Northwest Fisheries Science Center

National Marine Fisheries Service

NOAA Fisheries

Agency Report to the Technical Subcommittee

of the Canada-U.S. Groundfish Committee

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I. Agency Overview

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

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

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

During 2015, FRAMD continued to: implement a West Coast observer program; conduct a coast wide survey program that includes West Coast groundfish acoustic, hook and line, and trawl surveys; develop new technologies for surveying fish populations; and expand its stock assessment, economics, and habitat research. Significant progress continues in all programs.

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

Other Divisions at the NWFSC are:

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

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

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

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

II. Surveys

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

The NWFSC conducted its eighteenth annual bottom trawl resource survey for groundfish off the coasts of Washington, Oregon, and California. The objective of the 2015 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 2015, we also continued to utilize the FSCS data collection system with updated software applications, and wireless networking. Established NOAA national bottom trawl protocols were used throughout the survey. As in prior years, a series of special research projects were undertaken in cooperation with other NOAA groups and various Universities.

Additional data were collected during the trawl survey for collaborative research projects with several NMFS/academic colleagues: 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 – NWFSC, Conservation Biology Division, Environmental and Fisheries Sciences Division; 2) Collection of voucher specimens for multiple fish species – Northwest Fisheries Science Center; 3) Accumulation and maternal transfer of organic contaminants in the sandpaper skate collected from the eastern Pacific Ocean – University of Calgary; 4) An Investigation into a potential cryptic species of the pygmy rockfish, *Sebastes wilsoni* – Marine Science Institute, University of California; 5) Mitochondrial DNA barcodes to identify macrourid larvae – Alaska Fisheries Science Center; 6) Does Puget Sound represent a distinct population segment for yelloweye and canary rockfish? – NWFSC, Conservation Biology Division; 7) Request for Pacific Lamprey samples from Groundfish and Hake/Sardine surveys – 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– Moss Landing Marine Laboratories 12) Genus *Bathyraja* – Moss Landing Marine Laboratories; Collections of eastern North Pacific softnose skates, Genus *Bathyraja* – Moss Landing Marine Laboratories; 13) Collection of 25 Pacific spotted spiny dogfish, *Squalus suckleyi* between San Francisco, CA and Morro Bay, CA – Moss Landing Marine Laboratories; 14) Collection of any Pacific black dogfish, *Centroscyllium nigrum* – Moss Landing Marine Laboratories; 15) Collection of all unusual or unidentifiable skates, deepsea skate, *Bathyraja abyssicola*, Pacific white skate, *Bathyraja spinossisima*, fine-spined skate, *Bathyraja microtrachys*, Aleutian skate, *Bathyraja aleutica*, and broad skate, *Amblyraja badia* – Moss Landing Marine Laboratories; 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 *Hydrolagus colliei*, including: *Harriotta raleighana*, *Hydrolagus* spp. and *Hydrolagus trolli* – Moss Landing Marine Laboratories; 18) Collection of voucher specimens for multiple fish species – Oregon State University; 19) 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; 20) Shadow vessel study to compare rockfish in rocky habitat to nearby groundfish survey catch via video lander - Moss Landing Marine Laboratories and the Nature Conservancy.

Several other research initiatives were undertaken by the Survey Team including: 1) Use of stable isotopes and feeding habits to examine the feeding ecology of rockfish (genus *Sebastes*); 2) Fin clip collection for various shelf rockfish species; 3) Collection of stomachs for various rockfish species; 4) Collection and identification of cold water corals; 5) Fish distribution in relation to near-bottom dissolved oxygen concentration; 6) Composition and abundance of benthic marine debris collected during the 2015 West Coast Groundfish Trawl Survey; and 8) Collection of ovaries from blackspotted/rougheye rockfish, darkblotched rockfish, lingcod, petrale sole, sablefish, yelloweye rockfish, Pacific hake, aurora rockfish, shortspine thornyheads, and canary rockfish to assess maturity.

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

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

In early Fall 2015, FRAM personnel conducted the 12th hook and line survey for shelf rockfish in the Southern California Bight (SCB). This project is a cooperative effort with Pacific States Marine Fisheries Commission (PSMFC) and the southern California sportfishing industry aimed at developing an annual index of relative abundance and time series of other biological information for structure-associated species of rockfish (genus *Sebastes*) such as bocaccio (*S. paucispinis*), greenspotted rockfish (*S. chlorostictus*), cowcod (*S. levis*) and the vermilion rockfish complex (e.g., *S. miniatus* and *S. crocotulus*) 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 197 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. 2015 marked the second consecutive year of sampling within the Cowcod Conservation Areas (CCAs). Approximately 76 sites across several areas of the CCAs were sampled as part of an ongoing monitoring project and in response to research needs identified by the PFMC and stock assessment scientists. It is anticipated that monitoring at these sites will continue during subsequent surveys.

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.

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

C. 2015 joint U.S.-Canada integrated acoustic and trawl survey of Pacific hake and coastal pelagic species (SaKe 2015)

The joint U.S.–Canada integrated acoustic and trawl (IAT) survey was conducted in U.S. and Canadian waters by two U.S. teams (NWFSC/FRAM and SWFSC/FRD) on the NOAA ship *Bell M. Shimada* from 15 June 2015 to 10 September 2015, and by a Canadian team (DFO/Pacific region) on the CCGS *W.E. Ricker* from 22 August 2015 to 12 September 2015. The data collected during the survey were processed to provide an estimate of the abundance and spatial distribution of the coastal Pacific hake stock shared by both countries. The survey covered the slope and shelf of the U.S. and Canada West Coast with acoustic transects from roughly 32.7°N (off San Diego) to 55.1°N (Southeast Alaska and Dixon Entrance). Transects in the Southern California Bight were spaced 20 nmi apart and were oriented northeast-southwest. Transects from Point Conception and north (except for four in Dixon Entrance that were oriented north-south) were oriented east-west and were variably spaced 20, 15, or 10 nm apart. Twelve diagonal cross transects (oriented southwest-northeast) were also run. Acoustic data were collected on the *Shimada* with a Simrad EK60 echosounder operating at frequencies of 18, 38, 70, 120, and 200 kHz, and on the *Ricker* with a Simrad EK60 echosounder operating at frequencies of 18, 38, and 120 kHz. The survey resulted in 116 transects with 6,269 nautical miles of acoustical transect that were used for the hake biomass estimate. Aggregations of adult (age 2+) Pacific hake were detected on 63 transects from just south of Morro Bay (35.3°N), north along the U.S. coast, and along the west side of Vancouver Island and Haida Gwaii. Highest concentrations of Pacific hake were observed along the coasts of Oregon and Washington, as well as the west side of Vancouver Island. Hake sign was relatively light off the California coast. North of Vancouver Island and into Southeast Alaska, hake were absent, except for small amounts off Haida Gwaii. Midwater trawls equipped with a camera system were conducted to verify species composition of observed backscatter layers and to obtain biological information (e.g., size and sex distribution, age composition, sexual maturity). A total of 96 successful trawls (76 by the *Shimada* and 20 by the *Ricker*) resulted in a combined total hake catch of 17,645 kg (13,460 kg from the *Shimada* and 4,185 kg from the *Ricker*). The estimated total biomass of adult Pacific hake in 2015 was 2.156 million metric tons, which was the largest estimate observed since the NWFSC began conducting IAT surveys for Pacific hake in 2003. The 2015 estimate represented a slight increase over the previous biomass estimate from 2013 (1.929 mmt), and approximately 78% of the 2015 estimate was from U.S. waters. Age-5 hake (2010 year class) were dominant in 2015, accounting for approximately 57% of the total survey-wide observed adult biomass.

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 2015

B. Dogfish and other sharks

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 are limited to the spatial extent of the receivers. In this study we double tagged six spiny dogfish in Puget Sound, WA 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 Kelly Andrews at NOAA's Northwest Fisheries Science Center, Kelly.Andrews@noaa.gov.

b) Sibling rivalry: do sixgill sharks (*Hexanchus gris*eus) 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. To determine whether sixgill sharks move in kin-structured groups, we monitored the movement of 24 individuals from 2006 to 2009 in Puget Sound, WA. Using tissue samples from each shark, we were able to calculate the relatedness of all sharks collected. Using kinship coefficient values, pairs of sharks that were more closely related to each other were more likely to be detected at the same location during the same week than pairs of sharks that were not closely related to each other.

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

c) Incorporating movement in the modelling of shark and ray population dynamics: approaches and management implications

Investigators: M. Braccini, A. Aires-da-Silva, and I. Taylor

The explicit incorporation of movement in the modelling of population dynamics can allow improved management of highly mobile species. Large-scale movements are increasingly being reported for sharks and rays. Hence, the authors summarize the current understanding of long-scale movement patterns of sharks and rays and then present the different methods used in fisheries science for modelling population movement with an emphasis on sharks and rays. The use of movement data for informing population modelling and deriving management advice remains rare for sharks and rays. In the few cases where population movement was modelled explicitly, movement information has been solely derived from conventional tagging. Though shark and ray movement has been increasingly studied through a range of approaches these different sources of information have not been used in population models. Integrating these multiple sources of movement information could advance our understanding of shark and ray dynamics. This, in turn, would allow the use of more adequate models for assessing stocks and advising management and conservation effort.

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

C. Skates

1. Research

a) Improved life history parameters of longnose skate (*Raja rhina*): Estimation of spatial and temporal variability in growth and maturity with implications for stock assessment.

Investigators: T.E. Helser, T.E. Essington, V. Gertseva, M.E. Matta, and C. Gburski

Skates are commonly taken as bycatch in Pacific groundfish fisheries, yet relatively little is known regarding their life history parameters, and consequently most species are managed as data-poor stocks. The well-documented deleterious effects of fishing on North Atlantic skates emphasize the need for detailed biological information and effective management for this vulnerable group. In particular, accurate age data would enable the development of age-structured stock assessment models, resulting in a better understanding of population dynamics and the setting of sustainable catch limits. An NPRB-funded project was recently completed in which the age determination method for longnose skate (*Raja rhina*) was successfully validated by bomb-derived radiocarbon analysis. However, potential regional and temporal differences in length at age remain unknown. Furthermore, the project indicated possible inconsistencies in ageing protocols among management agencies along the Pacific coast of North America, casting uncertainty on life history parameters of this species, including unquantified effects on regional stock assessments. Improved estimates of age, growth, maturity, and natural mortality are vital to improve the stock assessment of this species. Therefore, three objectives of this collaborative study are to: 1) standardize the age determination protocol based on the validated ageing method across the three federal agencies responsible for skate management on the U.S. West Coast (NWFSC), British Columbia, Canada (DFO), and the Gulf of Alaska (AFSC), 2) age a backlog of approximately 2,000 longnose skate vertebrae collected since 2008, as well as reexamine 900 historically aged specimens based on standardized protocols, and 3) estimate important life history parameters including maximum age, growth rate, age at maturity, and natural mortality, and examine spatial and temporal variability in those vital rates for sensitivity analysis in the stock assessment. Together these parameters will allow for improved stock assessments of longnose skate across a significant portion of its range.

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

b) Developing spatial surplus production models including individual movement to monitor harvest rates for exploited fishes

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

Protected and managed species, including harvested fishes, exhibit spatial and temporal variation in their distribution and density. 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 rates. 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.

In this study, we develop a spatial population growth ("surplus production" in the fisheries literature) 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 2003-2013, 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. The 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 2010-2013, compared with annual harvest less than 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 for big skate substantially increase. We also recommend future research regarding spatial management regulations for regulating emerging fisheries.

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

D. Pacific cod: No research or assessments in 2015

E. Walleye Pollock: No research or assessments in 2015

F. Pacific whiting (hake)

1. Research

a) Biology, fisheries, assessment and management of Pacific hake (*Merluccius productus*)

Investigators: O. S. Hamel, P.H. Ressler, R. E. Thomas, D.A. Waldeck, A.C. Hicks, J.A. Holmes and G.W. Fleischer

Pacific hake (*Merluccius productus*), also known as Pacific whiting, is the most abundant commercial fish species in the California Current Large Marine Ecosystem (CCLME) and is an important part of the ecosystem as both predator and prey. A large migratory population occurs off California, Oregon, and Washington in United States waters and off British Columbia in Canadian waters. Smaller distinct non-migratory populations of Pacific hake occur in major inlets of the northeast Pacific Ocean, including the Strait of Georgia and Puget Sound. The coastal Pacific hake population has supported a fishery averaging 222 thousand tonnes per year since 1966. Coastal Pacific hake migrate to northern feeding areas in the summer and southern spawning areas in the winter. The extent of the northern migration and the distribution along the coast are related to the population age and size composition and to varying ocean-climatic conditions, which also influence growth and location of spawning aggregations. Pacific hake have a lifespan of around 20 years, reach maturity around age 4, and achieve an average asymptotic size of 53 cm.

Coastal Pacific hake are managed under the auspices of a treaty between the United States and Canada, and the two countries jointly conduct acoustic surveys of the resource, stock assessments, stock assessment reviews and management meetings. Prior to the treaty there were independent and competing stock assessments from the United States and Canada. The Hake Treaty established a default harvest policy, a fixed harvest allocation for each country, and a Joint Management Committee that determines the annual coastwide Total Allowable Catch based on the best available science, the treaty's default harvest policy, and input from industry advisors. Regulation and management of the individual fisheries continues to rest within each country.

The fishery is executed by four sectors in the United States: vessels that deliver to shore-based processors, vessels that deliver to at-sea processors (motherships), vessels that both catch and process at-sea (catcher-processors), and a tribal fishery. The Canadian fishery is prosecuted by vessels that deliver to shore-based processors, with a joint-venture mothership sector in some years. The Pacific hake fishery in the United States and Canada is jointly certified by the Marine Stewardship Council as a sustainable fishery. Pacific hake must be frozen or processed soon after harvest to achieve a marketable product. Currently, most Pacific hake is marketed as fillets or headed and gutted products, although previously a large portion of the harvest was turned into surimi. While none of these products demand a high price, the total revenue to the industry is in the tens of millions of U.S. dollars.

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

2. Assessment

a) Pacific Hake (*Merluccius productus*) stock assessment for 2015

Authors: I. Taylor, C. Grandin, A. Hicks, N. Taylor, 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 2015. Coast-wide fishery landings of Pacific hake averaged 225 thousand mt from 1966 to 2014, 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 2005–2014 have been above the long term average, at 283 thousand mt. Landings between 2001 and 2008 were predominantly comprised of fish from the very large 1999-year class, with the cumulative removal from that cohort exceeding 1.2 million mt. In 2014, U.S. fisheries caught mostly 6- and 4-year old fish from the 2008 and 2010 year classes, while the Canadian fisheries encountered older fish from the 2005, 2006, and 2008 year classes. 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 2015 assessment with the addition of new ages into the 2013 fishery age composition and the addition of a new age distribution from the 2014 fishery. 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 2010 year class being observed twice in the acoustic survey and four times in the fishery, although with uncertain selectivity. However, with recruitment being a main source of uncertainty in the projections and the survey not quantifying hake until they are 2 years old, 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 0.497 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 a large 2010 cohort and above average 2008 and 2009 cohorts. The 2015 female spawning biomass is estimated to be 73.6% of the unfished equilibrium level (B_0) with a 95% posterior credibility interval ranging from 34% to 150%. The median estimated 2015 female spawning biomass is 1.66 million mt.

Estimates of historical Pacific hake recruitment indicate very large year classes in 1980, 1984, 1999, and 2010. The U.S. fishery and acoustic age compositions both show the 2010 year-class comprised a very large proportion of the observations in 2014. Uncertainty in estimated recruitments is substantial, especially for 2010, 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 2008 and 2010 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), in retrospect the fishing intensity is estimated to have exceeded the target rate in two of the last 10 years (2008 and 2011). Recent catch and levels of depletion are presented in Figure 1.

A management strategy evaluation (MSE) continues to evolve for Pacific hake to investigate data inputs, stock assessment assumptions, and management actions. In 2015, a closed-loop simulation looking at the addition of an age-1 index in the stock assessment showed that on average it resulted in slightly less risk to the stock and a smaller annual variability in recommended total allowable catch. Other MSE activities in 2015 involved soliciting input from stakeholders and managers to better define fishery and management objectives.

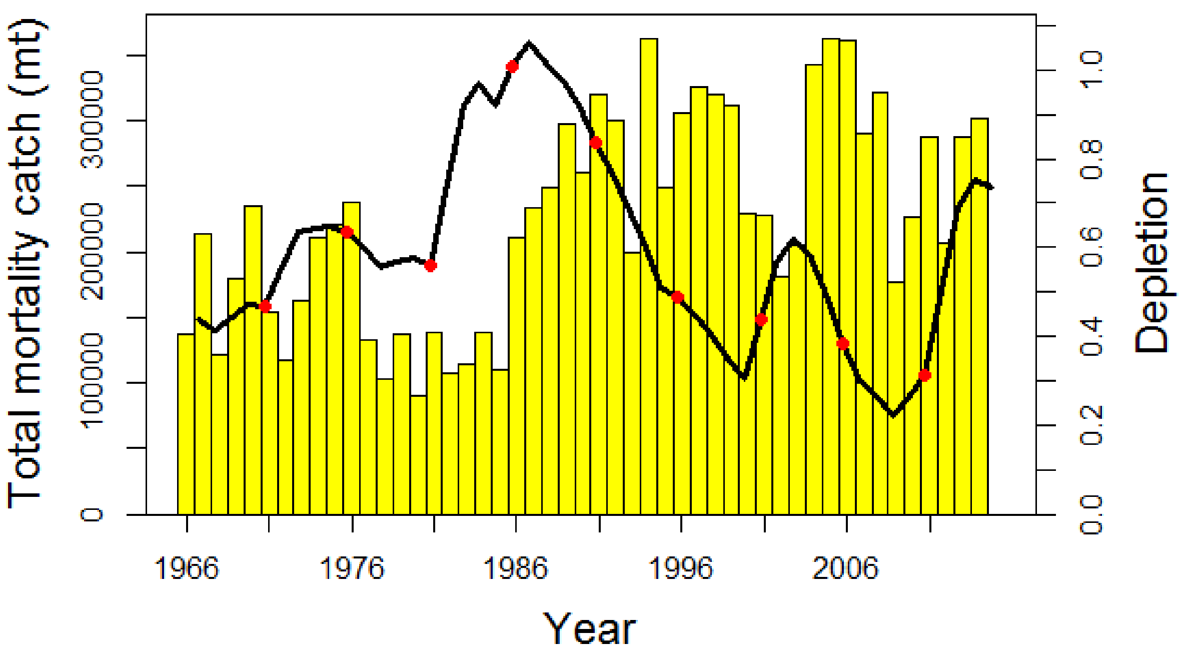

Figure 1. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Pacific hake, 1966-2015.

