Northwest Fisheries Science Center

National Marine Fisheries Service

Agency Report to the Technical Subcommittee of the Canada-U.S. Groundfish Committee

April 2017

Table of Contents

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 2016, 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 Acting Center Director, Dr. Mark Strom at Mark.Strom@noaa.gov, (206) 860 – 3356.

II. Surveys

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

The NWFSC conducted its nineteenth annual bottom trawl resource survey for groundfish off the coasts of Washington, Oregon, and California. The objective of the 2016 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 2016, we utilized a new backdeck data collection system with updated software applications, and wireless networking. We initiated use of a ruggedized printer for labeling specimens in 2016, as well as updating the power supply for backdeck equipment. 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) Assessing sublethal effects of hypoxia on greenstriped rockfish (*Sebastes elongatus*) – NWFSC, Conservation Biology Division, Environmental and Fisheries Sciences Division;
2) Collection of voucher specimens for multiple fish species – Northwest Fisheries Science Center;
3) Lingcod aging study – collect otolith and fin ray from one lingcod in any tow where they are collect – NWFSC Aging Laboratory;
4) 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;
5) Collect fin slips from all Pacific sleeper sharks (*Somniosus pacificus*) to examine genetics – NOAA, NWFSC – Cindy Tribuzio

6) Does Puget Sound represent a distinct population segment for yelloweye and canary rockfish? - collection of fin clips for yelloweye and canary rockfishes – NWFSC, Conservation Biology Division;
7) Request for photographs of lamprey scars and specimens for Pacific lamprey (*Lampetra tridentata*) and river lamprey (*Lampetra ayresii* – NWFSC, Conservation Division, Newport;
8) Lingcod study – whole specimens for stomachs, tissue, fecundity, DNA sampling – NWFSC, Conservation Biology Division;
9) Record all sightings of basking sharks – Moss Landing Marine Laboratories;
10) Collection of all thornback rays, *Platyrhinoidis triseriata* – Moss Landing Marine Laboratories;
11) Collection of 25 big skate (*Raja binoculata*) egg cases containing embryos– Moss Landing Marine Laboratories
12) Collection of all biological data and specimens of deepsea skate (*Bathyraja abyssicola)* and broad skate ((*Amblyraja badia*) - Moss Landing Marine Laboratories;
13) Collection of all longnose catsharks *(Apristurus kampae)* – Moss Landing Marine Laboratories;
14) Collection of all specimens of Pacific black dogfish, *Centroscyllium nigrum* – Moss Landing Marine Laboratories;
15) 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;
16) Collection of all unusual or unidentifiable sharks including small sleeper sharks, *Somniosus pacificus* and velvet dog shark (*Zameus squamulosus*) – Moss Landing Marine Laboratories;
17) 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;

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, splitnose rockfisk, 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 2016 West Coast Groundfish Trawl Survey; and 8) Collection of ovaries and finclips from copper rockfish, cowcod, bank rockfish, blackspotted/rougheye rockfish, vermilion/sunset rockfish, 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, sablefish, and lingcod; 11) Collection of voucher specimens for teaching purpose; 12) Collection of all specimens identified as sharpnose sculpin (*Clinocottus acuticeps*); 13) Photograph, tag, bag and freeze deep water species such as arbiter snailfish *Careproctus kamikawi*) and other rare or unidentified deep water species.

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

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

In early Fall 2016, FRAM personnel conducted the 13th 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 14 biologists participating during the course of the survey. The three vessels sampled a total of 185 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 2016 survey, but should be similar to results from the 2015 survey where approximately 6,822 sexed lengths and weights, 5,480 fin clips, and 5,371 otolith pairs were taken during the course of the entire survey representing 39 different species of fish. Several ancillary projects were also conducted during the course of the survey. Approximately 779 ovaries were collected from 17 different species to support the development of maturity curves. Several dozen individual fish were retained for use in species identification training for west coast groundfish observers and for a genetic voucher program conducted by the University of Washington. Researchers also deployed an underwater video sled to capture visual observations for habitat analysis, species composition, and fish behavior studies. In addition, the 2016 survey collected rockfish specimens to generate species-specific fatty acid profiles to support research into increased mortality of juvenile California sea lions along the West Coast and conducted a pilot environmental DNA (eDNA) project aimed at comparing presence/absence of species-specific genetic sequences in water samples with species positively observed on survey hooks or video observations.

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

C. 2016 Investigations of hake ecology, survey methods, and the California Current ecosystem.

The NOAA/ NMFS/ Fisheries Engineering and Acoustic Technologies Team (FEAT) conducted two Pacific Hake research cruise during the past year. The 2016 Investigations of hake ecology, survey methods, and the California Current ecosystem was conducted on the NOAA Ship

Bell M. Shimada from July 30, 2016 to August 14, 2016. The data collected during the research cruise were processed to provide improved understanding of Pacific Hake biology and ecology as related to the California Current Large Marine Ecosystem. Additionally, we conducted experimental trawls comparing our standard AWT to an AWT with a MMED added. The survey range was from 41 07.03N to 41 07.03N. A total of 73 trawls were attempted with 65 completed successfully and 8 aborted. Acoustic data were collected on the *Shimada* with a Simrad EK60 echosounder operating at frequencies of 18, 38, and 120, and 200 kHz. We also began testing and comparison to EK60 of the new wideband EK80 sytems at the 45-90 kHz and 160-260 kHz ranges. The EK80 system is the replacement system for the Midwater trawls equipped with a camera system were conducted to verify species composition of observed backscatter layers and to obtain biological information (e.g., species identification, size, time and position encountered).

For more information, please contact Larry Hufnagle at lawrence.c.hufnagle@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 Larry Hufnagle at lawrence.c.hufnagle@noaa.gov.

III. Reserves

A. How does the definition of 'home range' affect predictions of the efficacy of marine reserves?

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

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

of biomass. Our results suggest failing to account for the full extent of a fish's time overestimates the effectiveness of marine reserves.

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

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

A. Hagfish: No research or assessments in 2016

B. Dogfish and other sharks: No assessments in 2016

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.

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

C. Skates: No research or assessments in 2016

D. Pacific cod: No research or assessments in 2016

E. Walleye Pollock: No research or assessments in 2016

F. Pacific whiting (hake)

1. Assessment

a) Status of the Pacific (whiting) stock in U.S. and Canadian waters in 2017

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

This stock assessment reported the collaborative efforts of the official U.S. and Canadian JTC members in accordance with the Agreement between the government of the United States and the government of Canada on Pacific hake/whiting. The assessment reported the status of the coastal Pacific Hake (or Pacific whiting, 1*Merluccius productus*) resource off the west coast of the United States and Canada for 2017. Coast-wide fishery landings of Pacific hake averaged 226 thousand mt from 1966 to 2016, with a low of 90 thousand mt in 1980 and a peak of 363 thousand mt in 2005. Prior to 1966 the total removals were negligible relative to the modern fishery. Recent coast-wide landings from 2007–2016 have been above the long term average, at 262 thousand mt. Landings between 2013 and 2013 were predominantly comprised of fish from the very large 2010-year class, comprising around 70% of the total removals. In 2016, U.S. fisheries caught mostly 2- and 6-year old fish from the 2010 and 2014 year classes, while the Canadian fisheries encountered mostly 6-year old fish from the 2010 year-class. The Agreement between the United States and Canada establishes U.S. and Canadian shares of the coast-wide TAC at 73.88% and 26.12%.

Data were updated for the 2017 assessment with the addition of fishery catch and age compositions from 2016, reanalyzed acoustic survey biomass and age compositions for 1995 (completing the reanalyzed acoustic survey time series initiated in the 2016 model), and other minor refinements such as catch estimates from earlier years. The assessment used Bayesian methods to incorporate prior information on two key parameters (natural mortality, *M*, and steepness of the stock-recruit

relationship, *h*) and integrated over parameter uncertainty to provide results that can be probabilistically interpreted. The exploration of uncertainty was not limited to parameter uncertainty as structural uncertainty was investigated through sensitivity analyses. Pacific Hake displays the highest degree of recruitment variability of any west coast groundfish stock, resulting in large and rapid changes in stock biomass. This volatility, coupled with a dynamic fishery, which potentially targets strong cohorts resulting in time-varying selectivity, and little data to inform incoming recruitment until the cohort is age-2 or greater, will, in most circumstances, continue to result in highly uncertain estimates of current stock status and even less-certain projections of future stock trajectory. Uncertainty in this assessment is largely a function of the potentially large 2014 year-class, which has been observed twice by the fishery but has yet to be observed by the acoustic survey, and uncertain selectivity. However, with recruitment being a main source of uncertainty in the projections and the survey not able to monitor the 2014 year-class until they are 3 years old (i.e., summer 2017), short term forecasts are very uncertain.

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

Estimates of historical Pacific hake recruitment indicate very large year classes in 1980, 1984, 1999, and 2010. The U.S. fishery shows that the 2014 year-class comprised a very large proportion of the observations in 2016. Uncertainty in estimated recruitments is substantial, especially for 2014, as indicated by broad posterior intervals. The fishing intensity on the Pacific Hake stock is estimated to have been below the $F_{40\%}$ target except for 1999 when the median estimated fishing intensity was slightly above target. Fishing intensity has been substantially below the $F_{40\%}$ target since 2012. Although the official catch targets adopted by the U.S. and Canada have been exceeded only once in the last decade (2002), fishing intensity is estimated to have not exceeded the target rate in the last 10 years. Recent catch and levels of depletion are presented in Figure 1.

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

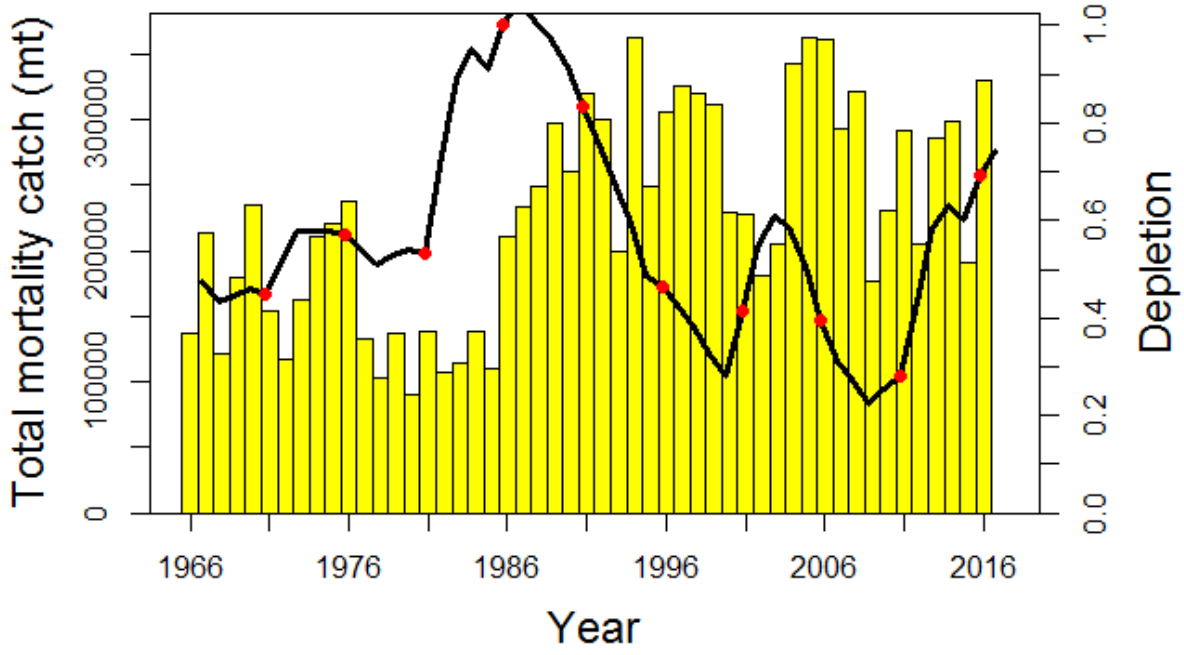

Figure 1. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Pacific hake, 1966-2016.

