Northwest Fisheries Science Center

National Marine Fisheries Service

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

April 2023

I. Agency Overview

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

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

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

During 2022, FRAMD continued to implement a West Coast observer program and expand its stock assessment, economics, and habitat research. The Southern California Hook and Line survey, and the coast wide groundfish trawl survey and a Pacific hake acoustic research cruise took place in 2022.

For more information on FRAMD and groundfish investigations, contact the Division Director, Craig Russell at Craig.Russell@noaa.gov, (206) 860 – 3402.

Other Divisions at the NWFSC are:

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

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

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

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

II. Surveys and Research Cruise

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

The NWFSC conducted its twenty-fourth annual bottom trawl resource survey for groundfish off the coasts of Washington, Oregon, and California in 2022. The objective of the 2022 survey was to provide information on the distribution and relative abundance of demersal species within this region at depths from 30 to 700 fathoms. Other biological information necessary to assess the status of groundfish stocks (e.g. length, weight, sex and age structures) was collected throughout the survey period.

The NWFSC chartered four commercial fishing vessels to conduct the survey in 2022 using standardized trawl gear. Fishing vessels Last Straw, Ms. Julie, Noah's Ark and Excalibur were contracted to survey the area from Cape Flattery, WA to the Mexican border in Southern California (Figure 1), beginning in the later part of May and continuing through October. Each charter was for a period of 11-12 weeks with the F/V Last Straw and F/V Ms. Julie surveying the coast during the initial survey period from May 16 to July 26 (Pass 1). The F/V Excalibur and F/V Noah's Ark surveyed the coast during a second pass from August 22 to October 28. Pass 1 and Pass 2 were subdivided into 4 legs to decrease the number of port calls and reduce the exposure to COVID-19. 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 2022, we continued to utilize an updated back deck data collection system with improved software applications, and wireless networking. Programming used to gather data for the groundfish survey was rewritten so that the various components were fully integrated, updated to include multiple sensor streams, and enhanced to increase flexibility for data input from special projects and future undefined data sources. The changes in the back-deck programming, wheel house programming and data QA/QC process resulted in overall improvements to data collection efficiency and anticipated future decreases in time requirements for data to be made available to the Data Warehouse. Established NOAA national bottom trawl protocols were used throughout the survey. As in prior years, a series of special research projects were undertaken in cooperation with other NOAA groups and various Universities.

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

1) Collect whole specimens of Pacific lamprey (*Entosphenus tridentatus*) > 30 cm total length – Laurie Weitkamp, NWFSC, Conservation Division, Newport, OR

2) Identify to species all river Lamprey (*Lampetra ayresii*) then collect and freeze each specimen > 30 cm total length individually – Laurie Weitkamp, NWFSC, Conservation Division, Newport;

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

3) Record sex, length, weight and collect whole specimens of Pacific white skate *(Bathyraja spinossisima)* – Moss Landing Marine Laboratories;

4) Record sex, length, weight and collect whole specimens of fine-spined skate (*Bathyraja microtrachys)* – Moss Landing Marine Laboratories;

5) Record sex, length, weight and collect whole specimens of broad skate (*Amblyraja badia*) – Moss Landing Marine Laboratories;

6) Record sex, length, weight and collect and freeze whole specimens of Pacific black dogfish (*Centroscyllium nigrum*) – Moss Landing Marine Laboratories;

7) Record sex, length, weight and collect and freeze whole specimens of velvet dog shark (*Zameus squamulosus*) – Moss Landing Marine Laboratories;

8) Record sex, length, weight and collect and freeze whole specimens of cookiecutter shark (*Isistius brasiliensis*) – Moss Landing Marine Laboratories;

9) Record sex, length, weight and collect and freeze whole specimens of any uncommon chimaeras such as North Pacific black ghost shark (*Hydrolagus melanophasma*), pointy-nosed blue chimaera (*Hydrolagus trolli*), narrownose chimaera (*Harriotta raleighana*) – Moss Landing Marine Laboratories;

10) Collect and freeze whole specimens of all unidentified or rare skates, batoids, ray, shark or chimaera – Moss Landing Marine Laboratories;

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

12) Collect DNA and whole specimens of rougheye rockfish (*Sebastes aleutianus*), blackspotted rockfish (*Sebastes melanostictus*), darkblotched rockfish (*Sebastes crameri*) and blackgill rockfish (*Sebastes melanostomus*) to reduce uncertainty in the assessment of morphologically-similar west coast rockfish – CB Division, Northwest Fisheries Science Center;

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

14) Collect voucher specimens for multiple fish species for ichthyology laboratory – Oregon State University (Peter Konstantinidis;

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, Institute of

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

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 – Joe Bizzarro, Institute of Marine Sciences and Fisheries Ecology Division, University of California, Santa Cruz and Southwest Fisheries Science Center;

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

18) Photograph, measure base and collect a small tissue sample of polyps from all species of bamboo coral (Isididae) – Carina R. Fish, University of California -Davis

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

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

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

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

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

5) Record composition and abundance of benthic marine debris collected during the 2022 West Coast Groundfish Trawl Survey;

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

7) Collect and/or photograph cold water corals;

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

9) Collect ovaries and finclips from bank, brown, copper, cowcod, blackspotted/rougheye, greenspotted, redbanded, shortbelly, widow and yellowtail rockfishes, sablefish, Dover sole and shortspine thornyhead;

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

11) Collect specimens of pyrosomes (*Pyrosoma atlanticum*) for energetics study from selected species.

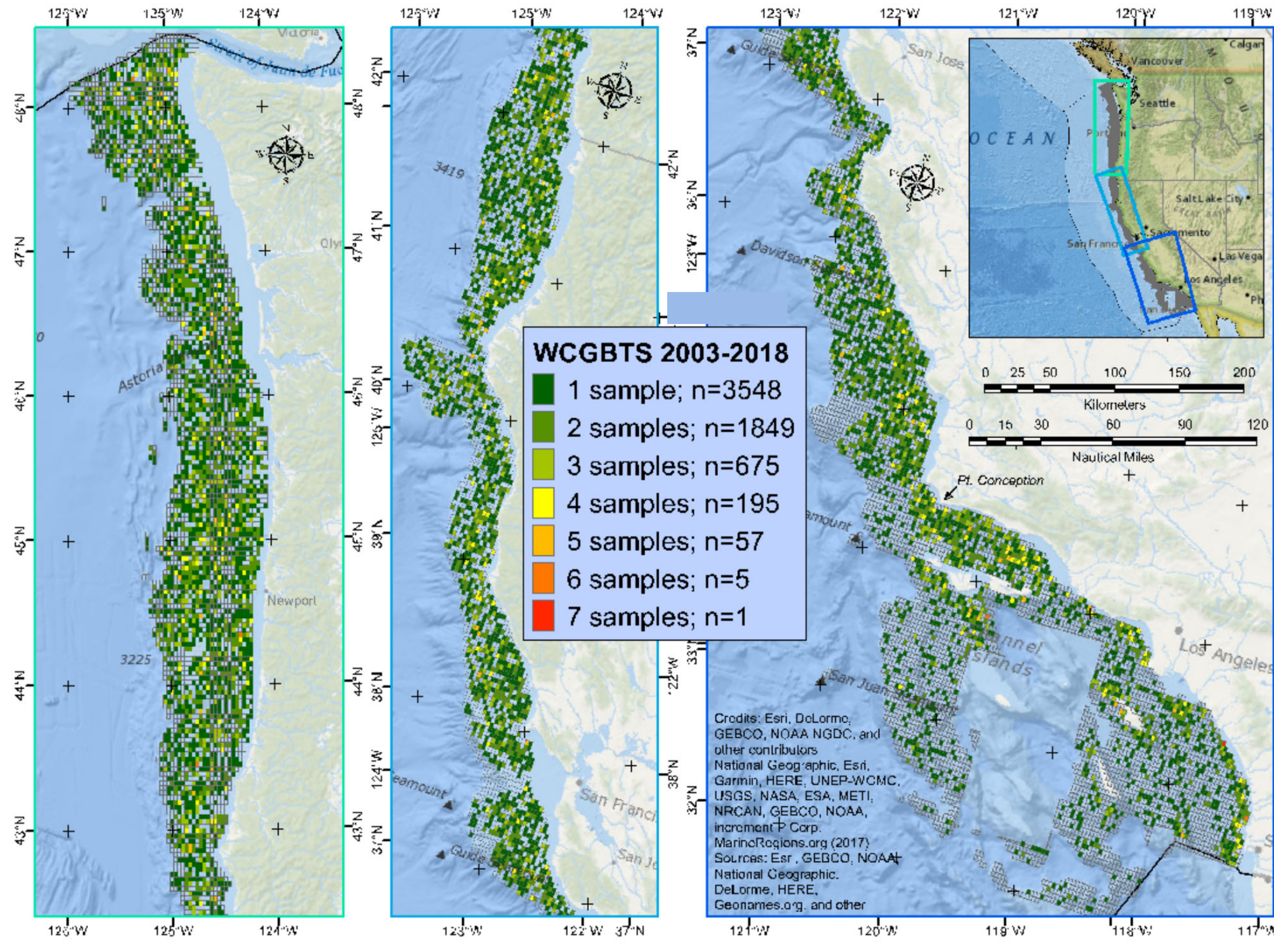


Figure 1. Summary of station locations and frequency for the West Coast Groundfish Bottom Trawl Survey 2003 to 2018.

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

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

In Fall 2022, NWFSC/FRAM conducted the 19th hook and line survey for shelf rockfish in the Southern California Bight (SCB). The survey was not conducted in 2020 due to the COVID-19 pandemic. This survey is a cooperative effort with Pacific States Marine Fisheries Commission (PSMFC) and the southern California sportfishing industry and is aimed at developing a time series of abundance and biological data for structure-associated groundfish species including bocaccio (*Sebastes paucispinis*), bank rockfish (*S. rufus*), copper rockfish (*S. caurinus*), greenspotted rockfish (*S. chlorostictus*), cowcod (*S. levis*) blue rockfish (*S. mystinus*), speckled rockfish (*S. ovalis*), the vermilion rockfish complex (e.g., *S. miniatus* and *S. crocotulus*) and lingcod (*Ophiodon elongatus*) within the SCB.

The F/V Aggressor (Newport Beach, CA), F/V Mirage (Port Hueneme, CA), and F/V Toronado (Long Beach, CA) were each chartered for 14 days of at-sea research, with 14 biologists participating during the course of the survey. During the 2022 survey, the three vessels sampled 200 of the survey's 201 fixed sites which range from Point Arguello in the north to the US-Mexico EEZ boundary in the south and in a depth range of 20 – 125 fth (37 – 229 m) (Figure 1). Sites are located inside and outside the two Cowcod Conservation Areas – two large spatial closures implemented in 2000 to help recover overfished rockfish species including cowcod (*S. levis*).

The survey caught 7,035 individual fish and collected biological data and specimens from captured individuals including 6,975 sexed lengths and weights, 4,340 age structures, and 5,804 finclips. Approximately 344 ovaries were collected from 11 different species to support the development of maturity curves and fecundity analysis. Approximately 17 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. In 2022, the survey captured individuals from 41 unique taxa including two rarely captured species: star-studded grouper (*Hyporthodus niphobles*) and whitespeckled rockfish (*Sebastes moseri*). To date, the survey has encountered at least 65 unique fish and invertebrate species. The survey continued to descend (or release at surface) and tag all individuals captured at six sites located inside federal marine reserves. Since tagging began in 2016, approximately 1,337 individuals have been tagged and released. Five individuals have been recaptured, either by the survey or by recreational anglers including a greenspotted rockfish (*S. chlorostictus*) recaptured by the survey in 2022 at the same site where it had been tagged and released in 2021.

The survey also collects information to support ecosystem-level analyses by deploying an array of oceanographic sensors to generate full water column profiles of temperature, salinity, dissolved oxygen, turbidity, and fluorescence at each site. In most years, researchers deploy an underwater video sled to capture visual observations of the seafloor for habitat analysis, species composition, and fish behavior studies, however the sled was not available in 2022 due to logistical constraints. 2022 was the fifth year of using the HookLogger wireless electronic data collection system on board survey vessels. Developed by NWFSC personnel, 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.

To date, information generated by the survey have informed 20 separate stock assessments representing 10 groundfish species and have helped monitor the rebuilding of formerly-overfished species such as bocaccio (*S. paucispinis*) and cowcod (*S. levis*). Survey data have been incorporated into at least 10 peer-reviewed publications including, within the past two years (Keller et al. 2022; Longo et al. 2022)

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

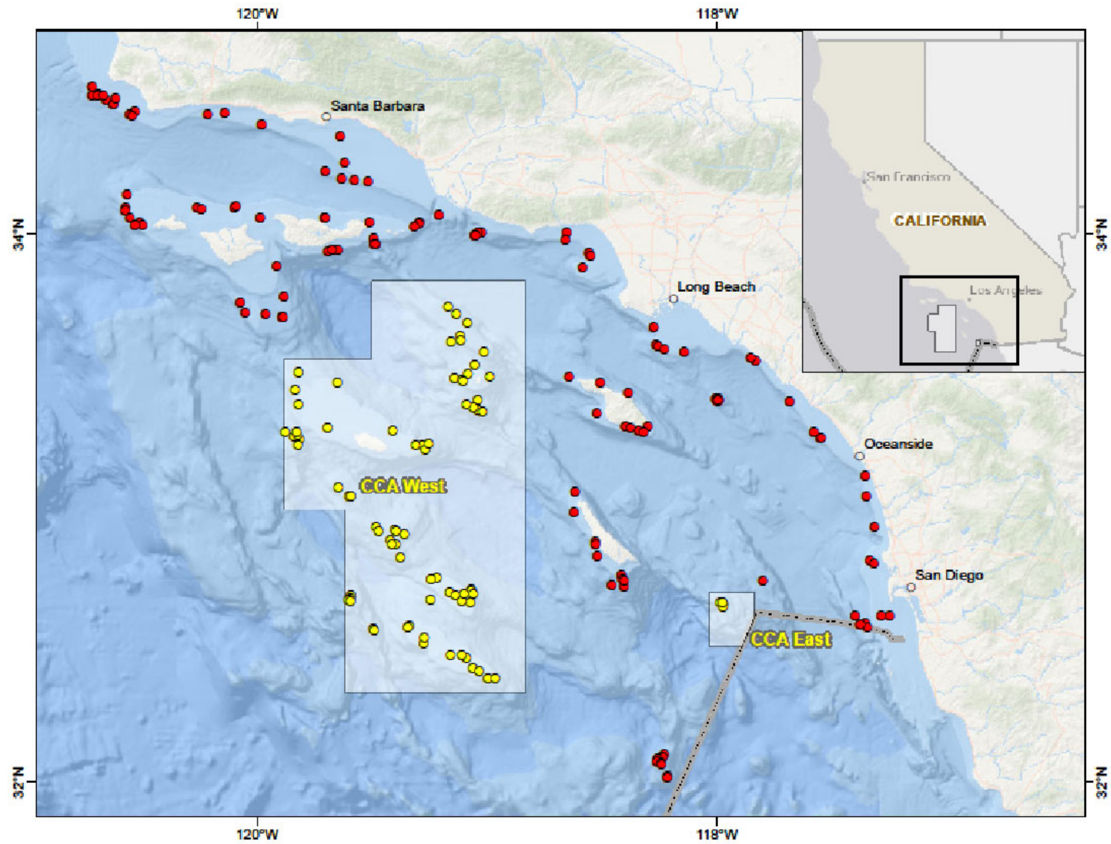


Figure 2. Sampling frame for the NWFSC Shelf Rockfish Hook and Line Survey

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

C) 2022 California Current Ecosystem (CCE22) Research Cruise: Investigations of Pacific hake ecology, survey methods, and the California Current ecosystem

The summer 2022 research cruise (CCE22) was conducted by scientists from the Northwest Fisheries Science center, Fishery Resource Analysis and Monitoring Division on the NOAA Ship Bell M. Shimada from 22 July 2022 to 25 August 2022 and, in part, by scientists from Fisheries and Oceans Canada (DFO) on the Canadian Coast Guard Ship Sir John Franklin. Scientists from the NWFSC Conservation Biology Division had a collaborative role on the Shimada with the collection of environmental DNA (eDNA) samples. The operating area of the research cruise was in U.S. waters from roughly 43.6°N (Reedsport, Oregon) to 48.1°N (Lake Ozette, Washington). Acoustic data were collected day and night with a Simrad EK80 wideband transceiver (WBT) scientific echosounder system operating at frequencies of 18, 38, 70, 120, and 200 kHz in primarily a CW (continuous wave or narrowband) pulse transmission mode.