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

G. Grenadiers: No research or assessments in 2015

H. Rockfish

1. Research

a) Feeding Ecology of Select Groundfish Species Captured in the Northwest Fisheries Science Center's West Coast Bottom Trawl Survey, Using Gut Contents and Stable Isotopes

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

The authors examined the diets of multiple groundfish species as an ongoing component of the NOAA Fisheries West Coast Bottom Trawl Survey. Stomachs and tissue samples were collected at sea and preserved for gut content and stable isotope analyses. Yellowtail, darkblotched, canary, sharpchin and stripetail rockfishes are largely zooplanktivorous, with euphausiids composing 48.0 to 84.7% of total prey weight. Darkblotched and canary rockfishes also feed on shrimp, which were 34.2% and 39.5% by weight, respectively. Sablefish, yelloweye rockfish, chilipepper and bocaccio are piscivorous, with fish making up 50.7% to 91.4% of total prey weight. Greenstriped and rosethorn rockfishes show a strong preference for benthic prey; various shrimp species make up 80.8% of greenstriped diets by weight, while rosethorn consumed 52.1% shrimp and 20.3% galatheid crab species. Finally, widow rockfish and Pacific ocean perch exhibit a more omnivorous feeding strategy, eating a variety of zooplankton including euphausiids (14.3% and 30.9%), amphipods (4.3% and 3.4%), shrimp (0.87% and 5.3%) and gelatinous organisms (2.6% and 60.94%). 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 John Buchanan at John.Buchanan@noaa.gov

b) Understanding relationships between biological population data and environmental variation for rockfish off the West Coast of the United States.

Investigators: V. Gertseva and S.E. Matson

Environment has complex effects on spatial and temporal dynamics of marine fish species. Several assessments for one groundfish sentinel species (darkblotched rockfish) reported noticeable year-to-year variability in size composition of the surveyed portion of the stock, with the most stark change observed during the 2014 warm anomaly. This variability had a pronounced effect of stock assessment results. Understanding how biological data such as length structure vary in relation to changing oceanographic conditions is critical for accurately interpreting results of the research surveys and assessing the status of our fisheries resources. We analyzed NMFS bottom trawl survey data on distribution and abundance of different darkblotched size classes in relation to environmental factors, such as temperature, salinity and dissolved oxygen, and found that there are indications of size-specific habitat preferences in darkblotched rockfish. To answer the question whether change in darkblotched rockfish size composition is triggered by oceanographic conditions, we present our findings, propose several mechanisms to explain variability in darkblotched rockfish size composition, and discuss the observed pattern in the context of the ecosystem dynamics.

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

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

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

Genetic research by Hyde et al. (2008) at NOAA Fisheries' Southwest Fisheries Science Center identified a cryptic pair of the vermilion rockfish from specimens collected along the U.S. West Coast and suggested some depth and biogeographic partitioning between the two species. NWFSC researchers are analyzing tissue samples taken from specimens captured during the survey to taxonomically separate vermilion rockfish and its cryptic twin, the sunset rockfish, to compare depth and distributional patterns between the two species. In addition, this research is developing separate life history parameters for each species including age at length, annual growth estimates, length-weight relationships, and age at maturity. This information can be combined with species-specific abundance indices using the methods described in Harms et al. (2010) to determine whether separate stock assessments for vermilion and sunset rockfish are warranted.

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

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

Investigators: A.C. Hicks, J.H. Harms, J.A Benante, and J.R. Wallace

Fishery-independent surveys are an important source of information for stock assessment and management worldwide. Research surveys often use trawl gear to capture commercially valuable species and calculate indices of relative abundance or density. However, many species of interest do not occur in direct contact with the bottom, or occur in areas where high-relief habitat precludes trawl operation. This research was undertaken during a standardized hook and line survey for rockfish conducted by NOAA Fisheries' Northwest Fisheries Science Center (NWFSC) in the Southern California Bight. The survey uses fishing gear similar to that used in many recreational fisheries to sample approximately 121 locations covering a wide range of depths and habitats. The methods described in Harms et al. (2010) were applied to hook and line survey data for six important species of shelf rockfish to generate fishery-independent abundance indices, including the first unique indices for vermilion rockfish (*S. miniatus*) and its cryptic pair, sunset rockfish (*S. crocotulus*). This survey is the only annual tuning index for the adult portion of many structure-associated shelf rockfish species in the region, as historically-used recreational catch per unit effort indices have been compromised due to changes in bag limits and other management restrictions.

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

e) Determining the distribution and abundance of shelf rockfish: A cooperative study in the Southern California Bight

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

We conduct an annual fishery-independent hook and line survey to monitor groundfish within the Southern California Bight (SCB). The survey was developed in 2003 and is a collaborative effort among Pacific States Marine Fisheries Commission (PSMFC), Northwest Fisheries Science Center (NWFSC), and southern California's sportfishing industry. The survey targets rocky, high-relief habitats that are generally not well-sampled using other survey techniques, such as bottom trawls and acoustic backscatter. The primary objective of this survey is to provide an annual index of relative abundance and a time series of biological data for several key species of shelf rockfish (genus *Sebastes*) in the SCB, including bocaccio (*S. paucispinis*), the vermilion rockfish complex (e.g., *S. miniatus* and *S. crocotulus*), and greenspotted rockfish (*S. chlorostictus*). The survey's sampling frame currently consists of 198 fixed sites including 77 sites within the Cowcod Conservation Areas (CCAs), which were added during the 2014 and 2015 surveys. We report here information on: (1) materials and methods used during the survey; (2) year class strength and trends for multiple species; (3) habitat characterization using a towable camera sled; (4) genetic and maturity analysis; and (5) potential impacts of the CCAs on important groundfish species in the region.

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

f) Does Puget Sound represent a distinct population segment for yelloweye and canary rockfish?

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

Yelloweye *Sebastes ruberrimus* and canary *Sebastes pinniger* rockfish were listed as "threatened" and bocaccio *S. paucispinis* populations were listed as "endangered" in Puget Sound, WA and the Strait of Georgia under the U.S. Endangered Species Act in 2010. However, considerable uncertainty characterizes the designation of these "distinct population segments" (DPS) due to limited genetic and demographic information. Much of the evidence for delineating these DPSs was based on genetic evidence from other species in Puget Sound, general life history characteristics of the listed species, and the geographic isolation of Puget Sound. The objectives of this project were (1) to collect new biological and genetic information to determine whether ESA-listed Puget Sound rockfish populations are genetically similar to or distinct from their respective coastal populations and (2) to create working relationships with the recreational fishing community in order to develop sustainable management practices. In 2014 and 2015, we worked with local recreational charter boat captains to collect fin clips from 49 yelloweye, 51 canary and 3 bocaccio inside the Puget Sound/Georgia Basin DPS. These samples were compared with samples gathered from the outer coasts of U.S. and Canada and the Strait of Georgia. Population structure was examined using three methods: principal components analysis, calculation of F_{ST} among geographic groups, and a population genetics based model clustering analysis (STRUCTURE). Each analytical method indicated significant genetic differentiation between the inland and coastal samples for yelloweye rockfish, confirming the existence of a separate Puget Sound/Georgia Basin DPS. In addition, yelloweye rockfish from Hood Canal were genetically differentiated from other Puget Sound/Georgia Basin fish, indicating a previously unknown degree of population differentiation within the DPS. The same analytical methods indicated a lack of genetic differentiation between coastal and Puget Sound/Georgia Basin samples for canary rockfish, suggesting there is no separate Puget Sound/Georgia Basin DPS. There were insufficient samples (n=3) to determine whether bocaccio in the Puget Sound/Georgia Basin DPS were genetically similar or dissimilar to coastal populations. These findings have direct implications for the listing status of canary rockfish and the boundaries of the DPS for yelloweye rockfish.

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

g) 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.H. 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). The authors collected IGF samples on the first and second passes of the 2015 survey. IGF is an indicator of feeding and somatic growth in fishes. Our objective was 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 collected samples from the smallest size-frequency bins of greenstriped 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 collected 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 collected and will analyze 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 NOAA's Northwest Fisheries Science Center, Chris.Harvey@noaa.gov.

h) A new approach to reproductive analysis for fisheries management, a case study on *Sebastes pinniger*

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

Since the initiation of the NWFSC's reproductive maturity program (FRAM Division) in 2009, we have identified several key factors to understanding reproductive biology of west coast groundfishes. These include: (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. In the past many stock assessments have 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

i) Challenges associated with assessing maturity, skipped spawning, and abortive maturation rates in groundfish: a case study of *Sebastes pinniger*

Investigators: M.A. Head, P.H. Frey, and A.A. Keller

Incorporating accurate estimates of life history parameters into population models can increase the reliability of biomass estimates used to manage groundfish stocks. In addition, understanding the reproductive biology and life history strategies of these fish provides support for sustainable management. However, seasonal data collection can create challenges for gaining a full understanding of the reproductive biology of some species. Many groundfish species on the U.S. West Coast spawn between November and March, when opportunities to collect biological data on research surveys or from fisheries landings are limited. We examined the reproductive biology and maturity schedule of canary rockfish, *Sebastes pinniger*, using ovary specimens collected on the West Coast groundfish bottom trawl survey (WCGBT) from 2009 – 2014 (n = 431) and from Oregon Department of Fish and Wildlife (ODFW) port biologists in 2014 and 2015 (n = 250). This allowed for comparisons of length and age at maturity estimates based on the histological examination of ovaries collected within and outside the canary rockfish spawning season. Temporal and spatial patterns in oocyte development, and rates of abortive maturation and skip-spawning, were investigated to determine their impact on canary rockfish reproductive patterns.

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

j) Using Genetic Analysis to Reduce Uncertainty in the Assessment of Morphologically-similar West Coast Rockfish

Investigators: A.A. Keller, J. Cope, A. Elz, J. Harms, J. Orr, L. Park, P.H. Frey, 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 Aimee Keller at Aimee.Keller@noaa.gov

k) Maturity and growth of darkblotched rockfish, *Sebastes crameri,* along the U.S. west coast

Investigators: P.H. Frey, M.A. Head, and A.A. Keller

Changes in the reproductive biology of fish stocks over time can affect the accuracy of recruitment estimates used by fisheries managers to determine harvest levels. For heavily depleted species, shifts in parameters such as age and size at maturity may occur over a relatively short time period in response to changes in selective pressure or population density. We examined the reproductive biology of darkblotched rockfish (*Sebastes crameri*), a commercially and ecologically important groundfish in the California Current ecosystem along the west coast of North America. The National Marine Fisheries Service currently lists darkblotched rockfish as “rebuilding” after years of intense overfishing in the 1980s and 1990s. We examined ovaries and age structures collected in 2011 and 2012 for oocyte development stage and maturity. Length and age at 50% maturity were estimated as 30.0 cm fork length and 6.0 years, respectively, indicating a 12% and 29% decrease compared to the length and age at 50% maturity previously reported for this stock based on specimens collected from 1986 to 1987. This reduction increased the estimate of spawning stock biomass in a recent darkblotched rockfish stock assessment. Our study also revealed spatial patterns in darkblotched rockfish maturity along the U.S. west coast, including a notable decrease in the proportion of mature fish encountered south of central Oregon. Our findings demonstrate the importance of periodically updating life history data used in stock assessment models, and also highlight the potential value of spatial management toward sustainable fishing of rockfish species.

2. Assessment

a) Status of the Darkblotched Rockfish Resource off the Continental U.S. Pacific Coast in 2015

Authors: V.V. Gertseva, S.E. Matson, and E. Councill

Darkblotched rockfish (*Sebastes crameri*) in the Northeast Pacific Ocean occur from the southeastern Bering Sea and Aleutian Islands to near Santa Catalina Island in southern California. This species is most abundant from off British Columbia to Central California. Commercially important concentrations are found from the Canadian border through Northern California. This assessment focuses on the portion of the population that occurs in coastal waters of the western United States, off Washington, Oregon and California, the area bounded by the U.S.-Canada border on the north and U.S.-Mexico border on the south. The population within this area is treated as a single coastwide stock, due to the lack of biological and genetic data supporting the presence of multiple stocks.

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

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

The first stock assessment of darkblotched rockfish was done in 1993 and stock assessments have been conducted frequently since then. This current assessment, conducted in 2015, shows that the stock of darkblotched rockfish off the continental U.S. Pacific Coast is currently at 39% of its unexploited level. This is above the overfished threshold of 25% of unexploited stock ($SB_{25\%}$), but slightly below the management target of 40% of unfished spawning output ($SB_{40\%}$). The spawning output of darkblotched rockfish started to decline in the 1940s, during World War II, but exhibited a sharp decline in in the 1960s during the time of the intense foreign fishery targeting Pacific ocean perch. Between 1965 and 1976, spawning output dropped from 94% to 65% of its unfished level. Spawning output continued to decline throughout the 1980s and 1990s and in 2000 reached its lowest estimated level of 16% of its unfished state. Since 2000, the spawning output has been slowly increasing, which corresponds to decreased removals due to management regulations.

The time series of total mortality catch (landings plus discards) and estimated depletion for darkblotched rockfish are presented in Figure 2.

The assessment model captures some uncertainty in estimated size and status of the stock through asymptotic confidence intervals estimated within the model. To further explore uncertainty associated with alternative model configurations and evaluate the responsiveness of model outputs to changes in key model assumptions, a variety of sensitivity runs were performed. A major source of uncertainty in the assessment is related to natural mortality, which was found to have a relatively large influence on the perception of current stock size. Female natural mortality in the assessment is fixed at the value estimated outside the model, based on other life history characteristics of the species, while male natural mortality is estimated within the model. Uncertainty from natural mortality is reported via alternate states of nature in the decision table, bracketing the base model results.

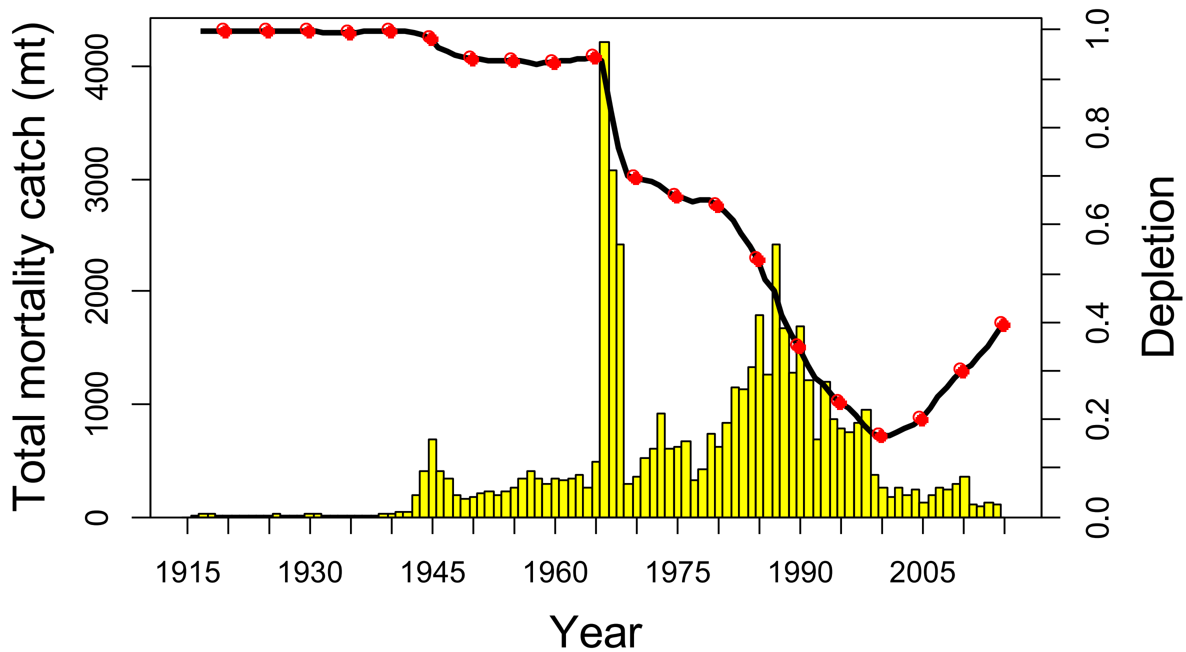

Figure 2. The time series of total mortality catch (bars) and estimated depletion (line) for darkblotched rockfish.

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

b) Assessments of Black Rockfish (*Sebastes melanops*) Stocks in California, Oregon and Washington Coastal Waters.