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

G. Grenadiers: No research or assessments in 2016

H. Rockfish: No assessments in 2016

1. Research

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

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

We 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 Kelly.Andrews@noaa.gov.

b) 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 Mr. Kelly Andrews at Kelly.Andrews@noaa.gov.

c) 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 Kelly.Andrews@noaa.gov.

d) 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, C.J. Harvey, N. Tolimieri, 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 Mr. Kelly Andrews at Kelly.Andrews@noaa.gov.

e) 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 will collect 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. Samples are being processed in the spring of 2016 and we plan to collect samples again during the FRAM groundfish trawl survey in 2016 and 2017.

For more information, please contact Dr. Chris Harvey at Chris.Harvey@noaa.gov.

f) MARSS models for estimating population status for data-poor species: three ESA listed rockfishes in Puget Sound

Investigators: N. Tolimieri, E.E. Holmes and G.D. Williams

Time-series analysis is a fundamental tool for evaluating the status of species thought to be potentially at risk of extinction. We show how multivariate autoregressive state-space models (MARSS) can combine gappy data from disparate gear types and multiple survey areas to estimate the regional population trajectory over time, the population growth rate, and the uncertainty in these estimates. MARSS can also test hypotheses about the spatial structure of subpopulations. We illustrate our approach with an analysis of population status for three, rockfishes listed in Puget Sound WA under the Endangered Species Act: bocaccio (endangered), yelloweye (threatened) and

canary rockfishes (threatened). Data were available from three sources: 1) Washington Department of Fish and Wildlife (WDFW) recreational fishery survey, 2) REEF scuba surveys, and a WDFW trawl survey. The surveys use different gear and sample different depths likely providing information on different rockfish assemblages. Changes in bag limits reduced catch by recreational fishers through time, and all three data sets have data gaps. Because there were few observations of the listed species, we estimate the population trajectory and growth for 'total rockfish'. We then make inferences about the listed species by evaluating evidence that they have increased or decreased as a proportion of the assemblage. Our analysis indicates that total rockfish declined ~3.1 – 3.8% per year from 1977-2014 with similar rates of decline north and sound of Admiralty Inlet. The listed species all declined as a proportion of the local assemblage suggesting stronger rates of negative population growth for the listed species than for total rockfish. Although rates of decline were similar in north and south of Admiralty Inlet, there was evidence of temporal independence in these two regions as evidenced by higher and more variable catch north of Admiralty Inlet and data support for unique trajectories (year to year abundances).

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

g) Genetic analysis to reduce uncertainty in the assessment of morphologically-similar west coast rockfish

Investigators: A. Keller, J. Cope, A. Elz, P. Frey, J. Harms, A. Hicks, J. Orr, L. Park, and V. Tuttle

Cryptic and incipient speciation within rockfishes (genus Sebastes) abounds on the U.S. West Coast. Investigation into morphological, life history, and genetic differences between similar species continues to reveal important distinctions among known species as well as within currently recognized species. Ambiguity in the taxonomy and biology of such species may result in historical data being pooled inappropriately, potentially obscuring important life history differences and adding uncertainty to stock assessments. We identify differences in the depth, spatial distribution, and growth for the rougheye (S. aleutianus)/blackspotted (S. melanostictus) complex while also offering preliminary results into newly discovered genetic variability within darkblotched rockfish (S. crameri). The West Coast Groundfish Bottom Trawl Survey, At-Sea Hake Observer Program, and Oregon Department of Fish and Wildlife provided over 900 tissue samples for the rougheye/blackspotted genetic analysis. The process employed a diagnostic Taqman assay of the ND3 mitochondrial region developed for this species pair. Morphometrics and meristics confirm these species are challenging to distinguish via visual diagnostics, but are definitively identifiable using genetic techniques. Results indicate over 15% of the catch previously considered as nominal rougheye rockfish may be blackspotted. These results have implications for long-term data sets including commercial landings and historical survey data. Color variability in darkblotched rockfish has elicited a similar investigation into stock structure. Preliminary analysis suggests consistent genetic variation among samples at multiple loci. However, voucher specimens examined to date have thus far not revealed a connection between observed genetic differences and various morphometric and meristic characteristics. Further investigations are underway.

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

h) Developing an index of abundance for yelloweye rockfish (*Sebastes ruberrimus*) off the Washington coast.

Investigators: T. –S. Tsou, J.M. Cope and B.W. Speidel

Yelloweye rockfish (Sebastes ruberrimus) was declared overfished in 2002 and since has been a "choke species" limiting groundfish fishing opportunities along the US west coast. One of the many challenges in monitoring and managing this stock is the lack of adequate fisheries-independent surveys. The conventional bottom trawl survey does not consistently sample Yelloweye rockfish habitat; and the only survey used in the past assessments was the International Pacific Halibut Commission's fixed-station setline survey. For Yelloweye caught by the IPHC survey off Washington coast, more than 90% was from one single station off Cape Alava and the minimum size was 40 cm (older than 10 years old). The abundance trend derived from the IPHC survey is uninformative for the population in Washington waters, thus the need for another survey. Beginning in 2006, the Washington Department of Fish and Wildlife has been conducting pilot projects to identify the best location, season, and hook-size for constructing a representative Yelloweye rockfish abundance index trend. In this presentation, we summarize findings from these pilot projects, compare abundance trends, and recommend future research.

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

I. Thornyheads: No research or assessments in 2016

J. Sablefish: No assessments in 2016

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 $^{\circ}$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: No assessments in 2016

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 demographic 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 Jameal.Samhouri@noaa.gov.

L. Atka mackerel: No research or assessments in 2016

M. Flatfish: No research or assessments in 2016

N. Pacific halibut & IPHC activities: No research or assessments in 2016

O. Other groundfish species: No assessments in 2016

1. Research

a) Size at maturity for grooved Tanner crab (*Chionoecetes tanneri*) along the U.S. west coast (Washington to California)

Investigators: A. Keller, J.C. Buchanan, E. Steiner, D. Draper, A. Chappell, P.H. Frey and M.A. Head

We conducted a multiyear study to examine interannual variability in mean size (carapace width, mm), maturity size (mm), and depth (m) for grooved Tanner crab (Chionoecetes tanneri Rathbun, 1893) along the U.S. west coast. An additional goal was to provide updated, estimates of carapace width (mm) at 50% maturity (W50) for male and female grooved Tanner crab and assess changes over time. Randomly selected samples came from trawl surveys undertaken annually by the Northwest Fisheries Science Center at depths of 55 to 1280 m. We used allometric relationships

between carapace width and either abdominal width (females) or chela length (males) to determine functional maturity by sex. We evaluated maturity by fitting logistic regression models to proportion mature. W50 varied significantly between males (125.2 mm) and females (89.1 mm) but interannual differences were slight. Annual mean carapace widths (CW) were greater for mature males (139.9 – 143.4 mm) relative to females (98.8 – 100.4 mm). Average sizes of immature grooved Tanner crab varied between sexes with males (75.7 – 84.6 mm) larger than females (66.7 – 71.9 mm). Size frequency distributions indicated little overlap in size of mature male and female grooved Tanner crab but considerable overlap between immature grooved Tanner crab. The best model expressing complexity in growth incorporated width, sex, and maturity stage. Depth ranged from 195 – 1254 m with the average depth of mature grooved Tanner crab (females, 737 m; males, 767 m) significantly shallower than immature (females, 949 m; males, 918 m) grooved Tanner crab.

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

b) 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) 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 (BRPs) 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 homogenously distributed). Incorporating spatially-generalized operating models, such as the one developed here, into management strategy evaluations (MSEs) will help develop management procedures that are more robust to spatial complexities.

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

b) Space Oddity: the Mission for Spatial Integration

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

Fishery management decisions are commonly informed by stock assessment models that aggregate outputs across the spatial domain of the species. However, refined understanding of spatial population structure has emphasized the need to address how spatiotemporal variation in ecological processes influences the validity of data collection programs and, ultimately, the determination of regional quotas. Recently, a surge of research activity has been dedicated toward developing and evaluating spatial modeling techniques to improve fisheries assessment and management. We overview the historical context and evolution of fisheries spatial models, highlight recent advances (focusing on research presented at a 2015 American Fisheries Society symposium on spatial modelling), and discuss incorporation of spatial models into the management process using symposium themes and lessons learned from several case studies. Continued investment in fine-scale data collection and associated spatial analyses will improve integration of spatial dynamics and ecosystem-level interactions across the stock assessment and fishery management interface. Despite the current shortage of examples where spatial assessment models are used as the basis for fisheries management, we believe that spatiotemporal modeling will soon be ubiquitous in fisheries science.

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

c) A framework for modelling spatial processes in stock assessments

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

We review approaches for incorporating spatial dynamics into stock assessments with a focus on data requirements, technical aspects, and performance of spatial harvest control rules. Results of the review will guide the development of a spatially-explicit simulation-estimation framework. A spatially-explicit operating model will be implemented to test the robustness of spatially-explicit and spatially-aggregated stock assessment models to estimation of stock status. The operating model will also be used to simulate spatially-explicit BRPs to evaluate the performance of commonly implemented harvest control rules assuming both correct and incorrect spatial structure. These simulations will provide an indication of how important assumed population structure is for the reliable determination of stock status and catch advice. We consider case studies of Atlantic menhaden, sablefish, Atlantic herring, Pacific hake/whiting, and Gulf of Mexico red snapper, which cover common population structures for marine fish populations (e.g., patchily distributed unit populations, natal homing, ontogenetic movement, and metapopulations). Several of these stocks have tag-recapture data sets to inform movement patterns or larval individual-based models to identify larval connectivity, which can inform the operating models.