During Leg 1, the Shimada ran 31 transects in three different research areas (A, B, and C), day and night, to acoustically classify bottom habitat into domains associated with rockfish (Sebastes sp.) and Pacific hake (*Merluccius productus*) and to investigate diel differencing methods for quantifying Pacific hake and rockfish (Figure 3). Twenty-four midwater trawls were successfully conducted. More trawls (n=17) were open codend (instead of closed) given that the net was fully deployed for the first time with a Semi-Autonomous Strobed Stereo Imager (SASSI) camera that was used not only for non-extractive trawling through dense schools with the codend open, but also for discriminating species identification (Figure 4). Overall catch weight was 1,992.5 kg of which Pacific hake, jack mackerel (*Trachurus symmetricus*), yellowtail rockfish (*Sebastes flavidus*), and Pacific herring (*Clupea pallasii*) were 76%, 9%, 7%, and 4%, respectively, of the catch.

During Leg 2, the Shimada and Franklin conducted an Intervessel Calibration (IVC) to compare acoustic backscatter data collected by both vessels from fish sign that daytime trawling verified was Pacific hake. Thirty-five transects off the Oregon coast, covering roughly 477 nm in six different areas, were run between 18 August and 23 August; analysis of acoustic data collected from both ships is ongoing, but preliminary findings indicate that there are no substantial differences in the acoustic backscatter observed by either vessel. The Shimada conducted four closed-codend midwater trawls during Leg 2; Pacific hake accounted for 95% of the 1,737.7 kg caught. The Shimada also sampled at nine stations along the Newport Hydrographic (NH) transect line with an Isaacs-Kidd Midwater Trawl Net (IKMT), a vertical plankton net, a bongo net, and/or CTD casts. Near the end of Leg 2, the Shimada ran six transects with the Simrad EK80 running in partial FM (broadband) mode to estimate sizes of krill based on scattering properties; comparison tows on krill were conducted between a Methot net and an IKMT. Tests were also conducted to examine effects that vessel speed had on noise levels in the EK80 system.

The results for the 2021 Joint U.S.–Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey were recently published as a NOAA report (de Blois et al. 2022). The report provides a brief description of the methods used in the survey and summarizes the distribution, biological composition, and biomass of hake in U.S. and Canadian waters off the Pacific coast in 2021. It also summarizes results of acoustic system calibrations and secondary survey objectives.

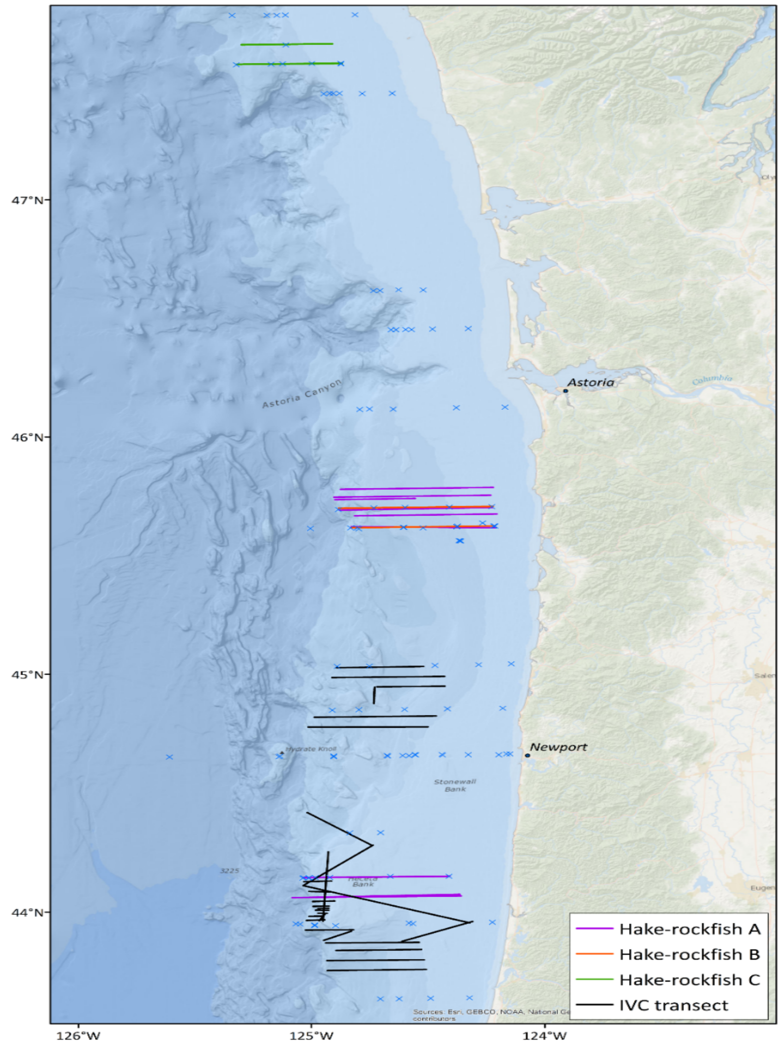


Figure 3. Acoustic transects run during the 2022 California Current Ecosystem research cruise for A) classifying bottom habitats associated with Pacific hake and rockfish, and B) conducting an Intervessel Calibration (IVC) between the NOAA Ship *Bell M. Shimada* and the CCGS *Sir John Franklin*.

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

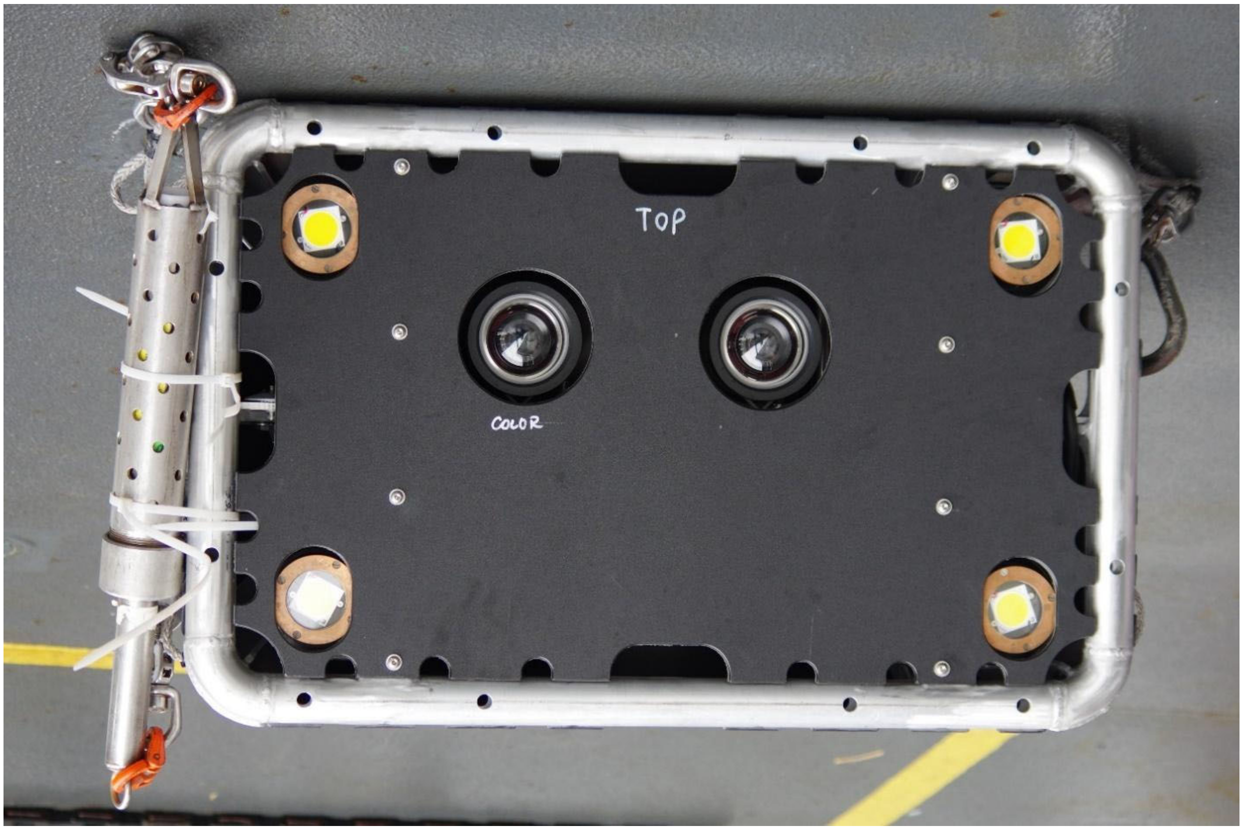


Figure 4. Photo of a Semi-Autonomous Strobed Stereo Imager (SASSI) camera used during trawling operations conducted during the 2022 California Current Ecosystem research cruise. A Sea-Bird SBE 39plus temperature and depth recorder, in its metal housing, is attached on the left side of the frame for a test run of SASSI.

III. Reserves

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

A. Hagfish

1. **No reported research occurred in 20222.**
2. **No assessment occurred in 2022**

B. Dogfish and other sharks

1. **No reported research occurred in 2022**
2. **No assessment occurred in 2022**

C. Skates

1. **No reported research occurred in 2022**
2. **No assessment occurred in 2022**

D. Pacific cod

1. **No reported research occurred in 2022**

2. **No assessment occurred in 2022**

E. Walleye Pollock

1. **No reported research occurred in 2022**
2. **No assessment occurred in 2022**

F. Pacific whiting (hake)

1. Research

a) Expecting the Unexpected: Designing the joint Pacific Hake Ecosystem and Acoustic Trawl Survey to enable sustainable fisheries management and a broader understanding of the California Current Ecosystem

Investigators: Elizabeth M. Phillips , Rebecca E. Thomas , Julia Clemons, Steve de Blois , Chelsea Stanley, and Stéphane Gauthier

The coast-wide Pacific hake (*Merluccius productus*) stock on the west coast of the US and Canada has been monitored since 1995, and since 2003 the Pacific Hake Ecosystem and Acoustic Trawl (PHEAT) Survey has been conducted by scientists at NOAA's National Marine Fisheries Service (NMFS), Northwest Fisheries Science Center (NWFSC) and Fisheries and Oceans Canada (DFO). The success of this large scale joint survey is due to a shared understanding of goals and data priorities for stock assessment under the International Hake Treaty, cooperative planning between NMFS and DFO scientists, and built-in flexibilities that ensure a complete survey of the Pacific hake stock between southern California and Dixon Entrance, Alaska. A key attribute of the survey is its two-vessel design, which provides the ability to survey the full geographic area and flexibility in the event that ship time is limited or one ship becomes unavailable. However, the modularity created by using multiple vessels requires additional considerations to ensure that data collected on different ships are comparable and can be combined for use in the stock assessment. We describe the timeline of the PHEAT Survey from its inception and provide examples of how the survey design accommodates within-survey changes, such as dropping regularly-spaced transects, as well as longer-term change such as shifting the boundaries and starting location of the survey, and how this impacts the time series. Finally, we describe how this flexibility has enabled a broader understanding of the California Current Ecosystem through expanded data collections and collaborations that maximize limited days at sea.

Frontiers in Marine Science Special Issue - Design Change to Fishery Independent: When to Adjust and How to Account For It

For more information, please contact Beth Phillips at beth.phillips@noaa.gov

b) Attributes of the U.S.-Canada Integrated Ecosystem and Acoustic Trawl Survey for Pacific hake that contribute to successful fisheries management, ecosystem monitoring, and expanded collaborations

Investigators: Elizabeth Phillips, Rebecca Thomas, Julia Clemons

ICES WKUSER2 Abstract: The Pacific Hake/Whiting Treaty was signed in 2003, and the joint U.S.-Canada Integrated Ecosystem and Acoustic Trawl Survey for Pacific hake has been led since then by scientists from Canada's Department of Fisheries and Oceans (DFO) and NOAA Fisheries Northwest Fisheries Science Center's (NMFS) newly formed Fisheries Engineering and Acoustic Technologies team. The coast-wide stock assessment survey is conducted biennially in odd years, and biomass estimates are provided to stock assessors working under the joint treaty. An additional stock assessment survey was also conducted in 2012 due to high uncertainty in the 2009 and 2011 assessments. During even years, research cruises are conducted to improve and expand survey capabilities, refine acoustic species discrimination and classification, and address Scientific Review Group (SRG) requests aimed at improving the stock assessment.

The success of this joint survey and management approach is due in large part to cooperation between scientists and managers from NMFS and DFO, which allows for a flexible survey design and greater ability to combine surveys and deal with data gaps. This includes coordinated survey and research planning throughout the year, open and transparent communication between NMFS and DFO survey and stock assessment scientists, and built-in modularities that ensure complete surveys of the entire coastal Pacific hake stock. A key attribute of the joint U.S.-Canada Integrated Ecosystem and Acoustic Trawl Survey for Pacific hake is its two-vessel design, which allows for the entire area from southern California to Dixon Entrance, Alaska to be surveyed in approximately 3 months between June and September. The survey consists of 10-nmi spaced transects along most of the coast, covering ~221,000 km^2 , and the two-vessel design overcomes limitations in days-at-sea allocations for each survey team, which typically are not enough to cover the full geographic area in the required time window. By splitting the survey effort between two vessels, one led by NMFS and one led by DFO, the spatiotemporal resolution of the sampling, including transect spacing, is less likely to be sacrificed. Furthermore, the use of two vessels allows for coordination of geographic coverage by vessel, including interleaving transects to increase efficiency, and flexibility in the northern and southern survey extent. The two-vessel design also provides flexibility in the event that either vessel becomes unavailable. Because both countries are committed to covering the entire geographic area without prioritizing work in their country waters over the other country, scientists can effectively collaborate on operations to ensure survey goals are met when ship time is limited or a ship becomes unavailable. For example, in 2021 survey scientists from NMFS and DFO coordinated efforts to maximize transect resolution to ensure complete geographic coverage when DFO's vessel became unavailable, resuming the original survey design after another DFO vessel was identified.

A critical component of combining data from two platforms is an inter-vessel calibration (IVC) to ensure that the data collected by each vessel are comparable and not biased. Each time a new vessel is used by either country, an IVC must be performed. In 2019 the CCGS Sir John Franklin became the primary survey platform for DFO, although mechanical issues and the COVID pandemic prevented use of this vessel until 2022, when a 7-day IVC was

conducted to combine data with NOAA Ship Bell M. Shimada. The IVC involved both vessels operating in close proximity, side-by-side, collecting simultaneous acoustic data from the same area to compare hake Nautical Area Scattering Coefficient (NASC) across multiple hake aggregation sizes and water depths. This involved constant communication between the vessels, and close coordination of transect and fishing efforts. Data sharing during the IVC and all survey effort is another important component of the joint survey, and applies to echo sounder calibration, data acquisition at-sea, expert scrutinized and judged echogram data exports, and the hake biomass estimate that is provided to stock assessment scientists. NMFS and DFO scientists coordinate acoustic and trawl data sharing throughout and after each survey, making data processing and biomass estimation efficient and collaborative. Furthermore, scientists from both groups have laid out clear priorities in terms of data requirements, making it easier to prioritize decisions related to survey effort and design that may impact data acquisition and quality. Open discussions about maximizing at-sea data collections have also led to broader ecological sampling and monitoring, including oceanographic data collections during nighttime operations when trawling operations are not occurring. This coordinated approach also facilitates expanded collaborations within NMFS and DFO programs, and with external partners that are expanding our ability to provide data to multiple stakeholders.