Authors: J.M. Cope, D. Sampson, A. Stephens, M. Key, P.P. Mirick, M. Stachura, Tien-Shui Tsou, P. Weyland, A. Berger, T. Buell, E. Councill, E.J. Dick, K.H. Fenske, M. Monk, and B.T. Rodomsky

Three state-based stock assessments were performed for the black rockfish. Each assessment used catches, indices (including recreational-based indices) and length and age compositions. Each state demonstrated distinct exploitation histories as well as recruitment time series, and ultimately different stock statuses.
Washington Assessment

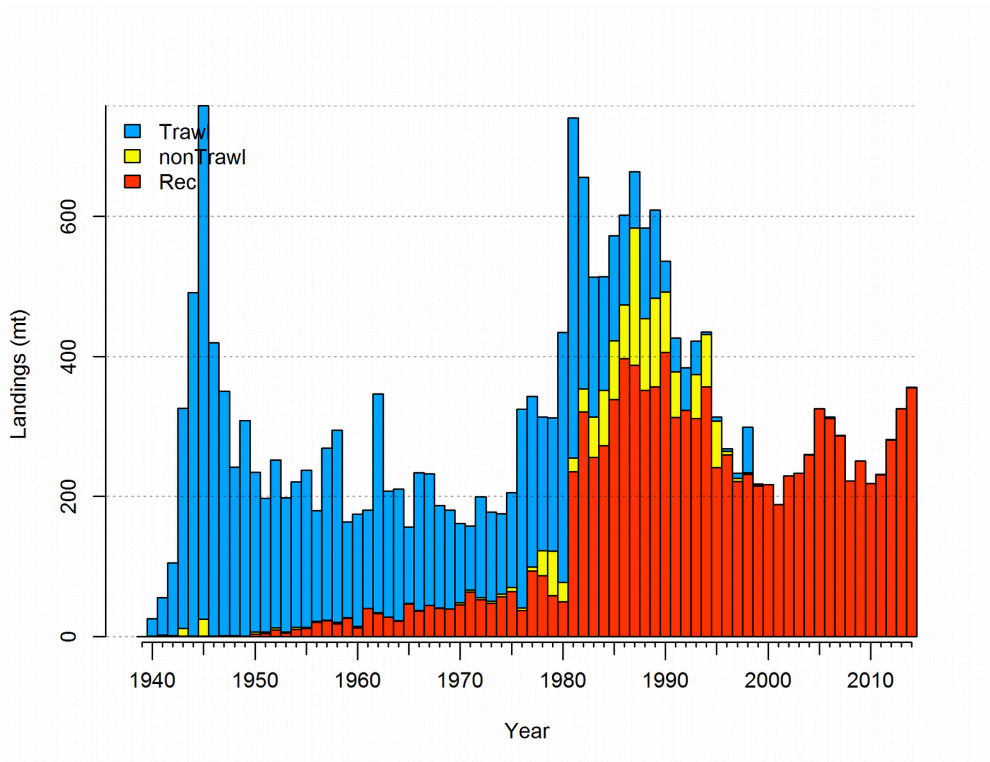

Figure 3. Washington Assessment: Landings (mt)

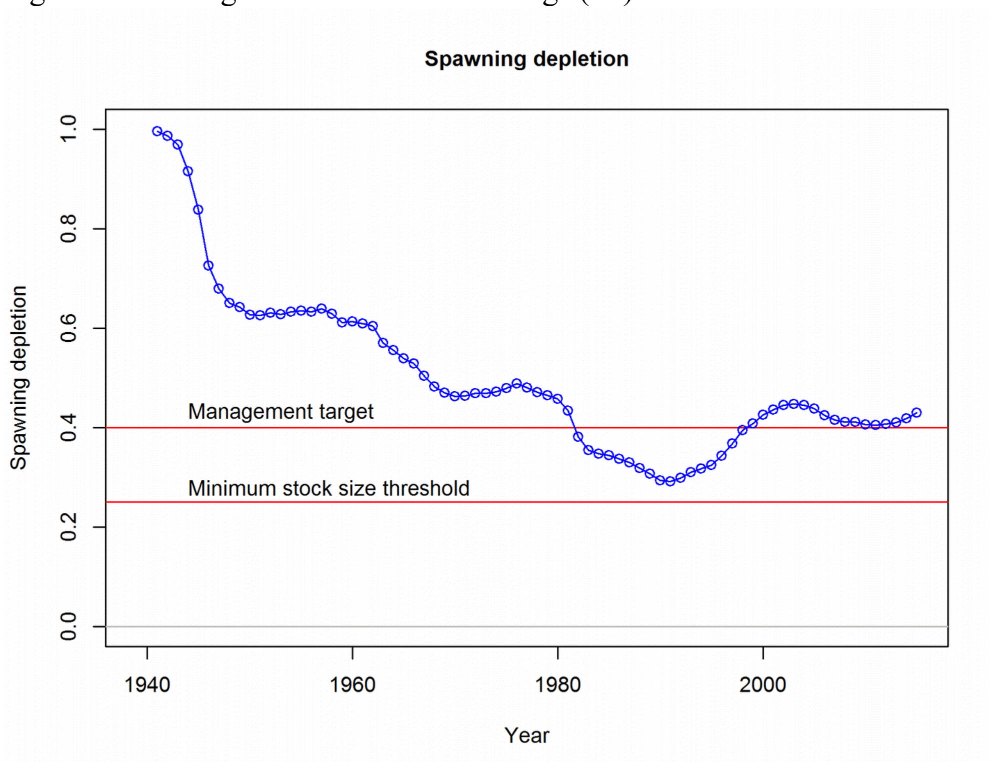

Figure 4. Washington Assessment: Spawing depletion

Oregon Assessment

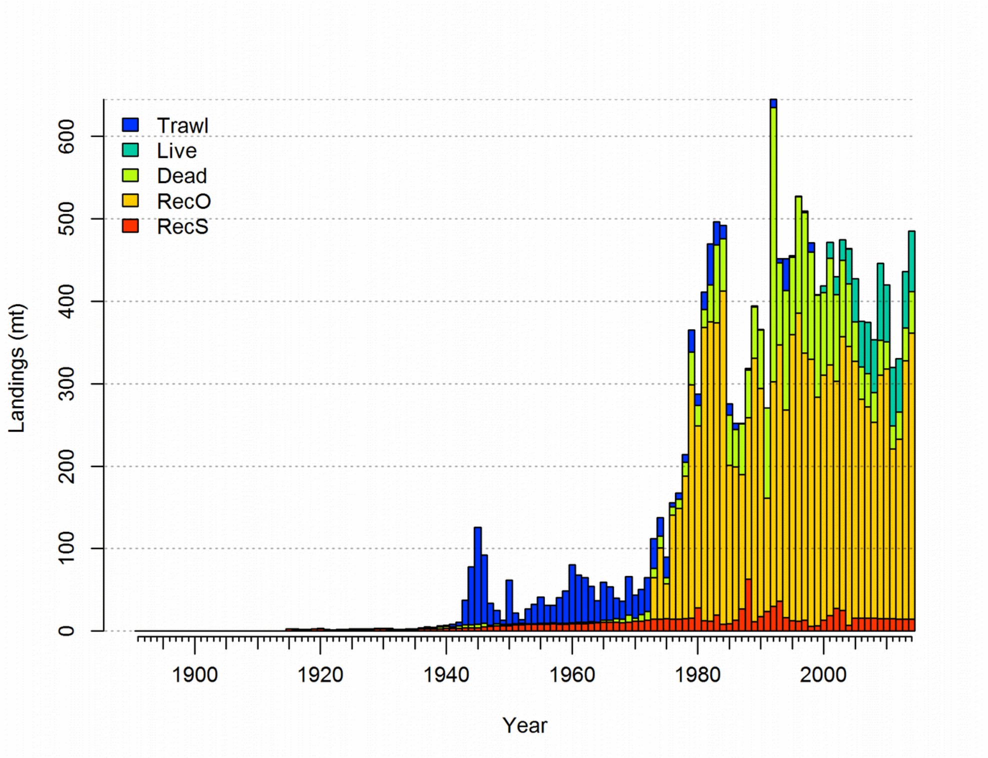

Figure 5. Oregon Assessment: Landings (mt)

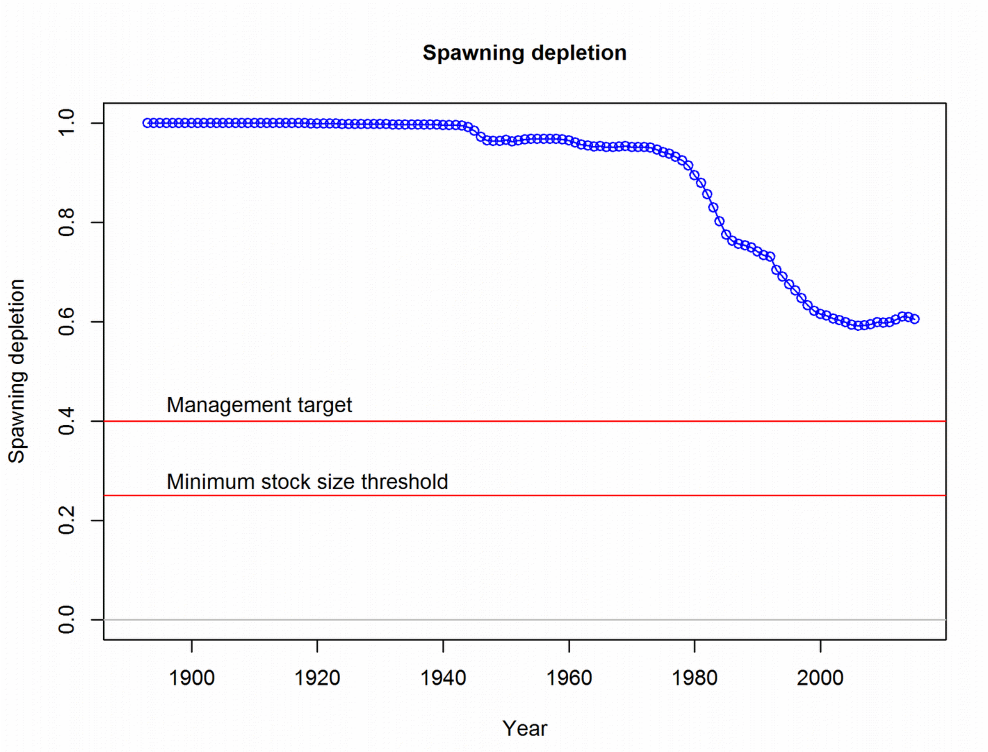

Figure 6. Oregon Assessment: Spawning depletion

California Assessment

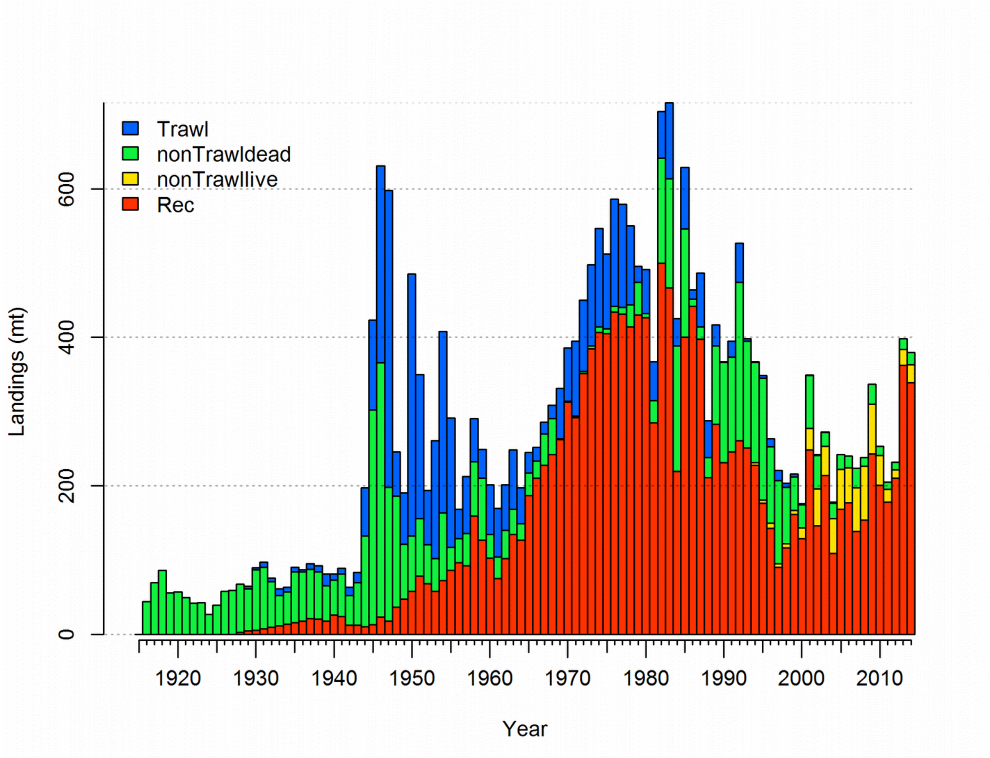

Figure 7. California Assessment: Landings (mt)

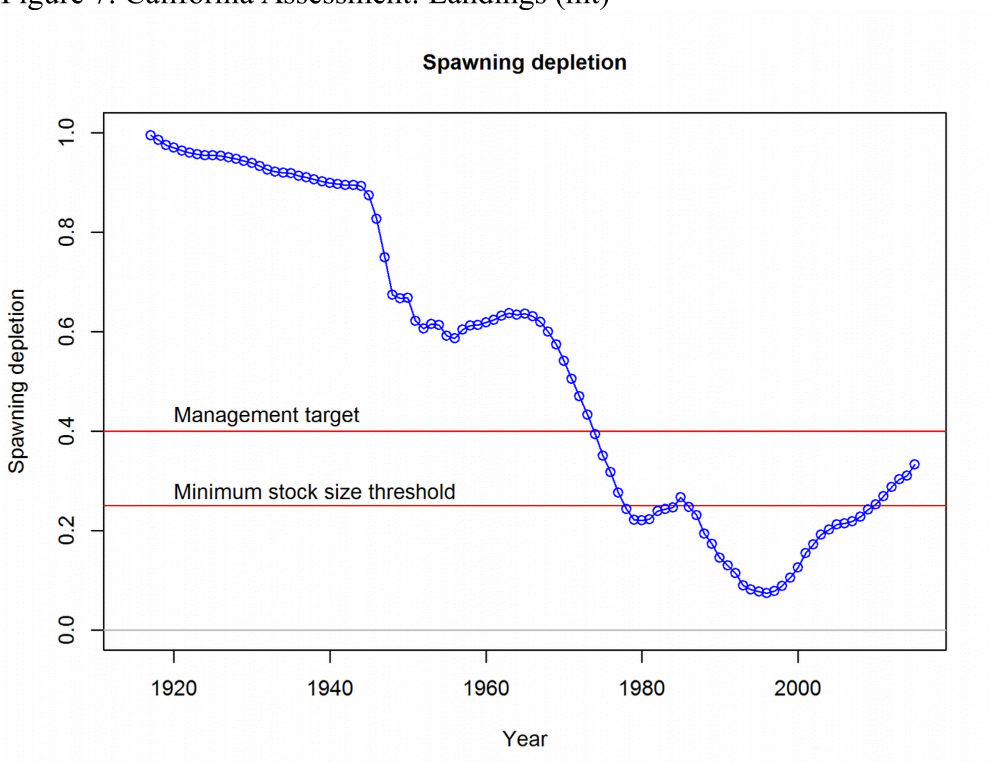

Figure 8. California Assessment: Spawning depletion

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

c) The status of Widow Rockfish (*Sebastes entomelas*) in 2015

Authors: A.C. Hicks and C.R. Wetzel

This is an assessment of widow rockfish (*Sebastes entomelas*) that reside in the waters off California, Oregon, and Washington from the U.S. – Canadian border in the north to the U.S. – Mexico border in the south. Widow rockfish inhabit water depths of 25 – 370 m from northern Baja California, Mexico to Southeastern Alaska. Although catches north of the U.S. – Canada border and south of the U.S. – Mexico border were not included in this assessment, it is not certain if those populations contribute to the biomass of widow rockfish off of the U.S. West Coast possibly through adult migration and/or larval dispersion.

Total landings of widow rockfish peaked in the early 1980s, increasing from approximately 1,000 metric tons (mt) in 1978 to a peak in landings exceeding 25,000 mt in 1981. After this sudden increase in catch, widow rockfish were given their own market category and often specifically identified in the landings. Uncertainty in species composition is greater in past years, thus landings of widow rockfish are not well known further back in history.

The large landings in the early 1980s were curtailed with trip limits beginning in 1982, which resulted in a decline in landings throughout the 1980s and 1990s following sequential reductions in the trip limits. From 2000 to 2003, landings of widow rockfish dropped from over 4,000 mt to about 40 mt and have been slowly increasing since, with a more rapid relative increase in 2013 and 2014 to above 700t. Widow rockfish are a desirable market species and it is believed that discarding was low historically. However, management restrictions (e.g., trip limits) resulted in a substantial amount of discarding beginning in 1982. Trawl rationalization was introduced in 2011, and since then very little discarding of widow rockfish has occurred.

This assessment was a new full assessment for widow rockfish which was last assessed in 2011. In this assessment, all aspects of the model including catches, data, and modelling assumptions were re-evaluated as much as possible. The assessment was conducted using the length- and age-structured modeling software Stock Synthesis (version 3.24U, pers. comm. Richard Methot, NMFS). The coastwide population was modeled assuming separate growth and mortality parameters for each sex (a two-sex model) from 1916 to 2015, and forecasted beyond 2015.

The data used in the assessment model consisted of survey abundance indices, length compositions, discard data, and age compositions. Model-based biomass indices and length compositions were determined from two different surveys. Length and age data were available for five fisheries (based on gear type).

Although there are many types of data available for widow rockfish since the late 1970s, which were used in this assessment, there is little information about steepness and natural mortality, and recent recruitment. Estimates of steepness are uncertain partly because of variable recruitment. Uncertainty in natural mortality is common in many fish stock assessments even when length and age data are available. Finally, there is little information about the strength of recent recruitment because the young fish are seen with a lower probability in the fisheries and surveys. These uncertainties were characterized as best as possible in the predictions and projections from this assessment.

The predicted spawning biomass from the base model generally showed a slight decline over the time series until 1966 when the foreign fleet began. A short, but sharp decline occurred, followed by a steep increase due to strong recruitment in 1970 and 1971. The spawning biomass declined rapidly with the developing domestic midwater fishery in the late 1970s and early 1980s. The stock continued to decline until 2000 when a combination of strong recruitment and low catches resulted in a quick increase. The 2015 spawning biomass relative to unfished equilibrium spawning biomass is above the target of 40% of unfished spawning biomass (75.1%), with a low of 37.3% in 1998.

Exploitation rates on widow rockfish were mostly above target throughout the 1980's and 1990's. Recent exploitation rates were predicted to be significantly below target levels. Recent catch and levels of depletion are presented in Figure 9.

