Northwest Fisheries Science Center

National Marine Fisheries Service

NOAA Fisheries

Agency Report to the Technical Subcommittee

of the Canada-U.S. Groundfish Committee

April 2019

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 2018, 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 Acting Division Director, Dr. Jim Hastie at Jim.Hastie@noaa.gov, (206) 860 – 3412.

Other Divisions at the NWFSC are:

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

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

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

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

II. Surveys

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

The NWFSC conducted its twenty-first annual bottom trawl resource survey for groundfish off the coasts of Washington, Oregon, and California. The objective of the 2018 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 2018, we continued to utilize an updated backdeck data collection system with improved software applications, and wireless networking. Programming used to gather data for the groundfish survey was rewritten so that the various components were fully integrated, updated to include multiple sensor streams, and enhanced to increase flexibility for data input from special projects and future undefined data sources. The changes in the back-deck programming, wheel house programming and data QA/QC process resulted in overall improvements to data collection efficiency and anticipated future decreases in time requirements for data to be made available to the Data Warehouse. Established NOAA national bottom trawl protocols were used throughout the survey. As in prior years, a series of special research projects were undertaken in cooperation with other NOAA groups and various Universities.

Additional data were collected during the trawl survey for collaborative research projects with several NMFS/academic colleagues:

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

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

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

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

4) Collect all specimens of sharpnose sculpin (*Clinocottus acuticeps*) for species confirmation – Dan Kamikawa

5) Request for photographs of lamprey scars and specimens for Pacific lamprey (*Lampetra tridentata)* and river lamprey (*Lampetra ayresii* – Laurie Weitkamp, NWFSC, Conservation Division, Newport;

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

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

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

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

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

11) Collection of all unusual or unidentifiable sharks including small sleeper sharks, *Somniosus pacificus* and velvet dog shark (*Zameus squamulosus*) – Moss Landing Marine Laboratories;

12) Collection of any chimaera that is not a spotted ratfish (*Hydrolagus colliei*), including: *Harriotta raleighana*, *Hydrolagus* spp. and *Hydrolagus trolli* – Moss Landing Marine Laboratories;

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

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

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

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

17) Pacific flatnose – Collect up to 30 fin clips per leg for DNA analysis, 25 random scale samples and 25 random fish – Alexei M. Orlov.

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

1) Use of stable isotopes and feeding habits to examine the feeding ecology of rockfish (genus *Sebastes*) and other species;

2) Fin clip collection for various shelf rockfish species;

3) Collection of stomachs for various rockfish species (darkblotched rockfish, canary rockfish, blackgill rockfish, blackspotted/rougheye rockfish, yelloweye rockfish, and cowcod;

4) Collection and identification of cold water corals;

5) Fish distribution in relation to near-bottom dissolved oxygen concentration;

6) Composition and abundance of benthic marine debris collected during the 2018 West Coast Groundfish Trawl Survey;

8) Collection of ovaries and finclips from bank rockfis, brown rockfish, copper rockfish, lingcod, shortspine thornyhead, Pacific hake, cowcod, vermilion/sunset rockfish, and Pacific cod, Dover sole, sablefish, yelloweye rockfish,

9) Collection of ovaries from cowcod and yelloweye rockfish species, thornyheads and other species to assess maturity;

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

11) Collection of stomachs for non-rockfish species (arrowtooth flounder, Pacific sanddab, petrale sole, sablefish, and lingcod;

12) Collection of voucher specimens for teaching purpose;

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

14) macroscopic analysis of maturity of big skate and longnose skate.

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

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

In early Fall 2018, FRAM personnel conducted the 15th hook and line survey for shelf rockfish in the Southern California Bight (SCB). This project is a cooperative effort with Pacific States Marine Fisheries Commission (PSMFC) and the southern California sportfishing industry aimed at developing an annual index of relative abundance and time series of other biological information for structure-associated species of groundfish including bocaccio (*Sebastes paucispinis*), bank rockfish (*S. rufus*), copper rockfish (*S. caurinus*), greenspotted rockfish (*S. chlorostictus*), cowcod (*S. levis*) blue rockfish (*S. mystinus*), speckled rockfish (*S. ovalis*), the vermilion rockfish complex (e.g., *S. miniatus* and *S. crocotulus*) and lingcod (*Ophiodon elongatus*) within the SCB.

The F/V Aggressor (Newport Beach, CA), F/V Mirage (Port Hueneme, CA), and F/V Toronado (Long Beach, CA) were each chartered for 14 days of at-sea research, with 14 biologists participating during the course of the survey. The three vessels sampled a total of 201 sites ranging from Point Arguello in the north to the US-Mexico EEZ boundary in the south. For the first nine field seasons, sampling was conducted aboard two chartered vessels, however a third vessel was added to the survey in 2013 in response to internal and external peer reviews recommending additional research into the role the vessel platform plays in abundance modeling. In response to research needs identified by the PFMC and stock assessment scientists, the survey began adding sites within the Cowcod Conservation Areas (CCAs). During the period 2014-16, the survey added 79 sites within the CCAs bringing the total number of sites in the sampling frame to 201. It is anticipated that monitoring at these sites will continue during subsequent surveys.

Some experimental resampling (7 sites)

47 species

8480 lengths

5280 oties

7100 finclips

279 Tagged fish

483 ovary specimens from 11 species

Including supplementary experimental sampling at 7 sites, the survey encountered 8,567 individual fish representing 47 species. Data collected included 8,480 sexed lengths and weights, 5,280 otolith pairs, 7,100 finclips. Approximately 483 ovaries were collected from 11 different species to support the development of maturity curves and fecundity analysis. Several dozen individual fish were retained for use in species identification training for west coast groundfish observers and for a genetic voucher program conducted by the University of Washington. For the third consecutive year, the survey encountered whitespeckled rockfish (S. moseri) - a species rarely captured with fishing gear. There are fewer than 12 documented captures of S. moseri, and several of the individuals caught on the hook and line survey were submitted to the University of Washington's Burke Museum. The survey captured two specimens not encountered on previous surveys: a Pacific round herring (Etrumeus acuminatus) and a Pelagic stingray (Pteroplatytrygon violacea). In most years, researchers also deploy an underwater video sled to capture visual observations for habitat analysis, species composition, and fish behavior studies, however the video sled was not available for this year's survey. The survey continued to descend or release and tag all individuals captured at 6 sites located inside federal marine reserves. To date, just under 900 individuals have been tagged. 2018 was the third year following implementation of the HookLogger wireless electronic data collection system on board survey vessels. This system networks two mobile tablet workstations on the back deck with a desktop computer inside the galley with each machine writing to a common database using customized UI and networking software. HookLogger has eliminated the need for post-survey manual data entry and has improved data quality by integrating real-time validations and other error checking.

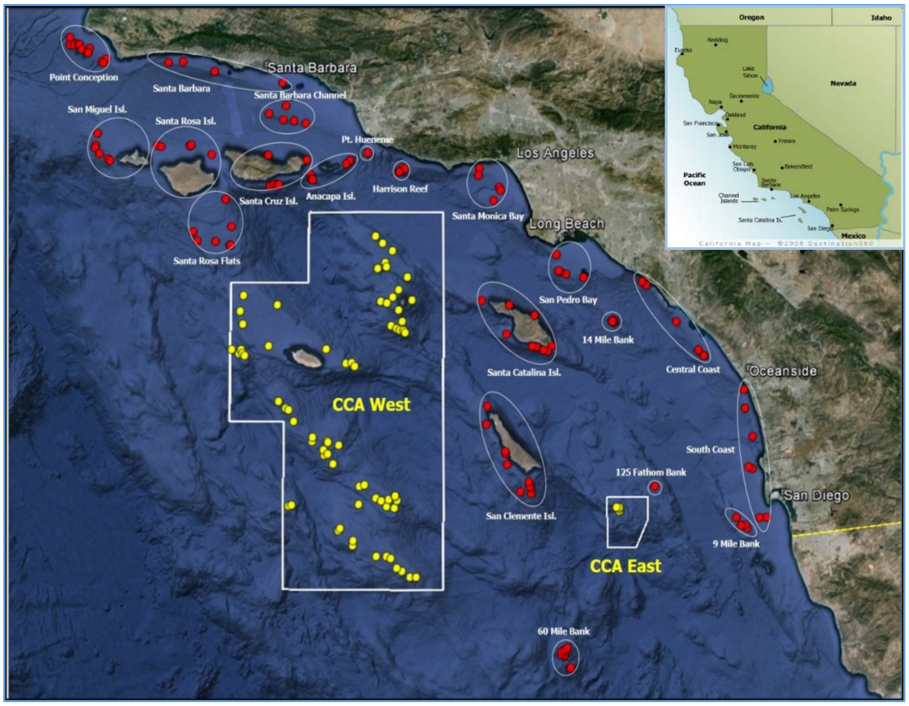

Figure 1. Sampling locations for the 2018 Hook and Line Survey located inside (yellow dots) and outside (red dots) the Cowcod Conservation Areas (CCAs).

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

C. 2018 California Current Ecosystem (CCE18): Investigations of hake ecology, survey methods, and the California Current ecosystem

The summer 2018 research cruise (CCE18) was conducted in U.S. and Canadian waters by scientists from the Northwest Fisheries Science Center, FRAM Division on the NOAA Ship *Bell M. Shimada* from 19 August 2018 to 14 September 2018. The operating area was from roughly 42.5°N (Cape Blanco, Oregon) to 48.6°N (southern Vancouver Island, British Columbia). The *Shimada* headed north from Newport, Oregon along Oregon and Washington to Vancouver Island on Leg 1; on Leg 2, the *Shimada* wert south from Seattle along the Washington and Oregon coasts. Acoustic transects were oriented east-west and were run during daylight hours only. Scouting for hake off acoustic transects was also conducted. Acoustic data were collected day and night with Simrad EK60 narrowband and EK80 broadband scientific echosounders operating at frequencies of 18, 38, 70, 120, and 200 kHz. The *Shimada* conducted 22 successful midwater trawls targeting hake, resulting in a combined total hake catch of 3,776 kg. Hake accounted for 21% of the total catch; widow rockfish accounted for 62%. Of the 22 trawls, six paired trawls compared codend liners of different mesh sizes (32 mm vs. 7 mm). Initial results show no significant difference between nets with regards to opening height and scope. Hake length frequencies displayed no obviously big or small cutoff. For catch composition, key fish and invertebrates were present in both nets; no pattern was observed in species proportions. Data for comparisons of the EK60 with the EK80 were collected in a wide variety of settings and conditions. In general, the comparison looked reasonable.