For more information, please contact Beth Phillips at Beth.Phillips@noaa.gov

c) Stage-specific drivers of Pacific hake (*Merluccius productus*) recruitment in the California Current Ecosystem

Investigators: C.D. Vestfals, K.N. Marshall, N. Tolimieri, M.E. Hunsicker, A.M. Berger, I.G. Taylor, M.G. Jacox and B.D. Turley

Understanding environmental drivers of recruitment variability in marine fishes remains an important challenge in fish ecology and fisheries management. We developed a conceptual life-history model for Pacific hake (*Merluccius productus*) along the west coast of the U.S. and Canada to generate stage-specific and spatiotemporally-specific hypotheses regarding the oceanographic and biological variables that likely influence their recruitment. Our model included seven life stages from pre-spawning female conditioning through pelagic juvenile recruitment (age-0 fish) for the coastal Pacific hake stock. Model-estimated log recruitment deviations from the 2020 hake assessment were used as the dependent variable, with predictor variables drawn primarily from a regional ocean reanalysis for the California Current Ecosystem. Indices of prey and predator abundance were also included in our analysis, as were predictors of local- and basin-scale climate (Figure 5). Five variables explained 59% of the recruitment variability not accounted for by the stock-recruitment relationship in the hake assessment. Recruitment deviations were negatively correlated with May – September eddy kinetic energy between 34.5° and 42.5°N, the North Pacific Current Bifurcation Index, and Pacific herring (*Clupea pallasii*) biomass during the spawner preconditioning stage, alongshore transport during the yolk-sac larval stage, and the number of days between storm events during the first-feeding larval stage. Other important predictors included upwelling strength during the preconditioning stage, the number of calm periods during the first-feeding larval stage, and age-1 hake predation on age-0 pelagic juveniles. These findings suggest that multiple mechanisms affect Pacific hake survival across different life stages, leading to variability in population-level recruitment. *Fisheries Oceanography.*

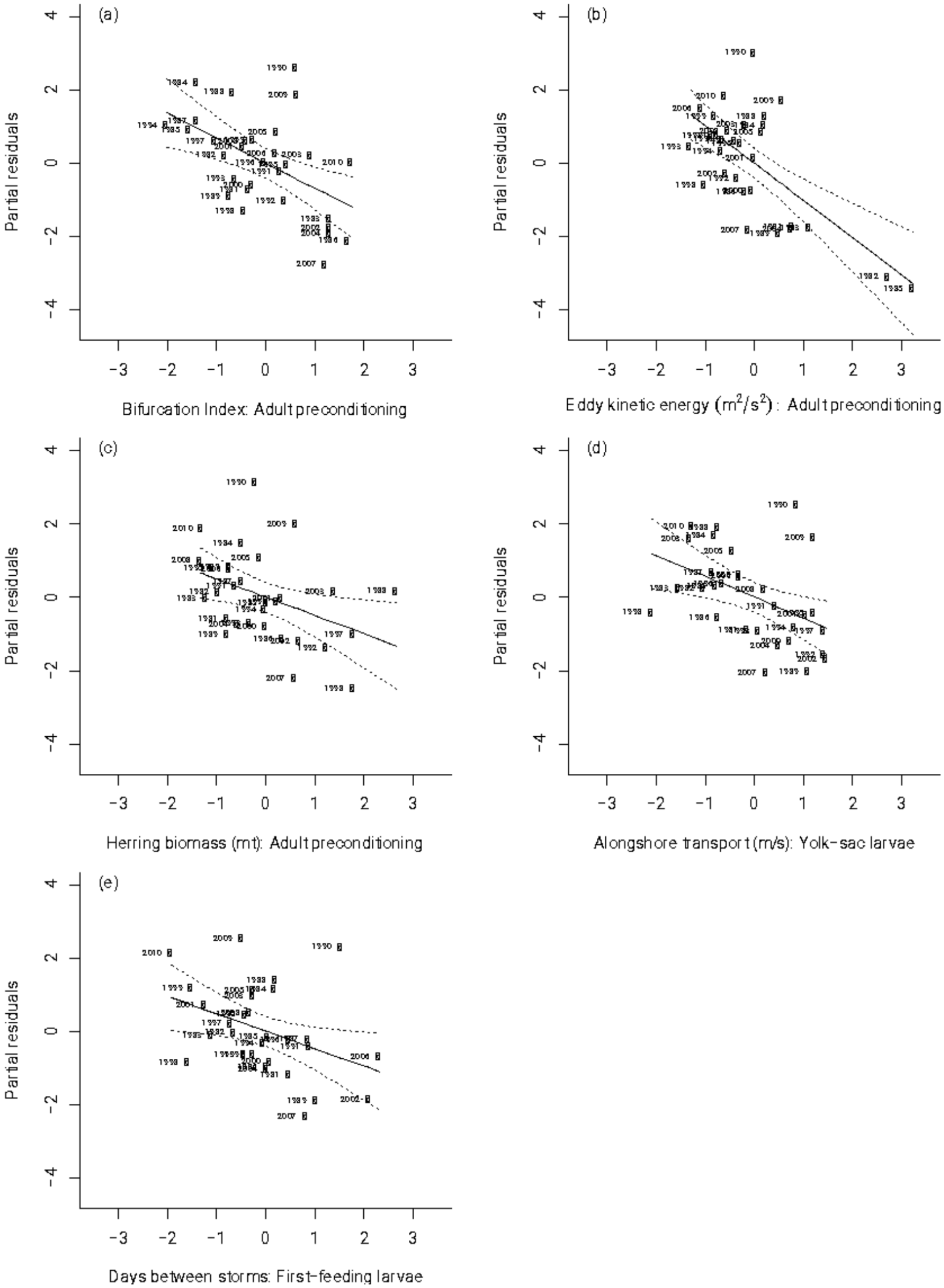


Figure 5. Partial residual plots of predictor variables in the the AIC-best model of Pacific hake (*Merluccius productus*) recruitment: (a) the bifurcation index, (b) May – September eddy kinetic energy (EKE) between 34.5° and 42.5°N, and (c) Pacific herring (*Clupea pallasii*) biomass off the west coast of Canada during the adult female preconditioning stage, (d) alongshore transport during the yolk-sac larval stage, and (e) number of days between storm events during the first-feeding larval stage.

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

d) Using spatio-temporal models to provide compositional data for acoustic surveys: facilitating autonomous vehicle sampling and inferences on non-target species in a fishery resource survey program

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

To estimate fish biomass-at-age with an acoustic survey, compositional (i.e., size, age) data must be paired with acoustic data. Accordingly, considerable effort is expended to collect biological samples of the species or species complex of interest in most fishery resource survey programs. This limits the use of acoustic data collected by alternative platforms (e.g., autonomous vehicles) or surveys focused on non-target species for generating biomass-at-age indices for the stock assessment of a target species, even if the target species can reliably be identified in the acoustic data. However, it might be possible to estimate compositional data with spatio-temporal models fit to datasets that are independent of the acoustic survey. To test the ability of spatio-temporal models to provide compositional data for acoustic surveys, we conducted a case study with Pacific Hake (*Merluccius productus;* 'hake') on the U.S. West Coast. We generated compositional data with a vector-autoregressive spatio-temporal (VAST) model fit to a combination of fishery-dependent and fishery-independent data that were independent of the hake acoustic trawl (AT) survey. The performance of the VAST model was assessed with simulation testing and comparisons between VAST estimates of age composition and those from midwater trawls in the hake AT survey. The challenges we encountered when fitting the VAST model to a relatively rich dataset (e.g., data coverage, age class resolution, model stability in simulation testing) indicated that this approach may not be suitable in all situations, but our model produced estimates of age composition that were reasonably comparable to midwater trawls (+/- ~ 10% overall, +/- ~ 2% in data-rich regions). Our approach allows us to use acoustic data collected in a Saildrone survey and survey targeting coastal pelagic species to estimate hake biomass-at-age, which could yield a dramatic increase in the amount of data used to understand hake biomass distribution. Ultimately, the ability to differentiate species in the acoustic data and the potential for differences between survey platforms remain major hinderances to using estimates derived from this approach in a stock assessment, but ongoing research is addressing these challenges (e.g., development of machine learning algorithms, broadband acoustics research, inter-vessel comparisons). In an increasingly challenging funding environment, using spatio-temporal models to provide compositional data for acoustic surveys could allow survey programs to maintain historical coverage or leverage acoustic data from other survey programs, ships of opportunity, and autonomous vehicles to expand coverage. *ICES conference.*

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

e) Spatiotemporal variability of euphausiids in the California Current Ecosystem: insights from a recently developed time series

Investigators: Elizabeth M Phillips, Dezhang Chu, Stéphane Gauthier, Sandra L Parker-Stetter, Andrew O Shelton, Rebecca E Thomas

Euphausiids, or krill, are important energy links between primary producers and higher trophic levels in the California Current Ecosystem (CCE), but a thorough understanding of their variability at the coast-wide scale is limited. Using fisheries acoustics data collected during biennial joint US–Canada Integrated Ecosystem and Acoustic Trawl Surveys for Pacific hake (*Merluccius productus*) (Figure 6), we developed a time series (n = 8 years; 2007–2019 odd years inclusive, and 2012) of krill abundance and examined relationships with environmental factors (Figure 7). Krill were located in waters off the west coasts of the United States and Canada, primarily in shallow basins and on the continental shelf, with greatest kernel density estimates near Cape Mendocino and the Juan de Fuca eddy system. Coast-wide krill abundance was variable, and lowest in 2015 during an extended marine heat wave, when 91% were located in British Columbia. Using hierarchical generalized additive models, we predicted greatest krill abundance in cooler waters (0.2◦C below the time series average), within 10–20 km of the shelf break, and in bottom depths between 200 and 400 m. This newly developed coast-wide time series of krill abundance and distribution will inform ecosystem-based fisheries management efforts, and offers additional opportunities for studies of krill-dependent fish, seabirds, and marine mammals.

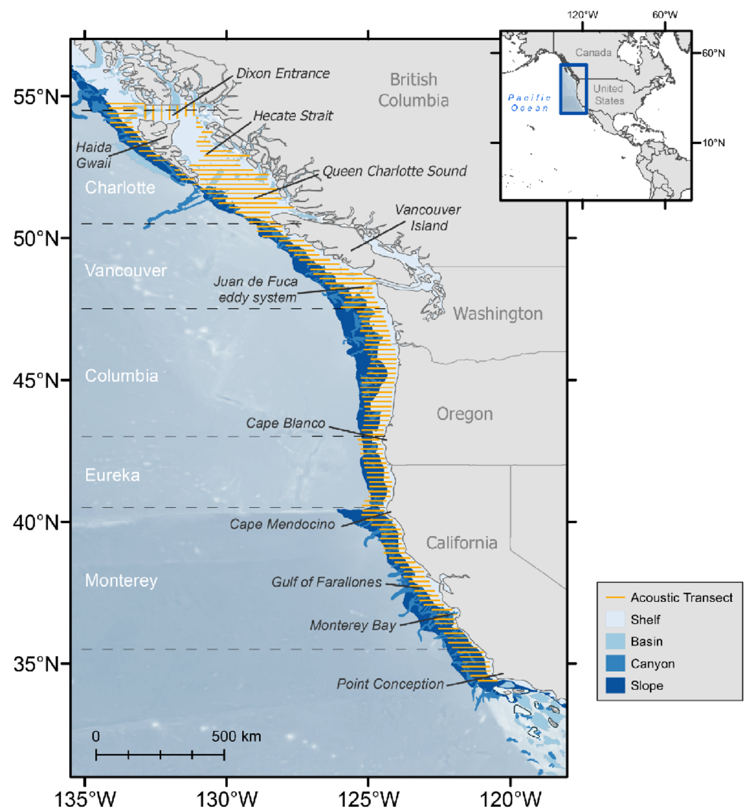


Figure 6. Study area along the west coast of the United States and Canada displaying bathymetric features and acoustic transect locations for a typical survey. Continental shelf habitat classifications are based on relief, from Harris *et al.* (2014). International North Pacific Fishery Commission (INPFC) geographical areas are labelled and separated by latitude with dashed lines.

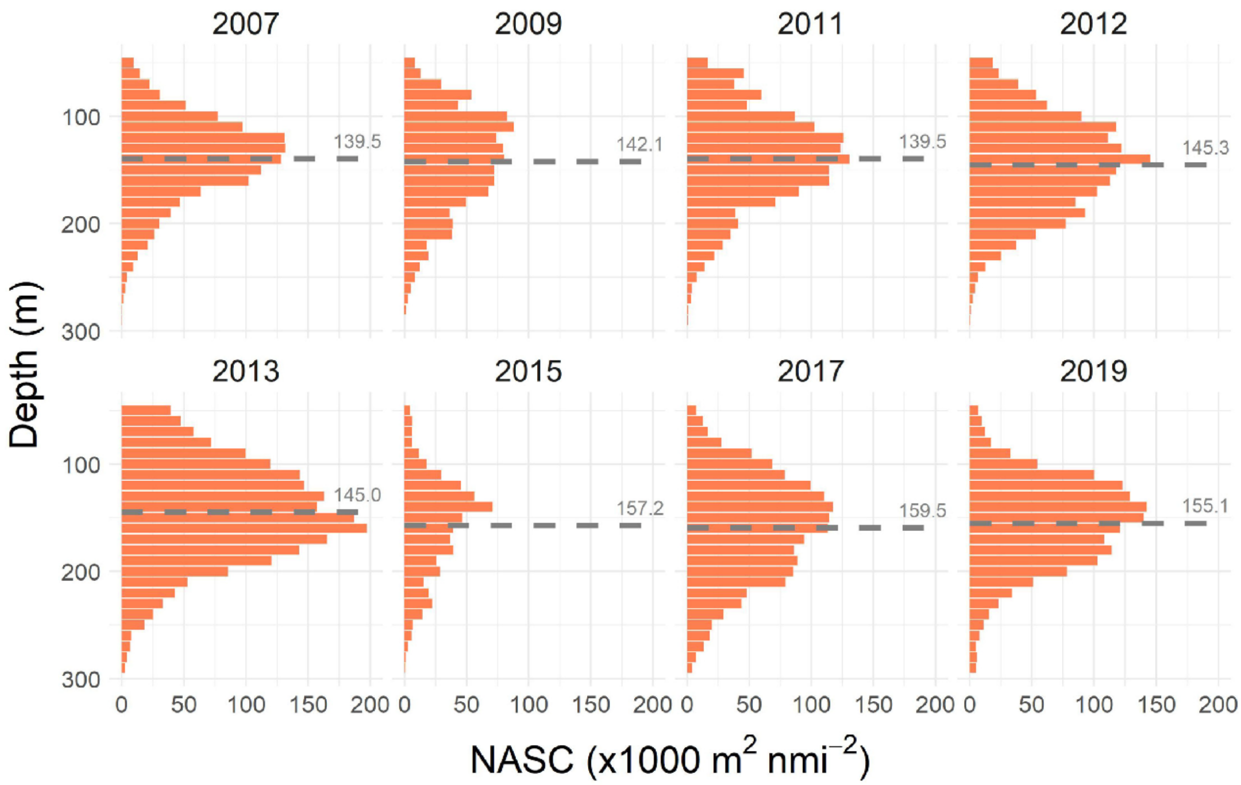


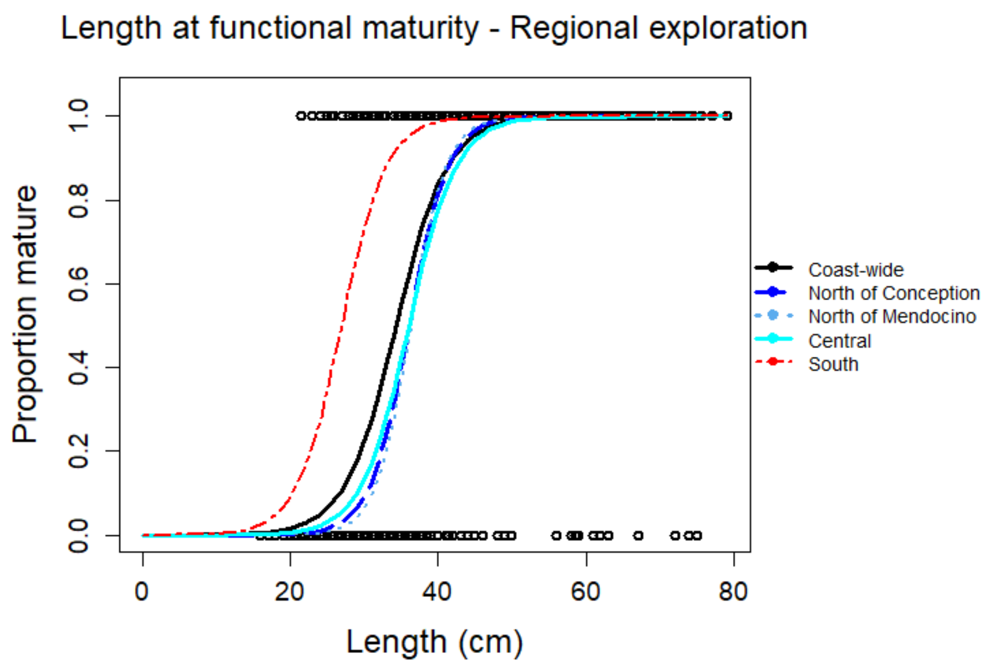
Figure 7. Annual depth distribution of krill abundance (NASC) in the 8-year time series. Data are presented in 10-m vertical depth bins. Labelled dashed lines indicate the weighted mean depth of krill within each year.

For more information, please contact Beth Phillips at Beth.Phillips@noaa.gov

f) Spatio-temporal variability in Pacific Hake maturity and reproductive strategies along the U.S. West Coast

Investigator: Melissa Head

Pacific Hake, *Merluccius productus*, is the most abundant groundfish in the California Current Large Marine Ecosystem, and therefore plays a vital role in sustaining marine ecosystems and fish communities. This species is subject to intense fishing pressure with boom and bust recruitment years. Thus, it is vital for fisheries management models to accurately reflect population trends that inform model parameters. The size or age a fish reaches maturity and the rate the mature adult population fails to spawn in a given year are essential to capture accurately in population dynamic models. We studied Pacific Hake's reproductive strategy from 2009 to 2021 and collected samples throughout their coastal range (53° 37' – 32° 38' N) to unravel the complex reproductive behaviors they exhibited over the last century. We uncovered spatio-temporal variability in size and age at maturity (Figure 8), a unique spawning strategy that includes a protracted spawning season with multiple egg batches (i.e. indeterminate batch spawners). We discovered significant differences in biological (physiological) and functional (spawners in a given year) length and age at maturity North (35.84 – 36.09 cm, 2.47 – 2.56 yrs) and South (26.79 – 27.00 cm, 1.45-1.46 yrs) of Pt. Conception, CA (34°26' N). North of Pt. Conception females reached maturity at a larger size (~9 cm longer) and greater age (~ 1 year older). We found interannual variability in size and age at functional maturity coast-wide (29.89 – 37.89 cm, 1.93 – 3.24 yrs) and in the North (34.03 – 38.24 cm, 2.04 – 3.29 yrs). In addition, we observed Pacific Hake spawning throughout the year and along the entire coast (52° 16' - 32° 39' N), which extended earlier reports of peak spawning occurring January – February South of Cape Mendocino, CA. Finally we used two methods to estimate biological and functional maturity: GLM (standard logistic) and a cubic spline (flexible asymptotic approach). Both methods produced similar 50% maturity estimates, but the cubic spline approach indicated a decrease in age and length at maturity for the adult population. This study informs Pacific Hake management and suggests a need to incorporate spatio-time varying rates of maturity into population dynamic models and a re-evaluation of basic life history assumptions for this species.