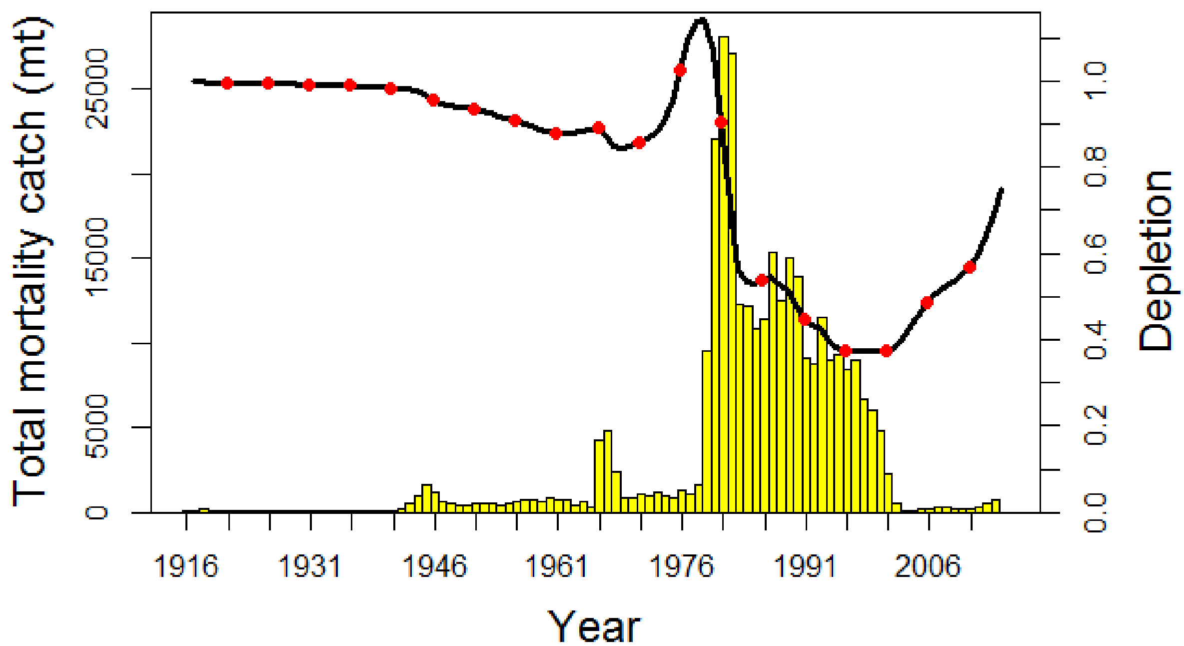

Figure 9. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for widow rockfish, 1916-2015.

d) Catch Report for Rebuilding Species Not Being Assessed in the 2015-16 Biennium

Investigator: J.R. Wallace

This catch report summarizes recent estimates of fishing mortality for three rebuilding species: yelloweye rockfish (*Sebastes ruberrimus*), Pacific ocean perch (*Sebastes alutus*), and cowcod (*Sebastes levis*), in waters off the coast of the United States from Southern California to the U.S.-Canada border (or the species spatial extent if not coast wide). These estimates are compared with annual catch limits (ACLs) adopted to promote rebuilding through 2014.

http://www.pcouncil.org/wp-content/uploads/2015/05/D8_Att9_CatchReports_JUN2015BB.pdf

e) Catch only Projection for Yelloweye Rockfish

Investigators: J.R. Wallace and J.Budrick

For yelloweye rockfish, a catch only projection was developed after updating the latest assessment with current total mortality information through 2014.

http://www.pcouncil.org/wp-content/uploads/2015/10/I4_Att3_SpexProjections_Arrowtooth_Yelloweye_Blue_CASF_Nov2015BB.pdf

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

f) Catch only Projection for Blue Rockfish

Investigators: J.R. Wallace and J. Budrick

For blue rockfish, a catch only projection was developed after updating the latest assessment with current total mortality information through 2014.

http://www.pcouncil.org/wp-content/uploads/2015/10/I4_Att3_SpexProjections_Arrowtooth_Yelloweye_Blue_CASF_Nov2015BB.pdf

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

I. Thornyheads: No research or assessments in 2015

J. Sablefish

1. Research

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

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

The U.S. west coast sablefish fishery is a valuable commercially targeted species, making assessing and understanding the interaction between climate change and fishing a priority for (1) forecasting future stock productivity and (2) for testing the robustness management strategies to climate variability and change. The horizontal-advection bottom-up forcing paradigm describes large-scale climate forcing that drives regional changes in alongshore and cross-shelf ocean transport, directly impacting the transport of nutrients, mass, and organisms. This concept provides a mechanistic framework through which climate variability and change alter sea surface height (SSH), zooplankton community structure, and sablefish recruitment, all of which are regionally correlated. This study assesses future trends in sablefish productivity as well as the robustness of harvest control rules to climate driven changes in recruitment by conducting a management strategy evaluation of the currently implemented harvest control rule as well as an alternative. We use GCM ensemble forecasts of sablefish productivity under a suite of future climate variability and change scenarios. Multi-decadal forecasts of sablefish productivity could provide long term strategic advice to allow fishers and managers to plan for and respond to shifts in productivity.

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

2. Assessment

a) Status of the U.S. sablefish resource in 2015

Authors: K.F. Johnson, M.B. Rudd, M. Pons, C.A. Akselrud, Q. Lee, F. Hurtado-Ferro, M.A. Haltuch, and O.S. Hamel

During the first half of the 20th century it is estimated that sablefish were exploited at relatively modest levels. With modest harvest rates continuing until the 1960s and above average, though highly uncertain, estimates of recruitment between 1960 and 1975, the spawning stock biomass rebounded to nearly unexploited levels in the late 1970s. Subsequently, between 1976 and 2001 estimates of biomass show a continuous decline, with large harvests during the late 1970s and lower than average recruitment throughout the 1980s and early-1990s as hypothesized drivers of the decline. Despite harvest rates that were below overfishing rates from1988 to 2008 along with higher than average recruitments in 1995, 1999, and 2000, the spawning biomass increased only slightly during the early-2000s. Since 2005 the stock has continued to decline, in large part due to extremely poor recruitments from 2002 to 2007. Although the relative trend in spawning biomass is quite robust to uncertainty in the leading model parameters, the productivity of the stock is highly uncertain due to confounding of natural mortality, absolute stock size, and productivity. The estimated spawning biomass in 2015 is 52,001 mt, however, the 95% interval ranges broadly from 25,698 to 78,303 mt. The relative spawning biomass is currently estimated at 35% of unexploited levels (95% interval: 22-48%). Forecasts from the 2011 assessment projected the spawning biomass to decrease by 6.4% from 2011 to 2015 given specified harvests, whereas the current assessment update estimated the decline was 9.8%. Furthermore, the current assessment update estimated unexploited spawning biomass 17% lower than what was estimated in 2011 and estimates depletion in 2015 higher than what was previously forecasted for 2015. The higher rate of decline appears to be because the current assessment update estimates the sum of the 2010 and 2011 recruitment events at 57% of what was estimated in the 2011 assessment.

Sablefish recruitment is estimated to be quite variable with large amounts of uncertainty in individual recruitment events. Within this variability, the average recruitment is estimated to have declined steadily between the 1970s and 2007. Recruitments during the 1970s were, on average, roughly six times that of the smaller cohorts between 2002 and 2005. It appears that large 1995, 1999, and 2000 year classes briefly slowed the rate of stock decline in the early 2000s and above-average cohorts from 2008, 2010, and 2013 are currently moving through the population. More specifically, the 2013 cohort appears to be the third largest recruitment event in the history of the fishery. However, of the three recent large recruitments, only the 2008 cohort has begun to mature and thus their contribution to the trend in spawning biomass remains minimal.

Unfished female spawning biomass was estimated to be 150,622 mt (95% interval: 114,728-186,516 mt). Therefore, the management target stock size (SB40%) is 60,249 mt and the overfished threshold (SB25%) is 37,656 mt. Total and age-4+ biomass at unexploited equilibrium were estimated to be 440,648 and 413,038 mt respectively. Steepness is not estimated in this assessment, thus uncertainty in reference point yields is grossly underestimated. Maximum sustainable yield (MSY), conditioned on current fishery selectivity and allocations, was estimated to occur at a spawning stock biomass of 44,090 (29% of unfished female spawning biomass), and produce a dead catch (excluding surviving discards) of 7,837 mt. However, dead catch at MSY varies almost linearly with steepness. MSY is estimated to be achieved at an SPR of 41%. This is very close to the yield, 7,476 mt, generated by the SPR (50%) that stabilizes the stock at the SB40% target. The fishing mortality target/overfishing level (SPR45%) results in an intermediate equilibrium yield of 7,759 mt at a spawning biomass of 51,212 mt (34% of the unfished equilibrium).

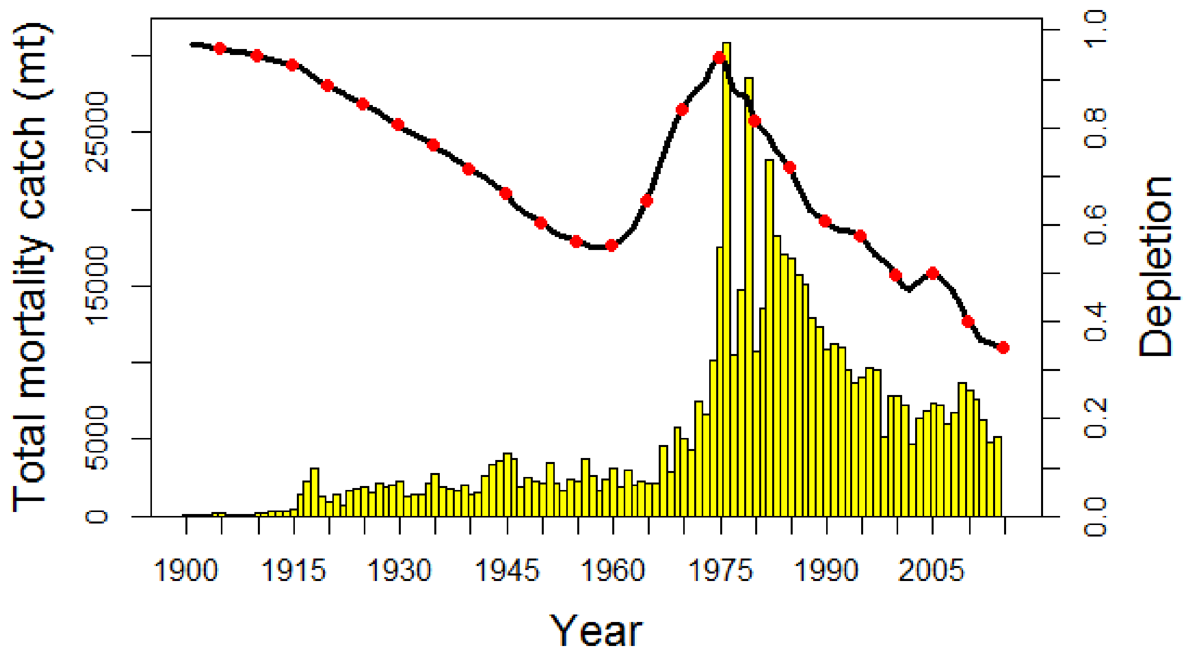

Figure 10. Time series of spawning stock biomass depletion and catch.

The complete stock assessment can be viewed online at:
http://www.pcouncil.org/groundfish/gfstocks.html

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

K. Lingcod: No research or assessments in 2015

L. Atka mackerel: No research or assessments in 2015

M. Flatfish

1. Research

2. Assessment

a) Stock Assessment Update: Status of the U.S. petrale sole resource in 2014

Authors: C.C. Stawitz, F. Hurtado-Ferro, P.K. Kuriyama, J.T. Trochta, K.F. Johnson, M.A. Haltuch, and O.S. Hamel

Petrale sole were lightly exploited during the early 1900s, but by the 1950s the fishery was well developed and showing clear signs of depletion and declines in catches and biomass. The rate of decline in spawning biomass accelerated through the 1930s–1970s reaching minimums generally around or below 10% of the unexploited levels during the 1980s through the early 2000s. The petrale sole spawning stock biomass is estimated to have increased slightly from the late 1990s, peaking in 2005, in response to above average recruitment. However, poor recruitments during the period of stock increase resulted in stock declines between 2005 and 2010, resulting in harvests that, in hind site, were great than those suggested by the current harvest policy. Since 2010 the total biomass of the stock has increased as large recruitments during 2007 and 2008 appear to be moving into the population. The estimated relative depletion level in 2015 is 30.70% of unfished biomass (~95% asymptotic interval: 22.2% - 39.2%, ~ 75% interval based on the range of states of nature: 27.3%-34.5%), corresponding to 10,290 mt (~95% asymptotic interval: 8,453 – 12,126 mt, states of nature interval: 9,969 – 10,572 mt) of female spawning biomass in the base model (Table c). The base model indicates that the spawning biomass was generally below 25% of the unfished level between the 1960s and 2013 and was rebuilt above this target in 2014.

Annual recruitment was treated as stochastic, and estimated as annual deviations from log-mean recruitment where mean recruitment is the fitted Beverton-Holt stock recruitment curve. The time-series of estimated recruitments shows a relationship with the decline in spawning biomass, punctuated by larger recruitments. The three strongest recruitments during the last 10 years are estimated to be from 2006, 2007, and 2008, with the 2007 and 2008 year classes being the third-largest and largest recruitments estimated during the assessed period. The four weakest recruitments are estimated to be from 2005, 2010, and 2011.

The abundance of petrale sole was estimated to have dropped below the $SB_{25\%}$ management target during the 1960s and stayed under that level through the beginning of 2013. The stock declined below the $SB_{12.5\%}$ overfished threshold from the early 1980s until the early 2000s. In 1984 the stock dropped below 10% of the unfished spawning biomass and did not rise above the 10% level until 2001. From 2000 to 2005 the stock increased, reaching a peak of 14.2% of unfished biomass in 2005, then declining through 2010, and again increasing from 2011-2014. Fishing mortality rates in excess of the current F-target for flatfish of $SPR_{30\%}$ are estimated to have begun during the 1950s and continued until 2010. Current F (catch/biomass of age-3 and older fish) is estimated to be 0.15 during 2015.

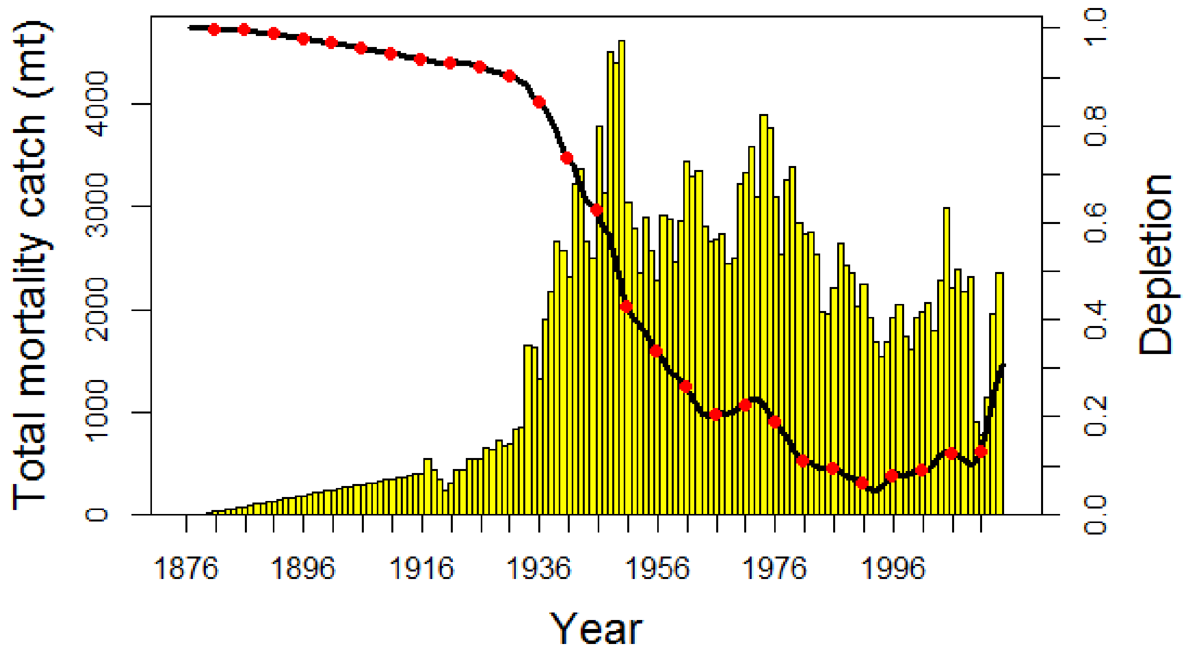

Figure 11. Petrale sole time series of spawning stock biomass depletion and catch.

The complete stock assessment can be viewed online at:
http://www.pcouncil.org/groundfish/gfstocks.html

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

b) The 2015 stock assessment of arrowtooth flounder (*Atheresthes stomias*) in California, Oregon, and Washington waters.

Author: J.M. Cope

A data-moderate approach, using only catch and index data, was used exploring several model specifications. No one model was used for setting catch targets, so not reported here, but several were used to consider stock status and how one could approach data-moderate assessments in the future.

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

c) Catch only Projection for Arrowtooth Flounder

Investigators: J.R. Wallace and J.Budrick

For arrowtooth flounder a catch only projection was developed after updating the latest assessment with current total mortality information through 2014.
http://www.pcouncil.org/wp-content/uploads/2015/10/I4_Att3_SpexProjections_Arrowtooth_Yelloweye_Blue_CASF_Nov2015BB.pdf

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

N. Pacific halibut & IPHC activities: No research or assessments in 2015

O. Other groundfish species

1. Research

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

Investigators: A.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, contact Aimee Keller at Aimee.Keller@noaa.gov

2. Assessment

a. Kelp Greenling stock assessment (OR waters)

Author: A. Berger

This is the second stock assessment of the population status of kelp greenling (*Hexagrammos decagrammus*) along the Oregon coast. Kelp greenling is endemic to nearshore rocky reef, kelp forest, and eelgrass habitats of the Northeast Pacific Ocean, ranging from southern California to the Aleutian Islands in Alaska, to depths usually less than 50 meters. Despite the overall range, this assessment applies to waters off the Oregon coast due to a lack of sufficient population information or catch in California and Washington.

The assessment is structured as a single, sex-disaggregated, unit population, spanning Oregon marine waters. It operates on an annual time step covering the period 1915 to 2015, assumes negligible catch prior to that time, and thus assumes a stable equilibrium population prior to 1915. Kelp Greenling spawning biomass was estimated to be 316 mt in 2015 (~95% asymptotic intervals: 116-516 mt), which when compared to unfished spawning biomass equates to a depletion level of 80% (~95% asymptotic intervals: 0.59-1.00) in 2015. Stock size is estimated to be at the lowest level throughout the historic time series in 1998, but has since increased as a result of strong recruitment in 2000 and 2009. Throughout the time series, the stock is estimated to be above the management target of B40%. Due to uncertainty associated with natural mortality and the resulting influence it had on overall population scale, a sigma value (representing uncertainty in current stock status) was calculated by taking the log of the ratio of the base model spawning biomass in 2015 to the assumed low values for natural mortality model spawning biomass in 2015 and dividing by 1.15 (the z-score equivalent to a probability of 0.125). This calculation resulted in a sigma of 0.441 for use in harvest management.