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

d) Shifts in stock productivity: on the use of dynamic management metrics

Investigators: A. Berger, I. Taylor, Z. A'mar and M.A. Haltuch

The concept of "Dynamic B_0" was developed 30 years ago by a team of scientist on the US west coast (MacCall *et al*., 1985), but since that time it has not been widely explored in this region. Dynamic B_0 involves projecting fish populations using a time series of recruitment deviations and other parameters estimated in a stock assessment, but with the impact of fishing removed. It can be used as an alternative to the static equilibrium unfished spawning biomass (B_0) as a basis for harvest control rules that takes into account changes in productivity attributed to external factors such as climate or shifting predator-prey interactions. We present dynamic B_0 time series relative to the fished population biomass time series for 18 recent west coast groundfish stock assessments and discuss differences in stock status as calculated from dynamic vs. static B_0. In general, many species do not show strong differences between the two measures. However, a few notable exceptions include Sablefish, Bocaccio, Pacific Hake, and Widow Rockfish which were all estimated to have experienced above average recruitments in the 1960s or 1970s resulting in a subsequent period of 30 years or longer where the dynamic B_0 was above the static B_0. These results are related to other stock assessment examples where dynamic B_0 trajectories warrant examination. We also highlight results from a management strategy evaluation that compares 40-10 harvest control rules for sablefish using static B_0 and dynamic B_0 based reference points to show how control rule performance can differ depending on the history of population productivity. We

conclude by describing some advantages and complexities of using dynamic B_0 time series at the assessment-management interface (e.g., assessment diagnostic, determining future reproductive potential of the stock, or as reference points for adaptive management).

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

e) Evaluating geostatistical tools for assessment model using spatial environmental and habitat-related covariates

Investigators: A. Berger, J. Thorson and C. Whitmire

Geostatistical models for survey data have shown improvements in terms of estimand (e.g., population density) bias and precision over traditional stratified design-based approaches. These models use random fields to approximate a function-valued variable representing population density within a given area, and can also incorporate covariates representing environmental and biological factors across the landscape. We applied random fields within a delta generalized linear mixed modeling framework to model three density-related processes: the probability of encountering a species at any particular sampling site, the probability distribution of the size of catch (biomass) at the sampling site given an encounter, and the relationship among discrete sampling sites and spatially continuous environmental and habitat-related covariates. We applied this model to data from the U.S. west coast groundfish bottom trawl survey to estimate changes in population density spatially across the survey time series. Several alternative spatially-continuous environmental and habitat-related covariates were evaluated (i.e., temperature, salinity, and distance to rocky habitat) to help explain spatial variation in density for several groundfish species. Abundance indices from the geostatistical delta general linear mixed model were compared with and without auxiliary habitat information for each species. Incorporating spatially-continuous covariate information improved prediction of relative abundance by facilitating a relational approach for spatial imputation of density across unsampled areas.

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

f) A synoptic approach to reconstructing west coast groundfish historical removals

Investigator: J.M. Cope

Quantifying the removal time series of a stock is an essential input to a variety of stock assessment methods and catch-based management. But estimating removals is REALLY hard. Sampling protocols, fishery diversity, catch versus landing location, dead discards, and species identification are just some of the complications that vary across time and space. Given that most groundfish stocks are distributed coastwide and a complete time series of removals is needed, this project aims to coordinate approaches across the states of Washington, Oregon and California to confront removal reconstruction challenges and establish common practices. Both California and Oregon have attempted historical removal reconstructions, while Washington is just beginning the process. We use the Washington effort to focus on six groundfish species that vary in the difficulty of

estimating removal histories: black (*Sebastes melanops*), canary (*S. pinniger*) and rougheye (*S. aleutianus*) rockfishes, petrale sole (*Eopsetta jordani*), sablefish (*Anoplopoma fimbria*), and lingcod (*Ophiodon elongatus*). The Washington reconstruction is compared to the approaches taken for the same species in Oregon and California with the goal of matching reconstruction protocols across states to the extent possible. Lastly, uncertainty levels across periods, species and states are established. This is a new feature of all three removal reconstructions which will improve treatment of uncertainty in future stock assessments.

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

g) Mixed-species management in the U.S. west coast groundfish fishery

Investigator: J.M. Cope

The US west coast groundfish fishery is comprised of 90+ fish stocks of varied life histories, most of which do not have formal stock assessments, but all of which require catch limits. Most major fisheries are mixed-stock, and management has often focused on the weak stock when implementing catch limits. While stocks with assessments have individual catch limits, the remaining species have been managed in stock complexes. This presentation offers an overview of those stock complexes and offers an analysis of how they could be restructured to better account for ecology, life history and technical interactions. The use of data-limited approaches to estimate catches for stock complexes are described, as well as the treatment of uncertainty and application of the precautionary principle when setting catch limits.

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

h) Extending integrated stock assessments models to use non-depensatory three-parameter stock-recruitment relationships

Investigators: A.E. Punt and J.M. Cope

Stock assessments based on the integrated paradigm often include an underlying stock-recruitment relationship, which 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 used in the harvest control rules 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 Beverton-Holt and Ricker. Use of 2-parameter stock-recruitments hence restricts the ability to fully quantify the uncertainty associated with estimating BMSY and FMSY because the use of 2-parameter SRRs restricts the potential range of values for BMSY/B0. In principle, BMSY and FMSY can be set independently if the stock-recruitment relationship is more general than the Beverton-Holt and Ricker relationships. 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 in the limit of zero population size. Bayesian assessments of three example species off the US west coast groundfish (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 moving to a 3-parameter stock-recruitment relationship.

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

i) A review of stock assessment packages in the United States.

Investigators: C.M. Dichmont, R.A. Deng, A.E. Punt, J. Brodziak, Y. Chang, J.M. Cope, J.N. Ianelli, C.M. Legault, R.D. Methot Jr., C.E. Porch, M.H. Prager and K.W. Shertzer

Stock assessments provide scientific advice in support of fisheries decision making. Ideally, assessments involve fitting population dynamics models to fishery and monitoring data to provide estimates of time trajectories of biomass and fishing mortality in absolute terms and relative to biological reference points such as BMSY and FMSY, along with measures of uncertainty. Some stock assessments are conducted sing software developed for a specific stock or group of stocks. However, increasingly, stock assessments are being conducted using packages developed for application to several taxa and across multiple regions. We review the range of packages used to conduct assessments of fish and invertebrate stocks in the United States because these assessments tend to have common goals, and need to provide similar outputs for decision making. Sixteen packages are considered, five based on surplus production models, one based on a delay-difference model, and the remainder based on age-structured models. Most of the packages are freely available for use by analysts in the US and around the world, have been evaluated using simulations, and can form the basis for forecasts. The packages differ in their ease of use and the types of data inputs they can use. This paper highlights the benefits of stock assessment packages in terms of allowing analysts to explore many assessment configurations and facilitating the peer-review of assessments. It also highlights the disadvantages associated with the use of packages for conducting assessments. Packages with the most options and greatest flexibility are the most difficult to use, and see the greatest development of auxiliary tools to facilitate their use.

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

j) Developing partnerships for enhanced data collections of West Coast Groundfish

Investigators: J. Field, S. Sogard, S. Beyer, S. Rienecke, M. Gleason and M.A. Haltuch

Accurate information on basic life history traits such as age at maturity, growth rates, and fecundity are vital to assessing population health and productivity. These traits are rarely static over space and time, and understanding the importance of geographic (as well as temporal) variability in life history traits is a frequent research priority in stock assessments. Moreover, in

California waters, age data for most species are increasingly less available for assessment purposes. Similarly, collection of reproductive ecology data (maturity, fecundity, condition) and genetic data (fin clips) has traditionally not been a component of port samplers data collection, due to the reluctance of most processors to cut fish (a voluntary, not mandatory, requirement in California) and the time consuming nature of sampling reproductive tissues (particularly subsamples of eggs or larvae) for such studies. In this study, we propose to develop a pilot study with a key fisheries stakeholder, The Nature Conservancy (TNC), and the fishermen partners they work with as part of the California Groundfish Collective (CGC), that will enable a localized data collection effort to complement existing port sampling efforts run by the Pacific States Marine Fisheries Commission (PSMFC). Samples have been collected for Petrale Sole, Chilipepper rockfish and Bocaccio rockfish and analysis is ongoing.

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

k) Identifying partial regulation in community dynamics using spatio-temporal models.

Investigators: J. Thorson, S. Munch, and D. Swain

Niche-based approaches to community analysis often involve estimating a matrix of pairwise interactions among species (the “community matrix”), but this task becomes infeasible using observational data as the number of modeled species increases. As an alternative, neutral theories achieve parsimony by assuming that species within a trophic level are exchangeable, but generally cannot incorporate stabilizing interactions even when they are evident in field data. Finally, both regulated (niche) and unregulated (neutral) approaches have rarely been fitted directly to survey data using spatio-temporal statistical methods. We therefore propose a spatio-temporal and model-based approach to estimate community dynamics that are partially regulated. Specifically, we start with a neutral spatio-temporal model where all species follow ecological drift, which precludes estimating pairwise interactions. We then add regulatory relations until model selection favors stopping, where the “rank” of the interaction matrix may range from zero to the number of species. A simulation experiment shows that model selection can accurately identify the rank of the interaction matrix, and that the identified spatio-temporal model can estimate the magnitude of species interactions. A forty-year case study for the Gulf of St. Lawrence marine community shows that recovering grey seals have an unregulated and negative relation with demersal fishes. We therefore conclude that partial regulation is a plausible approximation to community dynamics using field data, and hypothesize that estimating partial regulation will be expedient in future analyses of spatio-temporal community dynamics given limited field data. We conclude by recommending ongoing research to add explicit models for movement, so that meta-community theory can be confronted with data in a spatio-temporal statistical framework.

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

l) 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.

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

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

Investigators: J. Thorson and L. Barnett, L.

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.

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

n) 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.

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

o) 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.

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

p) 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.

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

q) 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.

Synthesis and applications. 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

r) Density-dependent changes in effective area occupied for sea-bottom associated marine fishes.