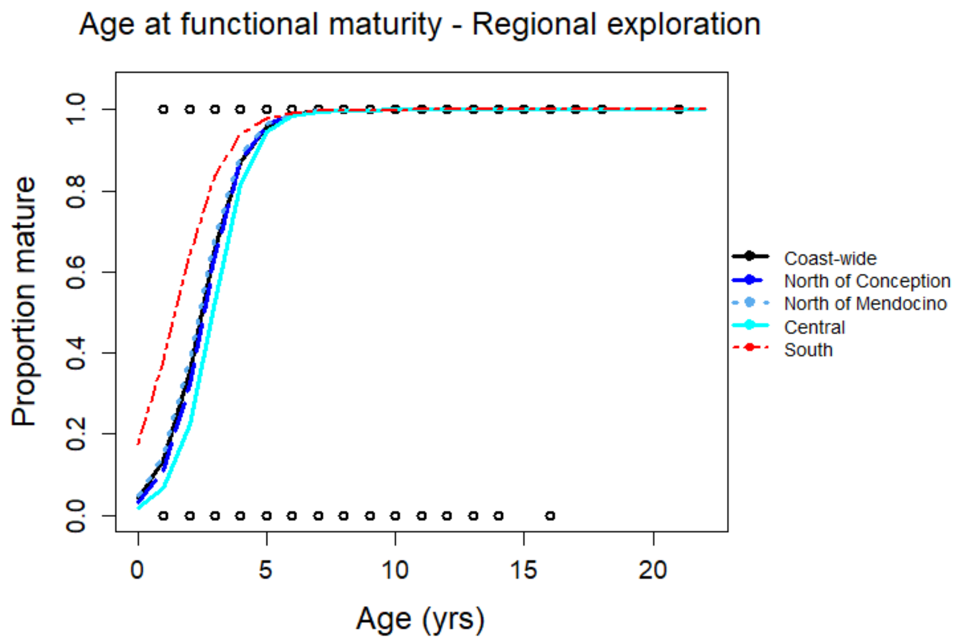


Figure 8. Length (top panel) and age (bottom panel) at functional maturity using the standard logistic GLM for regions: North of Pt. Conception (blue long-dash line), North of Cape Mendocino (steel blue dotted line), Central coast (cyan solid line), and South of Pt. Conception (red two-dash line) and coast-wide (black solid line) for all years sampled.

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

2. Assessments

a) Status of the Pacific (whiting) stock in U.S. and Canadian waters in 2023

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

This stock assessment reported the collaborative efforts of the official U.S. and Canadian Joint Technical Committee members in accordance with the Agreement between the government of the U.S. and the government of Canada to assess the status of the coastal Pacific Hake (or Pacific whiting, *Merluccius productus*) resource off the west coast of the U.S. and Canada for 2023. Coast-wide fishery landings of Pacific hake averaged 243 thousand Mt from 1966 to 2021, with a low of 90 thousand mt in 1980 and a peak of 441 thousand mt in 2017. Prior to 1966 the total removals were negligible relative to the modern fishery. Recent coast-wide landings from 2018–2022 have been above the long-term average, at 371 thousand Mt, with U.S. and Canadian catches averaging 297 thousand Mt and 74 thousand Mt, respectively. In the 2022 catch, the 2020 cohort was represented the most (33%), followed by the 2016 cohort (24%), then the 2014 (16%) and 2017 (9%) cohorts. The Agreement between the U.S. and Canada establishes U.S. and Canadian shares of the coast-wide TAC at 73.88% and 26.12%, respectively.

Data were updated for the 2023 assessment with the addition of the 2022 fishery catch and age-composition data, weight-at-age data for 2022, and minor changes to pre-2021 data. The assessment used Bayesian methods to incorporate prior information on four key parameters (natural mortality, M, steepness of the stock-recruitment relationship, h, and two Dirichlet data weighting parameters for fishery and survey age compositions) and integrate over parameter uncertainty to provide results that can be probabilistically interpreted. The exploration of uncertainty was not limited to parameter uncertainty as structural uncertainty was investigated through sensitivity analyses. Pacific Hake displays the highest degree of recruitment variability of any west coast groundfish stock, resulting in large and rapid changes in stock biomass. This volatility, coupled with a dynamic fishery, which potentially targets strong cohorts resulting in time-varying selectivity, and little data to inform recent recruitment, will, in most circumstances, continue to result in highly uncertain estimates of current stock status and even less-certain projections of future stock trajectory. Uncertainty in the results of this assessment is largely a function of the potentially above-average 2020 year-class, the lack of data informing recruitment in 2021 and 2022, uncertain selectivity, and uncertainty about historical equilibrium conditions prior to or in the absence of fishing. Short-term forecasts are very uncertain because recruitment is a main source of uncertainty in the projections.

Estimates from the 2023 base model indicate that since the 1960s, Pacific Hake female spawning biomass has ranged from well below to near unfished equilibrium biomass. The stock was estimated to have been below the unfished equilibrium in the 1960s before increasing rapidly to above unfished equilibrium in the mid-1970s and mid-1980s, followed by steady decline through the 1990s to a low in 1999. This long period of decline was followed by a brief peak in 2002 as the large 1999 year-class matured and subsequently supported the fishery for several years. Estimated female spawning biomass declined to a time-series low of 0.619 million Mt in 2010 because of low recruitment between 2000 and 2007, along with a declining 1999 year-class. Spawning biomass estimates peaked again in 2013 and 2014 due to a very large 2010 year-class and an above-average 2008 year-class. The subsequent decline from 2014 to 2016 is primarily from the 2010 year-class surpassing the age at which gains in weight from growth are greater than the loss in weight from mortality (growth-mortality transition). The 2014 year-class is estimated to be large, though not as large as the 1999 and 2010 year classes, increasing the biomass in 2017. The estimated biomass was relatively steady from 2017 to 2019, and then declined in 2020 and 2021 due to the 2014 and 2016 year classes moving through the growth-mortality transition during a period of high catches. The increase in female spawning biomass since 2021 is due to the expected above average 2020 cohort entering the maturity and the recent declining trend in catch. The 2023 female spawning biomass is estimated to be 104% of the unfished equilibrium level (B_0) with a 95% posterior credibility interval ranging from 42% to 300%. The median estimated 2023 female spawning biomass is 1.42 million Mt. Uncertainty in current stock status is considerable, largely due to the lack of information about recent recruitment.

The fishing intensity on the Pacific Hake stock is estimated to have been below $F_{SPR=40\%}$ in all years, with the median estimate for 1999 being only slightly below (95% of $F_{SPR=40\%}$). Fishing intensity has been considerably below $F_{SPR=40\%}$ since 2012 and has been decreasing over the last 5 years (from 69% in 2018 to 51% in 2022). The official coastwide total catch target adopted by the U.S. and Canada has not been exceeded since 2002. Recent catch and levels of depletion are presented in Figure 9.

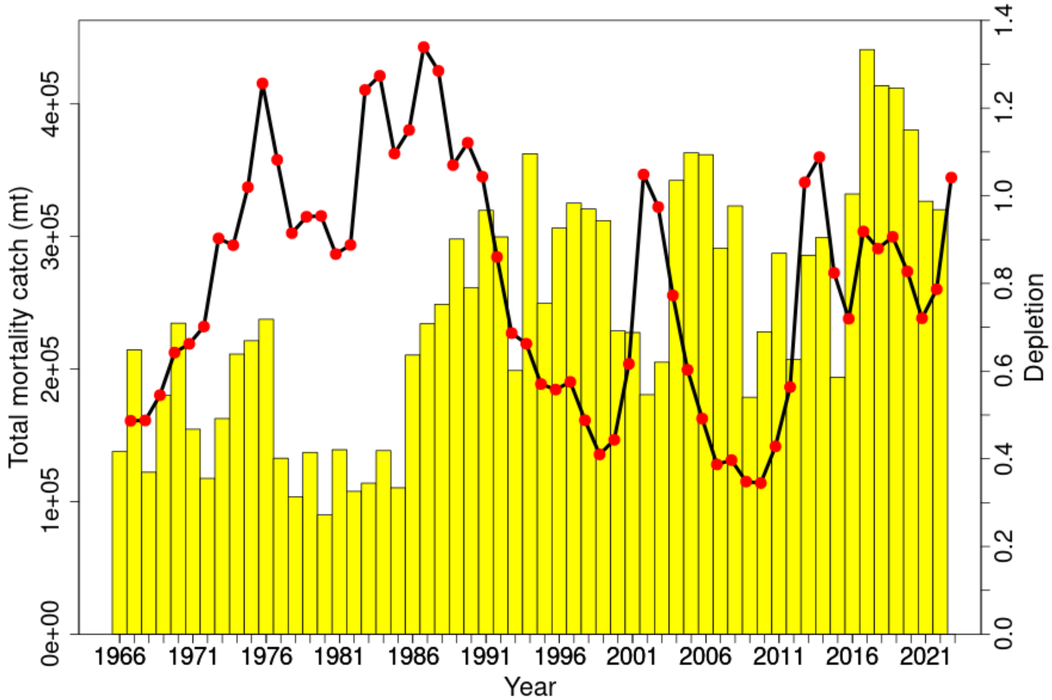


Figure 9. Total catch (mt; bars) and depletion (relative to average unexploited equilibrium level; line) for Pacific hake, 1966-2022.

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

3. Management

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

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

The environmental conditions that marine populations experience are being altered because of climate change. In particular, changes in temperature and increased variability can cause shifts in spatial distribution, leading to changes in local physiological rates and recruitment success. Yet, management of fish stocks rarely accounts for variable spatial dynamics or changes in movement rates when estimating management quantities such as stock abundance or maximum sustainable yield. To address this concern, a management strategy evaluation (MSE) was developed to evaluate the robustness of the international management system for Pacific hake, an economically important migratory stock, by incorporating spatio-temporal population dynamics. Alternative hypotheses about climate-induced changes in age-specific movement rates, in combination with three different harvest control rules (HCR), were evaluated using a set of simulations that coupled single-area estimation models with alternative operating models representing spatial stock complexity. Movement rates intensified by climate change caused a median decline in catches, increased annual catch variability, and lower average spawning biomass (Figure 10). Impacts varied by area and HCR, underscoring the importance of spatial management. Incorporating spatial dynamics and climate change effects into management procedures for fish stocks with spatial complexity is warranted to mitigate risk and uncertainty for exploited marine populations. *ICES Journal of Marine Science*.

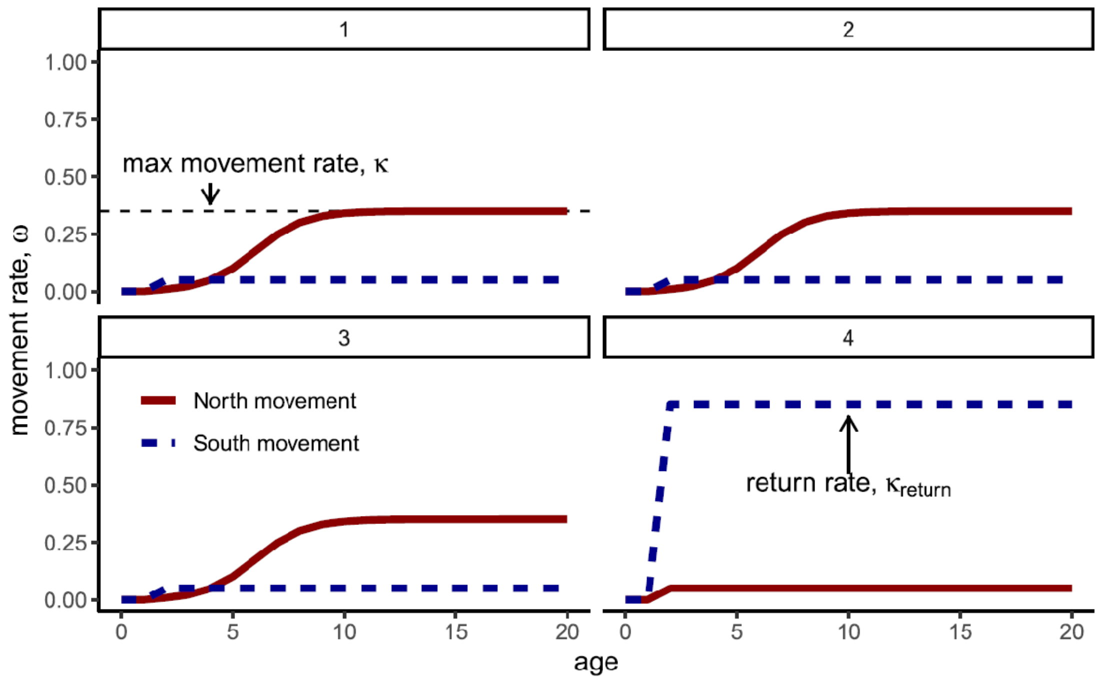


Figure 10. Movement rates as a function of age and season in the OM. Full lines indicate the fraction of the population moving into Canadian waters (red), and the dashed lines represent the fraction of fish into US waters (blue). The number above each plot represents the season. The OM is an age-based model with movement occurring between spatial areas i, Canada (i = 1) and the United States (i = 2), and across seasons t (four seasons per year evenly divided) and years y.

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

b) Dynamic reference points – gauging how you got to where you are today

Investigator: A.M Berger

Mentorship is an intentional structured engagement that can result in (among other things) the transfer of institutional knowledge and perspectives, often having a multiplicative effect on scholarship, over time. I present some of the key pedagogical effects of Dr. Michael Jones mentorship (e.g., relating to closed-loop adaptive management models, non-stationary population dynamics, ecosystem/climate shifts, and quantifying system uncertainties) that have collectively shaped recent research, and then highlight these using a case example. In particular, a Pacific Hake (*Merluccius productus*) management strategy evaluation modeling framework was used to explore methods to dynamically incorporate changes (or shifts) in stock productivity over time into existing adaptive management procedures. The incorporation of dynamic reference points into alternative harvest control rules were evaluated, and tradeoffs were examined between different fishing- and biomass-based reference points. While accounting for productivity shifts in fisheries management plans seems best practice, there can be unintended and counter-intuitive consequences when reference points and harvest control rules are not carefully designed and simulation tested. Gauging where you are at often relies on where you have come from, and both are critical to understanding where you are going. This is as true for managing fish stocks as it is for educating (and mentoring) the next generation of stock assessment scientists. *American Fisheries Society Annual Meeting.*

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

G. Grenadiers

1. **No reported research occurred in 2022**
2. **No assessment occurred in 2022**

H. Rockfish

1. Research

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

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

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

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

b) A tale of two species: vermilion and sunset rockfish in the Southern California Bight

Investigators: Aimee A. Keller, John H. Harms, Anna Elz, John R. Wallace, Jim A. Benante, Aaron Chappell

The vermilion rockfish complex consists of two distinct species, vermilion rockfish (*Sebastes miniatus*) and sunset rockfish (*S. crocotulus*) with clear haplotypic differences. Due to a one-way mitochondrial introgression from vermilion into sunset rockfish a high proportion (20-30%) of fish with a vermilion haplotype are characterized as sunset based on nuclear genotype (introgressed sunset, hereafter, introgressed). Here we examined differences in the distribution and biological attributes of vermilion and sunset rockfish (including introgressed individuals) collected during a fisheries independent groundfish survey conducted with hook and line gear in the Southern California Bight in 2014. We saw significant differences in spatial distribution (latitude, depth, and distance from the nearest port and mainland) and biological characteristics (average size, size frequency distribution, weight-length and size-depth relationships) between vermilion rockfish and both introgressed and sunset rockfish but no differences between sunset and introgressed fish. Our analyses established that introgressed and sunset rockfishes shared similar biological and geographic characteristics, with no significant differences based on the features we examined. Consequently, we explored the relationship between the catch of vermilion rockfish collected per site, relative to the combined presence of vermilion, introgressed and sunset rockfishes, and a suite of co-located environmental and geographic variables using binomial generalized additive models (GAMS). The best model explained 95.0% of the deviance, indicating that the occurrence of vermilion, introgressed, and sunset rockfishes depended on latitude, longitude, depth, dissolved oxygen, temperature and distance from port (Figure 11).