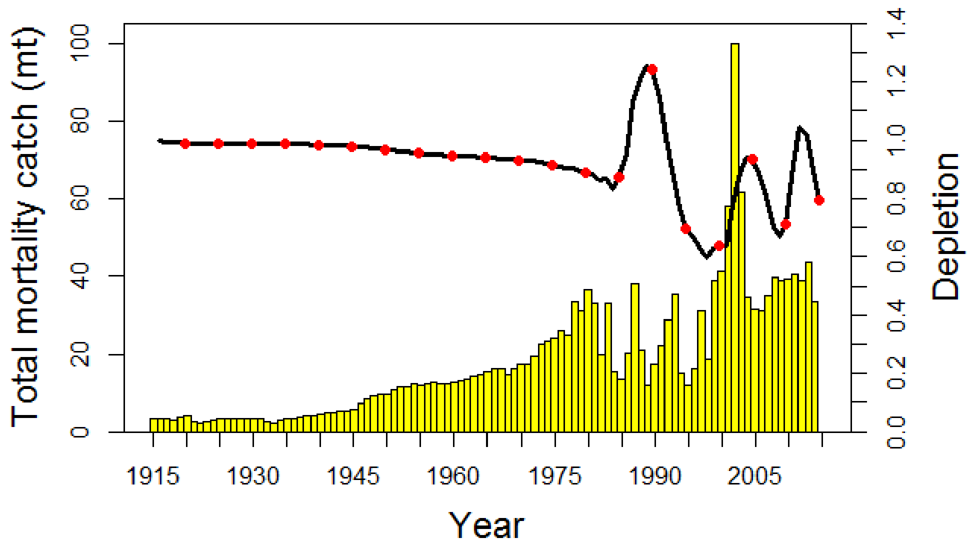

Figure 12. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Kelp Greenling, 1915-2014)

The complete assessment document: "Status of Kelp Greenling (*Hexagrammos decagrammus*) along the Oregon Coast in 2015" is available at:
http://www.pcouncil.org/groundfish/stock-assessments/by-species/

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

b) Catch only Projection for California Scorpionfish

Investigators: J.R. Wallace and J. Budrick

For California scorpionfish a catch only projection was developed after updating the latest assessment with current total mortality information through 2014.

http://www.pcouncil.org/wp-content/uploads/2015/10/I4_Att3_SpexProjections_Arrowtooth_Yelloweye_Blue_CASF_Nov2015BB.pdf

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

VII. Ecosystem Studies

A. Assessment Science

1. Modeling

a) Stock assessment model development

Investigator: R.D. Methot and C.R. Wetzel

Stock Synthesis (SS) is an assessment model in the class termed integrated analysis and is the basis for West Coast groundfish assessments and many other assessments around the world. SS is built with a population sub-model that simulates a stock's growth and mortality processes, an observation sub-model to estimate expected values for various types of data, and a statistical sub-model to characterize the data's goodness of fit and to obtain best-fitting parameters with associated variance. It includes a rich feature set including age- and size-based population dynamics and the ability to specify observational phenomena, such as ageing imprecision. Model parameters can vary over time or be specified as functions of environmental data. SS includes routines to estimate MSY and exploitation levels that correspond to various standard fishery management targets. It supports assessments spanning several geographic areas and can use tag-recapture data. A customizable harvest policy is used to conduct a forecast in the final phase of running the model. The model is coded in ADMB (www.admb-project.org). It is now at version 3.24y as of August 2015.

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

b) Random effect estimation of time-varying factor in Stock Synthesis

Investigators: J.T. Thorson, A.C. Hicks, and R.D. Methot

Biological processes such as fishery selectivity, natural mortality, and somatic growth can vary over time, but it is challenging to estimate the magnitude of time-variation of demographic parameters in population dynamics models, particularly when using penalized-likelihood estimation approaches. Random-effect approaches can estimate the variance, but are computationally infeasible or not implemented for many models and software packages. We show that existing models and software based on penalized-likelihood can be used to calculate the Laplace approximation to the marginal likelihood of parameters representing variability over time, and specifically demonstrate this approach via application to Stock Synthesis. Using North Sea cod and Pacific hake models as case studies, we show that this method has little bias in estimating variances for simulated data. It also provides a similar estimate of variability in hake recruitment (log-SD = 1.43) to that obtained from Markov chain Monte Carlo (MCMC) methods (log-SD = 1.68), and the method estimates a non-trivial magnitude (log-SD = 0.07) of variation in growth for North Sea cod. We conclude by discussing the generality of the proposed method and by recommending future research regarding its performance relative to MCMC, particularly when estimating multiple variances simultaneously.

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

c) Simulation testing the robustness of stock assessment models to error: some results from the ICES strategic initiative on stock assessment methods

Investigators: J.J. Deroba, D.S. Butterworth, R.D. Methot, J.A.A. De Oliveira, C. Fernandez, A. Nielsen, S.X. Cadrin, M. Dickey-Collas, C.M. Legault, J. Ianelli, J.L. Valero, C.L. Needle, J.M. O'Malley, Y-J. Chang, G.G. Thompson, C. Canales, D.P. Swain, D.C.M. Miller, N.T. Hintzen, M. Bertignac, L. Ibaibarriaga, A. Silva, A. Murta, L.T. Kell, C.L. de Moor, A.M. Parma, C.M. Dichmont, V.R. Restrepo, Y. Ye, E. Jardim, P.D. Spencer, D.H. Hanselman, J. Blaylock, M. Mood, and P.-J. F. Hulson

The World Conference on Stock Assessment Methods (July 2013) included a workshop on testing assessment methods through simulations. The exercise was made up of two steps applied to datasets from 14 representative fish stocks from around the world. Step 1 involved applying stock assessments to datasets with varying degrees of effort dedicated to optimizing fit. Step 2 was applied to a subset of the stocks and involved characteristics of given model fits being used to generate pseudo-data with error. These pseudo-data were then provided to assessment modelers and fits to the pseudo-data provided consistency checks within (self-tests) and among (cross-tests) assessment models. Although trends in biomass were often similar across models, the scaling of absolute biomass was not consistent across models. Similar types of models tended to perform similarly (e.g. age based or production models). Self-testing and cross-testing of models are a useful diagnostic approach, and suggested that estimates in the most recent years of time-series were the least robust. Results from the simulation exercise provide a basis for guidance on future large-scale simulation experiments and demonstrate the need for strategic investments in the evaluation and development of stock assessment methods.

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

d) Performance of a fish stock assessment model that incorporates a coefficient for catch calibration

Investigator: R.D. Methot, P.D. Lynch

The level of fishery catch in fish stock assessment models is nearly always treated as known with no bias and high precision. Recent findings with recreational fisheries in the U.S. challenge this assertion. Fishery assessment models need to evolve to address the uncertainty associated with catch time series. A prototype version of the Stock Synthesis (SS) assessment model (Methot and Wetzel, 2013) now incorporates a coefficient for catch calibration that operates on catch time series in essentially the same way that a catchability coefficient (q) operates on indices of stock abundance. The catch coefficient is implemented to be a fleet-specific estimable parameter that can be informed by a prior and can accommodate various time-varying protocols available in SS. The performance of SS with respect to this coefficient is investigated using simulated assessment data. Our evaluations focus on investigating the bias and imprecision of model results as the catchability coefficient is allowed to be estimated with varying biases and variances of its informative priors.

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

e) The limits of single species assessment models

Investigator: R.D. Methot

The essence of simple population models is that they can obtain information from contrasts. This can be as simple as a time series of catch and relative abundance showing a coupled pattern with changing levels of catch pushing abundance down or allowing it to grow, or a steeper slope to the size composition in areas or eras with higher catch levels. Integrated analysis models have evolved to a high level of statistical capability to simultaneously extract information from both types of data while taking into account various confounding factors. All models are simplifications of nature based upon simple concepts of population regulation. Models can make inferences about species abundance and sustainable levels of fishing because of these simplifications, especially when data are limited. Single species models generally are structured to take into account random perturbations caused by the larger system in which the species occurs. The limitation of single species models is that they cannot make good predictions when the whole system is shifting on longer time scales, whether through fishery-induced or natural changes in abundance of biologically interacting species, or through long-term shifts in climate. Addressing these factors requires information about those external processes and their effect on fish.

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

f) A method for calculating a meta-analytical prior for the natural mortality rate using multiple life-history correlates

Investigator: O.S. Hamel

The natural mortality rate *M* is an extraordinarily difficult parameter to estimate for many fish species. The uncertainty associated with *M* translates into increased uncertainty in fishery stock assessments. Estimation of *M* within a stock assessment model is complicated by the confounding of this parameter with other life history and fishery parameters which are also uncertain and some of which are typically estimated within the model. Ageing error and variation in growth, which may not be fully modeled, can also affect estimation of *M*, as can assumptions, including the assumed form of the stock recruitment function (e.g., Beverton-Holt, Ricker) and the level of compensation (or steepness), which may be fixed (or limited by a prior) in the model. To avoid this difficulty, stock assessors often assume point estimates for M derived from meta-analytical relationships between *M* and more easily measured life history characteristics. However, these relationships depend upon estimates of *M* for a great number of species, and those estimates are also subject to errors and biases (as are, to a lesser extent, the other life history parameters). Therefore, at the very least, some measure of uncertainty should be calculated and used for evaluating uncertainty in stock assessments as well as in fishery management evaluations. Given error-free data on *M* and the covariate(s) for the meta-analysis, prediction intervals provide the appropriate measure of uncertainty in *M*. In contrast, if the relationship between the covariate(s) and *M* is exact and the only error is observation error in *M*, confidence intervals are appropriate. In this talk I will describe both types of intervals, develop priors based upon multiple published meta-analyses of various life history correlates using the prediction interval calculation, and discuss some caveats and considerations when deciding which meta-analyses to use in developing priors.

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

g) Addressing cohort-strength correlated ageing error in fishery stock assessment

Investigators: O.S. Hamel, C. Legault, R. Methot and G. Thompson

Fishing intensity metrics describe the expected impact of fishing on a fish stock when setting management limits, such as OFLs, ABCs and ACLs. Three commonly used metrics are Spawning Potential Ratio (SPR), instantaneous fishing rate (F), and Exploitation Rate (H) but none is a perfect measure of either the short or long-term impact of fishing on the stock. H ignores the effect of age, size and gender selectivity on the impact the removals have on future spawning output and thus recruitment, but it is the only available measure for biomass dynamics models. SPR measures the expected long-term relative spawning output per recruit, assuming constant selectivity and fishing intensity, as well as no changes or variation in life history parameters, but is not informative about short-term removals. F is ambiguous because its impact depends upon the range of ages that are nearly fully selected hence experience that level of F. These differences impede consistent reporting of fishing intensity. In addition, SPR, F, and H can fail to measure the cumulative effects of multiple years of fishing under certain conditions such as substantial or systematic variation in selectivity, including fisheries targeting strong year classes.

Alternative metrics have been developed over the years which incorporate the cumulative effects of past fishing or measure future impacts of a particular year's fishing. We propose to develop simulation models and test previously developed as well as new metrics of fishing intensity and impact. In particular we will test how well management goals are met when using these alternative metrics. Performance metrics will include total catch, variability in catch, proportion of time above target, and proportion of simulations for which an overfished status is reached. The best metrics will also allow for better comparisons of fishing intensity among species.

The outcome of this work will be guidelines about which single or suite of impact metrics are appropriate under different circumstance of stock, fisheries, and assessment. This will improve the consistency and effectiveness of management in meeting goals, such as those regarding protecting stock status, optimizing yield, and minimizing variance in catch limits.

Presentations on this subject were given at the National Stock Assessment Workshop in Portland, OR in August 2015 and at the Western Groundfish Conference in Newport, OR in February 2016. Funding is being sought for further work on this topic.

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

h) The magnitude of time-variation in demographic rates for marine fishes, and their impact on fisheries management targets.

Investigators: J.T. Thorson, C. Monnahan, J.M. Cope

Fisheries scientists are increasingly concerned about changes in vital rates caused by environmental change and fishing impacts. Demographic parameters representing individual growth, maturity, mortality, and recruitment have previously been documented to change over decadal time scales. However, there has been relatively little comparison regarding which vital rates cause relatively greater or lesser impacts on commonly used fisheries management targets. We therefore use a life table (based on age-structured assessment models) to explore the sensitivity of fishing mortality, spawning biomass, and catch targets to changes in parameters representing growth, mortality, recruitment, and maturation rates for three representative life histories representing long-, medium-, and short-lived species. The elasticity analysis indicates that demographic changes can result in substantial variation in fisheries management targets, but that changes in mortality rates are particularly important for spawning biomass and catch targets while maturity and recruitment compensation are also important for fishing mortality targets. We conclude by discussing the importance of improved data repositories to address covariation among maturity, growth, and mortality parameters.

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

i) Decision Support System for Assessing and Managing Data and Capacity-Limited Fisheries

Investigators: N.A. Dowling, J.R. Wilson, M.B. Rudd, E.A. Babcock, M. Caillaux, J.M. Cope, D. Dougherty, R. Fujita, T. Gedamke, M. Gleason, N.L. Gutiérrez, A. Hordyk, G.W. Maina, P. Mous, D. Ovando, A.M. Parma, J. Prince, C. Revenga, J. Rude, C. Szuwalski, S. Valencia, and S. Victor

A majority of fisheries across the globe are data- and/or capacity-limited, in that they lack data and resources to generate statistical estimates of stock status, often leading to ineffective or non-existent management. Improving management actions and outcomes could be accomplished by using analytical methods and management measures that are effective even when data and capacity are limited, positively impacting the livelihoods of millions of people and generating significant conservation benefits. Cost-effective methods for analyzing and managing data-limited fisheries exist, but they are challenging to navigate due to the myriad options, different data requirements, unique outputs and a lack of understanding of the relative costs and advantages of each approach. There is also an increasing body of general guidance for the process of developing management strategies, i.e., the pre-agreed system of monitoring, assessment, and decision rules used to achieve management objectives for data-limited fisheries. However, this body of guidance has yet to be organized in a way that allows fishery management practitioners to apply it easily. Thus, there remains a disconnect between the development of assessment approaches and decision rule options, and their on-the-ground implementation in a management context. To fill this gap, we have developed FishPath: a decision support system that allows users to characterize their fishery with respect to i) available data; ii) biological/life history attributes of relevant species; iii) fishery operational characteristics; iv) socio-economic characteristics; and, v) governance context. FishPath allows users to identify a subset of management strategy options appropriate for the fishery based on this characterization. We are currently applying the DSS to a range of data-limited fisheries globally to evaluate its efficacy. FishPath is the first ever comprehensive and standardized approach to guiding the selection of monitoring, assessment and decision rule options for data-limited fisheries. If widely applied, FishPath will help ensure that more data-limited, capacity-limited fisheries, particularly those in developing countries, become assessed and managed, leading to improved conservation and fishery outcomes.

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

j) Toward a synoptic approach to reconstructing West Coast groundfish historical removals.

Investigators: J.M. Cope, T. Tsou, P. Weyland, G. Lippert, T. Buell, P. Mirick, V. Gertseva, J. Field, P. Pearson, R. Leos, and J. Budrick

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 extremely challenging. 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 Vladlena Gertseva at Vladlena.Gertseva@noaa.gov

k) 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).

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l) Exploring an Individual Based Modeling Approach in Fisheries.

Investigator: Andi Stephens

Much fishery modeling is focused on the average characteristics of a population and simulates the rates of survival or mortality, or changes in population size in terms of the population as a whole. The underlying support for these models comes from the mathematics associated with linear algebra and differential equations. Stock Synthesis is a well-known example of this type of top-down approach.

In contrast, an individual based model (IBM) is a bottom-up approach that allows emergent properties of a system to arise from individual contributions. A model of this type features a simulation framework in which individual organisms are tracked in time; these individuals may be subject to environmental forcing and to anthropogenic pressure (e.g., fishing). The responses of interest may range from survival to the evolution of genetic traits, while the timeframe of interest may range from days to decades.

This work presents an individual based model that evaluates intergenerational genetic drift in individual growth parameters in response to a variety of fishery management practices.

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m) Revisiting a Regression Technique for Recreational Data Analysis: a Simulation Study.

Investigator: Andi Stephens

This work addresses the interpretation of the logistic regression technique of Stephens and MacCall (2004), used to analyze recreational data from a multispecies fishery. This technique was used with varying degrees of success in the NWFSC/SWFSC 2015 assessments of near-shore species.

The method assumes that the species composition of the catch implies targeting of a species that uses a particular type of habitat. If this is true, catch records can be used to segregate the effort to catch a groundfish species from effort to catch other groundfish, or effort to catch tuna or salmon. Partitioning the data in this way results in improved calculation of catch per unit effort (CPUE).

For this study, I simulated data to resemble fishery records of catch in a multispecies fishery, and applied the method to those datasets to evaluate its ability to correctly infer whether habitat for the target species was fished on a particular "trip". Analysis of the regression results provides insight into the limitations of the method: it performs poorly when data are limited, when the target species or the covariate predictor species change habitats, or when the suite of covariatepredictor species are predominantly negative or predominantly positive predictors of the target species. However, the regression is relatively robust to changes in population size among the predictor species.

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n) Applying a length-frequency based analysis to inform regional-scale fisheries management

Investigator: Andi Stephens

Changes in population fecundity are typically used to inform fishery management. Spawning potential ratio (SPR) is often used to reflect fecundity, however this is an age-based method not available for use with data-limited stocks. An analogous method that can be used in data-limited situations is fractional lifetime egg production (FLEP).

FLEP quantifies the between-year change in fecundity from the change in the length-frequencies of the catch in those years. This estimation method has been shown to be relatively unbiased and less-sensitive than SPR to estimates of M. This work involves an FLEP analysis of fisheries in Oregon, performed at the state-wide and regional levels, investigating the potential of the method to inform regional management.

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

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

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p) 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.

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

Investigators: K. Ono, A.O. Shelton, E.J. Ward, J.T. 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 US West coast. 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.

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r) Using spatiotemporal species distribution models to identify temporally evolving hotspots of species co-occurrence

Investigators: E. Ward, O. Shelton, J. Thorson, K. Ono, K., and Y. Lee

Identifying spatiotemporal hotspots is important for understanding basic ecological processes, but is particularly important for species at risk. A number of terrestrial and aquatic species are indirectly affected by anthropogenic impacts, simply because they tend to be associated with species that are targeted for removals. Using newly developed statistical models that allow for the inclusion of time-varying spatial effects, we examine how the co-occurrence of a targeted and nontargeted species can be modeled as a function of environmental covariates (temperature, depth) and interannual variability. The nontarget species in our case study (eulachon) is listed under the U.S. Endangered Species Act, and is encountered by fisheries off the U.S. West Coast that target pink shrimp. Results from our spatiotemporal model indicated that eulachon bycatch risk decreases with depth and has a convex relationship with sea surface temperature. Additionally, we found that over the 2007–2012 period, there was support for an increase in eulachon density from both a fishery data set (+40%) and a fishery-independent data set (+55%). Eulachon bycatch has increased in recent years, but the agreement between these two data sets implies that increases in bycatch are not due to an increase in incidental targeting of eulachon by fishing vessels, but because of an increasing population size of eulachon. Based on our results, the application of spatiotemporal models to species that are of conservation concern appears promising in identifying the spatial distribution of environmental and anthropogenic risks to the population.

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

Investigators: J.T. 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.