Investigators: J. Thorson, A. Rindorf, J. Gao, D. Hanselman and H. Winker

The spatial distribution of marine fishes can change for many reasons, including density-dependent distributional shifts. Previous studies show mixed support for either the proportional-density model (PDM; no relationship between abundance and area occupied, supported by ideal-free distribution theory) or the basin model (BM; positive abundance–area relationship, supported by density-dependent habitat selection theory). The BM implies that fishes move towards preferred habitat as the population declines. We estimate the average relationship using bottom trawl data for 92 fish species from six marine regions, to determine whether the BM or PDM provides a better description for sea-bottom-associated fishes. We fit a spatio-temporal model and estimate changes in effective area occupied and abundance, and combine results to estimate the average abundance–area relationship as well as variability among taxa and regions. The average relationship is weak but significant (0.6% increase in area for a 10% increase in abundance), whereas only a small proportion of species–region combinations show a negative relationship (i.e. shrinking area when abundance increases). Approximately one-third of combinations (34.6%) are predicted to increase in area more than 1% for every 10% increase in abundance. We therefore infer that population density generally changes faster than effective area occupied during abundance changes. Gadiformes have the strongest estimated relationship (average 1.0% area increase for every 10% abundance increase) followed by Pleuronectiformes and Scorpaeniformes, and the Eastern Bering Sea shows a strong relationship between abundance and area occupied relative to other regions. We conclude that the BM explains a small but important portion of spatial dynamics for sea-bottom-associated fishes, and that many individual populations merit cautious management during population declines, because a compressed range may increase the efficiency of harvest.

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

s) Joint dynamic species distribution models: a tool for community ordination and spatiotemporal monitoring.

Investigators: J. Thorson, M. Scheuerell, C. Szuwalski, E. Zipkin, L. Ries and J. Ianelli

Spatial analysis of the distribution and density of species is of continuing interest within theoretical and applied ecology. Species distribution models (SDMs) are being increasingly used to analyse count, presence–absence and presence-only data sets. There is a growing literature on dynamic SDMs (which incorporate temporal variation in species distribution), joint SDMs (which simultaneously analyse the correlated distribution of multiple species) and geostatistical models (which account for similarity between nearby sites caused by unobserved covariates). However, no previous study has combined all three attributes within a single framework.

We develop spatial dynamic factor analysis for use as a ‘joint, dynamic SDM’ (JDSDM), which uses geostatistical methods to account for spatial similarity when estimating one or more ‘factors’. Each factor evolves over time following a density-dependent (Gompertz) process, and the log-density of each species is approximated as a linear combination of different factors. We demonstrate a JDSDM using two multispecies case studies (an annual survey of bottom-associated species in the Bering Sea and a seasonal survey of butterfly density in the continental USA), and also provide our code publicly as an R package.

Case study applications show that that JDSDMs can be used for species ordination, i.e. showing that dynamics for butterfly species within the same genus are significantly more correlated than for species from different genera. We also demonstrate how JDSDMs can rapidly identify dominant

patterns in community dynamics, including the decline and recovery of several Bering Sea fishes since 2008, and the ‘flight curves’ typical of early or late-emerging butterflies. We conclude by suggesting future research that could incorporate phylogenetic relatedness or functional similarity, and propose that our approach could be used to monitor community dynamics at large spatial and temporal scales.

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

t) Hierarchical analysis of phylogenetic variation in intraspecific competition across fish species.

Investigators: A. Foss-Grant, E. Zipkin, J. Thorson, O. Jensen and W. Fagan

The nature and intensity of intraspecific competition can vary greatly among taxa, yet similarities in these interactions can lead to similar population dynamics among related organisms. Variation along the spectrum of intraspecific competition, with contest and scramble competition as endpoints, leads to vastly different responses to population density. Here we investigated the diversity of intraspecific competition among fish species, predicting that functional forms of density-dependent reproduction would be conserved in related taxa. Using a hierarchical model that links stock–recruitment parameters among populations, species, and orders, we found that the strength of overcompensation, and therefore the type of intraspecific competition, is tightly clustered within taxonomic groupings, as species within an order share similar degrees of compensation. Specifically, species within the orders Salmoniformes and Pleuronectiformes exhibited density dependence indicative of scramble competition (overcompensation) while the orders Clupeiformes, Gadiformes, Perciformes, and Scorpaeniformes exhibited dynamics consistent with contest competition (compensation). Maximum potential recruitment also varied among orders, but with less clustering across species. We also tested whether stock–recruitment parameters correlated with maximum body length among species, but found no strong relationship. Our results suggest that much of the variation in the form of density-dependent reproduction among fish species may be predicted taxonomically due to evolved life history traits and reproductive behaviors.

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

u) Model-based inference for estimating shifts in species distribution, area occupied, and center of gravity.

Investigators: J. Thorson, M. Pinsky and E. Ward

Changing climate is already impacting the spatial distribution of many taxa, including bees, plants, birds, butterflies and fishes. A common goal is to detect range shifts in response to climate change,

including changes in the centre of the population's distribution (the centre of gravity, COG), population boundaries and area occupied. Conventional estimators, such as the abundance-weighted average (AWA) estimator for COG, confound range shifts with changes in the spatial distribution of available survey data and may be biased when the distribution of survey data shifts over time. AWA also does not estimate the standard error of COG in individual years and cannot incorporate data from multiple survey designs.

To explicitly account for changes in the spatial distribution of survey effort, we propose an alternative species distribution function (SDF) estimator. The SDF approach involves calculating distribution metrics, including COG, population boundary and area occupied, directly from the predicted species distribution or density function. We illustrate the SDF approach using a spatiotemporal model that is available as an r package. Using simulated data, we confirm that the SDF substantially decreases bias in COG estimates relative to the AWA estimator. We then illustrate the method by analysing data from two data sets spanning 1977–2013 for 18 marine fishes along the U.S. West Coast.

In our case study, the SDF estimator shows significant northward shifts for six of 18 species (with southward shifts for only 2), where two species (darkblotched and greenstriped rockfishes) have both a northward shift and a decreased area occupied. Pelagic species (e.g. Pacific hake and spiny dogfish) have more variable distribution than bottom-associated species. We also find substantial differences between AWA and SDF estimates of COG that are likely caused by shifts in sampling distribution (which affect the AWA but not the SDF estimator).

We caution that common estimators for range shift can yield inappropriate inference whenever sampling designs have shifted over time. We conclude by suggesting further improvements in model-based approaches to analysing climate impacts, including methods addressing the impact of local and regional temperature changes on species distribution.

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

v) Can autocorrelated recruitment be estimated using integrated assessment models and how does it affect population forecasts?

Investigators: K. Johnson, E. Councill, J. Thorson, L. Brooks, R. Methot and A. Punt

The addition of juveniles to marine populations (termed “recruitment”) is highly variable due to variability in the survival of fish through larval and juvenile stages. Recruitment estimates are often large or small for several years in a row (termed “autocorrelated” recruitment). Autocorrelated recruitment can be due to numerous factors, but typically is attributed to multi-year environmental drivers affecting early life survival rates. Estimating the magnitude of recruitment autocorrelation within a stock assessment model and examinations on its effect on the quality of forecasts of spawning biomass within stock assessments is uncommon. We used a simulation experiment to evaluate the estimability of autocorrelation within a stock assessment model over a range of levels of autocorrelation in recruitment deviations. The precision and accuracy of estimated autocorrelation, and the ability of an integrated age-structured stock assessment framework to forecast the dynamics of the system, were compared for scenarios where the autocorrelation parameter within the assessment was fixed at zero, fixed at its true value, internally estimated within the integrated model, or input as a fixed value determined using an external estimation procedure that computed the sample autocorrelation of estimated recruitment

deviations. Internal estimates of autocorrelation were biased toward extreme values (i.e., towards 1.0 when true autocorrelation was positive and −1.0 when true autocorrelation was negative). Estimates of autocorrelation obtained from the external estimation procedure were nearly unbiased. Forecast performance was poor (i.e., true biomass outside the predictive interval for the forecasted biomass) when autocorrelation was ignored, but was non-zero in the simulation. Applying the external estimation procedure generally improved forecast performance by decreasing forecast error and improving forecast interval coverage. However, estimates of autocorrelation were shown to degrade when fewer than 40 years of recruitment estimates were available.

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

w) Relative magnitude of cohort, age, and year-effects on growth of marine fishes.

Investigators: J. Thorson and C. Minte-Vera

Variation in individual growth rates contributes to changes over time in compensatory population growth and surplus production for marine fishes. However, there is little evidence regarding the prevalence and magnitude of time-varying growth for exploited marine fishes in general, whether it is best approximated using changes in length-at-age or weight-at-length parameters, or how it can be represented parsimoniously. We therefore use a database of average weight in each year and age for 91 marine fish stocks from 25 species, and fit models with random variation in length and weight parameters by year, age, or cohort (birth-year). Results show that year effects are more parsimonious than age or cohort effects and that variation in length and weight parameters provide roughly similar fit to average weight-at-age data, although length parameters show a greater magnitude of variability than weight parameters. Finally, the saturated model can explain nearly 2/3 of total variability, while a single time-varying factor can explain nearly 1/2 of variability in weight-at-age data. We conclude that time-varying growth can often be estimated parsimoniously using a single time-varying factor, either internally or prior to including ‘empirical’ weight at age in population dynamics models.

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

x) Space-time investigation of the effects of fishing on fish populations.

Investigators: K. Ono, A.O. Shelton, E.J. Ward, J. Thorson, B.E. Feist and R. Hilborn

Species distribution models (SDMs) are important statistical tools for obtaining ecological insight into species-habitat relationships and providing advice for natural resource management. Many

SDMs have been developed over the past decades, with a focus on space- and more recently, time-dependence. However, most of these studies have been on terrestrial species and applications to marine species have been limited. In this study, we used three large spatio-temporal data sources (habitat maps, survey-based fish density estimates, and fishery catch data) and a novel space-time model to study how the distribution of fishing may affect the seasonal dynamics of a commercially important fish species (Pacific Dover sole, Microstomus pacificus) off the west coast of the USA. Dover sole showed a large scale change in seasonal and annual distribution of biomass, and its distribution shifted from mid-depth zones to inshore or deeper waters during late summer/early fall. In many cases, the scale of fishery removal was small compared to these broader changes in biomass, suggesting that seasonal dynamics were primarily driven by movement and not by fishing. The increasing availability of appropriate data and space-time modeling software should facilitate extending this work to many other species, particularly those in marine ecosystems, and help tease apart the role of growth, natural mortality, recruitment, movement, and fishing on spatial patterns of species distribution in marine systems.

For more information, please contact Dr. Kot Ono at kotarono@uw.edu

y) A generic approach to bias correction in population models using random effects, with spatial and age-structured examples.