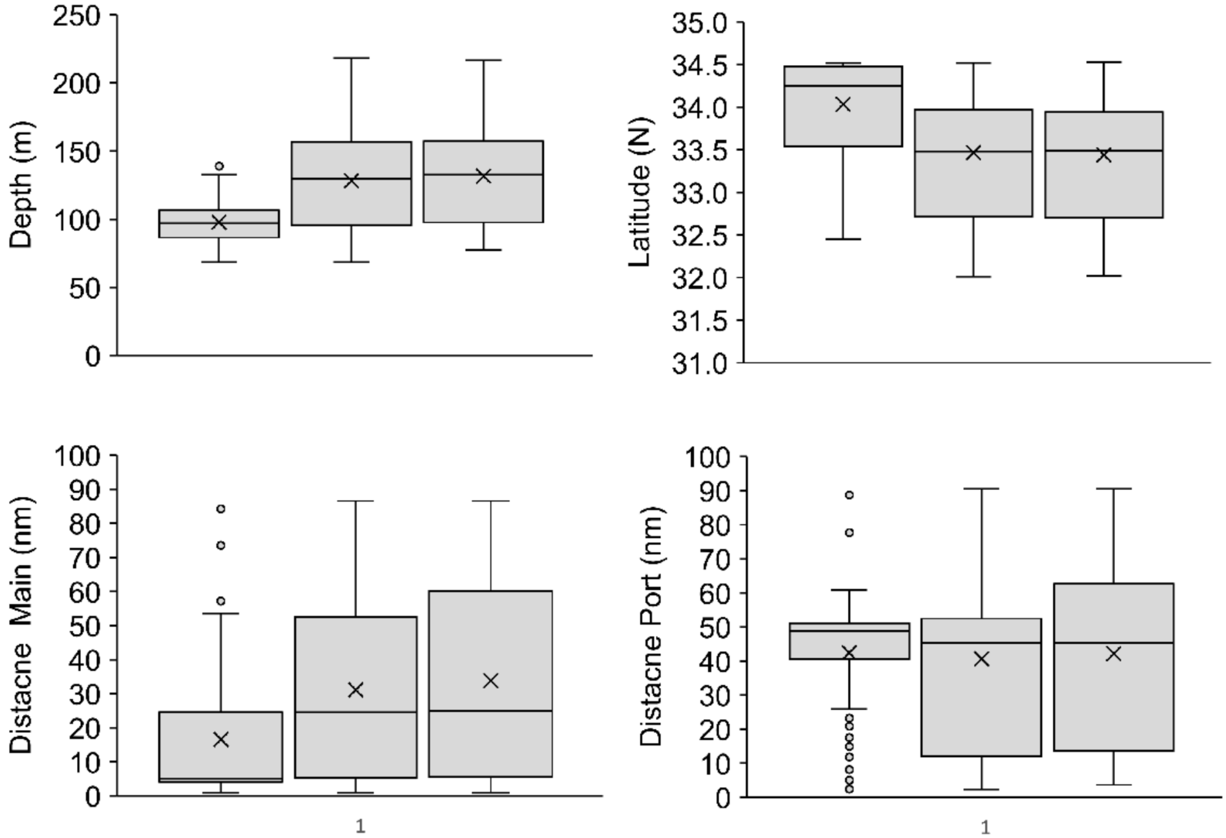


Figure 11. Box-whisker plots for: (a) depth (m); (b) latitude (ºN); (c) distance from mainland (nm); and (d) distance from nearest port (nm) for vermilion, sunset and introgressed rockfish. Box limits represent 25% and 75% quartiles; line in center represents the median; X the mean, whiskers the minimum and maximum values and points represent outliers.

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

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

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

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

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

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

d) Simulated effects of climate variability on yelloweye rockfish growth, maturation and reproductive potential in the California Current Ecosystem

Investigators: C. Harvey, S. Miller, E. Bjorkstedt, and academic collaborators

Climate variability and change have the potential to alter growth and reproductive capacity of groundfishes, through direct impacts such as temperature effects on metabolic rates, or indirect impacts such as changes to prey quality and quantity. Given the nature of groundfish life history, the timing and magnitude of climate variability and related effects is critical, as pelagic larval/juvenile stages may experience different climate effects than post-settled fish at greater depths, and climate impacts may have different effects on growth or reproductive potential if they happen before or after maturation. In this project, we are simulating the effects of contrasting states of climate variability on different life history stages of yelloweye rockfish (*Sebastes ruberrimus*). Simulations are done in rockfish bioenergetics models that are parameterized to yelloweye rockfish life history in the Oregon Coast region. The models simulate rockfish growth, maturation and reproduction based on functions dependent on temperature, fish size, fish age, and diet. Temperature estimates by date, depth, and distance from shore are generated in Regional Oceanographic Modeling System (ROMS) simulations from 1980 to 2020, and represent conditions including anomalous warm events (e.g., positive phases of the Pacific Decadal Oscillation; El Nino events; marine heatwaves) and cool events (negative phases of the Pacific Decadal Oscillation, La Nina events). We will compare how different types of climate events are expected to affect yelloweye rockfish growth and reproductive potential, as a function of prey quality and quantity as well as life history stage. This will provide insight into the vulnerability of this species to climate variability and change, and may also contribute information or context to yelloweye rockfish assessments that consider dynamic reference points, should climate change begin to have effects on yelloweye rockfish growth and reproductive output at different points along the coast.

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

e) Yelloweye rockfish vertical movement and activity in Puget Sound

Investigators: K.S. Andrews and Z. Danielson

Preliminary analyses using data from fifteen Yelloweye Rockfish collected and tagged with acoustic transmitters in the Hood Canal subbasin of Puget Sound, WA showed patterns of diel vertical movement and activity level. Individuals were generally slightly shallower, and more active during the night compared to daylight hours. However, during periods when dissolved oxygen (DO) concentrations were lowest, activity levels at night were reduced compared to periods with higher DO concentrations. If these measures of activity are specifically related to foraging activity, prolonged periods of low DO could significantly reduce foraging opportunities and bioenergetic capabilities and have consequences for individual and population-level growth and productivity.

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

2. Assessments

3. Management

I. Thornyheads

1. **No reported research occurred in 2022**
2. **No assessment occurred in 2022**

J. Sablefish

1. Research

a) Environmental drivers of groundfish recruitment in a stock assessment context

Investigators: N. Tolimieri, M. Haltuch, I. Taylor

Environmental recruitment indices may improve the precision of stock assessments, allow hindcasting, and aid in near-term forecasting. We used Bayesian dynamic factor analysis (DFA) to find common trends in sea level from 16 tide gauges spanning the US West Coast. We then used these dynamic factors as predictors of sablefish *Anoplopoma fimbria* recruitment deviations from the 2021 assessment. We evaluated the ability of the resulting northern sea-level index (north of Cape Mendocino, ~40°N) to inform recruitment estimates and its impacts on assessment model predictions by running two hindcast stock assessment models: (1) a catch-only model, which assumed average recruitment from the stock–recruit relationship, and (2) a catch plus sea-level model. In both cases, survey data were removed from 2011 forward. The model including sea-level index captured the observed increase in stock biomass from 2016 onwards, while the catch-only model did not, predicting a continued biomass decline. This work provides evidence of the potential to improve forward-looking stock projections by better capturing stock trends, providing an advance over average recruitment assumptions.

Ongoing work continues to examine potential drivers of past recruitment strength in sablefish, petrale sole, and other groundfish. Prior work used drivers from ROMS models as predictors of both sablefish and petrale sole recruitment for the 1980-2010 time frame. However, updates to the ROMS models have created potential discontinuities between the 1980-2010 and newer 2011-present time series. Ongoing work is focused on (a) analyzing the petrale sole and sablefish recruitment time series against updated ROMS output for 2011-2022, with the goal of incorporating informative indices into the assessments; and (b) extend analyses of environment-recruitment relationships to additional species (e.g., a high-priority rockfish), with the goal of enhancing stock assessments and informing the California Current Ecosystem Status Report.

Citation: N. Tolimieri and M.A. Haltuch. 2023. Sea-level index of recruitment variability improves assessment model performance for sablefish Anoplopoma fimbria. Canadian Journal of Fisheries and Aquatic Sciences. e-First https://doi.org/10.1139/cjfas-2022-0238

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

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

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

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

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

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2. Assessment

3. Management

K. Lingcod

1. Research

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

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

Understanding the spatial patterns as well as environmental and anthropogenic drivers of life-history variation for exploited fish populations is important when making management decisions and designating stock boundaries. These considerations are especially germane for stocks that are overfished or recently rebuilt, such as lingcod (*Ophiodon elongatus*), a commercially and recreationally valuable species of groundfish along the West Coast of North America (Figure 12). Between 2015 and 2017, we collected 2,189 lingcod from 24 port locations, spanning 28° of latitude from southeast Alaska (60°N) to southern California (32°N), to investigate latitudinal patterns in size and age structure, growth, timing of maturity, condition, and mortality, as well as to identify biologically relevant population breakpoints along the coast. We found strong latitudinal patterns in these life history and demographic traits consistent with Bergmann's Rule: lingcod from colder, northern waters were larger at age, lived longer, matured at larger sizes, and had lower natural mortality rates than lingcod from lower latitudes. Female lingcod were larger at age, lived longer, and matured at larger sizes compared to males within each examined region. In addition, we found evidence for strong associations between lingcod life-history traits and oceanographic variables. Cluster analysis using life history traits indicated that central Oregon is a biologically-relevant breakpoint for lingcod along the U.S. West Coast. This newfound breakpoint, in conjunction with a recently identified genetics breakpoint in central California discovered by Longo et al. (2020), highlights the need for future lingcod stock assessments to consider population dynamics and genetic connectivity when managing complex, trans-boundary stocks.

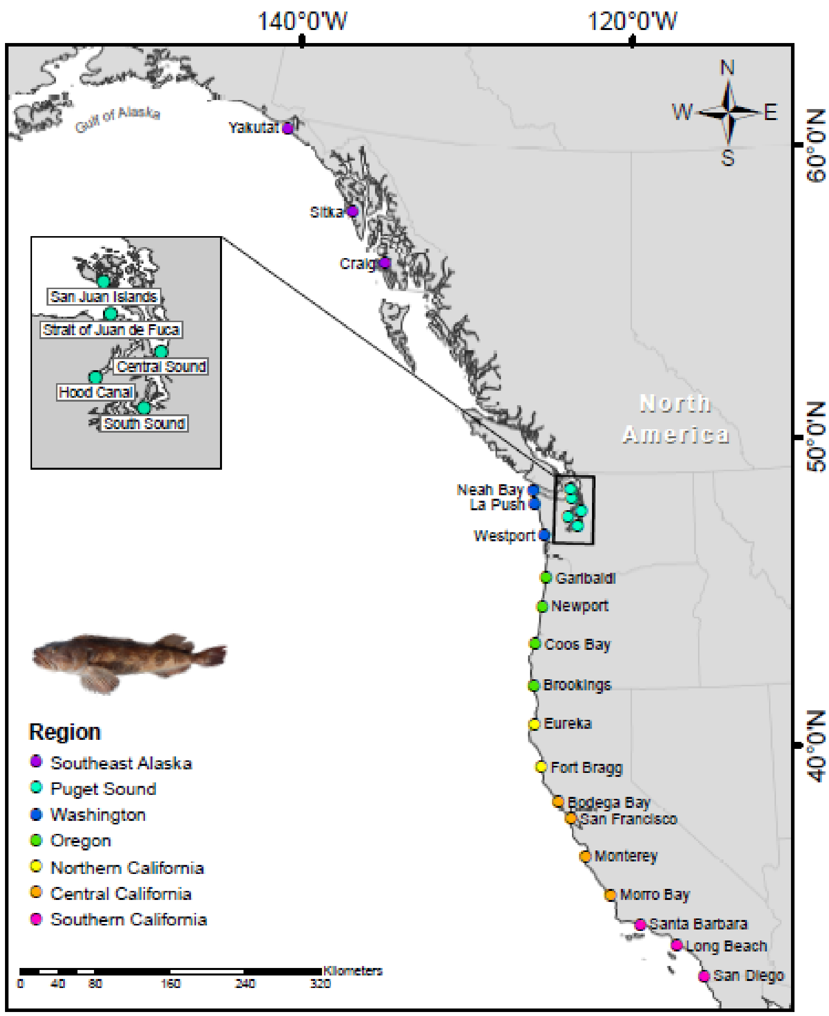

Figure 12. Map of study area. Ports are color-coded by region. 2 to 5 ports were chosen per region based on commercial passenger fishing vessel (CPFV) availability and accessibility.

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

b) Evaluation of spatial variability in reproduction of lingcod, *Ophiodon elongatus* along the U.S. West Coast

Investigators: Melissa Head, Aimee Keller, Laurel Lam

Accurate estimates of length and/or age at maturity are essential for determining reproductive potential for use in sustainable fisheries management. Failure to account for skip spawning and abortive maturation can lead to overestimation of spawning stock biomass. Examining variation in reproduction over time and space can provide information on stock structure for use in managing coast wide species, however it is equally important to identify the drivers, i.e. fishing pressure, genetics, and oceanographic conditions, behind spatio-temporal shifts in life history. The 2021 stock assessment of lingcod, *Ophiodon elongatus*, incorporated two population models, North and South of 40°10’ N, based on evidence of distinct population clusters and differences in life history characteristics. To address management needs, we evaluated the reproductive biology of this economically and ecologically important groundfish species (Figure 13). We collected 1035 lingcod ovaries along the contiguous U.S. West Coast over the span of seven years (2013 – 2019). We evaluated length (L_{50}) and age (A_{50}) at 50% maturity, both biologically (physiological maturity) and functionally (potential spawners in a given year) across eight regions: coast wide, between management areas (North and South of 40°10’ N), between genetic stocks (North and South of 38°17' N), and among biogeographic regions along the U.S. West Coast including North of Cape Mendocino, CA (40°26’ N), the Central coast (40°26’ - 34°26’ N), and South of Pt Conception, CA (34°26’ N). Biological L_{50} and A_{50} maturity estimates (43.36 – 52.76 cm and 1.66 – 2.88 yrs) were smaller than functional maturity estimates (46.31 – 56.71 cm and 1.89 – 3.23 yrs) across studied regions. We found lingcod South of 40°10’ N and 38°17' N (51.57, 49.63 cm) reached functional maturity at significantly smaller sizes than their counterparts in the North (56.65, 56.42 cm). Evaluation of size and age at maturity estimates across biogeographic regions produced a wide range of biological (52.76 – 43.36 cm and 2.88 – 1.66 yrs) and functional (56.71 – 46.31 cm and 1.89 – 3.23 yrs) maturity estimates. Overall, regional analyses showed a decline in size and age at 50% maturity with decreasing latitude, with females South of Pt. Conception, CA reaching biological and functional maturity at smaller sizes and younger ages than their northern counterparts. These updated coast wide and regional estimates of functional maturity are critical to fisheries managers and add to the growing body of literature that seeks to determine the best spatial management plan for lingcod sub-populations.

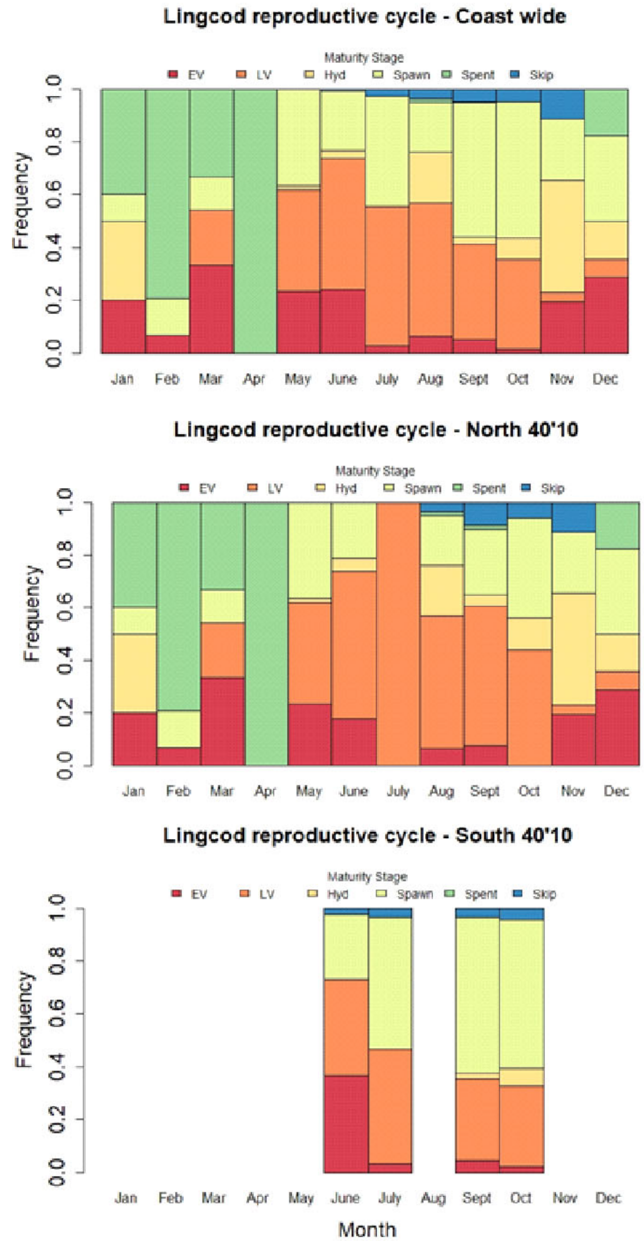

Figure 13 a - c. Reproductive development of mature females by month sampled a) coast wide, b) North of 40°10' and c) South of 40°10'. Frequency of samples by maturity stage shown: Early Vitellogenesis (EV, in red), Late Vitellogenesis (LV, in orange), Hydration (Hyd, in peach), Spawning and batch spawned (Spawn, in light green), Spent (in green), and Skip spawning (Skip, in blue).