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

D. Trig-cam Pilot Study

Investigators: Victor Simon, Peter Frey, John Harms and Aimee Keller

The Northwest Fishery Science Center's Fishery Research Survey team conducted a 2-day pilot study (July 22-23, 2018) using a stationary camera system, developed by the Alaska Fishery Science Center, to test its suitability for surveying rockfish abundance in untrawlable habitats along the U.S. west coast. The study involved 2 vessel days aboard the chartered west coast fishing vessel the F/ V Excalibur, following completion of the first half of our annual trawl survey in July 2018. A total of 79 camera drops occurred using six camera units equipped with environmental sensors, at depths of 48 to 146 m on or near Stonewall Bank off the Oregon coast (Figure 2). A total of 40 to 200 photographs were taken per site with yellowtail, yelloweye, canary, greenstriped, and other rockfishes the dominant species observed. Additionally, some flatfishes were present and some sites had no fish photographed. We determined that chartered commercial boats with extensive crabbing experience make excellent platforms for efficient deployment and retrieval of these systems and that the effort requires the same number of scientist and vessel crew as standard trawl survey operations (3 scientists, 1 captain, and 3 deckhands) to maintain operational efficiency over time. Scientists needed time during deployments to optimize the camera system by adjusting sinker weight, height off seafloor, camera angle and light in response to changing environmental conditions such as cloud cover, water clarity, and currents. Following deployment cameras remained in place for 10 to 50 minutes with many images of fish captured (canary, yelloweye, yellowtail, greenstriped and other rockfishes as well as some flatfish) but other images with no fish present. A wireless approach for downloading images proved effective; however, network and onboard hardware should be improved to increase downloading speed. The system could be readily adapted to incorporate additional environmental sensors to provide ecosystem data. Overall, the system holds promise for certain applications – particularly if a project does not require accompanying biological data. The value of the data for managing fisheries will be evaluate after we review images and attempt to use existing software to calculate lengths. We believe this camera system offers exciting potential for sampling untrawlable or sensitive habitats where bottom trawls cannot or should not be used, however additional rigorous testing and comparisons are needed to clearly identify pros and cons relative to other new and existing technologies. We are exceedingly grateful to our colleagues at the Alaska Fishery Science Center for both lending the cameras to us as well as providing guidance and support on their use.

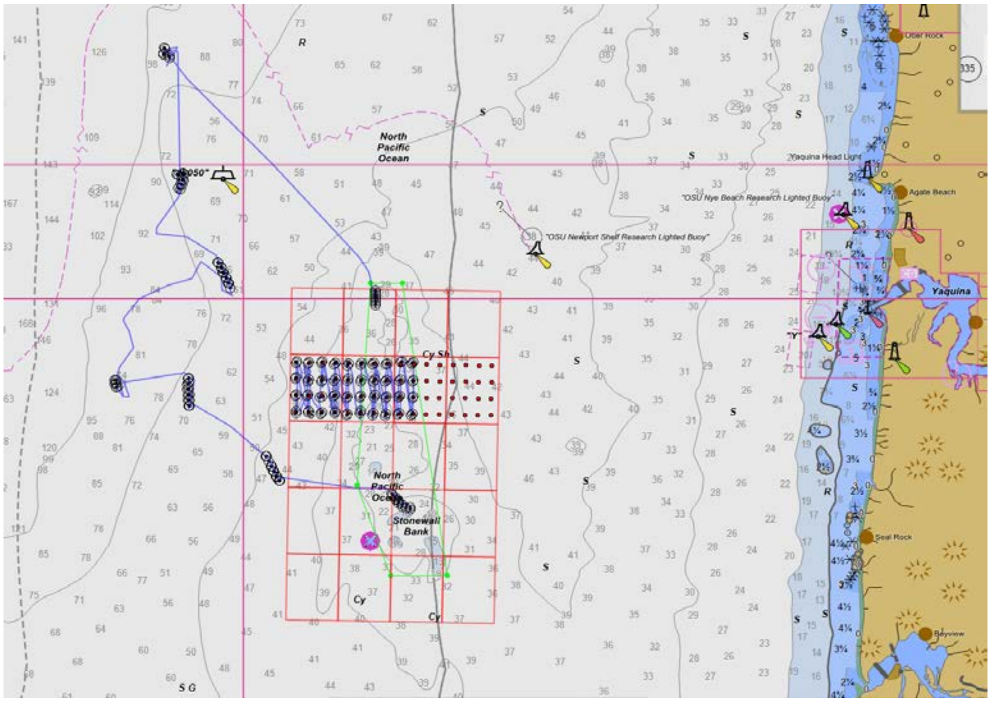

Figure 2. Locations where drop camera was deployed during 2018 pilot study.

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

III. Reserves

A. Size and catch of demersal fish within the Southern California Bight in relation to Cowcod Conservation Areas (2014 – 2016)

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

In 2001, the Pacific Fishery Management Council established two large (10878 km2 and 260 km2) Southern California Bight marine reserves called the Cowcod Conservation Areas (CCAs) in response to declining abundance of west coast rockfishes, particularly overfished cowcod. Following closure, no fishery independent monitoring took place for groundfishes within the CCAs through 2013. To assess the impact of the closures, we sampled multiple sites inside versus outside CCAs from 2014 to 2016 via the Northwest Fisheries Science Center's Hook and Line Survey. We investigated variations in catch per unit effort (CPUE), size, length frequency and percent of sites with positive catch for 14 abundant groundfish (bank, bocaccio, chilipepper, copper, cowcod, greenspotted, lingcod, olive, rosy, speckled, squarespot, starry, swordspine and the vermilion-sunset complex). General Linear Models (GLMs) that included area, year, depth and distance from port revealed significantly greater CPUE inside CCAs for 11 species and significantly lower CPUE ($P < 0.04$) for copper, lingcod, and the vermilion complex. For 11 species and the vermilion complex, we saw significant differences ($P < 0.05$) in size and length frequency with larger fish present inside CCAs. The percentage of sites positive for individual species tended to be greater inside CCAs for 11 species. We also observed significantly elevated species richness (species per site) and total CPUE inside the CCAs. Results indicated that establishment of the CCAs proved an effective management tool leading to larger individuals and greater CPUE for multiple rockfishes.

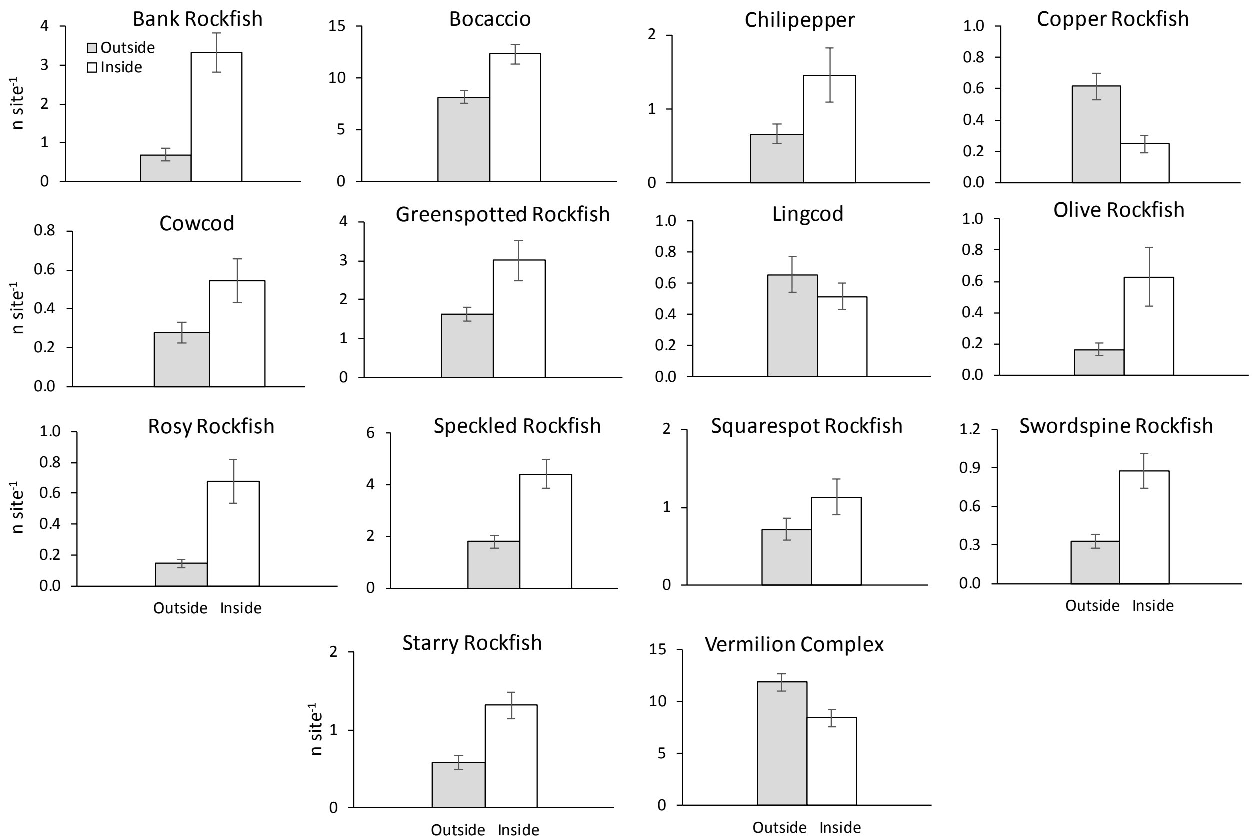

Figure 3. Species-specific standardized CPUE (n site^{-1}) for bank rockfish, bocaccio, chilipepper rockfish, copper rockfish, cowcod, greenspotted rockfish, lingcod, olive rockfish, rosy rockfish, speckled rockfish, squarespot rockfish, starry rockfish, swordspine rockfish, and the vermilion-sunset complex collected during the 2014 – 2016 Hook and Line Surveys. Means and standard errors ($\pm$ SE) are shown for each species inside (grey bars) and outside (white bars) the CCAs.

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

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

A. Hagfish

1. **No reported research occurred in 2018**
2. **No assessment occurred in 2018**

B. Dogfish and other sharks

1. **No reported research occurred in 2018**
2. **No assessment occurred in 2018**

C. Skates

1. No reported research occurred in 2018

2. No assessment occurred in 2018

D. Pacific cod

1. **No reported research occurred in 2018**
2. **No assessment occurred in 2018**

E. Walleye Pollock

1. **No reported research occurred in 2018**
2. **No assessment occurred in 2018**

F. Pacific whiting (hake)

1. Research

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

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

Over the last decade, fisheries managers increasingly identified a need for up-to-date, coast wide reproductive information on groundfishes along the west coast. Many management models used out of date maturity studies that were localized and often from unreliable macroscopic maturity estimates. In response to this, the NWFSC FRAM's division instituted a reproductive biology program in 2009 using two sampling platforms. We sampled Pacific hake ovaries from the West Coast Groundfish Trawl Survey in 2009 and 2012 - 2018. In 2012, we expanded the sampling platform to capture better spatio-temporal patterns. This included sampling from the Fisheries Engineering Acoustics and Technology (FEAT) summer survey, the at-sea hake observer program in the spring and fall months, and finally the FEAT winter survey in 2016 – 2017. From 2009 – 2017, we histologically assessed 2544 hake maturity samples. These coast wide collections allowed us to explore biogeographic relationships North and South of Pt. Conception, CA (34.44°N) within varying temporal patterns. Overall length and age at 50% (L50, A50) maturity were estimated at 33.4 cm and 2.3 years. However, L50 results north and south of Pt. Conception varied substantially, with corresponding L50 estimates of 35.0 and 26.2 cm. In addition, to the varying spatial relationships, we found temporal trends in their reproductive cycle; including time of spawning, shift in spawning locality, and interannual variability in the rate of skipped spawning. To account for skip spawning we estimated length at maturity using a spline model that incorporates the fraction of adult sexually mature skip spawners into a flexible asymptote.