Investigators: J. Thorson and K. Kristensen

Statistical models play an important role in fisheries science when reconciling ecological theory with available data for wild populations or experimental studies. Ecological models increasingly include both fixed and random effects, and are often estimated using maximum likelihood techniques. Quantities of biological or management interest ("derived quantities") are then often calculated as nonlinear functions of fixed and random effect estimates. However, the conventional "plug-in" estimator for a derived quantity in a maximum likelihood mixed-effects model will be biased whenever the estimator is calculated as a nonlinear function of random effects. We therefore describe and evaluate a new "epsilon" estimator as a generic bias-correction estimator for derived quantities. We use simulated data to compare the epsilon-method with an existing bias-correction algorithm for estimating recruitment in four configurations of an age-structured population dynamics model. This simulation experiment shows that the epsilon-method and the existing bias-correction method perform equally well in data-rich contexts, but the epsilon-method is slightly less biased in data-poor contexts. We then apply the epsilon-method to a spatial regression model when estimating an index of population abundance, and compare results with an alternative bias-correction algorithm that involves Markov-chain Monte Carlo sampling. This example shows that the epsilon-method leads to a biologically significant difference in estimates of average abundance relative to the conventional plug-in estimator, and also gives essentially identical estimates to a sample-based bias-correction estimator. The epsilon-method has been implemented by us as a generic option in the open-source Template Model Builder software, and could be adapted within other mixed-effects modeling tools such as Automatic Differentiation Model Builder for random effects. It therefore has potential to improve estimation performance for mixed-effects models throughout fisheries science.

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

z) Software: Shiny DLMtool. Shiny application of the DLMtool. https://shcaba.shinyapps.io/Shiny_DLMtool/

Application developed to improve utility of the DLMtool for data-limited method application and management strategy.

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

aa) Software: Natural Mortality Tool
https://github.com/shcaba/Natural-Mortality-Tool ; http://barefootecologist.com.au/shiny_m

Application developed to allow multiple calculation of natural mortality.

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

2. Survey and Observer Science

a) Resolving the issues of hook saturation, hook competition, and fixed-site design in the Southern California hook-and-line survey

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

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 a number of shelf rockfish species, such as bocaccio (*Sebastes paucispinis*) and vermilion rockfish (*S. miniatus*). 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) The Northwest Fisheries Science Center's (NWFSC) wireless back deck and data logging system

Investigators: V. Simon, T. Hay and A.A. Keller

The NWFSC's West Coast Groundfish Bottom Trawl Survey (WCGBTS) annually samples approximately 750 stations at depths from 55 to 1280 meters off the continental United States using four chartered commercial fishing vessels. To improve data capture efficiency, the FRAM division uses a sophisticated wireless network (802.11 protocols) to input data into several in-house applications. We demonstrated the use of all WCGBTS wireless back-deck data gathering instruments in concert with our new back deck data logging software at the 2016 TSC electronic data capture methods workshop held in Newport OR as part of the 2016 Western Groundfish Conference. We demonstrated the incorporation of the NWFSC's communication box that provides power, networking, and printing resources in the extremely harsh conditions of an open and small backdeck work environment. Electronic sampling components include scales, fish measuring boards, barcode wand, barcode gun, calipers, and label printers. We demonstrated a new Python language data-based logging program including refined and practical real-time validations which limit data input errors, expedite resolution of data errors and facilitate data dissemination.

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

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

Investigators: A. Keller, J. 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.

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

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

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.

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

e) West Coast Observer Program

The FRAM West Coast Groundfish Observer Program (WCGOP) continued collecting fishery-dependent data during 2016 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 2016

2016	
Number of catch share observers	**4**

	9
Number of non-catch share observers	**4 4**
Number of A-SHOP Observers	**4 4**

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

DESCRIPTION	SS IFQ Trawl	SS IFQ Fixed Gear	SS Hake	MSCV	A-SHOP
Number of vessels	58	13	3	2	15
Number of trips*	806	91	99	6	82
Number of Sea days*	3,019		245	91	2180
Number of Observers	49				44

*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 2,606 sea days in the non-catch share fisheries in 2016 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:

NCS Sea Days	
FISHERY DESCRIPTION	SEA DAYS*
CA Emley-Platt EFP	3
CA Halibut	150
CA Nearshore	144
CA Pink Shrimp	104
Electronic Monitoring EFP	185
Limited Entry Sablefish	528
Limited Entry Trawl	2
Limited Entry Zero Tier	68
OR Blue/Black Rockfish	95
OR Blue/Black Rockfish Nearshore	132
OR Pink Shrimp	732
PSMFC Discard Handling Research	33
WA Pink Shrimp	301
WC Open Access Fixed Gear	129

*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.

g) Development of the Pacific Groundfish Trawl IFQ Market

Investigators: D. Holland

In-season transferability of quota plays an important role in multispecies individual fishing quota (IFQ) systems since fishermen often need to acquire quota to balance incidental catch. The optimal utilization of quotas is thus dependent on development of an efficient quota market, but markets in multispecies IFQ fisheries develop slowly and may fail to perform efficiently even after several years. In 2011 an IFQ system was implemented for the Pacific groundfish trawl fishery in the US. After four years, the quota market does not appear to be yielding efficient prices for many species or distributing quota efficiently. I explore the structure and performance of the QP market and discuss the impediments to market efficiency. Drawing from theory and experience in other multispecies IFQ systems, I discuss other quota distribution and catch-balancing mechanisms that can supplement and perhaps improve inefficient markets and enable higher quota utilization rates

For more information, please contact Dr. Dan Holland at dan.holland@noaa.gov.

h) The Impact of Access Restrictions on Fishery Income Diversification of US West Coast Fishermen

Investigators: D. Holland and S. Kasperski

Access to most fisheries on the US West Coast was essentially open prior to the mid-1970s when state licenses were first limited for salmon fisheries. Subsequently, licenses to most fisheries on the West Coast have been limited, and the numbers of licenses in many fisheries have been reduced with buyback programs. More recently, catch share programs, which dedicate exclusive shares of catch to individuals or cooperatives, have been introduced in several sectors of the federally managed Pacific groundfish fishery. As access to fisheries has become more restricted, revenue diversification of West Coast fishing vessels has generally declined. This is a source of concern, since diversification has been shown to reduce year-to-year variation in revenue and thus financial risk. However, catch share programs may create more security and stability in vessels' landings which may offset effects of less diversification. Nevertheless, there may be a tradeoff between the efficiency gains enabled by restricting access and risk reduction benefits associated with greater diversification.

For more information please contact Dr. Dan Holland at dan.holland@noaa.gov.

i) The Pacific Coast Groundfish Fishery Social Study

Investigators: S. Russell, M.V. Oostenburg, A. Vizek and B. 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 suzanne.russell@noaa.gov.

j) West Coast Communities and Catch Shares: The Early Years of Social Change

Investigators: S. Russell, A. Arias-Arthur, K. Sparks and A. Varney

The Pacific Coast Groundfish Trawl Fishery transitioned to a catch shares program in January 2011. The Pacific Coast Groundfish Fishery Social Study was designed to measure associated social changes and impacts to individuals and communities. Selected survey and interview data from the baseline data collection in 2010 and the first supplemental data collection effort in 2012 are aggregated at the community level and analyzed for initial signs of social change. Communities are sorted into top, mid, and low tier communities based on the percentage of quota share (QS) permit owners that live in each community. A higher number of QS permit owners in a place is expected to result in relatively greater benefits to those communities. Questions analyzed include

percent of income from fishing, multiple jobs worked, job stability, job satisfaction, standard of living, and how individuals were personally affected. Significant results include improvements in job satisfaction and increases in multiple jobs worked for TOP tier communities, and improved standard of living in LOW tier communities. MID tier communities appear to be in the middle, with no significant changes. Interview data indicate variation between owners, where some can fish their allocations and others need to lease more to fish.

For more information, please contact Suzanne Russell at suzanne.russell@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 2016, CAP production aged 26,975 otoliths and completed over 970 training reads. Production ages will support the upcoming 2017 assessments on arrowtooth flounder, California scorpionfish, darkblotched rockfish, lingcod, Pacific hake, Pacific Ocean perch and yellowtail rockfish. California scorpionfish, lingcod and yellowtail rockfish are species that had previously never been aged by the lab before. The lab cored 31 black rockfish otoliths for C14 analysis at NOSAMS. Over 295 black 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, in support of research into alternative methods of age determination. Two age readers travelled to Olympia, WA to learn how to age lingcod from WDFW personnel.

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

b) 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. The first batch of radiocarbon ages have been processed for canary and black rockfish, focusing on producing both test and reference curves. Aging of a second set of samples for both species is underway in an effort to fill in gaps in both reference and test curves. The second set of bomb radiocarbon analyses are expected to be run during 2017.

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

c) FRAM's reproductive maturity program and its application for fisheries management

Investigator: Melissa A. Head

Since the initiation of the NWFSC's reproductive maturity program (FRAM Division) in 2009, we collected over 10,000 ovaries from 32 groundfish species. We identified several key factors essential for understanding reproductive biology of west coast groundfishes: (1) spatial and temporal patterns, (2) oceanographic conditions related to skip spawning and abortive maturation, and (3) estimating biological (sexual) versus functional (potential spawner) maturity. FRAM is currently obtaining reproductive samples for multiple groundfish species via multiple sampling platforms, (west coast groundfish trawl survey, Southern California hook and line survey, hake acoustics survey), observers (at sea hake observers), and collaboration with Washington and Oregon state departments (WDFW and ODFW). Samples are histologically assessed for maturity using a binocular microscope and imaging software. In the past, many stock assessments relied on outdated or incomplete life-history information from opportunistic or geographically/temporally limited data sources. Our goal is to provide updated, coast wide maturity information on an annual basis to reduce uncertainty in parameters used to estimate spawning biomass and recruitment. Ecosystem variables, such as habitat, predator-prey interactions, food availability, upwelling, and oceanographic patterns may also have an outsized influence on the reproductive behavior of groundfish stocks in a given year. We are investigating how these variables affect skip-spawning and abortive maturation patterns and how spatial/temporal relationships are associated with maturity schedules.

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

d) Techniques for improving estimates of maturity ogives in groundfish using double-reads and measurement error models

Investigators: M.A. Head, G.L. Stokes, J.T. Thorson and A.A. Keller

The reproductive output of a population depends upon physiological factors, including maturation rates and fecundity at size and age, as well as the rate at which post-maturation females fail to spawn (i.e. skipped spawning). These rates are increasingly included in stock assessment models, and are thought to change over time due to harvest and environmental factors. Thus, it is important to accurately estimate maturation and skipped spawning rates while including information on imprecision. For this task, we developed a new double-read and measurement-error modeling protocol for estimating maturity that is based on the use of multiple histological reads of ovaries to account for reader error caused by poorly prepared slides, nuclear smear, and early yolk development. Application to three U.S. West Coast groundfishes (Pacific hake *Merluccius productus*, darkblotched rockfish *Sebastes crameri*, and canary rockfish *Sebastes pinniger*) indicates that reader uncertainty is strongly predictive of reader error rates. Results also show differences in rates of skipped spawning among species, and should be further investigated. We recommend that future maturity studies record reader certainty, use models that incorporate covariates into the analysis, and conduct an initial double reader analysis. If readers exhibit little variation, then double reads may not be necessary. In addition, slide quality should also be recorded, so that future studies do not confuse this with reader imprecision. This improved protocol will assist in estimating life history, as well as environmental, and anthropogenic effects on maturity.