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

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

Investigators: K.S. Andrews and D. Tonnes

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

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

2. Assessment

L. Atka Mackerel

1. **No reported research occurred in 2022**
2. **No assessment occurred in 2022**

M. Flatfish

1. Research

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

Investigator: Douglas Draper

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

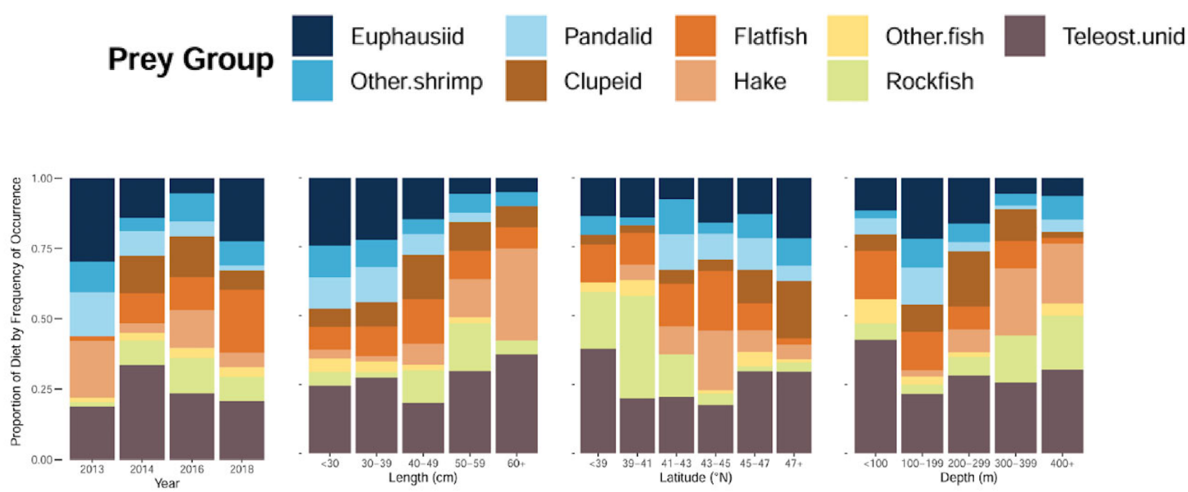

Figure 14. Stacked barplots of diet proportions by frequency of arrowtooth flounder prey groups for year, length, latitude, and depth bins.

2. Assessement

N. Halibut

1. **No reported research occurred in 2022**
2. **No assessment occurred in 2022**

O. Other Groundfish

1. Research

2. Assessments

3. Management

a) Applying a probability harvest control rule to account for increased uncertainty in setting precautionary harvest limits from past stock assessments

Investigators: C.R. Wetzel and O.S. Hamel

Estimates of current population status, derived from stock assessments and often expressed as spawning output, are uncertain. United States (U.S.) fisheries management has adopted approaches to account for this uncertainty when setting harvest limits with the goal of preventing overfishing, as mandated by the Magnuson Stevens Fishery Conservation and Management Act. For U.S. West Coast groundfish species, the Acceptable Biological Catch (ABC), since 2011, has been set to a fraction of the Overfishing Limit (OFL) based on the uncertainty (σ) surrounding the estimated final year spawning output, as a proxy for the OFL uncertainty, or the uncertainty around the OFL itself. However, uncertainty around population size is expected to increase during the projection period when the true population dynamics may differ from the model projected values. Age-structured, data-rich stock assessments for West Coast groundfish species were evaluated for changes in spawning output uncertainty during a ten-year projection period. The spawning output time series from a more pessimistic population projection, termed the "low state of nature", was compared to the spawning output time series from the base assessment model adopted for management, for each of 17 West Coast groundfish species (comprising a total of 21 modeled areas). The standardized median estimated σ increased, as measured between the low and base model spawning output, during the projection period for all species evaluated, increasing to a mean of 1.67 times greater than that in the first year after a ten-year projection. Combining the results by species groups used by the Pacific Fishery Management Council (rockfish, roundfish, and flatfish) elucidated that while the σ values increased for all species groups, the rockfish species had the smallest median multiplicative increase in σ (1.65) and the flatfish species had the largest increase in σ (2.66) during the projection period, although only two flatfish assessments were available. Across species, natural mortality was the best life history predictor of the rate of change in σ, however, the correlation between the two was low, though greater within species groups. Applying the estimated increase in σ by year, across species groupings, combined with an adopted risk tolerance probability for exceeding the true OFL (termed P^*) of 0.45 resulted in ABC values that decreased from 93.9 percent of the OFL in the first year following the assessment to 90.0 percent of the OFL by year ten of the projection period.

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

b) The stock assessment theory of relativity: deconstructing the term "data-limited" fisheries into components and guiding principles to support the science of fisheries management

Investigators: J.M. Cope, N.A. Dowling, S.A. Hesp, K. Omori, P. Bessell-Browne, L. Castello, R. Chick, D. Dougherty, S.J. Holmes, R. McGarvey, D. Ovando, J. Nowlis, J. Prince. https://link.springer.com/10.1007/s11160-022-09748-1

The term "data-limited fisheries" is a catch-all to generally describe situations lacking data to support a fully integrated stock assessment model. Data conditions range from data-void fisheries to those that reliably produce quantitative assessments. However, successful fishery assessment can also be limited by resources (e.g., time, money, capacity). The term "data-limited fisheries" is therefore too vague and incomplete to describe such wide-ranging conditions, and subsequent needs for management vary greatly according to each fishery's context. Here, we acknowledge this relativity and identify a range of factors that can constrain the ability of analyses to inform management, by instead defining the state of being "data-limited" as a continuum along axes of data (e.g., type, quality, and quantity) and resources (e.g., time, funding, capacity). We introduce a tool (the DLMapper) to apply this approach and define where a fishery lies on this relativity spectrum of limitations (i.e. from no data and no resources to no constraints on data and resources). We also provide a ranking of guiding principles, as a function of the limiting conditions. This high-level guidance is meant to identify current actions to consider for overcoming issues associated with data and resource constraints given a specific "data-limited" condition. We apply this method to 20 different fisheries to demonstrate the approach. By more explicitly outlining the various conditions that create "data-limited situations" and linking these to broad guidance, we aim to contextualize and improve the communication of conditions, and identify effective opportunities to continue to develop and progress the science of "limited" stock assessment in support of fisheries management.

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

c) The FishPath approach for fisheries management in a data- and capacity-limited world

Investigators: N.A. Dowling, J.R. Wilson, J.M. Cope, D.T. Dougherty, S. Lomonico, C. Revenga, B.J. Snouffer, N.G. Salinas, F. Torres-Cañete, R.C. Chick, A.M. Fowler, A.M. Parma. https://onlinelibrary.wiley.com/doi/abs/10.1111/faf.12721

Successful fisheries management systems tend to be underpinned by harvest strategies, specifying formally agreed data collection systems, assessment approaches and management measures used to regulate fishing pressure. While harvest strategies can be effective even in data- and capacity-limited (DCL) situations, their development remains challenging in such contexts. We present a process and decision-support tool, FishPath, to guide the identification of suitable harvest strategy component options given often debilitating conditions: (i) resource limitations and lack of technical management capacity; (ii) 'uniqueness' of DCL fisheries; (iii) the concept of harvest strategies is unfamiliar to managers and scientists, and the universe of options is hard to navigate; and (iv) the lack of an effective participatory process to identify solutions tailored to local contexts. These conditions can lead to either management paralysis or generic solutions that may be poor fits to specific conditions. The FishPath Tool uses a diagnostic questionnaire that elicits the key characteristics and specific circumstances of a fishery. It compares these with the requirements of alternative options from an inventory of possible harvest strategy components, identifies where these requirements are met and provides customised, transparent guidance on the appropriateness of component options of a harvest strategy, specific to the fishery of interest and its governance context. The FishPath Process is a facilitated multi-stakeholder, participatory engagement process aimed to set fisheries on the path to develop a harvest strategy. The FishPath Process and Tool combine to ensure a bottom-up, documented, transparent, replicable and efficient process.

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

V. Ecosystem Studies

A. Socioeconomics

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

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

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

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

b) Integrated Ecosystem Assessment of the California Current

Investigators: J.F. Samhouri, C.J. Harvey, G.D. Williams, N. Tolimieri, K.S. Andrews, B.E. Feist, T.P. Good, P.-Y. Hernvann, I.C. Kaplan, O. Liu, S.L. Moore, O.A. Shelton, A. Warlick, and 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 range of scenarios.

The California Current IEA team develops an ecosystem status report (ESR) of the California Current each year, which describes the status and trends of many ecosystem indicators, including some related to groundfish. The ESR is presented to the Pacific Fishery Management Council and developed into an annual tech memo. ESRs and tech memos can be found at www.integratedecosystemassessment.noaa.gov/regions/california-current/california-current-reports. Also, the California Current IEA team is conducting in-depth quantitative analysis of ecosystem indicators; assessing the risk posed by natural and anthropogenic stressors to key ecosystem resources and human wellbeing; and evaluating potential management strategies to determine which strategies are most effective in moving the ecosystem toward management goals and objectives, and to identify potential management tradeoffs. Many of these efforts also involve analyses related to groundfish.

Citation: Harvey, C., et al. 2023. 2022-2022 California Current ecosystem status report. Report to the Pacific Fishery Management Council, Portland, OR. Available at https://www.pcouncil.org/documents/2023/02/h-1-a-cciea-team-report-1-electronic-only-2022-2023-california-current-ecosystem-status-report-and-appendices.pdf/.

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c) Integrated Ecosystem Assessment support of condition reports for West Coast National Marine Sanctuaries

Investigators: G. Williams, J. Brown, C. Caldow, K. Andrews, N. Tolimieri, C. Harvey, and numerous contributors from the NWFSC, SWFSC, Office of National Marine Sanctuaries, and partner institutions

The California Current Integrated Ecosystem Assessment (IEA) team has provided extensive support to the Office of National Marine Sanctuaries (ONMS) toward the development of condition reports for sanctuaries located along the West Coast. Sanctuary condition reports are tools employed by NOAA to assess the condition and trends of national marine sanctuary resources. Condition reports provide a standardized summary of resources in NOAA's sanctuaries; drivers and pressures on those resources; current conditions and trends for resources and ecosystem services; and describe existing management responses to the pressures that threaten the integrity of the marine environment. Condition reports include information on the status and trends of water quality, habitat, living resources and maritime archaeological resources, and the human activities that affect them. They present responses to a set of questions posed to all sanctuaries. The reports also rate ecosystem service status and trends. Resource and ecosystem service status are rated on a six-point scale from good to poor, and the timelines used for comparison vary from topic to topic. Trends in the status of resources and ecosystem services are also reported, and are generally based on observed changes in status since the prior condition report, unless otherwise specified.

The primary roles of the IEA team in this collaboration have been: guidance in developing an IEA framework for assessment and management of sanctuaries; the screening of ecosystem indicators and the identification of relevant time series of data; and development of conceptual models of key sanctuary habitats and communities. The most recent West Coast sanctuary condition report to be published that features products from this collaboration is the Olympic Coast National Marine Sanctuary (OCNMS) condition report in 2022 (citation below); groundfish are broadly represented in indicators and conceptual models under many of the focal questions considered within the OCNMS condition report. We contributed similar information to the forthcoming condition report update for the Cordell Bank National Marine Sanctuary.

Citation: Office of National Marine Sanctuaries. 2022. Olympic Coast National Marine Sanctuary Condition Report: 2008–2019. U.S. Department of Commerce, National Oceanic and AtmosphericAdministration, Office of National Marine Sanctuaries, Silver Spring, MD. 453 pp. Available at: https://sanctuaries.noaa.gov/media/docs/2008-2019-ocnms-condition-report.pdf

For more information please contact Mr. Greg Williams at NOAA's Northwest Fisheries Science Center / Pacific States Marine Fisheries Commission, Greg.Williams@noaa.gov.

d) Representing fisheries' footprints in marine spatial planning suitability analyses for offshore wind energy development.

Investigators: Kelly Andrews, Blake Feist, J. Lilah Isé, Justin Ainsworth, Jessica Watson, Delia Kelly, Caren Braby

Offshore renewable energy development is becoming a reality off the U.S. West Coast, and an important goal for selecting the locations of these new ocean-use sectors is to minimize overlap and conflict with current ocean user groups and marine natural resources. Two of the most important ocean user groups along the U.S. West Coast are commercial and recreational fisheries. The objective of this research was to identify fisheries data to be included in a comprehensive suitability analysis to identify locations within two planning areas that would be most suitable to offshore wind energy (OWE) development. Here, we describe the methodology used to characterize and calculate the relative importance of space within the OWE planning areas for nine fisheries sectors and then calculate the suitability of this space for OWE development relevant to the overlap with fisheries. We used fisheries' logbook and observer program data to summarize annual and cumulative fishing effort (hours fished or amount of gear used) and revenue across the entire planning area and within 2x2-km grid cells within the planning area across a range of years of available data for each fishery. We then ranked, normalized and combined effort and revenue data into a single metric ('ranked importance') for each fishery for each grid cell. Combining metrics allowed for the most important characteristic of each fishery (effort or revenue) to be captured for each grid cell. Finally, we used the ranked importance values for each fishery to calculate an overall suitability score for OWE development for each grid cell relevant to the overlap with fisheries. Results showed that annual commercial fishing effort and revenue varied widely across the last two decades for many fisheries; however, some fleets showed steadily increasing and decreasing trends in fishing effort across the planning areas. Spatially, the locations of the highest ranked importance values varied among individual fishing sectors, typically corresponding to specific bottom depth contours or habitat features associated with targeted species. Overall, large regions of the planning areas, particularly at depths between ~200 and ~500 m, were important to fisheries, while the western half of the southern planning area had the highest suitability scores for OWE development. Comprehensive marine spatial planning analyses will continue to be a critical component for minimizing conflict among ocean-user groups and impacts to species and their habitats, and for the responsible, sustainable development of new ocean-use sectors.

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

e) Response of kelp forest communities along the coast of Washington, USA to the 2014-2016 marine heatwave and sea star wasting syndrome

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

We examined the response of kelp communities at five sites along the coast of Washington State, USA, to the recent perturbations of anomalous warm-water events and sea star wasting syndrome (SSWS) using a combination of SCUBA surveys (2015-2021) augmented by longer-term data on kelp canopy cover and sea surface temperature (SST). Anomalously warm SST in 2013 and 2014 corresponded with a loss of approximately 50% of the canopy cover of two kelps *Macrocystis pyrifera* and *Nereocystis luetkeana* in 2013-2014. However, the canopy quickly recovered to earlier levels, and stipe density increased after 2015. There was a 164-fold increase in the density of purple sea urchins (*Strongylocentrotus purpuratus*), largely at one site, but this increase was observed in 2017 and peaked in 2019, well after the onset of warming, before declining in 2021. We did not see evidence of any recovery of sea star populations from SSWS, with several species including *Pycnopodia helianthoides* continuing to decline. Multivariate analyses found that variation among sites explained the majority of variation in assemblage structure for three guilds: kelps, macroinvertebrates, and fishes, while yearly variation explained most of the variability in the abundance of rockfish (*Sebastes* spp.) juveniles. We found no evidence to support strong relationships between urchins and kelp that would suggest top-down impacts of urchins on kelp abundance, except at a small spatial scale at one site. We did find that juvenile rockfishes were more likely to occur where kelp stipe density was high. Our analyses point toward the importance of spatial variation in structuring the responses of kelp forest communities to disturbance across a range of spatial scales and that it is essential to ensure the protection of a diversity of kelp forests, each of which harbors habitats that can exhibit unique responses to ecological surprises yet to come.