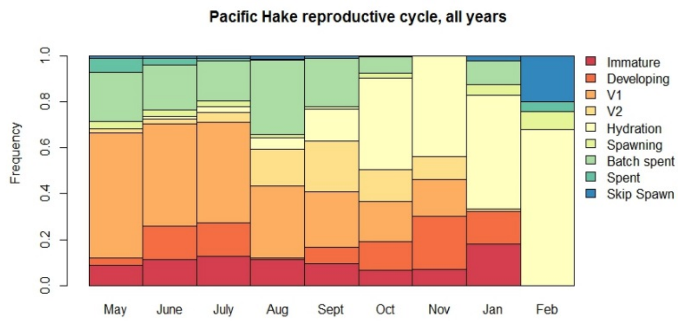

Figure 4. Temporal trends in Pacific hake reproductive cycle – coastwide with all years combined.

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

2. Assessment

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

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

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

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

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

Estimates of historical Pacific hake recruitment indicate very large year classes in 1980, 1984, 1999, and 2010. The U.S. fishery shows that the 2014 year-class comprised a very large proportion of the observations in 2016. Uncertainty in estimated recruitments is substantial, especially for 2014, as indicated by broad posterior intervals. The fishing intensity on the Pacific Hake stock is estimated to have been below the $F_{40\%}$ target except for 1999 when the median estimated fishing intensity was slightly above target. Fishing intensity has been substantially below the $F_{40\%}$ target since 2012. Although the official catch targets adopted by the U.S. and Canada have been exceeded only once in the last decade (2002), fishing intensity is estimated to have not exceeded the target rate in the last 10 years. Recent catch and levels of depletion are presented in Figure 5.

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

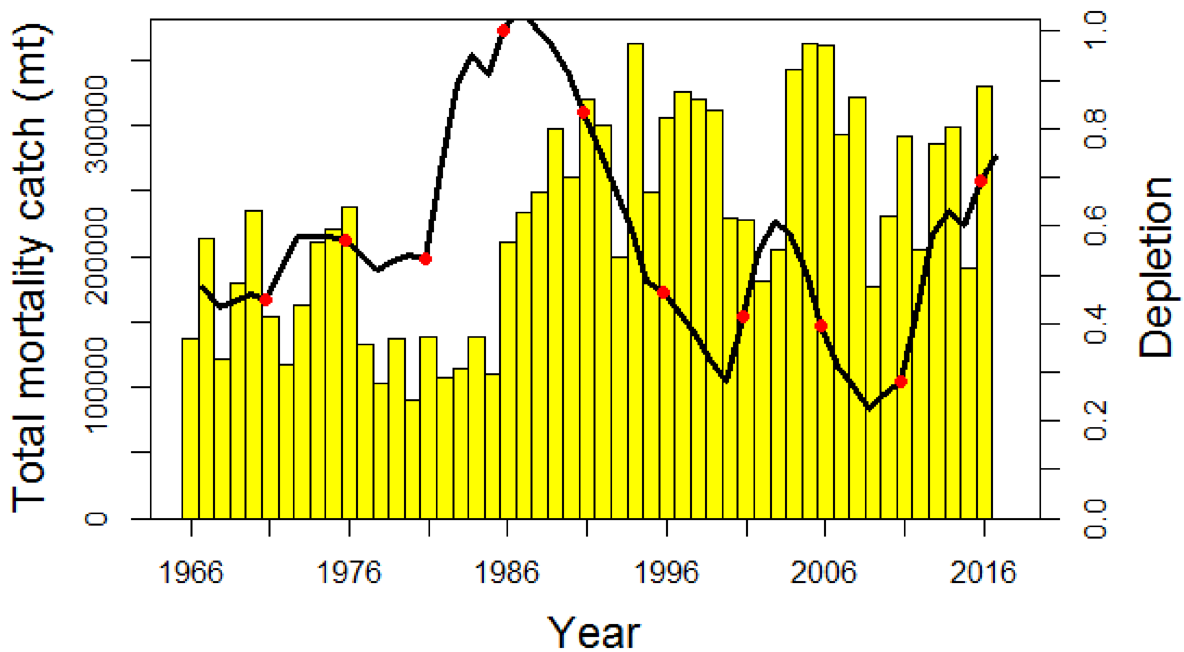

Figure 5. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Pacific hake, 1966-2016.

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

H. Rockfish

1. Research

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

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

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

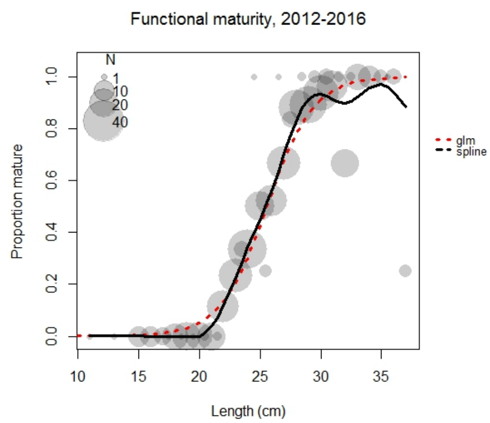

Figure 6. Length (cm) at maturity estimates for aurora rockfishes showing the coast-wide GLM (red dashed line) and spline (black solid line) fit for functional maturity (i.e. incorporating skip or abortive spawning events)

V. Ecosystem Studies

A. Identification of pelagic and demersal fish predators on gelatinous zooplankton in the Northeast Pacific Ocean

Investigators: Richard D. Brodeur, Troy W. Buckley, Richard E. Hibpshman, John C. Buchanan, and Douglas L. Draper

Pelagic coelenterates (Cnidaria and Ctenophora) and urochordates (salps and appendicularians) have been considered important consumers or predators in marine food webs for many years but have only more recently been recognized as important prey for many marine species. We summarize data obtained from > 100 Northeast Pacific fish predators based on extensive food habits analyses (~350,000 stomachs examined) from broad-scale surveys of pelagic and demersal fishes ranging from the Bering Sea to the Southern California Current. In the Bering Sea, we identified 16 predators on coelenterates and 14 on thaliaceans. In the Aleutian Islands, 16 and 18 predators were identified for the two jellyfish groups and a total of 15 and 24 predators, respectively, were found in the Gulf of Alaska. In the California Current, we identified 12 coelenterate predators and 4 thaliacean predators. We identified several hitherto unknown predators of jellyfish and examined factors related to predation on jellyfish. Dominant pelagic consumers of coelenterates include dogfish, rockfish, hake, medusafish, and saury and consumers of thaliacians included salmon, walleye pollock, and sablefish. We also show that the occurrence of coelenterate prey is generally much higher in stomachs of several fish species examined fresh at sea compared with that found in stomachs of the same species examined in the laboratory following preservation. Differences were less pronounced with the more durable salp prey. We suggest that many existing estimates of predation on readily digested gelatinous prey may underestimate the true predation rate and their importance in marine food webs.

B. Assessment Science

1. Modeling

a) Incorporating fishing time from the Southern California Bight Hook and Line Survey in model outputs to improve abundance indices used in stock assessments

Investigator: Danni Shi (Varanasi Scholar from the University of Washington)

This research focused on using survival analysis as a tool to analyze time series of rockfish catch to improve estimates of catch rate and abundance indices for use in stock assessments. In general, survival regression models can indicate the effects from different variables (i.e. continuous variables such as sea surface temperature or categorical variables such as sampling site) upon the survival rate. The author compared a parametric survival regression model (e.g. Weibull-distribution-based model) and a semi-parametric approach (Cox models with no assumption of the baseline function) using both categorical and continuous variables. For example, to determine if different levels of categorical variables affected survival rate, the survival rate was plotted against fishing time (catch rate) for each level of a factor (Figure 7, A-I). The resulting plots clearly indicated differences in survival rate by area (B), vessel (C) and location (inside versus outside the cowcod conservation area, I) with lesser or no influence by year (A), moon phase (D), drop number (E) , angler (F) , hook number (G) or tide phase (H). The results indicated a steeper decline in survival rate inside the cowcod area (either grouped by area of collectively) and by the Aggressor as indicated by shorter fishing time. Results varied by species and model but indicated that incorporating fishing time in model outputs via survival regressions has the potential to improve abundance estimates used in stock assessments

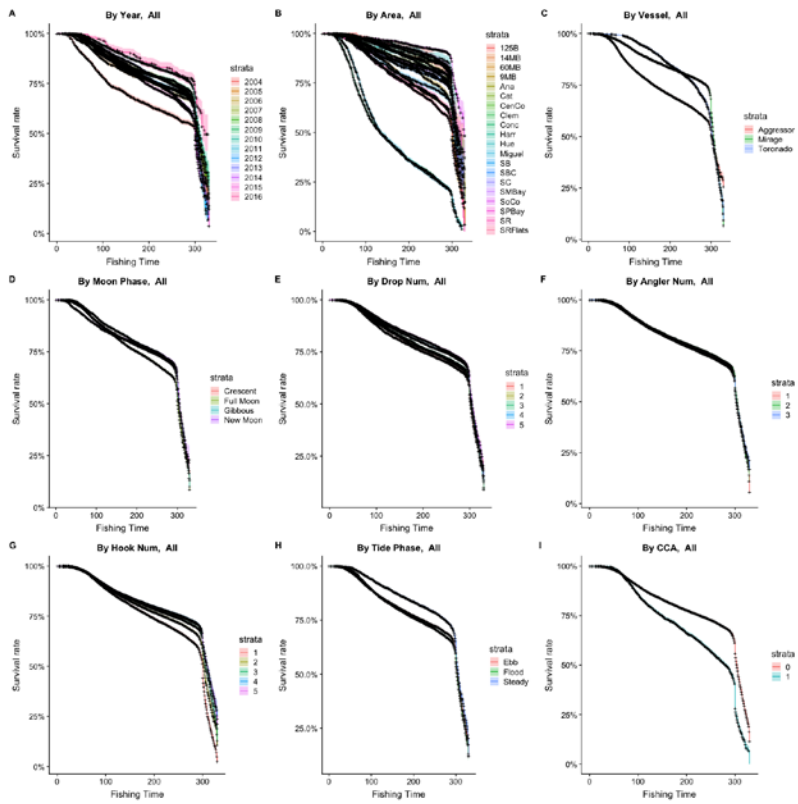

Figure 7.

b) The effect of survey frequency and intensity on U.S. West Coast stock assessment estimates

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

Fisheries management systems rely on stock assessments to inform management. Stock assessments, in turn, rely on well-designed and comprehensive surveys to provide data necessary to estimate scale and trends in fish populations. Given limited budgets and the financial demands of conducting surveys and the concomitant laboratory and analytical requirements, it is important to consider tradeoffs in designing our surveys, and evaluate alternative ways to reduce survey effort if required. We conducted a retrospective analysis of the impact of reducing the intensity or frequency of the U.S. West Coast Groundfish Bottom Trawl survey across eleven recently assessed species. We considered reducing the survey by approximately half through either an every-other year survey or reducing the number of charted vessels from four to two in each year. The influence of the survey reductions on assessment outputs and catch limits depend upon species life-history, frequency of occurrence in the current survey, and the data-richness of each assessment. All approaches to reducing survey sampling led to increased uncertainty in stock assessment results, while variability in assessment results among survey configurations was greatest for rockfish species, which are less commonly encountered in the survey, and for data-moderate assessments which rely more heavily on survey data.

