccius productus) midwater trawl fishery and the ocean shrimp (Pandalus jordani) otter trawl fishery. In general, findings among our studies were similar in that the presence of artificial illumination appears to enhance fishes optomotor response and their ability to perceive escape areas in and around the trawl gear that they would not be able to perceive as well under dark conditions. Upcoming in 2018, we have two studies occurring. The first study will evaluate the efficacy of elevated trawl sweeps in the West Coast LE groundfish bottom trawl fishery, while the second study seeks to measuring the overall effectiveness of LED fishing lights to reduce fish bycatch in the ocean shrimp trawl fishery. Further summarizes of the 2017 projects appear below.

1. Effects on the bycatch of eulachon and juvenile groundfishes by altering the level of artificial illumination along an ocean shrimp trawl fishing line

Investigators: M.J.M. Lomeli, S.D. Groth, M.T.O. Blume, B. Herrmann and W. Wakefield

This study examined how catches of eulachon (Thaleichthys pacificus), juvenile groundfishes, and ocean shrimp (Pandalus jordani) could be affected by altering the level of artificial illumination along an ocean shrimp trawl fishing line. In the ocean shrimp trawl fishery, catches of eulachon are of special concern as their southern distinct population segment (DPS) is listed as "threatened" under the U.S. Endangered Species Act (ESA). Using a double-rigged ocean shrimp trawl vessel, with one trawl serving as the treatment and the other as the control, we compared the catch efficiencies for eulachon, juvenile groundfishes, and ocean shrimp between alternating treatment trawls configured with 5-, 10-, and 20-LED fishing lights along the trawl fishing line and the control trawl (unilluminated). Findings showed that the addition of artificial illumination along the trawl fishing line significantly affected the average catch efficiency for eulachon, juvenile rockfishes (Sebastes spp.) and flatfishes with the three LED configurations tested each catching significantly fewer individuals than the control trawl, without impacting ocean shrimp catches. For Pacific hake, the 10-LED configured trawl caught significantly more fish than that control trawl. For the 5-LED configuration, mean Pacific hake catches did not differ from the control trawl whereas results for the 20-LED configuration were inconclusive due to large uncertainties in the estimated effect. Aside from Pacific hake, the three LED configurations tested generally performed equally at reducing fish bycatch while not affecting ocean shrimp catches. As the southern DPS of eulachon faces many uncertainties in their ESA recovery, our study contributes new data on how artificial illumination along an ocean shrimp trawl fishing line can affect eulachon catches (and other fishes) and contribute to their conservation. Funding for this study was provided by NOAA NMFS Saltonstall-Kennedy Competitive Research Program.

For more information, please contact Mark Lomeli at mlomeli@psmfc.org.

2. Influencing the behavior and escapement of Chinook salmon out a midwater trawl using artificial illumination

Investigators: M.J.M. Lomeli and W. Wakefield

The Pacific hake midwater trawl fishery is the largest groundfish fishery off the U.S. west coast by volume. While catches comprise mainly of Pacific hake, bycatch of Chinook salmon (Oncorhynchus tshawytscha) can be an issue affecting the fishery as ESA listed fish are caught at times. We conducted two separate experiments evaluating the influence of artificial illumination on Chinook salmon behavior and escapement out a bycatch reduction device (BRD) in a Pacific hake midwater trawl. In experiment-1, we tested if Chinook salmon could be attracted towards and out specific escape windows of a BRD (equipped with multiple escape windows) using artificial illumination. In experiment-2, we compared Chinook salmon escapement rates out the BRD between tows conducted with- and without-artificial illumination on the BRD to determine if illumination can enhance their escapement overall. In experiment-1, we found the proportion of Chinook salmon to exit out an illuminated escape window was significantly greater than the proportion of Chinook salmon to exit out a non-illuminated escape window. In experiement-2, our results showed the proportion of Chinook salmon to exit the BRD when artificial illumination was present was significantly greater than the proportion of Chinook salmon to exit the BRD when artificial illumination was absent. Findings from this study demonstrate that artificial illumination can influence where Chinook salmon exit out the BRD we tested, but also that illumination can be used to enhance their escapement overall. As conservation of ESA listed Chinook salmon is a management priority, our research contributes new information on how artificial illumination can minimize adverse interactions between Pacific hake trawls and Chinook salmon. Funding for this study was provided by NOAA NMFS Bycatch Reduction Engineering Program.

For more information, please contact Mark Lomeli at mlomeli@psmfc.org.

VII. Publications

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