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

B. Assessment Science

1. Research

a) Inclusion of ecosystem information in US fish stock assessments: progress towards ecosystem-based fisheries management?

Investigator: K.N. Marshall

The appetite for ecosystem-based fisheries management (EBFM) approaches continues to grow, and the perception persists that implementation is slow. Here, I synthesize a snapshot of one potential avenue for EBFM in the U.S.: expanding fish stock assessments to include ecosystem considerations and interactions between species, fleets, and sectors. I will give an overview of a synthesis where co-authors and I reviewed over 200 stock assessment reports from U.S. federal waters during 2004-2014 and assessed how the reports included information about system influences on the assessed stock. Our goals were to quantify whether and how assessments incorporated broader system-level considerations, and to explore factors that might contribute to the use of system-level information. Interactions among fishing fleets (technical interactions) were more commonly included than biophysical interactions (species, habitat, climate). Interactions within the physical environment (habitat, climate) were included twice as often as interactions among species (predation). Many assessment reports included ecological interactions only as background or qualitative considerations, rather than incorporating them in the assessment model. Our analyses suggested that ecosystem characteristics are more likely to be included when the species was overfished, the assessment is conducted at a science center with a longstanding stomach contents analysis program, and/or the species life history characteristics suggest it is likely to be influenced by the physical environment, habitat, or predation mortality. I will reflect on what this snapshot of stock assessments implies about progress on EBFM the U.S. and on what may have changed in more recent years. The future implications of the diversity of ways that assessments have taken into account ecosystem considerations for managing fisheries in a changing ecosystem will also be discussed. *National Scientific Coordination Subcommittee Meeting.*

For more information, please contact Kristin Marshall: kristin.marshall@noaa.gov

b) When should we do Management Strategy Evaluation?

Investigators: J.F. Walter, C. Peterson, K. Marshall, J.J. Deroba, S. Gaichas, B.C. Williams, S. Stohs, D. Tommasi, and R. Ahrens.

The basis of natural resource management is decision making under uncertainty while balancing competing objectives. Within fisheries management, a process described as Management Strategy Evaluation (MSE) is becoming increasingly requested globally to develop and test management procedures. In a fisheries or other natural resource context, a management procedure is a rule that predetermines the management response given feedback and is simulation tested to be robust to multiple uncertainties. MSEs are distinguished from other risk or simulation analyses by the explicit testing of the feedback mechanism that applies decision rule-based management advice back to the simulated population or ecosystem. Stakeholder input is frequently cited as a best practice in the MSE process, since it fosters communication and facilitates buy-in to the process. Nevertheless, due to the substantial additional cost, time requirement, and necessary scientific personnel, full stakeholder MSEs remain relatively uncommon. With this communication, we provide guidance on what constitutes an MSE, when MSEs should be undertaken or where simpler approaches may suffice, and in how to prioritize the degree of stakeholder participation. *ICES Journal of Marine Science*.

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c) Spatial awareness: good practices for implementing the continuum of stock assessment approaches that address spatial population structure and connectivity

Investigators: D.R. Goethel, A.M Berger, Steve X. Cadrin

Spatial population structure is a fundamental aspect of marine populations, yet it is rarely addressed in stock assessment models that form the basis of operational fisheries management advice. The de facto assumption used in most assessment models is that of a well-mixed, panmictic population, which is an artifact of the assessment discipline forming at a time (i.e., the mid-20th century) when the spatial resolution of fishery data was extremely coarse and uncertain, computing power limited, and the impact of biocomplexity on sustainable harvest levels not well understood. With rapid advances along all of these research fronts in the 21st century, spatial assessment frameworks have proliferated, yet remain rarely utilized as the basis of management decision-making. A potential hindrance is the general lack of guidance on how to implement spatial assessments and choose an appropriate spatial modeling framework for a given application. Thus, we aim to review the types of spatial assessment models available, summarize options to parameterize population structure, offer guidance to promote the development of candidate spatial assessment models and operationalize them in management procedures, and provide a pragmatic guide for choosing a spatial assessment model given observed spatial structure, data limitations, and management concerns. The primary goal of a spatial assessment is to match the assessment unit(s) to multidisciplinary stock identification of unit populations and simultaneously model multiple interacting population units, when appropriate. As data permits, higher resolution intra-population spatial structure can be addressed to increase homogeneity within the modeled unit, while connectivity among population units can be explicitly modeled. At finer scales, sample size limitations can become an issue with spatial assessment applications, but incorporating novel data sources and parameterizing models efficiently (e.g., sharing parameters among spatial units, implementing habitat preference functions to improve movement dynamics, and including spatial autocorrelation functions) can ease implementation. Closed-loop simulations, such as management strategy evaluation, should be utilized to identify minimally complex management procedures needed to provide robust management advice, while imprecision of spatial models should be weighed against the inherent bias of spatially aggregated panmictic assessments. *CAPAM Best Practices Meeting Society.*

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

d) Best practices for defining spatial boundaries and spatial structure in stock assessment

Investigators: S.X. Cadrin, D.R. Goethel, A.M Berger

The 'stock concept' in fisheries science conforms to theoretical assumptions of stock assessment models, involving negligible movement across stock boundaries, relatively homogeneous vital rates, and extensive mixing within stock areas. Best practices for addressing population structure in stock assessment involve 1) interdisciplinary stock identification to delineate spatially discrete populations or more complex population structure; 2) aligning the geographic extent of stock assessment with the most plausible population structure; 3) stratified sampling, fleet structure and spatial structure of models to account for heterogeneity, fishing patterns, and movement within stock areas; 4) routine stock composition sampling for overlapping populations; and 5) simulation testing the performance of assessments with mis-specified or uncertain population structure. In practice, spatial data may not be available to support stock assessment of discrete populations or complex population structure, and management units may not meet unit stock assumptions because they were delineated by jurisdiction or traditional fishing grounds. In these situations, simulation testing is needed to confirm that the mis-specified stock assessment sufficiently meets the needs of the management system management unit can be successfully assessed and managed to meet objectives. Such simulation testing relies on spatially structured operating models that are conditioned on the available information to represent plausible population structure(s). Practical assessment units that do not accurately represent population structure may not provide sufficient information to achieve fishery management objectives, so practical constraints should be addressed through iterative stock

identification, spatially structured assessment modeling, and performance testing. *CAPAM Best Practices Meeting.*
For more information, please contact Aaron Berger at Aaron.Berger@noaa.gov

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

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

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

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

f) Oceans of Plenty? Challenges, Advancements, and Future Directions for the Provision of Evidence-based Fisheries Management Advice. Rev. Fish. Bio. Fish

Investigators: D.R. Goethel, K.L. Omori, A.E. Punt, P.D. Lynch, A.M. Berger, C. de Moor, E. Plaganyi, J. Cope, N.A. Dowling, R. McGarvey, A. Preece, J.T. Thorson, M. Chaloupka, S. Gaichas, E. Gilman, A. Hesp, C. Longo, N. Yao, and R. Methot.

Marine population modeling, which underpins the scientific advice to support fisheries interventions, is an active research field with recent advancements to address modern challenges (e.g., climate change) and enduring issues (e.g., data limitations). Based on discussions during the 'Land of Plenty' session at the 2021 World Fisheries Congress, we synthesize current challenges, recent advances, and interdisciplinary developments in biological fisheries models (i.e., data-limited, stock assessment, spatial, ecosystem, and climate), management strategy evaluation, and the scientific advice that bridges the science-policy interface. Our review demonstrates that proliferation of interdisciplinary research teams and enhanced data collection protocols have enabled increased integration of spatiotemporal, ecosystem, and socioeconomic dimensions in many fisheries models. However, not all management systems have the resources to implement model-based advice, while protocols for sharing confidential data are lacking and impeding research advances. We recommend that management and modeling frameworks continue to adopt participatory co-management approaches that emphasize wider inclusion of local knowledge and stakeholder input to fill knowledge gaps and promote information sharing. Moreover, fisheries management, by which we mean the end-to-end process of data collection, scientific analysis, and implementation of evidence-informed management actions, must integrate improved communication, engagement, and capacity building, while incorporating feedback loops at each stage. Increasing application of management strategy evaluation is viewed as a critical unifying component, which will bridge fisheries modeling disciplines, aid management decision-making, and better incorporate the array of stakeholders, thereby leading to a more proactive, pragmatic, transparent, and inclusive management framework–ensuring better informed decisions in an uncertain world. *Reviews in Fish Biology and Fisheries*.

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

g) Best practices for defining spatial boundaries and spatial structure in stock assessment

Investigators: S.X. Cadrin, D.R. Goethel, A.M. Berger, and E. Jardim.

The ‘stock concept’ in fisheries science conforms to theoretical assumptions of stock assessment models, including negligible movement across stock boundaries, relatively homogeneous vital rates, and extensive mixing within stock areas. Best practices for representing population structure in stock assessment involve 1) interdisciplinary stock identification to delineate spatially discrete populations or more complex population structure; 2) stock boundaries that are aligned with the most plausible population structure; 3) spatially-explicit sampling, fleet structure or spatial structure in assessment models to account for heterogeneity, fishing patterns, and movement within stock areas; 4) routine stock composition sampling and analysis for spatially overlapping populations; and 5) simulation testing the performance of assessments with mis-specified or uncertain population structure. Practical assessment units that do not accurately represent population structure may not provide sufficient information to achieve fishery management objectives, so practical constraints should be addressed through iterative advances in routine stock identification, delineation of stocks to meet unit-stock assumptions, and stock assessment modeling. *Fisheries Research*.

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

h) Upgrading from M version 0.2: An application-based method for practical estimation, evaluation and uncertainty characterization of natural mortality

Investigators: J.M. Cope and O.S. Hamel

https://linkinghub.elsevier.com/retrieve/pii/S0165783622002703

Natural morality (M) is a notoriously difficult population parameter to estimate, yet it is also one of the most important measures of life history that sets, as Beverton and Holt called it, "the course of events". Stock as sessments that include this parameter often show great sensitivity to its value, reflecting the need to characetrize the uncertainty inherent in its estimation. Direct measurement of natural mortality is often limited to resource intensive tag-recapture studies. Indirect measures are more often used, and are built on life history theory, relating natural mortality to traits such as age, size, maturity and reproductive condition (or just assuming 0.2). The Natural Mortality Tool attempts to accumulate several empirical estimators of M into one application. Users simply input life history values to obtain estimates of natural mortality. These estimates can be taken individ ually or can be combined into a weighted density function that can be used to develop an M prior that integrates uncertainty across several estimates. Comparing estimators can also reveal inconsistencies in life history values that may lead to further refining of basic biological understanding. Two examples are used to demonstrate tool functionality and highlight general recommendations on implementation. Making these estimators and the development of uncertainty in estimating natural mortality more widely available hopefully supports transparent and defensible decision-making on the treatment of this important population parameter.

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

i) A review of estimation methods for natural mortality and their performance in the context of fishery stock assessment

Investigators: M.N. Maunder, O.S. Hamel, H.-H. Lee, K.R. Piner, J.M. Cope, A.E. Punt, J.N. Ianelli, C. Castillo-Jordán, M.S, Kapur, R.D. Methot.

https://doi.org/10.1016/j.fishres.2022.106489

Natural mortality (M) is one of the most influential parameters in fisheries stock assessment and management. It relates directly to stock productivity and reference points used for fisheries management advice. Unfortunately, M is also very difficult to estimate, and hence very uncertain. Representing the uncertainty in M and how this influences estimates of management quantities is therefore an important component of conducting stock assessments. This paper outlines the range of methods available to estimate M for use in stock assessment. The methods include those based on maximum age, life history theory, relationships between “well-known” values for M (those found in the literature and based on data for the stock being assessed) and covariates, use of tagging data and catch curve analysis, and estimation within a single- or multi-species stock assessment model. All methods are likely subject to bias and imprecision due to incorrect assumptions and incomplete data. Furthermore, M is generally assumed to be constant over time, age, and sex - assumptions that are unlikely to be true for any stock. Based on our review, there is an

obvious benefit to directly estimating M using data and within a stock assessment while assigning a prior based on empirical methods. This approach effectively uses all the available information while also representing the uncertainty. Carefully examining diagnostics and checking for model misspecification is required to ensure that the available data and stock assessment model assumptions are appropriately informative about M when it is estimated during the model fitting process. For situations where direct estimation is not possible (a condition found in data-limited to data-rich stock assessments), the use of multiple methods with robust sensitivity exploration is recommended. Even when direct data are integrated into a stock assessment, we recommend using other methods to estimate M and analyzing the direct data outside the stock assessment model as diagnostic tools.
For more information, please contact Jason Cope at Jason.Cope@noaa.gov

j) **National Standard 1 Technical Guidance on Managing with ACLs for Data- Limited Stocks: Review and Recommendations for Implementing 50 CFR 600.310(h)(2) Flexibilities for Certain Data-Limited Stocks**

Investigators: M. Macpherson, M., **J.M. Cope**, P. Lynch, A. Furnish, M. Karp, J. Berkson, D. Lambert, L. Brooks, K. Siegfried., E.J. Dick, C. Tribuzio
NOAA Tech. Memo. NMFS-F/SPO-237
http://spo.nmfs.noaa.gov/tech-memos/

Annual catch limits (ACLs) have been effective management tools for preventing overfishing in many fisheries. However, our current ACL-based management has been difficult in certain datalimited fisheries including those that lack information on stock biomass and those in which there is limited ability to monitor removals and enforce management requirements. Our current ability to implement ACL-based management in data-limited situations has advanced through improved data collection as well as the development of new tools to more effectively use available data and increase understanding of uncertainty in managing these stocks. Nevertheless, situations remain where data limitations challenge our ability to effectively manage with ACLs using the standard approach set forth in the National Standard 1 (NS1) guidelines. To address these concerns, in 2016, the National Marine Fisheries Service (NMFS) amended the NS1 guidelines to clarify that, for certain stocks, including those for which data are not available either to set reference points or manage stocks based on MSY or proxies, alternative approaches for satisfying statutory requirements other than that set forth in the NS1 guidelines can apply (i.e., "the (h)(2) flexibilities." 50 CFR 600.310(h)(2).

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

k) Challenges in developing a spatially explicit stock assessment: a case study in applying "SPASAM" to an international spatial stock assessment experiment

Investigators: Brian Langseth, Jon Deroba

Incorporating spatial dynamics into assessments is an important consideration, but hands-on experience with spatially-explicit assessments is rare. We report on our experiences applying a spatially-explicit assessment model, “SPASAM”, to data based on yellowfin tuna (YFT) in the Indian Ocean. The data generating model included 7 fleets, one CPUE survey, a quarterly time step from 1952-2015, 7 ages, and used 159, 5’x5’ spatial cells with heterogeneity in mortality and movement aggregated to 4 spatial areas. New modeling features within SPASAM had to be implemented and diagnostic code generalized to accommodate these dimensions. Run-times were in the range of 4-20 hours. To shorten run-times, model dimensions (e.g., areal and fleet dynamics) were reduced. Data-weighting was also explored, and sensitivity to weighting varied depending on the dimensions of the model. Reducing dimensionality of models may be helpful for development and reducing run-times, but will require circularity in modeling choices (e.g, weighting). Spatial heterogeneity in fleet dynamics may require maintaining several distinct fleets, but this will increase the number of parameters and run-times. More guidance is needed on defining dimensionality of spatially-explicit models. Treating movement and fishing as state-state processes may provide the ability to retain high dimensionality but with improved efficiency (e.g., faster run-times). Data-weighting will remain a challenge for spatially explicit models. Experience from this work is application to spatial models in general, including the spatially explicit canary rockfish assessment, which is slated for 2023.

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

l) Building next generation stock assessment capabilities: a generalizable management strategy evaluation framework to examine robust management procedures that incorporate spatial ecosystem considerations

Investigators: Aaron Berger, Jonathan Deroba, Dana Hanselman, Dan Goethel, Brian Langseth, Amy Schuller

For nearly two decades, spatial processes and analyses have been identified as a high priority research need for “next generation stock assessments” (NMFS 2001; Punt et al., 2020). The ability to model and predict spatial patterns improves understanding of population and ecosystem dynamics, while supporting management that promotes resilient fishing communities. While many advancements have been made, particularly in defining best practice for stock assessments, little research has been conducted that evaluates spatially explicit stock assessment models in combination with management actions to search for options robust to uncertainties and likely to achieve ecosystem- and climate-based management objectives. This research seeks to understand how best to incorporate spatial drivers of population dynamics into tactical management procedures as a direct pathway to operationalize NOAA climate-ready and ecosystem-based fisheries management strategic priorities. Specifically, the proposed research will perform fully iterative (closed-loop) spatial management simulations that holistically evaluate the necessarily inter-connected management procedures that are common in national and international fisheries management plans. A management strategy evaluation (MSE) framework will be developed to explore combinations of available data, spatially explicit stock assessment approaches, and spatial harvest options (i.e., combined to define a set of management procedures). Evaluations will assess what combinations are likely to meet common fishery management objectives, with performance that is robust to current and future uncertainties (e.g., due to climate change). Results will inform what management strategies are robust to spatial structure, distributional shifts, and ecosystem changes, while also highlighting potential adaptive management strategies that may be warranted as specific types of distributional changes are observed.