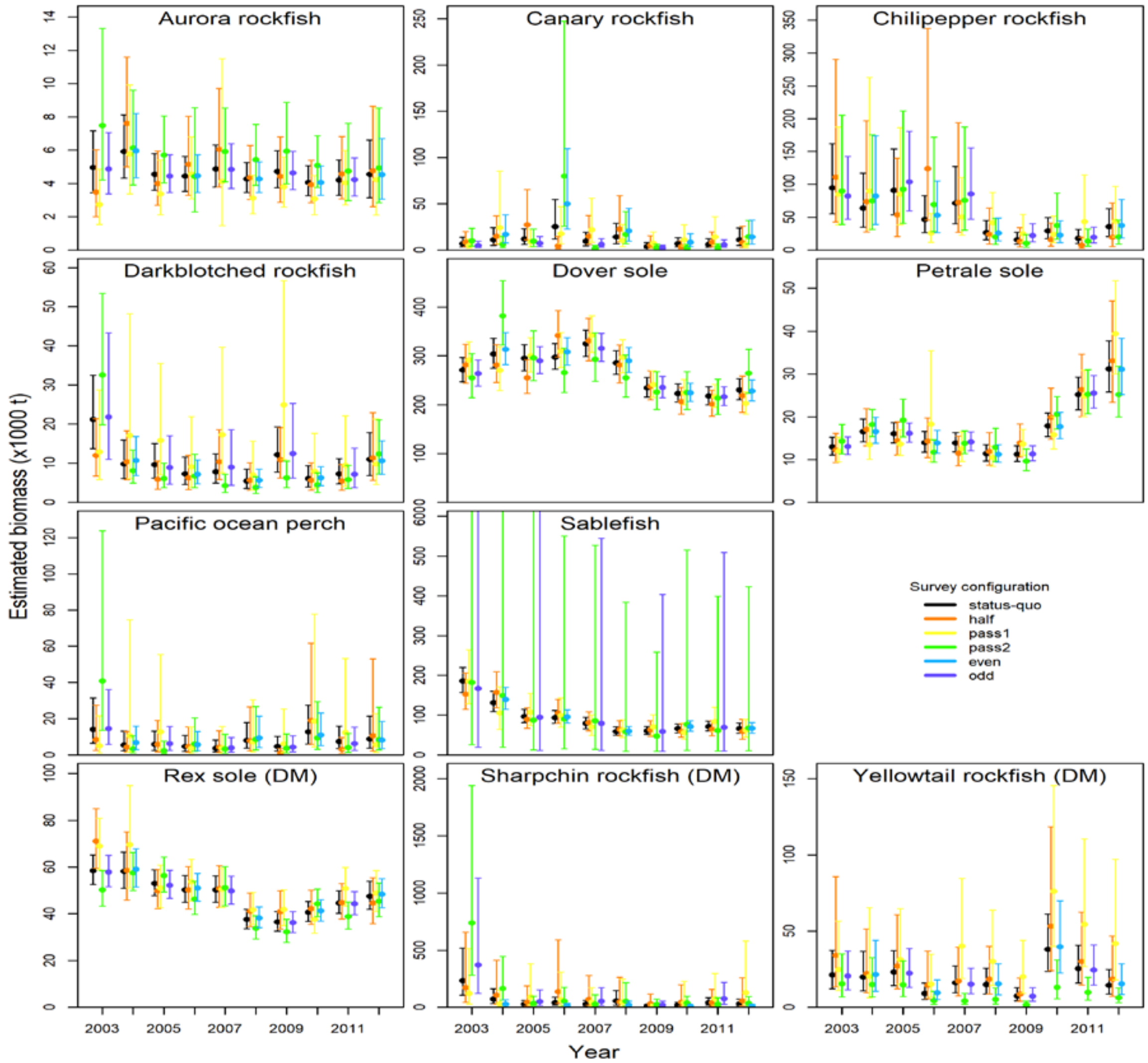

Figure 8. GLMM-derived indices of abundance and 75% lognormal confidence intervals for each survey configuration for each species. "DM" indicates species with Data Moderate stock assessments. The upper limit of the confidence intervals for sablefish that extend beyond the range of the figure are 1,451,000 t and 777,000 t for "odd" in 2003 and 2005, and 1,314,000 t, 1,131,000 t, and 616,000 t for "pass2" in 2003-2005.

2. Survey Science and Observer Science

a) Disease epidemic and a marine heat wave are associated with the continental-scale collapse of a pivotal predator (*Pycnopodia helianthoides*)

Investigators: C. D. Harvell, D. Montecino-Latorre, J. M. Caldwell, J.M. Burt, K. Bosley, A. Keller, S.F. Heron, A.K. Salomon, L. Lee, O. Pontier, C. Pattengill-Semmens, J.K. Gaydos

Multihost infectious disease outbreaks have endangered wildlife, causing extinction of frogs and endemic birds, and widespread declines of bats, corals, and abalone. Since 2013, a sea star wasting disease has affected >20 sea star species from Mexico to Alaska. The common, predatory sunflower star (*Pycnopodia helianthoides*), shown to be highly susceptible to sea star wasting disease, has been extirpated across most of its range. Diver surveys conducted in shallow nearshore waters (n = 10,956; 2006–2017) from California to Alaska and deep offshore (55 to 1280 m) trawl surveys from California to Washington (n = 8968; 2004–2016) reveal 80 to 100% declines across a ~3000-km range. Furthermore, timing of peak declines in nearshore waters coincided with anomalously warm sea surface temperatures. The rapid, widespread decline of this pivotal subtidal predator threatens its persistence and may have large ecosystem-level consequences.

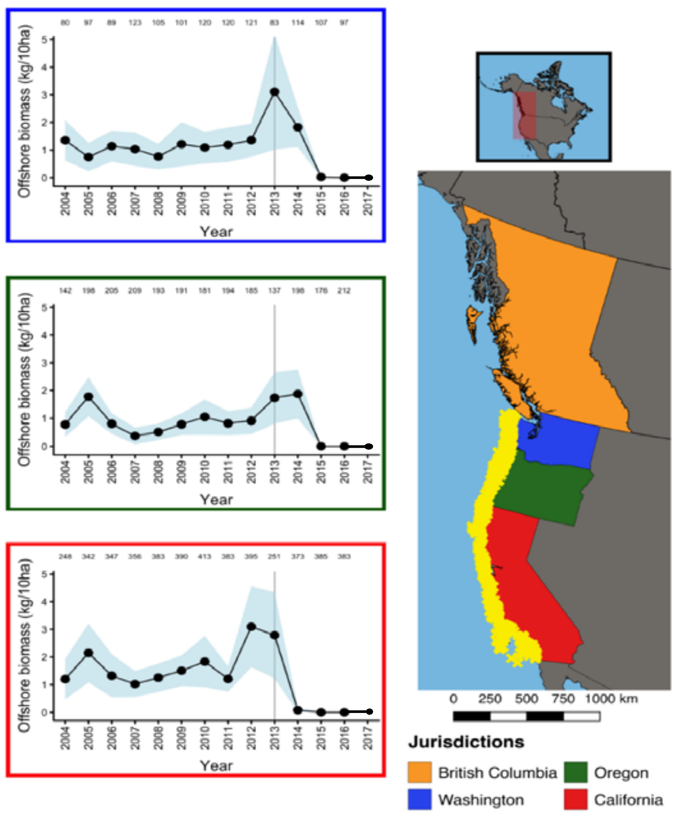

Figure 9. Collapse of *Pycnopodia* in WA, OR and CA in 2014-2018: yellow dots show trawl survey locations. Decline associate with warming and began earlier in CA. This sea star is a pivotal predator on sea urchins with depletion producing cascading ecosystem effects (Harvell et al., 2019: Science Advances)

b) West Coast Observer Program

The FRAM West Coast Groundfish Observer Program (WCGOP) continued collecting fishery-dependent data during 2018 on groundfish fleets along the entire U.S. west coast. The groundfish fishery is broken down into two main categories the catch share fisheries and the non-catch share fisheries. The catch share fishery can be further broken down into the shorebased fleet and the at sea fleet. The at sea fleet includes catcher-processors (CPs) and motherships. The catch share fisheries require 100% observer and shore side monitoring. The non-catch share fisheries require observer coverage upon request and coverage is randomly assigned by fishery and port group.

Catch Shares

There are three sectors in the catch share program: shorebased, motherships (includes motherships and mother ship catcher-vessels), and catcher-processors. All vessels participating in the shorebased sector or acting as mother ship catcher-vessels (MSCV's) must carry one observer on all trips. Motherships and catcher-processors carry two observers each trip. The shorebased sector is managed through Individual Fishing Quotas (IFQ's) and includes all vessels that land catch at shore side processors. Catch shares regulations allow the shorebased sector to use trawl, longline, or pots to harvest IFQ species. The mother ship and catcher-processor sectors target Pacific hake using trawl gear and process it entirely at-sea. Motherships and catcher-processors have formed cooperatives to ensure sectors can attain Pacific hake quota without exceeding bycatch caps for overfished species or salmon.

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

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

Non-catch shares

The observer program collects data in other west coast fisheries that are not part of the catch share program. The program had vessels ranging in size from skiffs to larger fixed gear vessels and depths ranging from less than 20 ft. to more than 300 ft. Due to its unique data collection circumstances in both the catch shares and non-catch shares fisheries, the program continues to stress safety and data quality.