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

e) Challenges associated with assessing maturity, skipped spawning, and abortive maturation rates for fisheries managers: a case study of *Sebastes pinniger*

Investigator: M.A. Head, P.H. Frey, J.M. Cope and A.A. Keller

Incorporating accurate estimates of life history parameters into population models can 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, seasonal data collections 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. We examined the reproductive biology of canary rockfish, *Sebastes pinniger*, using ovaries collected by the West Coast groundfish bottom trawl survey (WCGBT) from 2009 – 2015 (n = 533) and Oregon Department of Fish and Wildlife (ODFW) port biologists from 2014 – 2016 (n = 308). This 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) oceanographic conditions effect on reproductive patterns related to skip spawning and abortive maturation, and (3) estimating biological (sexual) 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 reproductive behavior can provide useful information

for predicting shifting oceanographic conditions influence on the spawning output of groundfish stocks.

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

f) A new approach to reproductive analysis for fisheries management.

Investigators: M. Head, J. M. Cope, P. Frey and A. Keller

As part of the NWFSC's reproductive maturity program (FRAM Division), we have identified several key factors to study in assessing West Coast groundfish reproductive biology. To date, these include: (1) spatial and temporal patterns, (2) oceanographic conditions effect on maturity schedules and reproductive patterns related to skip spawning and abortive maturation, and (3) estimating biological (sexual) versus functional (potential spawner) maturity. Based on ongoing analyses, our goal is to provide updated, coast wide maturity information, at annual intervals to alleviate the need for fish managers to make assumptions about life history strategies in models used for biomass estimates. Prior to the initiation of our research, data were often lacking or if available outdated and/or from localized rather than widespread sources. Ecosystem variables, such as habitat, predator-prey interactions, food availability, upwelling, and oceanographic changes influence reproductive behavior of groundfishes. If we can understand how these variables affect skip-spawning and abortive maturation patterns in fish, and how spatial/temporal relationships are associated with maturity schedules, we can make fewer assumptions in current biomass estimates and have more reliable data for climate model forecasts. Using up to-date information may be critical to accurately estimating future rebuilding patterns. In addition, modelling maturity data accurately to reflect current biological patterns may reduce uncertainty and change spawning biomass estimates.

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

Some cold-water corals and sponges occur in such dense aggregations that they provide structurally complex habitats which support a diverse assemblage of associated invertebrates and fish. For this study we investigated the relationship between structure-forming invertebrates (SFIs), specifically corals, sea pens and sponges, and their associations with demersal fish using trawl

survey data from 2003-2015, covering continental shelf and slope waters from Cape Flattery, Wash., to the Mexican border. Survey data were divided into one of four groups by haul location and tow depth: north vs. south of Cape Mendocino (Calif.) and shallow (<=300m) vs. deep (>300m). General linear models (GLMs) and generalized additive models (GAMs) were used to correlate species richness and fish biomass with SFI densities. GLMs showed that average species richness was slightly lower and finfish biomass slightly higher in hauls with no SFIs. GAMs indicated a weak, non-linear relationship between species richness and sponge density (<1% of deviance explained) and slightly higher fish biomass in hauls with low or zero densities of sea pens or sponges. Multivariate analyses were used to relate fish community structure in each group to SFI densities, and to environmental parameters including depth, latitude and bottom temperature. Bottom temperature and depth were the primary drivers of community composition, but there were no strong correlations with SFI densities. Indicator species analysis identified species that were associated with three levels of SFI densities (high, low and none). Some flatfishes (Pacific sanddab, petrale sole, arrowtooth flounder and curlfin sole) were associated with high and low densities of corals and sea pens while others (Dover, Rex and slender soles) were associated with the absence of sponge. Short- and longspine thornyheads, greenstriped rockfish and chilipepper rockfish were associated with low (thornyheads) or zero (rockfishes) coral and sea pen densities and high sponge density, suggesting a preference for sponges. Sablefish were the opposite and were associated with hauls containing either no sponge or high levels of corals and sea pens. These results provide information about broad-scale associations between SFIs and demersal fish that may be useful for developing studies that are specifically focused on the function of SFIs as habitats for fish, and the role they may play in their life-histories.

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

b) Fine-scale benthic habitat classification as part of the Northwest Fisheries Science Center's (NWFSC) Southern California Hook and Line Survey

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

The NWFSC's Southern California Shelf Rockfish Hook and Line Survey samples hard bottom habitats within the Southern California Bight via rod and reel to provide management information for multiple demersal rockfishes (*Sebastes* spp.). To compliment the fishing component of the survey, a towed camera-sled equipped with a low-light analog camera and mini-DV recording system is deployed opportunistically to collect video data on fish presence and benthic habitat. Through 2013, we have analyzed 6,982 benthic habitat observations collected during 69 dives at 59 unique sites.

Benthic habitat observations were categorized both by major strata (primary, ≥50% of habitat in the field of view (FOV); secondary, ≥20% of the next most abundant habitat in the FOV; and, all other habitats in the FOV), and by eight previously-defined substrata categories: mud, sand, pebble, cobble, boulder, continuous flat rock, diagonal ridge and vertical rock-pinnacle top.

When compared with existing National Oceanic and Atmospheric Administration's Essential Fish Habitat (EFH) maps in these areas, we found significantly different habitat classification values, especially for hard habitats. Our analysis found significantly more hard bottom substrata from the reviewed camera-sled video, when compared to EFH designations in the same areas. This suggests

hard-bottom habitat features, especially smaller reefs, rock outcrops and boulder patches are not fully resolved within available habitat maps. Incorporating habitat designation from EFH charts into the development of abundance indices for groundfish stock assessments may misrepresent the total available hard-bottomed habitats available to many species that use them, resulting in biased results.

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

c) 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 UW SAFS, lewisakbarnett@gmail.com

d) Species-specific responses of demersal fishes to near-bottom oxygen levels within the California Current large marine ecosystem

Investigators: A. A. Keller, L. Ciannelli, W. Waldo Wakefield, V. Simon, J.A. Barth and S. D. Pierce

Long-term environmental sampling provided information on catch and near-bottom oxygen levels across a range of depths and conditions from the upper to the lower limit of the oxygen minimum zone and shoreward across the continental shelf of the U.S. west coast (U.S. – Canada to U.S. – Mexico). During 2008 – 2014, near-bottom dissolved oxygen concentrations (DO) ranged from 0.02 to 5.5 mL L^{-1} with 63.2% of sites experiencing hypoxia (DO<1.43 mL L^{-1}). The relationship

between catch per unit effort (CPUE) and DO was estimated for 34 demersal fish species in five subgroups by life history category (roundfishes, flatfishes, shelf rockfishes, slope rockfishes and thornyheads) using Generalized Additive Models. Models included terms for position, time, near-bottom environmental measurements (salinity, temperature, oxygen) and bottom depth. Significant positive relationships between CPUE and DO occurred for 19 of 34 groundfish species within hypoxic bottom waters. Community effects (total CPUE and species richness for demersal fishes) also exhibited significant and positive relationships with low near-bottom oxygen levels. GAM analysis revealed an apparent threshold effect at lower oxygen levels, where small changes in oxygen produced large changes in catch for several species, as well as total catch and species richness. An additional seven species displayed negative trends. Based on AIC-values, near-bottom oxygen played a major role in the distribution of flatfishes, roundfishes and thornyheads. By examining similarities and differences in the response of various subgroups of commercially important groundfish species to low DO levels, we uncovered ecological inferences of potential value to future ecosystem-based management.
Investigators: A.A. Keller, L. Ciannelli, W. Waldo Wakefield, V. Simon, J.A. Barth, S.D. Pierce

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

e) A Taxonomic Guide to Deep-Sea Corals of the U.S. Pacific Coast: Washington, Oregon and California

Investigators: C.E. Whitmire, M.V. Everett, R.P. Stone, J.C. Buchanan, T. Mitchell and E.A. Berntson

Deep-sea corals are invertebrates in the Phylum Cnidaria. Cnidarians are distinguished from other invertebrates in that they possess specialized cells, called cnidocytes, which have several functions including prey capture, defense, and transfer of gametes/larvae. In contrast to their tropical cousins, deep-sea corals live in either the mesophotic or aphotic zones of the ocean. Because they lack the symbiotic relationship with photosynthetic algae, they must sustain themselves by passively capturing particulate organic matter and plankton. Whitmire et al. (2017) inventoried 134 unique taxa of corals within the Pacific Coast region, representing two classes, three subclasses, five orders, eight suborders and 33 families. Octocorals, including gorgonians, sea pens and soft corals are the most speciose (100 taxa), followed by stony corals (19), black corals (9) and lace corals (6).

We describe the distinctive morphological characteristics of taxonomic groups, highlighting species that are known to occur off the U.S. West Coast. The taxonomic hierarchy used here follows that of the World Register of Marine Species (WoRMS). In addition, this guide will be used to improve field identification of deep-sea corals and sponges in the Pacific Council Region by enhancing the pictorial field guides used by fishery observers and field survey biologists.

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

f) Deep-sea octocoral *Swiftia simplex* (Nutting 1909) on the United States West coast

Investigators: M.V. Everett, L.K. Park, E.A. Berntson, A.E. Elz, C.E. Whitmire, A. A. Keller, M.E. Clarke

Deep-sea corals are a critical component of habitat in the deep-sea, existing as regional hotspots for biodiversity, and are associated with increased assemblages of fish, including commercially important species. Because sampling these species is so difficult, little is known about the connectivity and life history of deep-sea octocoral populations. This study evaluates the genetic connectivity among 23 individuals of the deep-sea octocoral *Swiftia simple*x collected from Eastern Pacific waters along the west coast of the United States. We utilized high-throughput restriction-site associated DNA (RAD)-tag sequencing to develop the first molecular genetic resource for the deep-sea octocoral, *Swiftia simplex*. Using this technique, we discovered thousands of putative genome-wide SNPs in this species, and after quality control, successfully genotyped 1,145 SNPs across individuals sampled from California to Washington. These SNPs were used to assess putative population structure across the region. A STRUCTURE analysis as well as a principal coordinates analysis both failed to detect any population differentiation across all geographic areas in these collections. Additionally, after assigning individuals to putative population groups geographically, no significant FST values could be detected (FST for the full data set 0.0056), and no significant isolation by distance could be detected ($p = 0.999$). Taken together, these results indicate a high degree of connectivity and potential panmixia in *S. simplex* along this portion of the continental shelf.

For more information, please contact Meredith Everet at meredith.everet@noaa.gov

2. Ecosystems

B. Ecosystem Research

1. Ecosystems

a) Integrated Ecosystem Assessment of the California Current

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

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 2017.