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t) Spatial delay-difference models for estimating spatiotemporal variation in juvenile production and population abundance

Investigators: J. Thorson, J. Ianelli, S. Munch, K. Ono, and P. Spencer

Many important ecological questions require accounting for spatial variation in demographic rates (e.g., survival) and population variables (e.g., abundance per unit area). However, ecologists have few spatial modelling approaches that (i) fit directly to spatially referenced data, (ii) represent population dynamics explicitly and mechanistically, and (iii) estimate parameters using rigorous statistical methods. We therefore demonstrate a new and computationally efficient approach to spatial modelling that uses random fields in place of the random variables typically used in spatially aggregated models. We adapt this approach to delay-difference dynamics to estimate the impact of fishing and natural mortality, recruitment, and individual growth on spatial population dynamics for a fish population. In particular, we develop this approach to estimate spatial variation in average production of juvenile fishes (termed recruitment), as well as annual variation in the spatial distribution of recruitment. We first use a simulation experiment to demonstrate that the spatial delay-difference model can, in some cases, explain over 50% of spatial variance in recruitment. We also apply the spatial delay-difference model to data for rex sole (*Glyptocephalus zachirus*) in the Gulf of Alaska and show that average recruitment (across all years) is greatest near Kodiak Island but that some years show greatest recruitment in Southeast Alaska or the western Gulf of Alaska. Using model developments and software advances presented here, we argue that future research can develop models to approximate adult movement, incorporate spatial covariates to explain annual variation in recruitment, and evaluate management procedures that use spatially explicit estimates of population abundance.

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u) Evaluating a prior on relative stock status using simplified age-structured models

Investigators: J. Cope, J. Thorson, C. Wetzel, and J. DeVore

Fisheries management aimed to support sustainable fisheries typically operates under conditions of limited data and analytical resources. Recent developments in data-limited analytical methods have broadened the reach of science informing management. Existing approaches such as stock reduction analysis and its extensions offer simple ways to handle low data availability, but are particularly sensitive to assumptions regarding relative stock status. This study develops and introduces a prior on relative stock status using Productivity-Susceptibility Analysis vulnerability scores. Data from U.S. west coast groundfish stocks (n = 17) were used to develop and then test the performance of the new relative stock status prior. Traditional simulation testing via an operating model was not possible because vulnerability scoring could not be simulated; we instead used the "best available scientific information" (BASI) approach. This approach uses fully-realized stock assessments (deemed the best available scientific information by management entities) and reduces data content available to simpler models. The Stock Synthesis statistical catch-at-age framework was used to nest within the full assessment two simpler models that rely on stock status priors. Relative error in derived estimates of biomass and stock status were then compared to the BASI assessment. In general, the new stock status prior improved performance over the current application of stock status assumed at 40% initial biomass. Over all stocks combined, stock status showed the least amount of bias, while initial biomass was better estimated than current biomass. The BASI approach proved a useful and possibly complimentary approach to simulation testing with operating models in order to gain insight into modelling performance germane to management needs, particularly when system components (e.g., susceptibility scoring) cannot be easily simulated.

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v) Catch curve stock-reduction analysis: an alternative solution to the catch equation

Investigators: J. Thorson and J. Cope

Legislative changes in the United States and elsewhere now require scientific advice on catch limits for data-poor fisheries. The family of stock reduction analysis (SRA) models is widely used to calculate sustainable harvest levels given a time series of harvest data. SRA works by solving the catch equation given an assumed value for spawning biomass relative to unfished levels in the final (or recent) year, and resulting estimates of recent fishing mortality are biased when this assumed value is mis-specified. We therefore propose to replace this assumption when estimating stock status by using compositional data in recent years to estimate a catch curve and hence estimating fishing mortality in those years. We compare this new "catch-curve stock reduction analysis" (CC-SRA) with an SRA or catch curve using simulated data for slow or fast life histories and various magnitudes of recruitment variability. Results confirm that the SRA yields biased estimates of current fishing mortality given mis-specified information about recent spawning biomass, and that the catch curve is biased due to changes in fishing mortality over time. CC-SRA, by contrast, is approximately unbiased for low or moderate recruitment variability, and less biased than other methods given high recruitment variability. We therefore recommend CC-SRA as a data-poor assessment method that incorporates compositional data collection in recent years, and suggest future management strategy evaluation given a data-poor control rule.

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w) Spatial factor analysis: a new tool estimating multispecies spatial distributions and correlated distributions among species

Investigators: J. Thorson, H. Skaug, A.O. Shelton, K. Kristensen, and M. Scheuerell

Predicting and explaining the distribution and density of species is one of the oldest concerns in ecology. Species distributions can be estimated using geostatistical methods, which estimate a latent spatial variable explaining observed variation in densities, but geostatistical methods may be imprecise for species with low densities or few observations. Additionally, simple geostatistical methods fail to account for correlations in distribution among species and generally estimate such cross-correlations as a post hoc exercise.

We therefore present spatial factor analysis (SFA), a spatial model for estimating a low-rank approximation to multivariate data, and use it to jointly estimate the distribution of multiple species simultaneously. We also derive an analytic estimate of cross-correlations among species from SFA parameters.

As a first example, we show that distributions for 10 bird species in the breeding bird survey in 2012 can be parsimoniously represented using only five spatial factors. As a second case study, we show that forward prediction of catches for 20 rockfishes (Sebastes spp.) off the U.S. West Coast is more accurate using SFA than analysing each species individually. Finally, we show that single-species models give a different picture of cross-correlations than joint estimation using SFA.

Spatial factor analysis complements a growing list of tools for jointly modelling the distribution of multiple species and provides a parsimonious summary of cross-correlation without requiring explicit declaration of habitat variables. We conclude by proposing future research that would model species cross-correlations using dissimilarity of species' traits, and the development of spatial dynamic factor analysis for a low-rank approximation to spatial time-series data.

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x) Mixed effects: a unifying framework for modelling in aquatic ecology

Investigators: J.T. Thorson and C. Minto

Fisheries biology encompasses a tremendous diversity of research questions, methods, and models. Many sub-fields use observational or experimental data to make inference about biological characteristics that are not directly observed (called "latent states"), such as heritability of phenotypic traits, habitat suitability, and population densities to name a few. Latent states will generally cause model residuals to be correlated, violating the assumption of statistical independence made in many statistical modelling approaches. In this exposition, we argue that mixed-effect modelling (i) is an important and generic solution to non-independence caused by latent states; (ii) provides a unifying framework for disparate statistical methods such as time-series, spatial, and individual-based models; and (iii) is increasingly practical to implement and customize for problem-specific models. We proceed by summarizing the distinctions between fixed and random effects, reviewing a generic approach for parameter estimation, and distinguishing general categories of non-linear mixed-effect models. We then provide four worked examples, including state-space, spatial, individual-level variability, and quantitative genetics applications (with working code for each), while providing comparison with conventional fixed-effect implementations. We conclude by summarizing directions for future research in this important framework for modelling and statistical analysis in fisheries biology.

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y) Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes

Investigators: J. Thorson, O. Shelton, E. Ward, and H. Skaug

Indices of abundance are the bedrock for stock assessments or empirical management procedures used to manage fishery catches for fish populations worldwide, and are generally obtained by processing catch-rate data. Recent research suggests that geostatistical models can explain a substantial portion of variability in catch rates via the location of samples (i.e. whether located in high- or low-density habitats), and thus use available catch-rate data more efficiently than conventional "design-based" or stratified estimators. However, the generality of this conclusion is currently unknown because geostatistical models are computationally challenging to simulation-test and have not previously been evaluated using multiple species. We develop a new maximum likelihood estimator for geostatistical index standardization, which uses recent improvements in estimation for Gaussian random fields. We apply the model to data for 28 groundfish species off the U.S. West Coast and compare results to a previous "stratified" index standardization model, which accounts for spatial variation using post-stratification of available data. This demonstrates that the stratified model generates a relative index with 60% larger estimation intervals than the geostatistical model. We also apply both models to simulated data and demonstrate (i) that the geostatistical model has well-calibrated confidence intervals (they include the true value at approximately the nominal rate), (ii) that neither model on average under- or overestimates changes in abundance, and (iii) that the geostatistical model has on average 20% lower estimation errors than a stratified model. We therefore conclude that the geostatistical model uses survey data more efficiently than the stratified model, and therefore provides a more cost-efficient treatment for historical and ongoing fish sampling data.

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z) The potential impact of time-variation in vital rates on fisheries management targets for marine fishes

Investigators: J. Thorson, C. Monnahan, and J. Cope

Fisheries scientists are increasingly concerned about changes in vital rates caused by environmental change and fishing impacts. Demographic parameters representing individual growth, maturity, mortality, and recruitment have previously been documented to change over decadal time scales. However, there has been relatively little comparison regarding which vital rates cause relatively greater or lesser impacts on commonly used fisheries management targets. We therefore use a life table (based on age-structured assessment models) to explore the sensitivity of fishing mortality, spawning biomass, and catch targets to changes in parameters representing growth, mortality, recruitment, and maturation rates for three representative life histories representing long-, medium-, and short-lived species. The elasticity analysis indicates that demographic changes can result in substantial variation in fisheries management targets, but that changes in mortality rates are particularly important for spawning biomass and catch targets while maturity and recruitment compensation are also important for fishing mortality targets. We conclude by discussing the importance of improved data repositories to address covariation among maturity, growth, and mortality parameters.

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aa) The importance of spatial models for estimating the strength of density dependence

Investigators: J. Thorson, H. Skaug, K. Kristensen, E. Ward, O. Shelton, J. Harms, and J. Benante

Identifying the existence and magnitude of density dependence is one of the oldest concerns in ecology. Ecologists have aimed to estimate density dependence in population and community data by fitting a simple autoregressive (Gompertz) model for density dependence to time series of abundance for an entire population. However, it is increasingly recognized that spatial heterogeneity in population densities has implications for population and community dynamics. We therefore adapt the Gompertz model to approximate local densities over continuous space instead of population-wide abundance, and allow productivity to vary spatially using Gaussian random fields. We then show that the conventional (nonspatial) Gompertz model can result in biased estimates of density dependence (e.g., identifying oscillatory dynamics when not present) if densities vary spatially. By contrast, the spatial Gompertz model provides accurate and precise estimates of density dependence for a variety of simulation scenarios and data availabilities. These results are corroborated when comparing spatial and nonspatial models for data from 10 years and ~100 sampling stations for three long-lived rockfishes (*Sebastes* spp.) off the California, USA coast. In this case, the nonspatial model estimates implausible oscillatory dynamics on an annual time scale, while the spatial model estimates strong autocorrelation and is supported by model selection tools. We conclude by discussing the importance of improved data archiving techniques, so that spatial models can be used to reexamine classic questions regarding the existence and magnitude of density dependence in wild populations.

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bb) Spatio-temporal variation in fish condition is not consistently explained by density, temperature, or season for Northeast Pacific groundfishes

Investigator: J. Thorson

Condition (the relationship between individual weight and length) has been researched in fisheries science for over 100 yr and is claimed to be an integrated measure of physiological status for fishes. Spatial or temporal variation in condition can contribute to otherwise unexplained variation in the relationship between spawning biomass and recruitment. Individual condition is also included in age-structured population models, which use weight at age to convert population estimates between numbers and biomass. However, no study has analyzed spatial and temporal variation in condition for multiple marine species. Here I apply recent improvements in spatial modeling to analyze coastwide variation in condition for 28 groundfishes in the California Current. I show that, on average, 22% of individual-level variation in condition can be explained via persistent (constant over time) and annually varying spatial differences in condition, and condition for many species varies 10 to 20% spatially and among years. While population density, bottom temperature, and calendar date are parsimonious descriptors of condition in several species, the sign of these coefficients varies, and their magnitude is small relative to the magnitude of residual spatial and temporal variation. Additionally, annually varying spatial differences have nearly twice the magnitude of persistent spatial differences in condition. I therefore conclude that dynamic habitat conditions contribute a substantial portion of variation in individual condition for these groundfishes. Spatial and temporal variation in condition will be important for population models that convert between numbers, fishery catch, and population biomass, and may also clarify unexplained variability in productivity for marine fishes.

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cc) Giants' shoulders 15 years later: Lessons, challenges, and guidelines in fisheries meta-analysis

Investigators: J.T. Thorson, K. Kleisner, J. Samhouri, E. Ward, A. Shelton, A., and J. Cope

Meta-analysis has been an integral tool for fisheries researchers since the late 1990s. However, there remain few guidelines for the design, implementation or interpretation of meta-analyses in the field of fisheries. Here, we provide the necessary background for readers, authors and reviewers, including a brief history of the use of meta-analysis in fisheries, an overview of common model types and distinctions, and examples of different goals that can be achieved using meta-analysis. We outline the primary challenges in implementing meta-analyses, including difficulties in discriminating between alternative hypotheses that can explain the data with equal plausibility, the importance of validating results using multiple lines of evidence, the trade-off between complexity and sample size and problems associated with the use of model output. For each of these challenges, we also provide suggestions, such as the use of propensity scores for dealing with selection bias and the use of covariates to control for confounding effects. These challenges are then illustrated with examples from diverse subfields of fisheries, including (i) the analysis of the stock–recruit relationship, (ii) fisheries management, rebuilding and population viability, (iii) habitat-specific vital rates, (iv) life-history theory and (v) the evaluation of marine reserves. We conclude with our reasons for believing that meta-analysis will continue to grow in importance for these and many other research goals in fisheries science and argue that standards of practice are therefore essential.

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dd) Probability of stochastic depletion: an easily interpreted diagnostic for stock assessment modelling and fisheries management

Investigators: J. Thorson, O. Jenson, and R. Hilborn

Marine fish populations have high variation in cohort strength, and the production of juveniles (recruitment) may have persistent positive or negative residuals (autocorrelation) after accounting for spawning biomass. Autocorrelated recruitment will occur whenever average recruitment levels change between oceanographic regimes or due to predator release, but may also indicate persistent environmental and biological effects on shorter time-scales. Here, we use estimates of recruitment variability and autocorrelation to simulate the stationary distribution of spawning biomass for 100 real-world stocks when unfished, fished at FMSY, or fished following a harvest control rule where fishing mortality decreases as a function of spawning biomass. Results show that unfished stocks have spawning biomass (SB) below its deterministic equilibrium value (SB0) 58% of the time, and below 0.5SB0 5% of the time on average across all stocks. Similarly, stocks fished at the level producing deterministic maximum sustainable yield (FMSY) are below its deterministic prediction of spawning biomass (SBMSY) 60% of the time and below 0.5SBMSY 8% of the time. These probabilities are greater for stocks with high recruitment variability, positive autocorrelation, and high natural mortality—traits that are particularly associated with clupeids and scombrids. An elevated probability of stochastic depletion, i.e. biomass below the deterministic equilibrium expectation, implies that management actions required when biomass drops below a threshold may be triggered more frequently than expected. Therefore, we conclude by suggesting that fisheries scientists routinely calculate these probabilities during stock assessments as a decision support tool for fisheries managers.

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ee) The determination of data-poor catch limits in the United States: Is there a better way?

Investigators: J. Thorson and J. Berkson

Methods for determining appropriate management actions for data-poor stocks, including annual catch limits (ACLs), have seen an explosion of research interest in the past decade. We perform an inventory of methods for determining ACLs for stocks in the United States, and find that ACLs are assigned to 371 stocks and/or stock complexes with 193 (52%) determined using methods involving catch data only. The proportion of ACLs involving these methods varies widely among fisheries management regions, with all the 67 ACLs in the Caribbean determined using recent catch when compared with 1 of 33 ACLs in the New England region (US Northeast). Given this prevalence of data-poor ACLs, we recommend additional research regarding the potential effectiveness of simple management procedures for data-poor stocks that are currently managed using ACLs. In particular, simple management procedures may allow a broader range of data types and management instruments that better suit the particulars of individual regions and stocks.

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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 pauicispinis*) and vermillion 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. Here, I will present empirical results from the hook-and-line data and results of 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 have high catch rates of vermilion rockfish. 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. These results identify 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.

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b) The Northwest Fisheries Science Center's (NWFSC) wireless back deck and data logging system

Investigators: V. Simon, T. Hay, 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.

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

Investigators: A. Keller, J. Wallace, 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) Refinement and upgrades of the EchoPro software package with inclusion of a geo-statistical technique (kriging) to process and re-process Integrated Acoustic and Trawl Survey (IATS) data for hake biomass estimate from 1998 to 2015

The EchoPro software package developed in FY11 has been updated to increase flexibility and reduce program complexity. The historical Integrated Acoustic and Trawl survey data of Pacific hake from 1998 to 2015 have been processed and re-processed. It reads the Nautical Area Scattering Coefficient exported from EchoView (Myriax) and can provide length-, age-, and sex-structured biomass estimates promptly. Data processing is totally independent of any Oracle database and the processing cycle is much shorter.

With the updated software, the historical and 2015 survey data have been processed using consistent formats of the input files and processing procedures. The results are shown in Figure 13. Geostatistics-based (kriging) biomass analysis is the accepted technique for biomass estimate by the Pacific hake Science Review Group (SRG). The Kriging has been considered suitable for estimating fish abundance and precision by an ICES Study Group. In addition, a sensitivity analysis of the biomass estimate in terms of the extrapolation (Figure 14), stratification scheme, variogram and kriging variables, and the kriging parameters was performed, which indicated that the biomass estimate was robust.

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

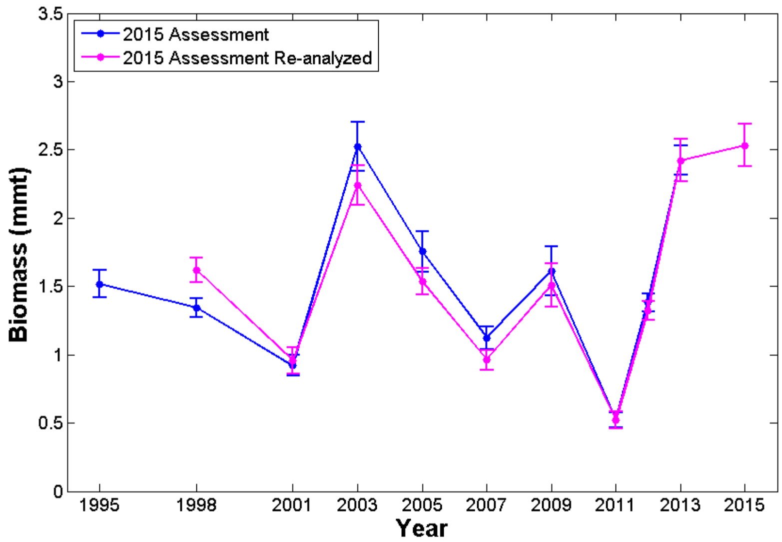

Figure 13. Re-processed estimated biomass of Pacific hake from 1998 to 2015. The 2015 Assessment curve is the old biomass estimate.