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

c) Fisheries Observation Science Program Coverage Rates, 2002–17. U.S. Department of Commerce, NWFSC Processed Report 2018-02

Investigators: Somers, K.A., J.E. Jannot, K. Richerson, V. Tuttle, and J. McVeigh.

NWFSC Processed Report 2018-02 (https://doi.org/10.25923/e2pz-0w11)

The Fisheries Observation Science (FOS) Program at the Northwest Fishery Science Center consists of two programs, the At-Sea Hake Observer Program (A-SHOP) and the West Coast Groundfish Observer Program (WCGOP). The A-SHOP observes the hake fleet that processes catch at sea, while the WCGOP observers a number of fleets that deliver catch shoreside for processing, including sectors that target and incidentally impact groundfish. Both programs place trained scientists on board commercial fishing vessels to observe and sample all catch; the WCGOP specifically focuses on at-sea discard estimates. This report also includes fish ticket landings data from the Pacific Fishery Information Network (PacFIN). This processed report describes the level of observer coverage, as the proportion of targeted landings associated with observed trips to the total targeted landings across all trips in the fleet, for 2002 to 2017. The species targeted are defined based on the fishery and described in the header of each table. The total targeted landings by each fleet are reported even in years when the FOS did not observe any trips. In some cases, fewer than three active vessels in a stratum result in confidential data, which are masked using asterisks. The level of observer coverage and sampling can vary greatly between fisheries, years, and spatial strata. This report quantifies the magnitude of expansions required to use observer data to estimate fleetwide levels of discard and can highlight areas where estimates are less certain. Every year this report is updated to include the newest year of data, the most current data from the FOS and PacFIN for previous years, and the most recent data processing procedures. This report includes the three new sectors which WCGOP observed for the first time in 2017: Sea Cucumber Trawl, Pacific Halibut Derby, and Ridgeback Prawn. All updates are described in the Groundfish Mortality report, which is available in draft form annually in the Pacific Fishery Management Council September Briefing Book and later in the year in final form via a Technical Memorandum. The tables in this processed report are also available as spreadsheets.

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

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

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

ICES Journal of Marine Science, Volume 76, Issue 1, 1 January 2019, Pages 255–267, https://doi.org/10.1093/icesjms/fsy153

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

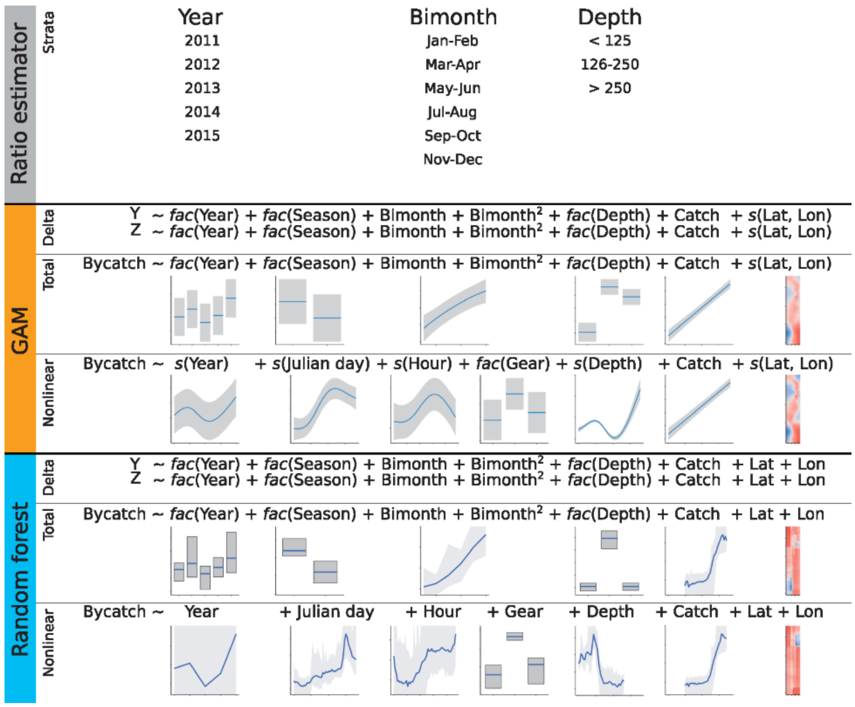

Figure 10. Summary of models fit to the West Coast Groundfish Observer Program bycatch dataset. The ratio estimator was stratified by year, bimonthly period, and depth (fathoms). The Delta and Total models were fit to the same covariates, meant to mimic the stratified ratio estimator. Covariates treated as factors are indicated by fac(). The Delta models split the bycatch data into presence/absence (Y) and positive catches (Z), then calculated bycatch as Y × Z. The Nonlinear models incorporate all available covariates using nonlinear terms, e.g. spline terms in GAMs, s(). Covariate effect plots are shown for models fit to Pacific hake. The following R packages were used in analyses: “mgcv” to fit GAMs, “visreg” to visualize GAM covariate effects, “randomForest” to fit RFs, and “forestFloor” to visualize RF covariate effects.

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

e) Towards stewardship: beyond the basics and how do we go further

Investigators: Vanessa J. Tuttle, Jason Jannot, Tom Good

Well-established observer programs have been turning the crank collecting haul and catch data for decades. Observer programs and data collections evolve and change over time, but how do we take data collection the next step and encourage greater stewardship in the industry? Can we smooth the path and identify conservation needs through careful examination of existing data? Can we encourage and guide fisheries towards sustainability by co-leading the way? The At-Sea Hake Observer Program is leading the charge by monitoring seabird trawl cable strikes. We are assessing injury and mortality from these interactions in the Pacific hake processing fleet off the U.S. West Coast. The challenge with cable strikes is they were only infrequently and opportunistically observed in the past, meaning this mortality was both cryptic in nature and under-reported. Taking a collaborative approach with industry, we hope to reduce seabird injury and mortality through the development of successful bycatch mitigation strategies. We began with a new, randomized data collection aimed at monitoring trawl cables and recording seabird strikes to document the interactions. This helped reveal the scope of the problem and indicated which species are most vulnerable to cable strikes. We then convened a workshop bringing fishers, scientists and managers together to brainstorm potential mitigation strategies. Feasible and practical mitigation strategies are at the heart of success for this project. The workshop group identified and agreed upon five distinct strategies, keeping in mind that there must be real potential to field test these strategies. Finally, we hope to push towards sea trials of the most promising strategies. Ultimately, the goal is to develop a catalog of best practices that will result in reduced injury and mortality of seabirds in trawl fisheries. We hope that a strong, transparent, collaborative process will move us towards improved stewardship, with relative ease.

For more information, please contact Vanessa Tuttle at Vanessa.Tuttle@noaa.gov

f) Migration to OPTECS Introduces Positive Changes in Sampling Flow and Observer Life

Investigator: Eric Brasseur
West Coast Groundfish Observer Program, Pacific States Marine Fisheries Commission, Newport, Oregon, USA

The North West Fisheries Science Center’s Fisheries Observation Science (FOS) program is in the process of migrating from paper data collection on trawl vessels to direct tablet data entry. Initial introduction of tablet-based sampling indicates that observers will spend more time on deck at first, until they become conditioned to the new process, and will in turn see a significant reduction in time spent with post data collection duties such as cleaning and drying forms, performing calculations and transcribing data. When not engaged in sampling, observers will be able to undertake additional program duties, devote more time to computer maintenance and data security, and have more time to rest, resulting in a safer work experience. The Observer Program Technology Enhanced Collection System (OPTECS) software was designed to complement and direct observer sampling rather than rely on mirroring a paper form. The software is divided into sections based on how the observer encounters the data. This natural flow allows the observer to sample quickly and move from task to task fluidly. During testing one observer noted that entering paper collected data, with the app on a tablet, was simpler than entering the same data via the web portal, attesting to its usability. Future enhancements to the software flow will incorporate user experience based improvements in a second version.

Complementing the technological changes, we developed a stand that attaches to a Marel M-1100 scale that can be adjusted to various heights and angles to allow the observer to work hands free. This helps minimize the risk of damage to the tablet and potential data loss, while freeing up the observers hands. Upon return, data are transmitted to shore along with a copy of the database for debriefer analysis. The observer then enters forms not currently available in the OPTECS software. Due to the data collection methods and built in validations, corrections to the data are minimal.

The program results in quick and efficient data availability as electronic data collection expands and the debriefing process is finalized.

For more information, please contact Eric Brasseur at Eric.Brasseur@noaa.gov

g) Uniting electronic monitoring and observer data to improve management of the US West Coast groundfish fishery

Investigators: K.A. Somers, J. Jannot, J. McVeigh
NOAA – NWFSC – West Coast Groundfish Observer Program, USA

In 2015, to explore the potential for reducing the financial burden of monitoring costs borne by industry, electronic monitoring (EM) systems were adopted in-lieu of observers by some vessels. This subset of the fleet is no longer required to maintain 100% observer coverage and is instead randomly selected to achieve ~30% observer coverage, which is focused on biological and supplementary data collection. Rather than viewing observer and EM programs as opposing forces, we presented three specific ways that we have integrated these two programs and datasets to continue to provide total catch estimates for all species and essential biological data.

First, we assessed the strengths of both EM and observer data to identify the most appropriate source to utilize in calculating discard estimates for each species impacted by the fishery. EM provides excellent estimates of at-sea discards of a subset of IFQ species that are identifiable on video, as well as total weight estimates of unsampled, operational discharge (Figure 11). However, quota species account for only ~75 of the more than 300 species encountered by the bottom trawl fleet, which include both actively managed groundfish species and currently unmanaged nongroundfish species. Much of the non-quota groundfish species discards consist of Ecosystem Component Species (ECS) and other groupings that the Pacific Fishery Management Council (PFMC) has identified as likely to be increasingly targeted in the future. Observer data remains the only source of discard rates for these components of the ocean ecosystem, which are essential to estimating fleetwide at-sea discard amounts and understanding overall fishery impacts.

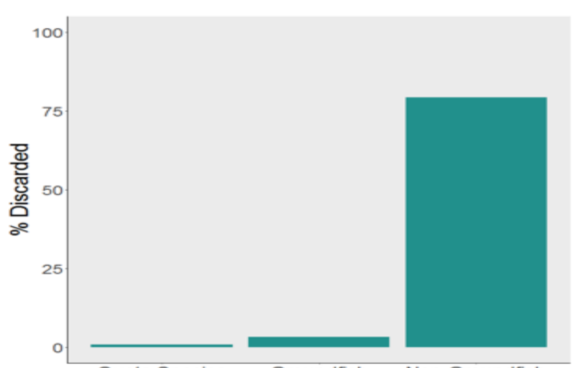

Figure 11. Proportion of the total catch discarded at sea in the 2015 and 2016 catch shares EM bottom trawl fishery by management group.