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 Chris.Harvey@noaa.gov.

b) Feeding ecology of select groundfish species captured in the NWFSC bottom trawl survey, from gut contents and stable isotopes

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

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

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

c) 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, 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. 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 Dr. Isaac Kaplan at Isaac.Kaplan@noaa.gov

d) The impacts of climate variability on the distribution of groundfish along the Northeast Pacific coastal shelf.

Investigators: L. Li, A. Hollowed, S. Barbeaux, J. Boldt, E. Cokelet, T. Garfield, S. Gauthier, D. Jones, A. Keller, J. King, M. McClure, O. Ormseth, W. Palsso1, P. Ressler, D. Sweetnam, P. Stabeno and C. Wilson.

Global warming has impacted marine organisms in many different ways, including changes in species distribution. In addition to higher latitude and deeper waters, many species have been observed to move to a wide range of directions. However, to date, ontogenetic changes have rarely been accounted for. Due to different habitats across their life stages, changes in the species composition likely play an important role in the distributional shifts reported for the species as a whole in many studies. Here we present distributional responses of groundfish, across all size ranges of their lives, to climate variability in the Northeast Pacific with an emphasis on the unusual warm event "the Blob". We analyzed survey data from bottom trawl and acoustic surveys, along the west coast of US, the west coast of Canada and the Gulf of Alaska 1984 - 2016. A group of commercially exploited fish species of gadids, sablefish, rockfish, and flatfish were selected as representatives for the three regions and length bins were chosen through expert opinion to capture ontogenetic differences in distribution for each species. We computed the centroids (bottom depth and bottom temperature) and the leading edges of the distribution for each species each size bin and link their distributions with environmental changes. We applied different predictors including absolute value of temperature, temperature anomalies, and climate velocities. In the end, we

summarized the sensitive and resilient species and size bins to environmental changes and discussed the different mechanisms.

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

e) The West Coast Ocean Acidification and Hypoxia Science Panel

Investigators: W. Wakefield and R. Feely

Global carbon dioxide (CO_2) emissions over the past two centuries have altered the chemistry of the world's oceans, threatening the health of coastal ecosystems and industries that depend on the marine environment. This fundamental chemical alteration is known as ocean acidification (OA), a phenomenon driven by the oceans absorbing CO_2 generated through human activities. Although OA is a global phenomenon, emerging research indicates that, among coastal zones around the world, the West Coast of North America will face some of the earliest, most severe changes in ocean carbon chemistry. The threats posed by OA's progression will be further compounded by other dimensions of global climate change, such as the intensification and expansion of low dissolved oxygen – or hypoxic – zones. In the coming decades, the impacts of ocean acidification and hypoxia (OAH), which are already being felt across West Coast systems, are projected to grow rapidly in intensity and extent. Even if atmospheric CO_2 emissions are stabilized today, many of the ongoing chemical changes to the ocean are already "locked in" and will continue to occur for the next several decades. In an effort to develop the scientific foundation necessary for West Coast managers to take informed action, the California Ocean Protection Council in 2013 asked the California Ocean Science Trust to establish and coordinate a scientific advisory panel in collaboration with California's ocean management counterparts in Oregon, Washington and British Columbia. The resulting West Coast Ocean Acidification and Hypoxia Science Panel, was comprised of 20 scientific experts, including from NOAA, Richard Feely (Pacific Marine Environmental Laboratory) and Waldo Wakefield (Northwest Fisheries Science Center). The panel was charged with summarizing the current state of knowledge and developing scientific consensus about available management options to address OAH on the West Coast. A report of the major findings, recommendations and actions is was released in April 2016 and available through the panel's website (http://westcoastoah.org/). The website also provides access to an array of panel products and supporting appendices.

For more information, please contact Waldo Wakefield at Waldo.Wakefield@noaa.gov, other panelists (http://westcoastoah.org/panelists/) or staff members at the California Ocean Science Trust (www.oceansciencetrust.org/)

C. Bycatch Reduction Research

Investigators: W. Wakefield and M. Lomeli

Recent Conservation Engineering Work in US West Coast Groundfish Fisheries

Beginning in 2004, the NOAA Fisheries Northwest Fisheries Science Center (NWFSC) initiated a fisheries conservation engineering program within its Fisheries Resource Analysis and Monitoring Division. Through key regional collaborations with the Pacific States Marine Fisheries Commission, Oregon Department of Fish and Wildlife, Alaska Fisheries Science Center, and the fishing industry, the NWFSC has been able to pursue a wide-ranging array of conservation engineering projects relevant to reducing bycatch in the west coast groundfish and ocean shrimp trawl fisheries. In the past several years, these projects included: 1) Reducing Chinook salmon, eulachon, rockfish, and Pacific halibut bycatch in midwater and bottom trawl fisheries using BRDs, 2) Providing loaner video camera systems to the fishing industry, and 3) Examining selectivity characteristics of codends that differ in mesh size and configuration in the bottom trawl fishery, 4) Developing and testing selective flatfish sorting grid bycatch reduction devices in the bottom trawl fisheries, 5) Evaluating how illuminating fishing gear in situ can influence selectivity and reduce bycatch. Much of our current work has been in response to the fishing industries concerns over catches of overfished rockfishes and Pacific halibut IBQ (Individual Bycatch Quota) allocated in the Pacific coast Groundfish Trawl Rationalization Catch Share Program. The trawl rationalization program, starting in January 2011, established formal Annual Catch Limits (ACLs) and individual catch share quotas. In addition to ACLs, fishing opportunities may also be limited by hard caps or IBQs for non-groundfish species (e.g., Chinook salmon, and Pacific halibut). Bycatch of overfished, rebuilding, and prohibited species in the West Coast groundfish trawl fishery has the potential to constrain the fishery such that a substantial portion of available harvest may be left in the ocean. Several recently completed conservation engineering projects are highlighted below.

1. Artificial light: Its influence on Chinook salmon escapement out a bycatch reduction device in a Pacific whiting midwater trawl

The Pacific whiting (*Merluccius productus*) midwater trawl fishery represents the largest groundfish fishery by volume along the U.S. west coast. While landed catches consist of mostly Pacific whiting, bycatch of Chinook salmon (*Oncorhynchus tshawytscha*) is an issue affecting the fishery. Although the catch ratio of Chinook salmon caught in the fishery is typically <0.03 fish per metric ton of Pacific whiting, bycatch is a concern because of the high volume of the fishery and the incidental capture of Endangered Species Act listed salmon. In this study, we examined the use of artificial light as a technique to reduce Chinook salmon bycatch. Specifically, we tested if Chinook salmon can be attracted towards and out of specific escape windows/openings of a bycatch reduction device (BRD) using artificial light. Data on fish behavior and escapement was collected using underwater video camera systems. During sea trials, video observations were made on 437 Chinook salmon with escapement occurring in 298 individual (68.2% of fish). At trawl depths, 266 Chinook salmon escaped with 230 individuals (86.5% of fish) exiting out a window that was illuminated. This result was highly significant ($P<0.00001$). These data show that light can influence where Chinook salmon exit a BRD, but also suggest that light could be used to

enhance their escapement overall. In 2017, the PSMFC / NWFSC – MHE group will continue this line of research switching from the use of underwater video to the use of a recapture net to compare escapement rates between tows conducted with and without the use of artificial light.

2. Illuminating the headrope of a selective flatfish trawl: Effect on catches of groundfishes and Pacific halibut

This study evaluated how illuminating the headrope of a selective flatfish trawl could affect catches of groundfishes and Pacific Halibut in the U.S. West Coast limited entry groundfish bottom trawl fishery. Lindgren-Pitman LED Electralume® fishing lights (color = green) were used to illuminate the headrope. Lights were grouped into clusters of three, with each cluster attached ca. 1.35 m apart along the 40.3 m long headrope. Using an alternate tow randomized block design, catch comparisons and ratios were compared between tows conducted with (treatment) and without (control) LED lights attached along the trawl headrope. Catches of rex sole, Arrowtooth Flounder, Greenstriped Rockfish, and Lingcod were fewer in the treatment compared to the control trawl, however, not at a significant level. Bycatch of Pacific halibut was substantially different between the two trawls, with the treatment trawl catching an average of 57% less Pacific halibut. As for Dover Sole and Sablefish, significantly fewer fish were caught in the treatment than the control trawl. Compared to the control, the treatment trawl on average caught more rockfishes (with the exception of Greenstriped Rockfish), English Sole, and Petrale Sole, but not at a significant level. Findings show that illuminating the headrope of the selective flatfish trawl can affect the catch comparisons and ratios of several groundfish species and Pacific Halibut and depending on the target or avoidance species, the effect can be positive or negative.

3. Testing of two selective flatfish sorting grid bycatch reduction devices in the U.S. West Coast groundfish bottom trawl fishery

In the U.S. West Coast limited entry (LE) groundfish bottom trawl fishery, catches of constraining species (e.g., rockfishes, sablefish, Pacific halibut) continue to hinder some fishermen’s ability to maximize catches of more abundant flatfish stocks (e.g., Dover Sole, Petrale Sole). In this study, the size-selection characteristics of two flexible sorting grid bycatch reduction devices (BRDs), termed BRD-1 (6.4 x 25.4 cm grid size) and BRD-2 (6.4 x 30.5 cm grid size), designed to retain flatfishes while reducing catches of rockfishes, other roundfishes, and Pacific halibut were evaluated using a recapture net. The size selectivity parameters for rockfishes, other roundfishes, and Pacific Halibut did not differ significantly between the two designs. The size-selection characteristics between BRD-1 and -2 did not differ significantly for English Sole or Rex Sole. However, for Arrowtooth Flounder 53-58 cm in total (TL), Dover Sole 39-53 cm TL, and Petrale Sole 36-49 cm TL, BRD-1 retained significantly more fish of these length classes than BRD-2. Combined, the mean flatfish retention (not including Pacific halibut) was 89.3% for BRD-1 and 81.7% for BRD-2. Compared to previous flatfish sorting grid selectivity work conducted in the LE groundfish bottom trawl fishery, BRD-1 enhanced the retention of flatfishes while substantially reducing catches of non-target species.

4. Improving catch utilization in the U.S. West Coast groundfish bottom trawl fishery: an evaluation of T90-mesh and diamond-mesh cod ends

The limited-entry bottom trawl fishery for groundfish along the U.S. West Coast operates under a catch share program, which is implemented with the intention of improving the economic efficiency of the fishery, maximizing fishing opportunities, and minimizing bycatch. However, stocks with low harvest guidelines have limited the ability of fishermen to maximize their catch of more abundant stocks. Size-selection characteristics of 114-mm and 140-mm T90-mesh cod ends and the traditional 114-mm diamond-mesh cod end were examined by using the covered cod end method. Selection curves and mean L50 values (length at which fish had a 50% probability of being retained) were estimated for two flatfish species (Rex Sole and Dover Sole) and two roundfish species (Shortspine Thornyhead and Sablefish). Mean L50 values were smaller for flatfishes but larger for roundfishes in the 114-mm T90 cod end compared to the diamond-mesh cod end. For Rex Sole, Dover Sole, and Shortspine Thornyheads, selectivities of the 140-mm T90 cod end were significantly different from those of the other cod ends; the 140-mm T90 cod end was most effective at reducing the catch of smaller-sized fishes but with a considerable loss of larger-sized marketable fishes. Findings suggest that T90 cod ends have potential to improve catch utilization in this multispecies fishery.