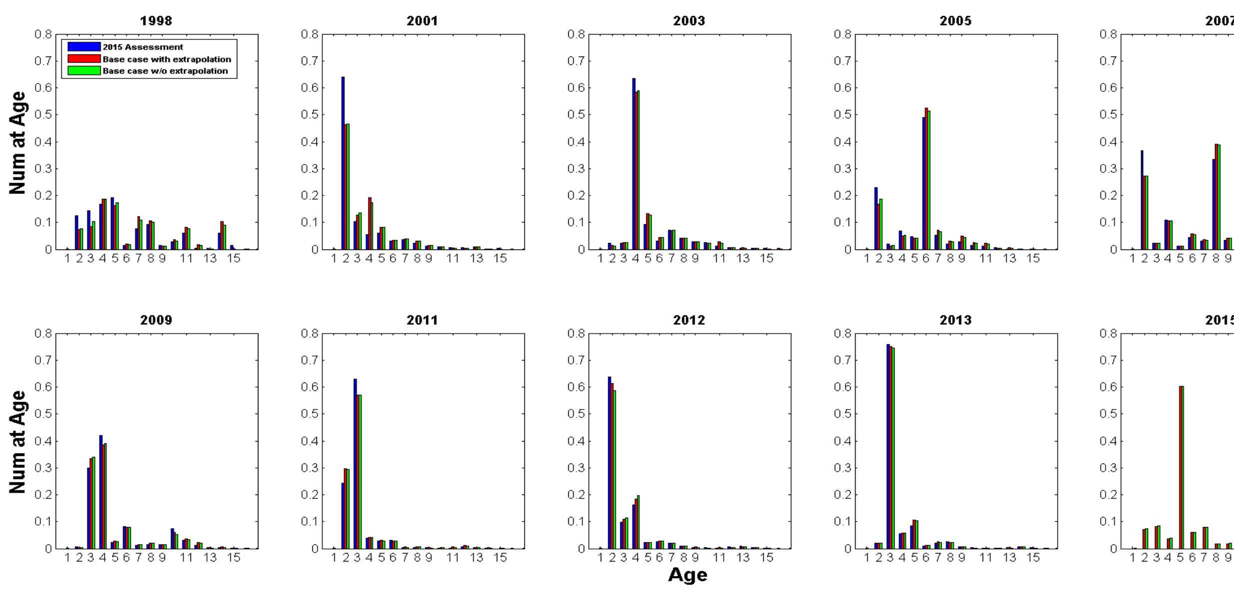

Figure 14. Comparison of age composition of the re-processed estimated biomass of Pacific hake from 1998 to 2015 with different processing method.

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

An age-1 index for Pacific hake is under development, with a preliminary analysis of 2003 to 2015 data concluded February 2016. The results are shown in Figs. 15 and 16. This analysis included an overall index of abundance as well as a spatial component of age-1 echosign. This index of abundance was joined to the 1995–2001 historic AFSC data set of age-1 abundance. Results indicate that the age-1 index was consistent with major recruitment events; however, more years of data and a full spatial analysis are needed. Currently, work is proceeding on converting historical

1995–2001 echogram data, with hopes to get a full spatial component similar to that in spatial years. Also, as the adult hake biomass estimate is currently calculated using kriging methods, but the age-1 index currently is calculated using simple linear interpolation, a goal is for the age-1 index to incorporate kriging as well eventually.

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

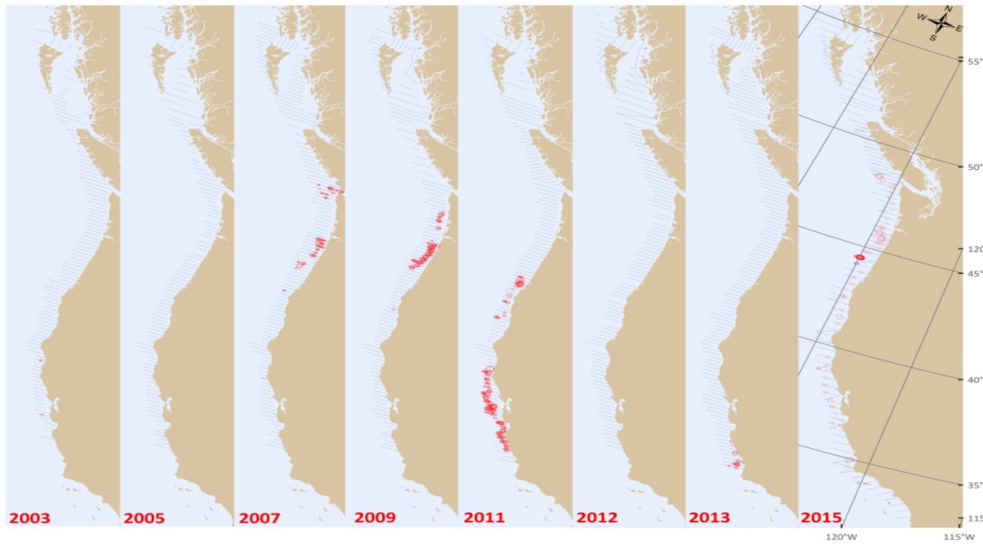

Figure 15. Acoustic backscatter of the Age-1 hake spatial distribution from 2003 to 2015.

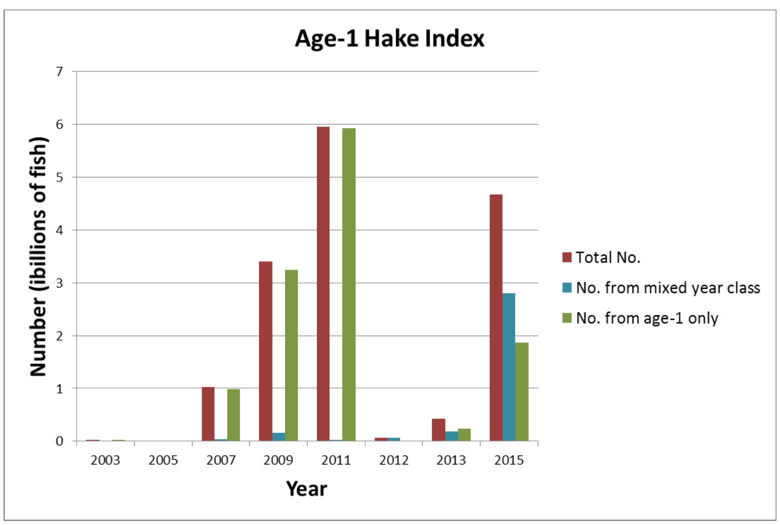

Figure 16. Age-1index of Pacific hake from 2003 to 2015.

f) Laboratory measurements of the acoustic absorption coefficient in seawater

The absorption coefficient of seawater is an important component to the sonar equation underlying fisheries and zooplankton acoustic investigations. The equations currently considered most accurate and widely used for calculating the coefficient are the three decades-old work of Francois and Garrison (1982a, 1982b). However, there is evidence to suggest that these equations are inadequate for the higher frequencies increasingly used today in both fisheries and ecosystem investigations (Fig. 17). To address this, a systematic investigation of sound absorption (up to 500 kHz) will be undertaken by varying temperature, salinity, pressure, and pH within a resonance chamber equipped with interchangeable end caps mounting a 30-500 kHz broadband transducer. By analyzing the decay rate using statistical and computational tools developed in the decades since Francois and Garrison's work, we can develop a new systematic curve for absorption at these higher frequencies.

Francois, R.E., Garrison, G.R. 1982a. Sound absorption based on ocean measurements. Part I: Pure water and magnesium sulphate contributions. J. Acoust. Soc. Am. 72(3): 896- 907.

Francois, R.E., and Garrison, G.R. 1982b. Sound absorption based on ocean measurements. Part II: Boric acid contribution and equation for total absorption. J. Acoust. Soc. Am. 72(3): 1879-1890.

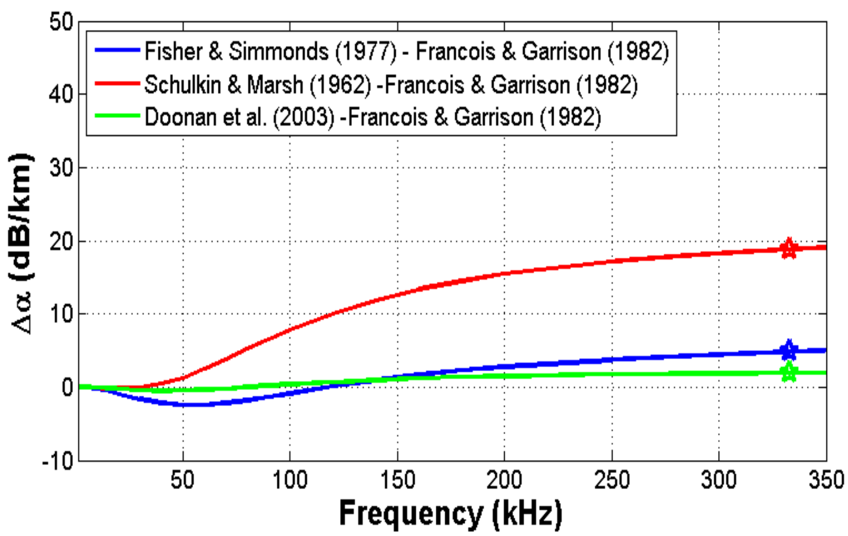

Figure 17. Comparison between various absorption models. Each model's 333 kHz absorption coefficient is indicated by the appropriately colored star (Ona et al., 2012).

During CY 2015, we have constructed the most part of the pressure housing to conduct the absorption coefficient measurements (Fig. 18). The experiments will be conducted with the various parameters given in Table 1.

Table 1. Proposed ranges in insonification frequency, temperature, salinity, pressure ranges, and pH, in evaluating experimental effect on seawater's absorption coefficient.

Frequency (kHz)	Temperature (^{o}C)	Salinity (PSU)	Pressure (psi)	pH
30 – 500	2 – 25	0 – 40	0 –1125 (~760m)	7.5 – 8.4

Numerical simulations of the acoustic absorption in seawater will be performed using a finite element software package COMSOL Multiphysics®. COMSOL Multiphysics® is a finite-element based software package that enables programmers to model and analyze any physics-based system. It can import a variety of 3D CAD data formats including SolidWorks®, generate a 3D mesh automatically, and refine the mesh size and density easily. COMSOL Multiphysics® represents a far more sophisticated analytic approach than was available to Francois and Garrison in the 1970-80's.

The modular nature of the program provides customizable modeling capabilities. The acoustics module enables modeling for thermo-acoustics, vital for accurate simulation of acoustics in geometries with small dimensions such as the pressure vessel we propose to use (Fig. 18). Additionally, the physics interfaces for thermo-acoustics, will allow us to solve coupled equations dealing with thermo-effects of acoustic radiation and scattering.

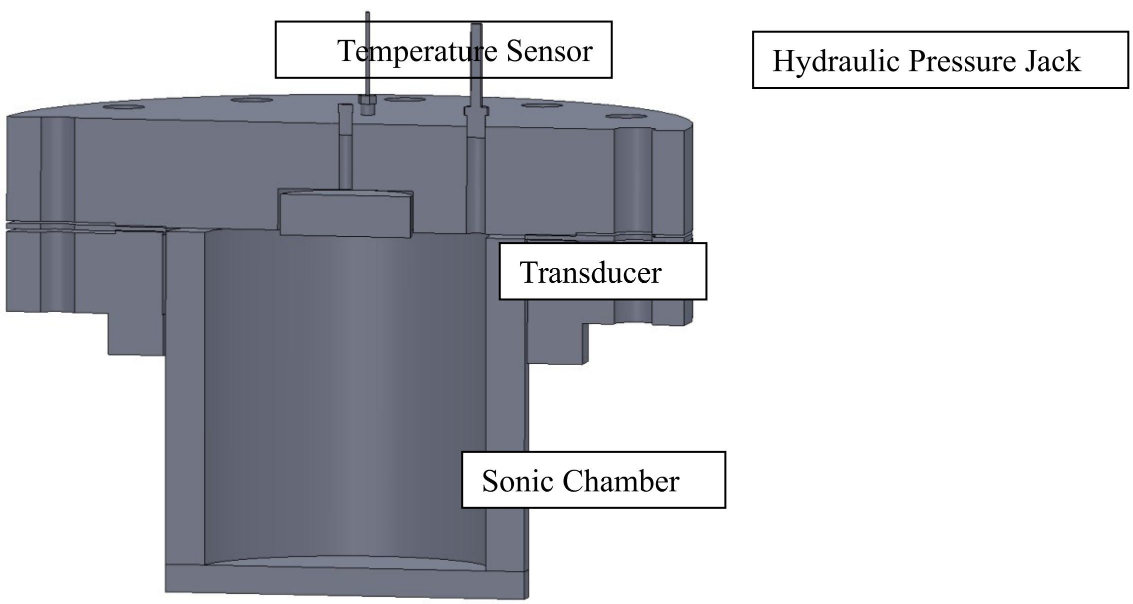

Figure 18. Schematic diagram of the cylindrical pressure vessel.

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

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

The National Marine Fisheries Service, Untrawlable Habitat Strategic Initiative (UHSI) team conducted a pilot multi-tiered field experiments in the Gulf of Mexico during August 2014 and

July 2016. The object of the experiment is to evaluate tools and sampling methods appropriate for estimating the sampling efficiency of imaging systems mounted on stationary-arrays, ROV, AUV, and towed vehicles used to count fish within a measureable sampling path. Three modular underwater sampling systems (MOUSS) that coupled stereo cameras and digital imaging sonars (DIDSON) were deployed along a transect line approximately 60m apart to create a sampling corridor that was constantly observed for between 7-10 hours. Following two hours of deployment of the MOUSS systems the vehicles navigated through the corridor to measure species specific changes to those stimuli. Ongoing analyses are being conducted for the stereo and DIDSON imaging systems, as well as the mobile platforms. For the 2016 field season, the UHSI field program will transition to untrawlable habitats off the U.S. West Coast.

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h) West Coast Observer Program

The FRAM West Coast Groundfish Observer Program (WCGOP) continued collecting fishery-dependent data during 2015 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 2. Number of observers that were deployed by the WCGOP in 2015

2015	
Number of catch share observers	**66**
Number of non-catch share observers	**33**
Number of A-SHOP Observers	**36**

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

DESCRIPTION	SS IFQ Trawl	SS IFQ Fixed Gear	SS Hake	MSCV	A-SHOP
Number of vessels	59	14	5	5	12
Number of trips*	938	74	129	7	74
Number of Sea days*	3,471		340	139	1506
Number of Observers	66				36

*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 2,490 sea days in the non-catch share fisheries in 2015 aboard vessels ranging in size from skiffs to larger fixed gear vessels at depths from < 20 ft. to > 300 ft.

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

Non-catch share coverage by fishery	
FISHERY DESCRIPTION	SEA DAYS*
OR Blue/Black Rockfish Nearshore	126
OR Blue/Black Rockfish	71
OR Pink Shrimp	597
WC Open Access Fixed Gear	103
WA Pink Shrimp	446
Limited Entry Sablefish	464
CA Emley-Platt EFP	3
Electronic Monitoring EFP	93
Limited Entry Zero Tier	123
CA Halibut	120
CA Nearshore	280

CA Pink Shrimp	64

*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

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 2015, CAP aged more than 26,056 otoliths. Ages were produced to support the 2015 assessments on petrale sole, black rockfish, canary rockfish, china rockfish, darkblotched rockfish, widow rockfish, Pacific hake and sablefish. Widow rockfish age reading was taken over from the SWFSC in 2014. China and black rockfish were species that previously had never been aged by CAP before. The lab also provided 346 vermilion rockfish ages from the Hook and Line Survey. Throughout 2015, 6.703 hake otoliths were aged for use in the 2016 joint hake assessment with Canada. CAP also completed over 650 training age reads during the year. CAP continued the practice of recording otolith weights prior to breaking and burning, in support of research into alternative methods of age determination. The lab also acquired a Micromill for coring otoliths with the intent to conduct age validation studies. Considerable time was spent learning the new operating system and developing SOP's for sample preparation and lab hygiene. Resources were also allocated to acquiring the skills and equipment for lingcod fin ray preparation which includes pinning, drying, gluing, sectioning and mounting.

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.S. Hamel, P. McDonald, J. Field, 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.

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

c) 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, 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 also 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 which 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

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

Investigator: M.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

e) A state-space approach for measuring growth variation and application to North Pacific groundfish CJFAS. In Review.

Christine C. Stawitz, T.E. Essington, T.A. Branch, M.A. Haltuch, A.B. Hollowed, P.D. Spencer

Understanding demographic variation in recruitment and somatic growth is key to improving our understanding of population dynamics and forecasting ability. Although recruitment variability has been extensively studied, somatic growth variation has received less attention, in part because of difficulties in modeling growth from individual size-at-age estimates. Here we develop a Bayesian state-space approach to test for the prevalence of alternative forms of growth rate variability (e.g. annual, cohort-level, or during early life-history) in size-at-age data. We apply this technique to twenty-nine Pacific groundfish species across the California Current, Gulf of Alaska, and Bering Sea/Aleutian Islands marine ecosystems. A significant proportion of stocks (15/37) exhibited substantial growth variability. Most commonly (18/37 stocks), growth trends fluctuated annually across ages in single year, suggesting that either there are shared environmental features that dictate growth across multiple ages, or some temporally-fluctuating observation error remains in the estimate of growth process. This method represents a novel way to use size-at-age patterns from fishery-dependent or -independent data to test hypotheses about growth dynamics while allowing for annual variation and measurement error.

For more information contact Christine C. Stawitz: cstawitz@uw.edu

B. Ecosystem Research

1. Habitat

a) Fine-scale benthic habitat classification as part of the NWFSC Southern California Shelf Rockfish Hook and Line Survey

Investigators: A. Chappell, C.E. Whitmire, J.H. Harms, J.A. 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 gear to provide management information for multiple demersal rockfishes (*Sebastes* spp.). The survey, initiated in 2004, traditionally samples 121 fixed stations annually from Pt. Arguello (34.6^{o} N) to the Mexican border (32.1^{o} N) at depths of 37 – 229 m. To complement 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 the 2015 survey, we have analyzed nearly 10,000 benthic habitat observations collected during 90 dives at 78 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 the areas of our camera-sled tows, we found significantly different habitat classification values, especially for hard habitats. 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 substrate maps into the development of abundance indices or other metrics for groundfish stock assessments may misrepresent the total available hard-bottomed habitats available to many species that use them, resulting in biased estimates. Additionally, users of EFH substrate data on small-scale projects should be aware of the associated limitations.