Second, we recognized that differing rules in the EM fleet require new sampling protocols for observers. Prohibitions on which species can be discarded while using EM resulted in the regular landing of unmarketable species, which are frequently undocumented on landings receipts. Without the deployment of observers, the catch of these "shoreside discards" would be under-estimated and unknowable.

Finally, observers continue to collect valuable biological and genetic data necessary to meet the needs of stock assessments and inform legally-mandated biological opinions. These data are often either completely unavailable from EM and shoreside monitoring or not associated with specific temporal and spatial attributes. For quota, non-quota groundfish, and non-groundfish species, WCGOP observers collect length-frequency data. Since 2015, the WCGOP and the EM program have worked together to collect and synthesize datasets that can be used to inform management while helping fishers navigate a new world of monitoring.

h) Green Sturgeon Research with the California Halibut Trawl Fishermen of the San Francisco Bay Area

Investigator: Kevin Stockmann

NOAA Fisheries West Coast Groundfish Observer, San Francisco, USA

According to the International Union for Conservation of Nature, sturgeons are more critically endangered than any other group of species. Green sturgeon (*Acipsenser medirostris*) are anadromous fish occurring along the West Coast of North America. In 2006, the Southern Distinct Population Segment (DPS) of green sturgeon was listed as threatened under the Endangered Species Act. The most recent 5-Year Review: Summary and Evaluation affirmed the green sturgeon's status as threatened. A recovery plan is under development. Green sturgeon are encountered as bycatch in the California halibut trawl fishery centered outside San Francisco Bay. Observers provide important contributions to the science and management of this species. Biological data collected by observers provide critical information for the analysis and continued monitoring of bycatch effects, supporting catch and mortality estimates by life stage, and clarifying the proportion of Southern DPS fish encountered versus the non-listed Northern DPS. Observer data also play an important role in addressing uncertainties regarding catch estimates and post-release impacts. Observers applied over 315 Passive Integrated Transponder (PIT) tags to determine a recapture rate. Observer data from the halibut trawl fishery represent valuable monitoring of the sub-adult population.

To assess post release impacts, NOAA Fisheries led a collaborative study with halibut fishermen, observers and the California Department of Fish and Wildlife. Observers and fishermen applied satellite tags to 76 randomly selected bycaught green sturgeon to estimate post release survival and to learn more about green sturgeon movement patterns. Tags were programmed to stay on the fish 3-4 weeks before popping off and transmitting depth, temperature and acceleration data. Of the 49 satellite tags that transmitted sufficient data, analysis suggested 81.5% of released sturgeon survived to three weeks, post release. This is the first study in the United States to quantify a post trawl interaction survivorship rate for any sturgeon species.

i) Observer Contributions to a U.S. West Coast Success Story

Investigator: Ryan Shama

NOAA Fisheries Northwest Fisheries Science Center, Fisheries Resource Analysis & Monitoring Division, West Coast Groundfish Observer Program

Due to overcapitalization, the U.S. Secretary of Commerce declared the West Coast groundfish fishery a failure in 2000. To meet sustainability mandates, NOAA Fisheries adopted a strategy that would further limit access to the fishery, reduce catch of sensitive species, and significantly improve the quality and availability of fishery-dependent data for West Coast groundfish stocks. The U.S. West Coast groundfish fishery is now in the midst of a truly remarkable success story. Of the 10 species deemed overfished between 1999 and 2010, all but two have been declared rebuilt, as of 2017. Observers played a crucial role in this recovery by providing accurate accounts of at-sea discards, a major piece of the puzzle previously unavailable to fishery managers. Along with at-sea discard estimates, biological sampling provided valuable fishery-dependent data for stock assessments.

Prior to the deployment of fishery observers on West Coast groundfish vessels, fishery managers were missing data for at-sea discards. From 2002-2017, WCGOP observers accounted for 2,974,384.96 lbs. of discards (expanded) from nine species : lingcod, widow rockfish, petrale sole, canary rockfish, Pacific ocean perch, darkblotched rockfish, bocaccio, cowcod and yelloweye rockfish. WCGOP observers also provided the primary component of fishery-dependent biological data, used for West Coast groundfish stock assessments. During their 82,830 sea days, WCGOP observers have collected biological data from 105,446 individuals from the nine species noted previously. Biological data collected varied by species but included length, sex, otoliths (age), and fin clips (genetics). The observer component became even more instrumental in the recovery of overfished species, when the Catch Share program was implemented on January 1, 2011. With catch shares, came the requirement for 100% observer coverage in the trawl sector. While controversial, this management strategy provided an immediate and significant reduction in the catch of overfished species from ~250 mt yr^{-1} to <25 mt yr^{-1}.

j) Observer Program Annual Reports

Jannot, J.E., K. Somers, K. Richerson, N.B. Riley, J. McVeigh. 2018. Pacific halibut bycatch in US West Coast Fisheries (2002-17). FOS Observer Program, NWFSC. National Marine Fisheries Service, NWFSC, 2725 Montlake Blvd E., Seattle, WA 98112.

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Somers, K.A., J. Jannot, V. Tuttle, N.B. Riley, and J. McVeigh. 2018. Groundfish Expanded Mortality Multiyear for 2002-2017 US west coast fisheries. NOAA Fisheries, NWFSC Observer Program, 2725 Montlake Blvd E., Seattle, WA 98112. https://www.nwfsc.noaa.gov/data/map

Somers, K.A., J.E. Jannot, V. Tuttle, J. McVeigh. 2018. Observed and estimated total bycatch of salmon in the 2002-2016 U.S. west coast fisheries. West Coast Groundfish Observer Program. NOAA Fisheries, NWFSC Observer Program, 2725 Montlake Blvd E., Seattle, WA 98112.

Somers, K.A., J.E. Jannot, V. Tuttle, & J. McVeigh. 2018. FOS coverage rates, 2002-2017. Last updated: May 2018. NOAA Fisheries, NWFSC Observer Program, 2725 Montlake Blvd E., Seattle, WA 98112.

k) Involving Industry in the Collection of Needed West Coast Groundfish Data

Investigators: Jim Benante1, John Lafargue
Pacific States Marine Fisheries Commission, USA

Groundfish species on the West Coast of the United States were declared a federal disaster in 2000. Observer programs had seen dramatic growth in the United States from 1995-2000 in response to the need to better manage commercial fisheries. The fishery dependent data observer programs collected was helping to fill in some of the data gaps, but Southern California did not have much commercial fishing activity so there were very few data collection opportunities. Commercial sport fishing opportunities in Southern California were being severely limited due to several important species being declared overfished and harvest limits being greatly reduced. In response fishers began to ask tough questions about the data being used to manage their fisheries. In 2003 after meetings and discussions with a variety of active commercial and sport fishers in the Southern California Bight region, a study was developed with the help of the local fishers to survey shelf rockfish resources in untrawlable habitats in Southern California using commercial sportfishing vessels as the research platforms. 14 years later a substantial data set has been compiled on the relative abundance of a large number of shelf rockfish in untrawlable areas of the Southern California Bight. In addition a variety of biological samples and oceanographic data has been collected. The survey has supplied annual abundance indices and/or biological data or samples for a variety of species and made available for use in stock assessments for the following species: Blue Rockfish (2017); Bocaccio (2009, 2011, 2013, 2015, 2017); Cowcod (2013); Greenspotted Rockfish (2011); Lingcod: (2017); Yelloweye Rockfish (2009); Vermilion Rockfish (2005). The cooperative approach employed by this survey has been effective in efficiently generating fishery-independent abundance indices and biological data collection for multiple groundfish species in untrawlable habitats. Industry vessels provide effective and relatively inexpensive research platforms that are reliable. The local fishers can provide valuable insight into the gear selection, fish behavior, location of viable habitats, local weather conditions, moorages, etc.

l) Everything the same is different: bycatch trends in the At-Sea Pacific hake fishery

Investigator: Vanessa Tuttle

NOAA Fisheries Northwest Fisheries Science Center, Fisheries Resource Analysis & Monitoring Division, West Coast Groundfish Observer Program

A review of the bycatch trends in the at-sea Pacific hake (*Merluccius productus*) fishery seems timely given the interesting set of recent ocean conditions (warm blob), change in the status of several formerly-overfished rockfish species, and the record-breaking size of recent hake quotas. Rockfish, spiny dogfish, salmon, squid and several roundfish species make up the vast majority of bycatch in the at-sea hake fishery. An inspection of rockfish bycatch trends, under recent fishery-constraining hard caps, reveals the challenges imposed by these constraints (including temporary fishery closures). Chinook salmon bycatch, which is closely monitored by the West Coast Region to ensure the fishery does not exceed the take threshold outlined in the Biological Opinion, shows high inter-annual variation. Bycatch of various round fish, including sablefish, lingcod, jack and Pacific mackerel, show interesting cyclical patterns with sometimes-extreme variability. Finally, we have seen some incredibly rare swordfish and bluefin tuna bycatch, two species who seemed to have had temporary range extensions due to the warm blob. The NWFSC's At-Sea Hake Observer Program deploys fisheries observers in the at-sea hake fleet to collect data essential to the management of this largest-by-volume fishery off the U.S. West Coast.

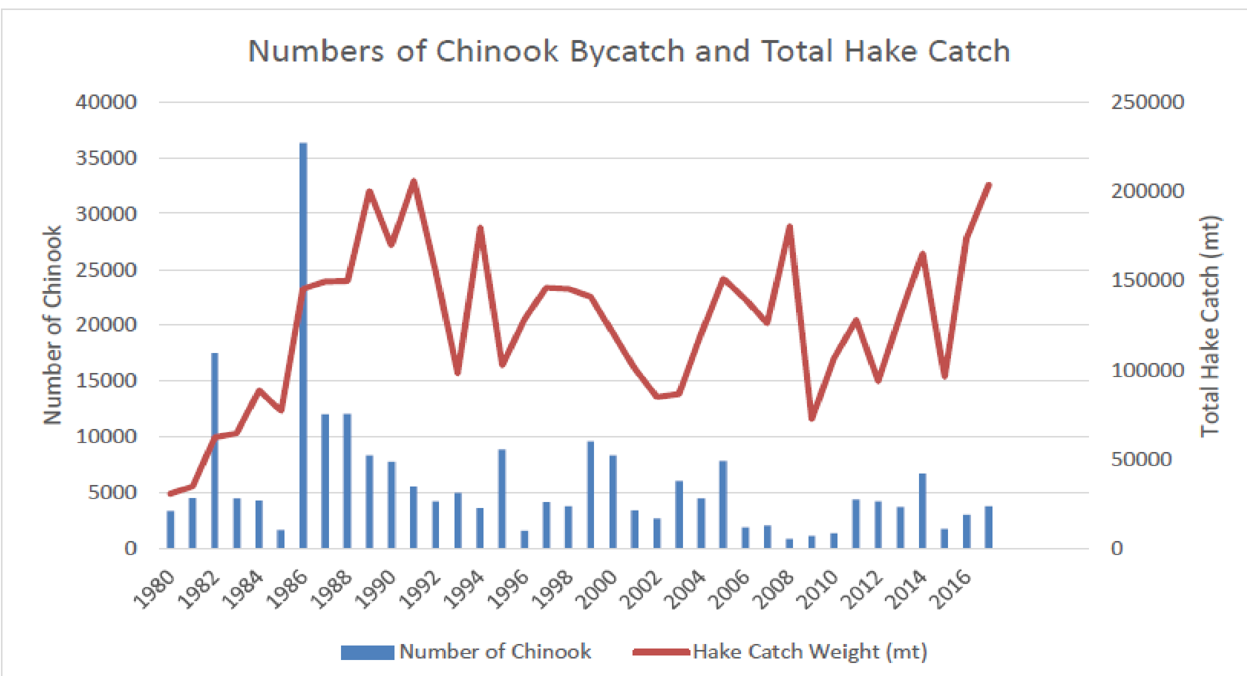

Figure 12. Chinook salmon bycatch in the at-sea hake fishery shows strong inter-annual variability. Vigorous efforts to avoid Chinook bycatch have been relatively successful in the last decade, with a mean catch rate of 3107 individual fish per year, a decline from the previous decade

with a mean catch rate of 5011 individual fish per year. Bycatch of other salmonids in the at-sea hake fishery are nominal.