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

VII. Publications

Anderson, S.C., Cooper, A.B., Jensen, O.P., Minto, C., Thorson, J.T., Walsh, J.C., Afflerbach, J., Dickey-Collas, M., Kleisner, K.M., Longo, C., Osio, G.C. 2017. Improving estimates of population status and trend with superensemble models. Fish and Fisheries.

Andrews, K.S., Nichols, K.M., Elz, A., Harvey, C.J., Tolimieri, N., Tonnes, D., Lowry, D., Pacunski, R., Yamanaka, K.L. Submitted. Cooperative research sheds light on population structure and listing status of threatened and endangered rockfish species. Conservation Genetics.

Barnett, L.A.K., Hennessey, S.M., Essington, T.E., Shelton, A.O., Feist, B.E., Branch, T.A., McClure, M.M. In revision. Getting to the bottom of fishery interactions with living habitats: spatiotemporal trends in disturbance of corals and sponges on the US west coast. Marine Ecology Progress Series.

Benaka, L., Sharpe, L., Abrams, K., Campbell, M., Cope, J., Darby, F., Dick, E.J., Hyde, J., Linton, B., Lunsford, C., Rioux, D. 2016. Action Plan for Fish Release Mortality Science.

Bizzarro, J.J., Yoklavich, M.M., Wakefield, W.W. 2016. Diet composition and foraging ecology of U.S. Pacific Coast groundfishes with applications for fisheries management. Environmental Biology of Fishes. Environ Biol Fish DOI 10.1007/s10641-016-0529-2.

Bosley, K.L., Bosley, K.M., Keller, A.A., Whitmire, C.E. In prep. 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. Mar. Ecol. Prog. Ser.

Bosley, K.L., Buchanan, J.C., Chappell, A.C., D. Draper, D., Bosley, K.M. In prep. A comparative analysis of food habits for several Northeast Pacific rockfishes (*Sebastes* sp.), using gut contents and stable isotopes. Can. J. Fish. Aquat. Sci.

Colburn, L., Norman, K., Jepson, M., Himes-Cornell, A., Kasperski, S., Weng, C., Clay, P.M. 2017. Community Participation in U.S. Catch Share Programs. NOAA Technical Memorandum.

Everett, M., Park, L., Berntson, E., Elz, A., Whitmire, C., Keller, A.A., Clarke, E. 2016. Large-scale genotyping-by-sequencing reveals lack of structure in the deep-sea octocoral Swiftia simplex (Nutting 1909) on the west coast of the United States. PLoS ONE 11(10): e0165279. doi:10.1371/journal.pone.0165279

Foss-Grant, A.P., Zipkin, E.F., Thorson, J.T., Jensen, O.P., Fagan, W.F. 2016. Hierarchical analysis of taxonomic variation in intraspecific competition across fish species. Ecology 97(7), pp.1724-1734. DOI: 10.1890/15-0733.1

Frey, P.H., Keller, A.A., Simon, V. 2017. Dynamic population trends observed in the deep-living Pacific flatnose, *Antimora microlepis*, on the US West Coast. Deep Sea Research Part I: Oceanographic Research Papers.

Head, M.A., Frey, P.H., Cope, J.M., Keller, A.A. 2016. Challenges associated with assessing maturity, skipped spawning, and abortive maturation rates for fisheries managers: a case study of *Sebastes pinniger*. Presentation at the North Pacific Marine Science Organization (PICES), San Diego, CA, Nov 2 - 13.

Head, M.A., Haltuch, M.A., Frey, P.H., Cope, J.M., Keller, A.A. 2016. Spatio-temporal variability in canary rockfish (*Sebastes pinniger*) maturity. Presentation, NWFSC Ecosystem Science Review, July 12 – 14.

Head, M.A., Stokes, G.L., Thorson, J.T., Keller, A.A. 2016. Techniques for improving estimates of maturity ogives in groundfish using double-reads and measurement error models. Fisheries Research 179, pp.251-258.

Holland, D.S. 2016. Development of the Pacific Groundfish Trawl IFQ Market. Marine Resource Economics 31(4):453-464. DOI: 10.1086/687829

Holland, D.S., S. Kasperski. 2016. The Impact of Access Restrictions on Fishery Income Diversification of US West Coast Fishermen. Coastal Management 44:452-463.

Johnson, K.F., Councill, E., Thorson, J.T., Brooks, E., Methot, R.D., Punt, A.E. 2016. Can autocorrelated recruitment be estimated using integrated assessment models and how does it

affect population forecasts? Fisheries Research 183, pp.222-232. DOI: 10.1016/j.fishres.2016.06.004

Keller, A., Buchanan, J.C., Steiner, E., Draper, D., Chappell, A., Frey, P.H., Head, M.A. 2016. Size at maturity for grooved Tanner crab (*Chionoecetes tanneri*) along the U.S. west coast (Washington to California). Fisheries Oceanography 25(3):292-305.

Keller, A.A., Ciannelli, L., Wakefield, W.W., Simon, V., Barth, J., Pierce, S.D. 2017. Species-specific responses of demersal fishes to near-bottom oxygen levels within the California Current large marine ecosystem. Mar. Ecol. Prog. Ser. 568:151-173

Keller, A.A., Wallace, J.R., Methot, R.D. 2017. The Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl Survey: Survey History, Design, and Description. NOAA Technical Memorandum NMFS-NWFSC-136, 47pp.

Lomeli, M.J.M., Hamel, O.S., Wakefield, W.W., Erickson, D.L. 2017. Improving catch utilization in the U.S. West Coast groundfish bottom trawl fishery: an evaluation of T90-Mesh and diamond-mesh cod ends, Marine and Coastal Fisheries 9:149-160, DOI: 10.1080/19425120.2016.1274697.

Lomeli, M.J.M., Wakefield, W.W. 2016. Evaluation of a selective flatfish sorting grid bycatch reduction device in a U.S. west coast bottom trawl fishery. Fisheries Research 183:294–303.

Marshall, K.N., Kaplan, I.C., Hodgson, E.E., Hermann, A., Busch, D.S., McElhany, P., Essington, T.E., Harvey, C.J., Fulton, E.A. 2017. Risks of ocean acidification in the California Current food web and fisheries: ecosystem model projections. Global Change Biology.

Monnahan, C.C., Thorson, J.T., Branch, T.A. 2016. Faster estimation of Bayesian models in ecology using Hamiltonian Monte Carlo. Methods in Ecology and Evolution.

Ono, K., Shelton, A.O., Ward, E.J., Thorson, J.T., Feist, B.E., Hilborn, R. 2016. Space‐time investigation of the effects of fishing on fish populations. Ecological Applications 26(2), pp.392-406.

Ono, K., Shelton, O.A., Ward, E.J., Thorson, J.T., Feist, B.E., Hilborn, R. 2016. Space-time investigation of the effects of fishing on fish populations. Ecological Applications 26(2): 392-406. DOI: 10.1890/14-1874.1

Russell, S.M., Arias-Arthur, A., Sparks, K., Varney, A. 2016. West Coast Communities and Catch Shares: The Early Years of Social Change. 2016. Coastal Management 44 441-451.

Thorson, J.T., Barnett, L.A. 2017. Comparing estimates of abundance trends and distribution shifts using single-and multispecies models of fishes and biogenic habitat. ICES Journal of Marine Science.

Thorson, J.T., Fonner, R., Haltuch, M.A., Ono, K., Winker, H. 2016. Accounting for spatiotemporal variation and fisher targeting when estimating abundance from multispecies

fishery data 1. Canadian Journal of Fisheries and Aquatic Sciences 73(999), pp.1-14. DOI: 10.1139/cjfas-2015-0598

Thorson, J.T., Ianelli, J.N., Larsen, E.A., Ries, L., Scheuerell, M.D., Szuwalski, C., Zipkin, E.F. 2016. Joint dynamic species distribution models: a tool for community ordination and spatio-temporal monitoring. Global Ecology and Biogeography 25(9), pp.1144-1158. DOI: 10.1111/geb.12464

Thorson, J.T., Jannot, J., Somers, K. 2016. Using spatio-temporal models of population growth and movement to monitor overlap between human impacts and fish populations. Journal of Applied Ecology. DOI: 10.1111/1365-2664.12664

Thorson, J.T., Johnson, K.F., Methot, R.D., Taylor, I.G. 2016. Model-based estimates of effective sample size in stock assessment models using the Dirichlet-multinomial distribution. Fisheries Research. DOI: 10.1016/j.fishres.2016.06.005

Thorson, J.T., Kristensen, K. 2016. Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. Fisheries Research 175, pp.66-74.

Thorson, J.T., Minte-Vera, C.V. 2016. Relative magnitude of cohort, age, and year effects on size at age of exploited marine fishes. Fisheries Research 180, pp.45-53.

Thorson, J.T., Munch, S.B., Swain, D.P. 2017. Estimating partial regulation in spatio-temporal models of community dynamics. Ecology.

Thorson, J.T., Pinsky, M.L., Ward, E.J. 2016. Model-based inference for estimating shifts in species distribution, area occupied and centre of gravity. Methods in Ecology and Evolution 7(8), pp.990-1002. DOI: 10.1111/2041-210X.12567

Thorson, J.T., Rindorf, A., Gao, J., Hanselman, D.H., Winker, H. 2016. Density-dependent changes in effective area occupied for sea-bottom-associated marine fishes. In Proc. R. Soc. B (Vol. 283, No. 1840, p. 20161853). The Royal Society. DOI: 10.1098/rspb.2016.1853

Tolimieri, N., Holmes, E.E., Williams, G.D., Pacunski R., Lowry D. 2017. Population assessment using multivariate time-series analysis: A case study of rockfishes in Puget Sound. Ecology and Evolution 00:1–15. https://doi.org/10.1002/ece3.2901

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

West Coast Groundfish Observer Program Data Reports. Available at: http://www.nwfsc.noaa.gov/research/divisions/fram/observer/datareport/index.cfm.

Whitmire, C.E., Everett, M.V., Stone, R.P., Buchanan, J.C., Mitchell, T., Berntson, E.A. In prep. A Taxonomic Guide to Deep-Sea Corals of the U.S. Pacific Coast: Washington, Oregon and California. Deep Sea Coral Research & Technology Program 2016-17.