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

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

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

Some cold-water corals and sponges occur in such dense aggregations that they provide structurally complex habitats which support a diverse assemblage of associated invertebrates and fish. In many cases, marine fishes have been linked to the presence of epibenthic invertebrates, although the specific nature of this relationship is often unknown. The Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl Survey has collected approximately 250 coral specimens per year since 2006, and has identified, on average, 200 sites (of 750) per year where sponges are present. For this study we investigated the relationship between these two groups of epibenthic invertebrates and their associations with demersal fish using trawl survey data from 2003-2013, when the survey covered continental shelf and slope waters from Cape Flattery, Wash., to the Mexican border. Regression models were used to correlate fish biomass and species richness with coral and sponge densities. Fish biomass was correlated with sponge density, but the relationship was not precise ($P<0.0001$, $R^2=0.043$). No other significant correlations were uncovered among these variables. Multivariate analyses were used to assess fish community structure in relation to coral and sponge densities, and to environmental parameters including depth, latitude and bottom temperature. There were strong correlations between species composition and both depth and bottom temperature, but no strong correlations with coral or sponge densities. Indicator species analysis was done to determine species that were associated with four levels of sponge and coral densities (high, medium, low and zero). Shortspine thornyhead, rosethorn rockfish and greenspotted rockfish were associated with high sponge catches, while flatfishes were typically associated with the absence of sponges. Shortspine thornyhead, Dover sole, longspine thornyhead, aurora rockfish and darkblotched rockfish were associated with high coral catches, and rex sole, English sole, and greenstriped rockfish with the absence of corals. These results provide information about broad-scale associations between corals, sponges and demersal fish that may be useful for developing studies that are specifically focused on the function of corals and sponges as habitats for fish, and the role they may play in their life-histories.

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

c) Can we increase our confidence about the locations of biodiversity 'hotspots' by using multiple diversity indices?

Investigators: N. Tolimieri, A. O. Shelton, B. E. Feist, AND V. Simon

Some have suggested that targeting conservation efforts on biodiversity hotspots—areas of exceptionally high diversity—is the most efficient way to use limited resources to protect the most or rarest species. Moreover, the preservation of biodiversity is a focus for resource management and conservation because of the links between biodiversity and ecosystem function. However, there are many ways to define biodiversity and a plethora of diversity indices. Do these indices agree on where biodiversity hotspots are, and by extension, where conservation should take place? Here we use a habitat modeling approach to map spatial and temporal patterns in five community metrics of the demersal fish community in the California Current Large Marine Ecosystem: species density, species evenness, taxonomic distinctness, functional divergence and total biomass. Depth, bottom temperature, sediment grain size, and distance to hard substratum were included as covariates in the model. All indices showed strong spatial patterns and relationships with depth. Spatial patterns for functional divergence and total biomass varied among years, but other indices did not show temporal variation. We identified hotspots as cells where at least one index was in the top 5% or 10% of its range. There was minimal spatial overlap among 10% hotspots for the five indices. Over 40% of the study area was classified as a biodiversity hotspot by at least one metric. However, no area was identified as a hotspot by all five metrics, and only slightly more than one percent of the coast was identified as within a hotspot for three or more metrics. Since different indices represent various aspects of diversity, our results caution against the uninformed use of these indices in the identification of biodiversity hotspots. Instead, we must define our objectives and then choose the relevant metrics for the problem.

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

d) Genotyping-by-sequencing reveals lack of structure in the 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 provide important habitat in the deep ocean and have been recognized as regional hotspots for biodiversity. Despite their ecological importance, little is known about the connectivity and life history of deep-sea octocoral populations. An understanding of the population structure of deep-sea corals is critical to ascertaining the effects of habitat loss and genetic connections between distant populations. Next generation sequencing, including restriction site-associated DNA sequencing, has allowed the discovery and application of thousands of novel SNP markers in non-model species, including marine invertebrates. In this study we utilized high-throughput RAD-tag sequencing to develop the first molecular resource for the deep-sea octocoral *Swiftia simplex* (Nutting 1909). Using this technique, we discovered thousands of putative genome-wide SNPs from twenty-three *S. simplex* individuals collected from along the U.S. West Coast. After quality control, we successfully assayed up to 1,145 SNPs across all individuals, and analyzed the resulting multi-locus genotypes to assess putative population structure across the region. Across all areas, no geographic genetic structure was detected for this species, suggesting a high degree of connectivity and potential panmixia along the U.S. West Coast.

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

e) Distribution of demersal fishes in relation to near-bottom oxygen levels within the California Current ecosystem

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

The Northwest Fisheries Science Center conducts an annual groundfish bottom trawl survey in cooperation with the fishing industry within the California Current Large Marine Ecosystem along the U.S. West Coast upper continental slope and shelf. The survey occurs from May to October and targets commercial groundfish resources inhabiting depths of 55-1280 m from U.S.-Canada to

U.S.-Mexico. In response to hypoxia observed on the continental shelf of the Pacific Northwest, environmental sensing packages (e.g., depth, temperature, salinity, dissolved oxygen, chlorophyll fluorescence, turbidity, and light) were added to trawls in 2008. Near-bottom dissolved oxygen (DO) concentration was monitored along tow tracks in conjunction with fishery sampling from 2008 to the present. Temporal and spatial variations in near-bottom DO and catch are explored to evaluate the severity and extent of hypoxia in recent years. DO ranged from 0.02 to 5.5 mL L^{-1} with 64% of the 3394 stations experiencing hypoxic conditions. Catch and species richness exhibited significant and positive relationships with near-bottom oxygen concentration. Based on general additive models (GAMs) sensitivity to changes in near-bottom oxygen varied among 33 demersal fish species.

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

2. Ecosystems

a) 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 Drs. Kristin Marshall or Isaac Kaplan at Kristin.Marshall@noaa.gov, Isaac.Kaplan@noaa.gov

b) Integrated Ecosystem Assessment of the California Current

Investigators: C.J. Harvey, N. Garfield, E.L. Hazen and G.D. Williams, eds.; numerous contributors from the NWFSC, SWFSC and partner institutions

An integrated ecosystem assessment (IEA) is a science support element for ecosystem-based management (EBM); the IEA process involves synthesizing and analyzing information through steps that include scoping, indicator development, risk analysis, and evaluating management strategies. The primary goal of the California Current IEA is to inform the implementation of EBM by melding diverse ecosystem components into a single, dynamic fabric that allows for coordinated evaluations of the status of the California Current ecosystem. We also aim to involve and inform a wide variety of stakeholders and agencies that rely on science support for EBM, and to integrate information collected by NOAA and other federal agencies, states, non-governmental organizations, and academic institutions. The essence of IEAs is to inform the management of diverse, potentially conflicting ocean-use sectors. As such, a successful California Current IEA must encompass a variety of management objectives, consider a wide-range of natural drivers and human activities, and forecast the delivery of ecosystem goods and services under a multiplicity of scenarios. This massive undertaking will evolve over time.

We are entering 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.

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

c) California Current IEA Phase III Report: Ecological Integrity

Investigators: G.D. Williams, K.S. Andrews, J.F. Samhouri, N. Tolimieri, C. Barcelo, R.D. Brodeur, J. Field, B. Peterson, and A. Thompson.

Ecological integrity is "the ability of an ecological system to support and maintain a community of organisms that has a species composition, diversity, and functional organization comparable to those of natural habitats within a region" (Parrish et al. 2003). We identified and evaluated potential indicators of ecological integrity across a variety of species and foraging guilds, using the ecological literature as a basis for their rankings. We selected the mostly highly ranked indicators to track two aspects of the California Current Large Marine Ecosystem (CCLME):

- Trophic structure: mean trophic level, scavenger biomass ratio, biomass of gelatinous zooplankton, and the northern copepod biomass anomaly

- Biodiversity: Simpson's diversity, species richness or species number for multiple taxa.

The indicators reported in this section are designed to be integrative, community-based measures that draw information from across the taxonomic spectrum. Indicators derive from monitoring time series through recent years (2011-2013, depending on the time series). Indicators specific to individual ecological components, such as coastal pelagic species, groundfishes, and protected species (marine mammals, seabirds, and Pacific salmon), also provide information that can influence ecological integrity and are covered in other sections in this report.

The spatial extent of CCLME data coverage varies among taxa. The groundfish data span the U.S. West Coast (~32 to 48°N, ~55-1280 m depths) and conclusions related to this dataset (mean trophic level, scavenger biomass, species richness, species density, and Simpson diversity) are applicable to the full CCLME. Note, however, that the trawl survey does not adequately sample complex, rocky habitats and any conclusions are limited to trawlable areas. Data for ichthyoplankton (including groundfish) are drawn from southern California and Oregon survey transect lines, while those for gelatinous zooplankton are taken from surveys conducted off central California and the Oregon/Washington coasts. Data for pelagic fishes (including pelagic stages of groundfish) are also drawn from the Oregon/Washington survey, whereas the copepod data are limited to survey stations in waters off of central Oregon. Thresholds and targets are not currently set for indicators of ecological integrity, and time series are evaluated based on internal statistical properties.

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d) The legacy of a crowded ocean: indicators, status, and trends of anthropogenic pressures in the California Current ecosystem

Investigators: Andrews, K. S., G. D. Williams, J. F. Samhouri, K. N. Marshall, V. V. Gertseva, P. S. Levin.

As human population size and demand for seafood and other marine resources increase, understanding the influence of human activities in the ocean and on land becomes increasingly critical to the management and conservation of marine resources. In order to account for human influence on marine ecosystems while making management decisions, linkages between various anthropogenic pressures and ecosystem components need to be determined. Those linkages cannot be drawn until it is known how different pressures have been changing over time. This paper identifies indicators and develops time series for 22 anthropogenic pressures acting on the USA's portion of the California Current ecosystem. Time series suggest that seven pressures have decreased and two have increased over the short term, while five pressures were above and two pressures were below long-term means. Cumulative indices of anthropogenic pressures suggest a slight decrease in pressures in the 2000s compared to the preceding few decades. Dynamic factor analysis revealed four common trends that sufficiently explained the temporal variation found among all anthropogenic pressures. This reduced set of time series will be a useful tool to determine whether links exist between individual or multiple pressures and various ecosystem components.

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

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

This is a collaborative project between the Northwest Fisheries Science Center (NWFSC) and University of Washington funded by the NOAA Fisheries and the Environment (FATE) Program. Biological characteristics of managed fishes are likely to vary with time due to environmental variability. Growth of splitnose and yelloweye rockfishes has been previously found to be highly correlated with several productivity indicators in the California Current Ecosystem, and time-series of climate-growth indices have been developed for these two species, using otolith band reading techniques. These indices, however, have not been used to inform stock assessments, due to a lack of guidance for when and how to incorporate indices of time-varying individual growth into an assessment model. This project uses a generic decision table approach to evaluate the effects of incorporating climate-driven time-varying growth into stock assessment models. Values in the decision table represent management outcomes (i.e. lost yield and the probability of overfishing) and are generated using simulation modeling, while existing data for splitnose and yelloweye rockfishes used to estimate the prior probability of time-varying growth. This simulation-based decision table approach provides guidance on whether and how to include the environmental indices in future splitnose and yelloweye rockfish assessments. It could also be used generically to help evaluate the utility of including environmental data in stock assessment models.

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

f) Developing ecological indicators for Washington State's Marine Spatial Planning Process

Investigators: K.S. Andrews, J.M. Coyle, C.J. Harvey, and P.S. Levin

In March 2010, the Washington State legislature enacted a new state law on marine spatial planning (MSP; Substitute Senate Bill 6350). One of the primary objectives of this law was to develop a comprehensive marine management plan for the state's marine waters. The law stipulated that the "plan must include an ecosystem assessment that analyzes the health and status of Washington marine waters including key social, economic, and ecological characteristics. This assessment should seek to identify key threats to plan goals, analyze risk and management scenarios, and develop key ecosystem indicators." In support of Washington State's MSP process, we are developing conceptual models and corresponding ecosystem indicators that describe the important ecological components, oceanographic drivers, and human pressures in Washington State waters. The conceptual models serve as the basic frameworks for the development of ecosystem indicators and assessing the status and trends of key components of the ecosystem in Washington marine waters. We are focusing on non-human ecological components, oceanographic drivers and human pressures in major types of habitat found along and off the coast: coastal estuaries, rocky intertidal shores, sandy beaches, kelp forests, seafloor, and the pelagic zone. Key components of each habitat (e.g., focal species, oceanographic drivers, and human pressures) were linked within each conceptual model based on reviews of the literature and expert opinions of how the ecological systems worked. We then used an evaluation framework to select and evaluate potential indicators that could be tracked for each of the key components of each habitat's conceptual model. Future research will focus on integrating social, economic and cultural characteristics into the conceptual models.

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

g) Learning to review end-to-end marine ecosystem models for management applications

Investigators: I.C. Kaplan and K.N. Marshall

In recent years, the shift toward ecosystem-based management of marine resources has led to the development of new analytical tools that simultaneously consider multiple human impacts and multiple species. End-to-end marine models are one type of modelling tool that simulates full ecosystems from oceanography to food webs and fisheries. End-to-end models differ from single species models in some key aspects (e.g., external parameter estimation, long run times, complex and uncertain mathematics to describe ecological interactions) that ultimately lead to different criteria for model review and application. We draw on recent experience with an end-to-end model of the California Current Ecosystem to address how, despite these challenging properties, end-to-end models can nonetheless be subject to rigorous external peer review.

For more information, please contact Dr. Isaac Kaplan Isaac.Kaplan@noaa.gov.

C. Bycatch Reduction Research

Recent Conservation Engineering Work in US West Coast Groundfish Fisheries

Beginning in 2004, the NOAA Fisheries Northwest Fisheries Science Center (NWFSC) initiated a fisheries conservation engineering program within its Fisheries Resource Analysis and Monitoring Division. Through key regional collaborations with the Pacific States Marine Fisheries Commission, Oregon Department of Fish and Wildlife, Alaska Fisheries Science Center, and the fishing industry, the NWFSC has been able to pursue a wide-ranging array of conservation engineering projects relevant to reducing bycatch 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. 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.

1. Evaluation of a Sorting Grid Bycatch Reduction Device for the Selective Flatfish Bottom Trawl in the U.S. West Coast Fishery

The U.S. West Coast limited entry groundfish trawl fishery is managed under an individual fishing quota program. For many fishermen targeting flatfishes in this fishery, catches of rockfishes

(*Sebastes* spp.), sablefish (*Anoplopoma fimbria*), and Pacific halibut (*Hippoglossus stenolepis*) can be a concern because quota is limited relative to flatfish quotas. Thus, approaches to minimize bycatch of limiting species are important to the economic viability of the fishery. In this study, we examined the size-selection characteristics of a flexible sorting grid bycatch reduction device (designed to retain flatfishes while reducing catches of rockfishes, sablefish, and Pacific halibut) using a recapture net. The mean codend retention of target flatfishes (five species evaluated) ranged from 68.1% to 92.3%. Combined, the mean flatfish retention was 85.6%. Codend catches of shelf rockfishes, slope rockfishes, sablefish, and Pacific halibut were reduced by 80.3%, 64.0%, 97.0%, and 90.3% by weight, respectively. Significant differences in selectivity parameters between flatfishes, rockfishes, sablefish, and Pacific halibut were observed. Over fishing grounds where fishermen need a more selective trawl to harvest flatfishes, the experimental gear tested could provide fishermen a technique to reduce catches of non-target species.
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

2. 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.

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

3. Tests of artificial light for bycatch reduction in an ocean shrimp (*Pandalus jordani*) trawl: Strong but opposite effects at the footrope and near the bycatch reduction device

This Study investigated how the addition of artificial light in the vicinity of the rigid-grate bycatch reductiondevice (BRD) and along the fishing line of an ocean shrimp (Pandalus jordani) trawl altered fish bycatch andocean shrimp catch. In separate trials using double-rigged shrimp nets, with one net incorporating artifi-cial lights and the other serving as a control, we 1) attached one to four Lindgren-Pitman Electralume®LEDlights (colors green or blue) in locations around the rigid-grate BRD, and 2) attached 10 green lights alongthe trawl fishing line. Both experiments were conducted with rigid-grate BRDs with 19.1 mm bar spacinginstalled in each net. Contrary to expectations, in 12 paired hauls the addition of artificial light aroundthe rigid-grate increased the bycatch of eulachon (Thaleichthys pacificus), a threatened anadromous smeltspecies, by 104% (all by weight, $P = 0.0005$) and slender sole (Lyopsetta exilis) by 77% ($P = 0.0082$), withno effect on ocean shrimp catch or bycatch of other fishes ($P > 0.05$). In 42 paired hauls, the addition of10 LED lights along the fishing line dramatically reduced the bycatch of a wide variety of fishes with noeffect on ocean shrimp catch ($P > 0.05$). Bycatch of eulachon was reduced by 91% ($P = 0.0001$). Bycatch ofslender sole and other small flatfishes were each reduced by 69% ($P < 0.0005$). Bycatch of darkblotchedrockfish (Sebastes crameri), a commercially important but depressed rockfish species, was reduced by 82%($P = 0.0001$) while the bycatch of other juvenile rockfish (Sebastes spp.) was reduced by 56% ($P = 0.0001$).How the addition of artificial light is causing these changes in fish behavior and bycatch reduction is notknown. However, in both experiments the addition of artificial light appears to have greatly increasedthe passage of fishes through restricted spaces (between BRD bars and the open space between trawlfishing line and groundline) that they typically would not pass through as readily under normal seafloorambient light conditions.

For more information, contact Bob Hannah at bob.w.hannah@state.or.us or 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

4. Reducing the Bycatch of Overfished and Rebuilding Rockfish Species in the U.S. Pacific Hake Fishery

This study examined a flexible sorting grid excluder designed to reduce rockfish (*Sebastes* spp.) bycatch in the U.S. Pacific hake (*Merluccius productus*) fishery. Tests occurred off Oregon during 2013 aboard a commercial trawler. A recapture net was used to quantify the retention of Pacific hake and rockfish bycatch. During this study, widow rockfish (*S. entomelas*) was the primary rockfish species caught. Their bycatch was reduced 26.2% by weight. The retention of Pacific hake was 92.7% by weight. Widow rockfish caught in the recapture net were statistically larger than widow rockfish retained in the trawl. Mean lengths of Pacific hake caught between the trawl and recapture net did not differ significantly. Estimated single haul catches of Pacific hake ranged from 40 to 100 mt. Catches producing over 90 mt of Pacific hake in haul durations less than 2.5 hours were made. However, under heavier fish volumes (over 90 mt of Pacific hake caught in less than 45 minutes of towing) the excluder tended to clog. While further refinement of the excluder is needed for the gear to function under heavy volumes of fish, this project has developed a bycatch reduction device that can assist Pacific hake fishermen in reducing rockfish bycatch when fishing conditions are moderate to high.

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

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