B. Ecosystem Research

1. Habitat

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

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

Structure-forming invertebrates (SFIs: corals, sea pens and sponges) inhabit the world's oceans and are often associated with high numbers of fish. But the precise nature and extent of any association is difficult to quantify and poorly understood. We investigated the associations between SFIs and demersal fish using data from the Northwest Fisheries Science Center's bottom trawl survey (2003-2015). General linear models (GLMs) showed that average species richness was slightly lower and finfish biomass slightly higher in hauls with no SFIs. Generalized additive models (GAMs) indicated non-linear relationships between species richness and sponge density across all geographic regions we examined. Finfish biomass was also related to SFIs and environmental variables but those relationships varied geographically. Multivariate analyses were used to examine relationships among fish community structure, SFI densities, and environmental parameters (depth, latitude and bottom temperature). No strong correlations occurred between community structure and SFI densities, but bottom temperature and depth were the primary drivers of community composition. Indicator species analysis showed various species-specific associations. Depending on species, flatfishes exhibited relationships with high and low densities of corals and sea pens or the absence of sponges. Thornyheads and some rockfishes were associated with high sponge densities but low or zero coral and sea pen densities. Sablefish Anoplopoma fimbria exhibited opposite trends. These results provide information about broad-scale associations between SFIs and demersal fish that may be useful for developing studies focused on the function of SFIs as essential fish habitat and the role they play in the life-history of demersal fishes.

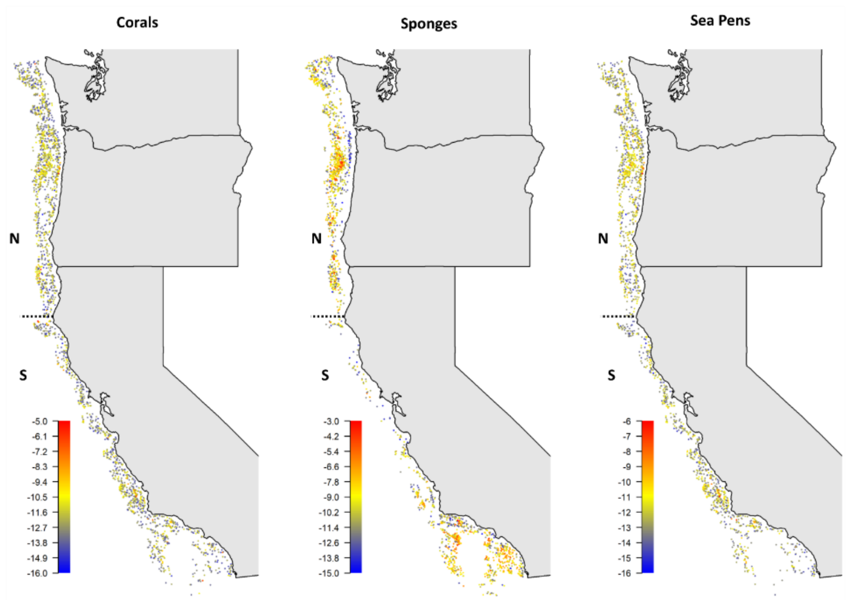

Figure 13. Location of trawls containing corals, sponges and sea pens during the bottom trawl survey 2003 to 2015. Density is on a log scale to better represent low CPUE (ka ha^{-1}). dashed lines indicate Cape Mendocino, CA.

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

b) Return of the dead zone: severe hypoxia observed off Oregon and Washington during the 2017 West Coast Groundfish Bottom Trawl Survey

Investigators: Aimee A. Keller, Peter Frey, Victor Simon, Lorenzo Ciannelli, and Stephen D. Pierce

Seasonal hypoxia has occurred in near-bottom waters off the Oregon continental shelf since 2002. Potentially linked to shifts in climate and upwelling, the severity of these hypoxic events has varied considerably over time. In 2017, the West Coast Groundfish Bottom Trawl Survey encountered severe hypoxia in shelf tows with depths ranging from 62 to 160 m off the coasts of Oregon and Washington. Near-bottom dissolved oxygen levels (DO) as low as 0.10 ml l^{-1} correlated strongly with reductions in catch and species richness. Large quantities of decomposing Dungeness crabs encountered in other areas suggested that these hypoxic conditions may have been widespread and resulted in local die-offs of benthic invertebrates. We examine the extent and intensity of near-bottom hypoxia observed in 2017, analyze catches of groundfish and invertebrates from oxygen-poor locations, and explore environmental factors that may have contributed to the severity of this phenomenon in 2017. Our prior research revealed significant positive relationships between catch and DO for 19 of 34 groundfish species within hypoxic bottom waters using generalized additive models. We utilize an expanded time series (2008 to 2017) to examine similarities and differences in the response of various subgroups of groundfish species to low DO levels, information of value to future ecosystem-based management in the face of changing oceanographic conditions.

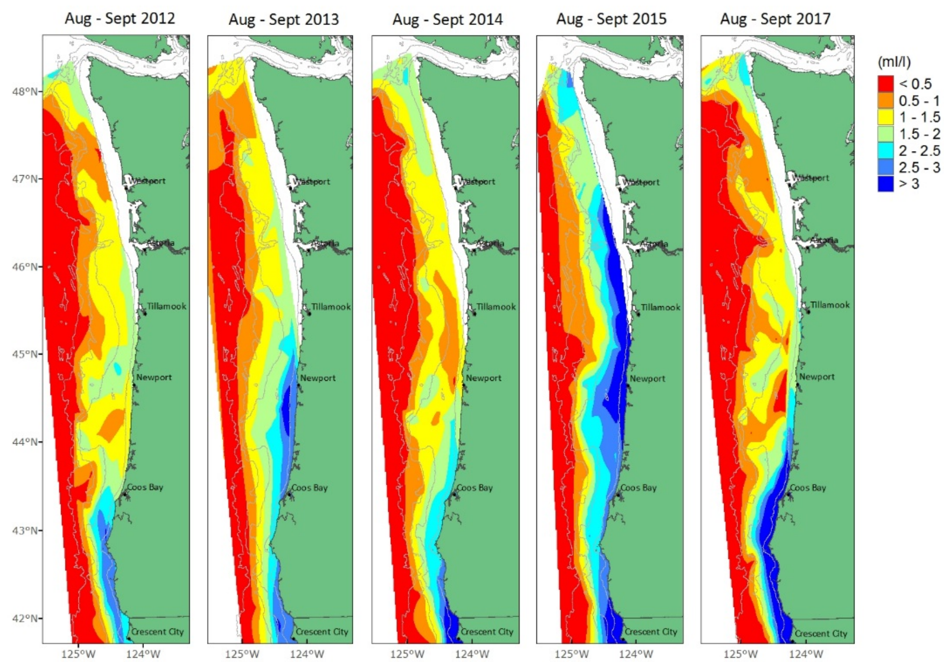

Figure 14. Near bottom dissolved oxygen concentrations (ml l^{-1}) north of Crescent City 2012 – 2017 – demonstrating the return to hypoxic conditions after 2015.

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

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

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

Although climate-induced shifts in fish distribution have been widely reported at the population level, studies that account for ontogenetic shifts and sub-regional differences when assessing responses are rare. In this study, species-specific changes in groundfish distributions were assessed at different size classes within sub-regions based on shifts in depth, latitude, and longitude. The authors examined large, quality-controlled datasets from depth-stratified, random bottom trawl surveys conducted during summer in the Gulf of Alaska, along the west coast of Canada and the U.S. from 1996 to 2015, a period punctuated by a marine “heat wave”. Temporal biases in bottom temperature were minimized by partitioning each survey into three sub-regions. Near-bottom temperatures, weighted by stratum area, were unsynchronized and exhibited varying interannual variability across sub-regions. The sub-regions also varied by weighted bottom depth from the shallowest in the western Gulf of Alaska and Hecate Strait (100 m) to the deepest in southern west coast of the U.S. (300 m). The centroids (centres of gravity) of groundfish distribution were weighted by catch per unit effort (CPUE) and stratum area for ten important species subdivided by sub-region and size classes. Multivariate analyses showed significant differences in aggregate fish movements in response to temperature across sub-regions but not among species or size class. Groundfish demonstrated poleward responses to warming temperatures in relatively few sub-regions but tended to move vertically (either upward or downward) to seek colder waters within sub-regions. Within sub-region, the temperature responses of groundfish varied between species but not by size class. Shallower species exhibited highly varied distributional responses to temperature changes across sub-regions while deeper-water species tended to have similar temperature responses. Choosing an appropriate spatial scale is highly recommended for future climate change studies.

2. Ecosystems

C. By-catch Reduction Engineering

a) Illuminating the headrope of a selective flatfish trawl: effect on catches of groundfishes, including Pacific halibut

Investigators: Mark Lomeli, W. Waldo Wakefield and Bent Herrmann

This study evaluated how illuminating the headrope of a selective flatfish trawl can affect catches of groundfishes, including Pacific halibut *Hippoglossus stenolepis*, in the U.S. West Coast limited-entry (LE) groundfish bottom trawl fishery. Over the continental shelf, fishermen engaged in the LE bottom trawl fishery target a variety of flatfishes, roundfishes, and skates. Green LED fishing lights (Lindgren-Pitman Electralume) were used to illuminate the headrope. The lights were grouped into clusters of three, with each cluster attached ~1.3 m apart along the 40.3-m-long headrope. Catch comparisons and ratios of mean fish length classes were compared between tows conducted with (treatment) and without (control) LEDs attached along the trawl headrope. Fewer Rex sole *Glyptocephalus zaphirus*, arrowtooth flounder *Atheresthes stomias*, and lingcod *Ophiodon elongatus* were caught in the treatment than in the control trawl, though not at a significant level. Pacific halibut catches differed between the two trawls, with the treatment trawl catching an average of 57% less Pacific halibut. However, this outcome was not significant due to a small sample size. For Dover sole *Microstomus pacificus* 31–44 cm in length and sablefish *Anoplopoma fimbria* 43–61 cm in length, significantly fewer fish were caught in the treatment than in the control trawl. On average, the treatment trawl caught more rockfishes *Sebastes* spp., English sole *Parophrys vetulus*, and petrale sole *Eopsetta jordani*, but not at a significant level. These findings show that illuminating the headrope of a selective flatfish trawl can affect the catch comparisons and ratios of groundfishes, and depending on fish length and species, the effect can be positive or negative.

Figure 15. Images of an LED cluster attached (Left) near the center of the trawl headrope on the starboard side and (Right) along the wing tip on the port side, and their orientations.

b) Effects on the bycatch of eulachon and juvenile groundfish by altering the level of artificial illumination along an ocean shrimp trawl fishing line

Investigators: Mark Lomeli, Scott D. Groth, Matthew T. O. Blume, Bent Herrmann, and W. Waldo Wakefield (ICES Journal of Marine Science, 75:2224–2234)

The authors examined how catches of ocean shrimp (*Pandalus jordani*), eulachon (*Thaleichthys pacificus*), and juvenile groundfish could be affected by altering the level of artificial illumination along the fishing line of an ocean shrimp trawl. In the ocean shrimp trawl fishery, catches of eulachon are of special concern, as the species' southern Distinct Population Segment is listed as "threatened" under the US Endangered Species Act. Using a double-rigged trawl vessel, with one trawl illuminated and the other unilluminated, catch efficiencies for ocean shrimp, eulachon, and juvenile groundfish were compared between an unilluminated trawl and trawls illuminated with 5, 10, and 20 LED fishing lights along their fishing line. The addition of artificial illumination along the trawl fishing line significantly affected the average catch efficiency for eulachon, rockfish (*Sebastes* spp.), and flatfish, with the three LED configurations each catching significantly fewer individuals than the unilluminated trawl without impacting ocean shrimp catches. For Pacific hake (*Merluccius productus*), the ten LED-configured trawl caught significantly more fish than the unilluminated trawl. For the five and 20 LED configurations, mean Pacific hake catches did not differ from the unilluminated trawl. This study contributes new data on how artificial illumination can affect eulachon catches (and other fish) and contribute to their conservation.

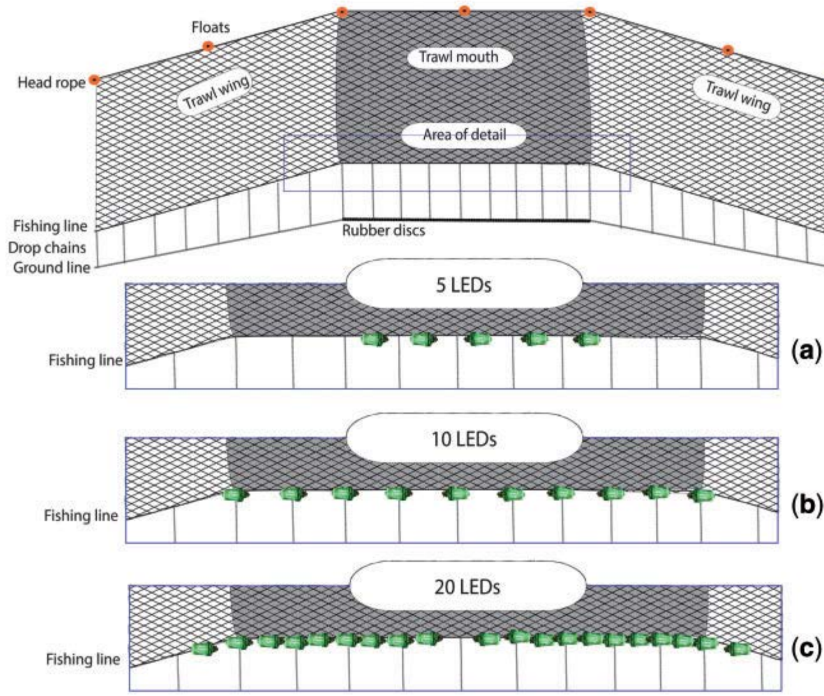

Figure 14. Schematic of an ocean shrimp trawl viewed from the front (top image) and diagrams depicting the placement and orientation of the LEDs along the trawl fishing line for the 5- (a), 10- (b), and 20-LED (c) configurations. Note: diagram not to scale.

c) Evaluating off-bottom sweeps of a U.S. West Coast groundfish bottom trawl: Effects on catch efficiency and seafloor interactions

Investigators: Mark Lomeli, W. Waldo Wakefield and Bent Herrmann

In the U.S. West Coast groundfish bottom trawl fishery, lengthy sweeps (>85 m) that maintain seafloor contact are traditionally used. While these sweeps are effective at herding groundfishes, their bottom tending characteristics increase the potential to cause seafloor disturbances, and injury and unobserved mortality to benthic organisms. In this study, we examined if changing from conventional to modified sweeps (with sections elevated 6.5 cm off bottom) would affect catch efficiency of target groundfishes and seafloor interactions. We used a DIDSON imaging sonar to observe how each sweep configuration interacted with the seafloor. An altimeter was periodically placed on the modified sweep to measure height off bottom. Results detected no significant catch efficiency effect of changing from conventional to modified sweeps. The DIDSON and altimeter data showed the modified sweeps exhibit elevated sections where infaunal and lower-profile epifaunal organisms can pass under without disturbance. Results demonstrate that seafloor interactions can be substantially reduced using elevated sweeps in this fishery without impacting catch efficiency. Further, findings from this research could be potentially applicable to other fisheries nationally and internationally.

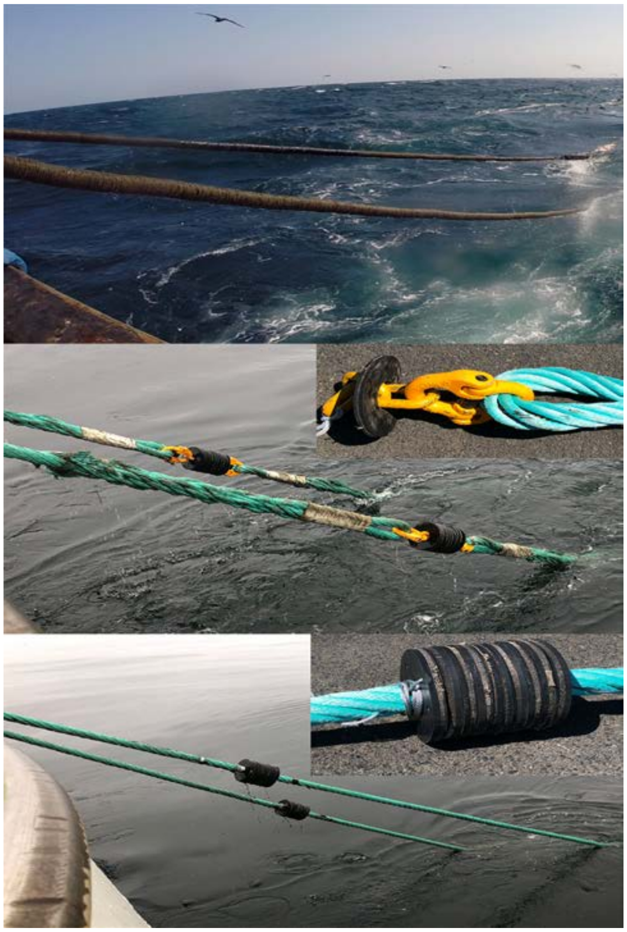

Fig. 15. Images of the conventional sweeps (top image) and the mechanisms used to attach the disc clusters to the modified sweeps (middle and bottom images).

d) Influencing the behavior and escapement of Chinook salmon out of a midwater trawl using artificial illumination

Investigators Mark J.M. Lomeli and W. Waldo Wakefield

The Pacific hake (*Merluccius productus*) midwater trawl fishery is the largest groundfish fishery off the U.S. west coast by volume. Catches comprise mainly Pacific hake, however, bycatch of Chinook salmon (*Oncorhynchus tshawytscha*) can be an issue affecting the fishery as individuals belonging to Endangered Species Act (ESA) listed Evolutionarily Significant Units are caught at times. We conducted two separate experiments evaluating the influence of artificial illumination on Chinook salmon behavior and escapement out a bycatch reduction device (BRD) in a Pacific hake midwater trawl. In Experiment 1, we tested whether Chinook salmon could be attracted out specific escape windows of a BRD equipped with multiple escape windows using artificial illumination. In Experiment 2, we compared Chinook salmon escapement rates out of the BRD between tows conducted with and without artificial illumination on the BRD to determine if illumination can enhance their escapement. Our results show that artificial illumination can influence where Chinook salmon exit out of the BRD we tested, but also demonstrate that illumination can be used to enhance their escapement overall. As conservation of ESA-listed Chinook salmon is an ongoing management priority, our research contributes new information on how artificial illumination can minimize adverse interactions between Pacific hake trawls and Chinook salmon.

e) The efficacy of illumination to reduce bycatch of eulachon and groundfishes before trawl capture in the Eastern North Pacific Ocean shrimp fishery

Investigators: Mark Lomeli, Scott Groth, Matt Blume, Bent Herrmann, and W. Waldo Wakefield

This study examined the extent that eulachon (*Thaleichthys pacificus*) and groundfishes escape trawl entrainment in response to artificial illumination along an ocean shrimp (*Pandalus jordani*) trawl fishing line. Using a double-rigged trawler, we compared the catch efficiencies for ocean shrimp, eulachon, and groundfishes between an unilluminated trawl and a trawl illuminated with 5 green LEDs along its fishing line. Results showed a significant reduction in the bycatch of eulachon and yellowtail rockfish (*Sebastes flavidus*) in the presence of LED illumination. As eulachon are an Endangered Species Act listed species, this finding provides valuable information for fishery managers implementing recovery plans and evaluating potential fishery impacts on their recovery and conservation. For other rockfishes (*Sebastes* spp.) and flatfishes, however, we did not see the same effect as the illuminated trawl caught similarly or significantly more fishes than the unilluminated trawl. Prior to this research, the extent that eulachon and groundfishes escape trawl capture in response to illumination along an ocean shrimp trawl fishing line was unclear. Our study has provided results to fill that data gap.

VI. Publications

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