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

m) Guidance for applying logistic regression in selecting species-specific records from multispecies data

Investigators: Brian Langseth, Andi Stephens, Alec MacCall

Regression techniques can be used to make predictions about missing information within a dataset. Stephens and MacCall (2004) outlined an approach applying logistic regression to multispecies catch data to select data points expected to contain information on individual species, and therefore be used to calculate species-specific trends in abundance. This approach has been applied for both research and assessment purposes and using both fishery-dependent and fishery-independent data. Although the approach continues to be used, and updated, there remains limited information about where and when the approach is best applied. We present results from a simulation study to provide guidelines for applying logistic regression for subsampling data in general, with an emphasis on the approach used by Stephens and MacCall (2004) and incorporating recent improvements. We identify instances where this approach performs well, and where this approach performs poorly. Specifically, we explore scenarios under different strengths of habitat overlap in time and space, the magnitude of sampling effort, and the strength of co-occurrence with other species. Applying logistic regression works best for moderately sampled species that are neither too sparse nor too ubiquitous, are strongly associated with habitat or with other species, and when covariates contain a mix of positive and negative relationships. These guidelines will help enhance application of logistic regression to the situations best suited for determining information on individual species within multispecies data.

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2. Cooperative Ageing Unit

The Cooperative Ageing Project (CAP) operates under a grant from the Northwest Fisheries Science Center to Pacific States Marine Fisheries Commission and provides direct support for U.S. West Coast groundfish stock assessments by providing fish ages derived primarily from otoliths. In 2022, CAP production aged 22,498 age structures and production double read 5,800 age structures. Production ages supported the 2023 stock assessments on canary rockfish, petrale sole, rex sole and copper rockfish. Resources were allocated to train personnel for production ageing support of the black rockfish assessment. CAP continued the practice of recording otolith weights prior to breaking and burning most specimens when possible. Over 36,300 otolith weights were collected in 2022 to support research into alternative methods of age determination. In the fall of 2022 our Fourier Transform Near-Infrared (FT-NIRS) Spectrometer was delivered from AFSC, Seattle. The remainder of the year was spent performing reference scans on samples scanned at AFSC in 2021 and early 2022. This was to calibrate the machine and ensure data consistency. CAP ended 2022 with six age reading staff, one FT-NIRS technician and a team lead..

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

3. Modeling

a) Oceans of plenty? Challenges, advancements, and future directions for the provision of evidence-based fisheries management advice.

Investigators: D. R. Goethel, K.L. Omori, A.E. Punt, P.D. Lynch, A.M. Berger, C.L. de Moor, É.E. Plagányi, **J.M. Cope**, N.A. Dowling, R. McGarvey, A.L. Preece, J.T. Thorson, M. Chaloupka, S. Gaichas, E. Gilman, S.A. Hesp, C. Longo, N. Yao, R.D. Methot https://doi.org/10.1007/s11160-022-09726-7

Marine population modeling, which underpins the scientific advice to support fisheries interventions, is an active research field with recent advancements to address modern challenges (e.g., climate change) and enduring issues (e.g., data limitations). Based on discussions during the 'Land of Plenty' session at the 2021 World Fisheries Congress, we synthesize current challenges, recent advances, and interdisciplinary developments in biological fisheries models (i.e., data-limited, stock assessment, spatial, ecosystem, and climate), management strategy evaluation, and the scientific advice that bridges the science-policy interface. Our review demonstrates that proliferation of interdisciplinary research teams and enhanced data collection protocols have enabled increased integration of spatiotemporal, ecosystem, and socioeconomic dimensions in many fisheries models. However, not all management systems have the resources to implement model-based advice, while protocols for sharing confidential data are lacking and impeding research advances. We recommend that management and modeling frameworks continue to adopt participatory co-management approaches that emphasize wider inclusion of local knowledge and stakeholder input to fill knowledge gaps and promote information sharing. Moreover, fisheries management, by which we mean the end-to-end process of data collection, scientific analysis, and implementation of evidence-informed management actions, must integrate improved communication, engagement, and capacity building, while incorporating feedback loops at each stage. Increasing application of management strategy evaluation is viewed as a critical unifying component, which will bridge fisheries modeling disciplines, aid management decision-making, and better incorporate the array of stakeholders, thereby leading to a more proactive, pragmatic, transparent, and inclusive management framework–ensuring better informed decisions in an uncertain world.

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

b) Catch and Length Models in the Stock Synthesis Framework: Expanded Application to Data-Moderate Stocks.

Investigators: M.B. Rudd, **J.M. Cope, C.R. Wetzel**, J. Hastie

Many fisheries in the world are data-moderate, with data types (e.g., total removals, abundance indices, and biological composition data) of varied quality (e.g., limited time series or representative samples) or available data. Integrated stock assessments are useful tools for data-moderate fisheries as they can include all available information, can be updated due to the availability of more information over time, and can directly test the inclusion and exclusion of specific data types. This study uses the simulation testing and systematic data reduction from the US West Coast benchmark assessments to examine the performance of Stock Synthesis with catch and length (SS-CL) compositions only. The simulation testing of various life histories, recruitment variabilities, and data availability scenarios found that the correctly specified SS-CL can estimate unbiased key population quantities such as stock status with as little as 1 year of length data although 5 years or more may be more reliable. The error in key population quantities is decreased with an increase in years and the sample size of length data. The removal of the length compositions from benchmark assessments often caused large model deviations in the outputs compared to the removal of other data sources, indicating the importance of length data in integrated models. Models with catch and length data, excluding abundance indices and age composition, generally provided informative estimates of the stock status relative to the reference model, with most data scenarios falling within the CIs of the reference model. The results of simulation analysis and systematic data reduction indicated that SS-CL is potentially viable for data-moderate assessments in the USA, thus reducing precautionary buffers on catch limits for many stocks previously assessed in a lower tier using catch-only models. SS-CL could also be applied to many stocks around the world, maximizing the use of data available via the well tested, multifeature benefits of SS.

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c) Translating the ecosystem approach to fisheries management into practice: Case of anchovy management, Raja Ampat, West Papua, Indonesia.

Investigators: I. Sari, A. White, M. Ichsan, **J.M. Cope**, J. Nowlis, C. Rotinsulu, S. Mandagi, E. Menai, Z. Henan, R. Sharma, S. Tuharea, R. Tabalessy, M. Masengi https://doi.org/10.1016/j.marpol.2022.105162

The Ecosystem Approach to Fisheries Management (EAFM) strives to balance multiple objectives of ecological wellbeing, social and economic wellbeing, and good governance. The Provincial Government of West Papua with technical support from the USAID Sustainable Ecosystems Advanced Project (SEA) has developed a fisheries management plan (FMP) for the anchovy fishery in Raja Ampat, West Papua Province of Indonesia. EAFM is the appropriate approach to manage the fishery because EAFM multiple objectives reflect the challenges and needs to ensure the sustainability of the fishery resources and to contribute to local communities. The FMP includes management issues, operational objectives, appropriate management measures, and action plans defined through a participatory process. The issues include overfishing as shown by declining anchovy catches, resource competition between local small-scale fishers and industrial fishers, limited livelihood opportunities, and an absence of a functional fishery governance institution. To address these challenges, the FMP has multiple operational objectives: to empower local livelihoods, strengthen institutional management mechanisms, and ensure anchovy resources sustainability. The integration of the socioeconomic aspect means there must be management decision trade-offs that weigh trade-offs of stock sustainability, local poverty, interests of the pri vate sector, and addressing the horizontal conflict between locals and industrial fishers. Strengthening fisheries institutions is critical to ensure integration in resource investments and in detailing activities to implement the FMP because of the complementary roles, and lack of synergy of the multiple agencies. This holistic approach is expected to support the long-term use of the anchovy resources while partially alleviating local poverty.

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

d) Common model diagnostics for fish stock assessments in the United States

Investigators: Melissa A. Karp, Peter Kuriyama, Kristan Blackhart, Jon Brodziak, Felipe Carvalho, Kiersten Curti, E.J. Dick, Daniel Hennen, Jim Ianelli, Skyler Sagarese, Kyle Shertzer, and Ian Taylor

Fishery stock assessments are mathematical models that estimate the current status of a fish stock and are the foundation of sustainable fisheries management. Stock assessments typically rely on a number of data types to estimate key biological processes, the effects of fishing activity, and, in some cases, the influence of environmental conditions on the past and current stock status. Each stock assessment is unique and there is no objective criterion that simultaneously summarizes the results of an assessment, determines if the model fits the data adequately, and evaluates whether the model is well-specified. As a result, stock assessment analysts rely on a suite of model diagnostics to ultimately arrive at a single base model (or in some cases a suite of base models termed an ensemble of models) to inform management decisions for a specific fish stock. There are a number of regional differences in developing stock assessment models, and our goal here is to document the model diagnostics commonly used to develop a base model, or ensemble of models, for stocks managed by NOAA Fisheries, while incorporating the regional variation in methods. Models, modeling software, and diagnostic methods are tailored based on data availability, species life history, and unique fishery conditions, all of which vary from stock to stock and region to region. We note that some model diagnostics are broadly applicable to all regions of the country, whereas others have more limited use or may be applied differently across regions.

Karp, Melissa A., Peter Kuriyama, Kristan Blackhart, Jon Brodziak, Felipe Carvalho, Kiersten Curti, E.J. Dick, Dana Hanselman, Daniel Hennen, Jim Ianelli, Skyler Sagarese, Kyle Shertzer, and Ian Taylor. 2022. Common model diagnostics for fish stock

assessments in the United States. NOAA Tech. Memo. NMFS-F/SPO-240, 28 p. https://spo.nmfs.noaa.gov/sites/default/files/TMSPO240A.pdf

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

d) Development and considerations for application of a longevity-based prior for the natural mortality rate.

Investigators: O.S. Hamel, J.M. Cope

The natural mortality rate M is a key parameter in estimating the productivity of a fish stock. However, it is quite difficult to estimate given its correlation with other parameters, variation in processes governing population dynamics and data acquisition, as well as other factors such as ageing error. Meta-analytical approaches relating M to other life history parameters are often used to provide an estimate and/or Bayesian prior for M. Longevity is the one of these life history parameters most directly related to M. The maximum observed or estimated age serves as a proxy for longevity in predicting, or developing a prior for, M to be used within a stock assessment or other population model. Consideration of the age data and factors that might influence its quality for determining a maximum age is important in using a meta-analytically derived relationship between maximum age and M, though these factors are not completely absent from the data used to develop that relationship. Here, we discuss these issues, propose a relationship between maximum age and M, and develop an updated prior for M based upon maximum age.

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

C. Survey Science

1. Research

a) The relative influence of temperature and ontogeny on groundfish distribution varies across life stages.

Invstigators: Li L., Hollowed A., Cokelet E., Keller A., Barbeaux S. McClure M., Palsson W.

Distributional changes for fish populations may be difficult to interpret since temperature responses are often confounded with ontogenetic shifts. However, the relative importance of these two types of fish movement (temperature responses and ontogenetic shifts) to population distribution remains largely unstudied. This study presents the first attempt to compare the two types of movement in depth, latitude, and longitude for ten abundant groundfish species across size class and subregion. We utilized large, quality-controlled datasets from random depth-stratified, bottom trawl surveys consistently conducted during the summer along NE Pacific shelf from 1996 to 2015. We show that the size structure of each species varied across years and subregions with dramatically strong or poor recruitments for some species in 2015 during a marine heatwave. Principal Component

Analysis (PCA) demonstrated that ontogenetic shifts in depth represented the primary movement pattern while temperature responses in latitude and longitude constituted a major, but a secondary pattern. Re-run by size class, PCA results further showed that the influence of temperature and ontogeny on population distribution varied by size classes with greater ontogenetic shifts in smaller fish and elevated temperature responses in larger fish. We further show substantial ontogeny-induced movements by depth, latitude, and longitude with high variability among species and subregions (Figure 15). Our analyses suggest that failing to account for size structure can lead to serious misinterpretation of population distributional changes in all three dimensions: depth, latitude, and longitude for populations with or without episodic recruitments.

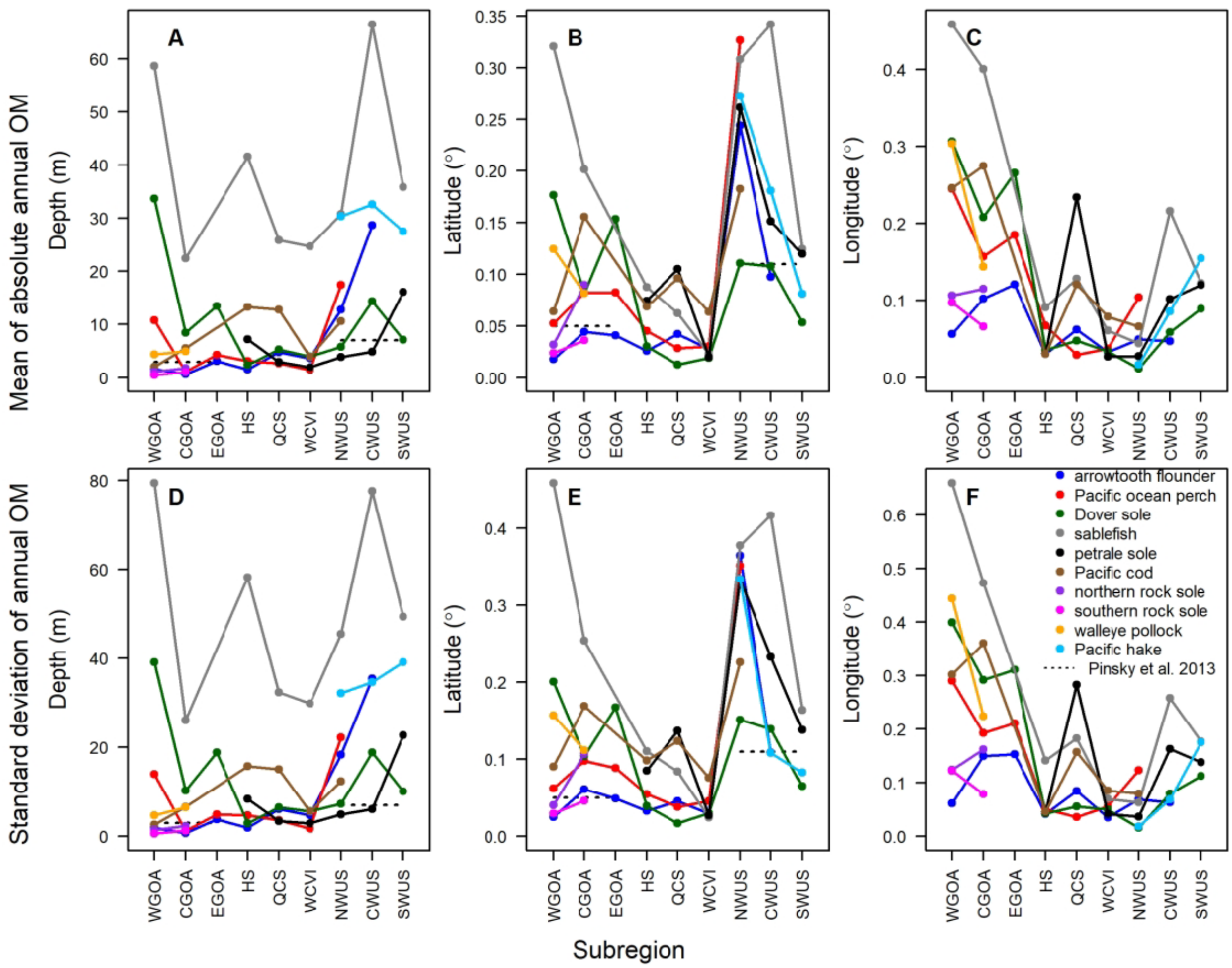

Figure 15. Ontogeny-induced movement (OM) by species and subregion. Mean of absolute annual OM in depth (A), latitude (B), and longitude (C) and standard deviation of annual OM in depth (D), latitude (E), and longitude (F) for each species (by color) across subregion. No points for some species in certain subregions represent being excluded in the analyses due to low abundance or absence in those areas. Dashed lines show the maximum absolute movements (with a couple of outliers excluded) in depth and latitude in the GOA and west coast of U.S.

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

b) The 2021 U.S. West Coast Bottom Trawl Survey of Groundfish Resources off Washington, Oregon, and California: Estimates of Distribution, Abundance, and Length Composition

Investigators: Aimee A. Keller, Douglas L. Draper, Aaron Chappell, Keith L. Bosley, John C. Buchanan, Peter H. Frey, John H. Harms, Melissa A. Head, Victor H. Simon

The authors completed a NOAA Technical Memorandum for the 2021 survey. The Northwest Fisheries Science Center's Fishery Resource Analysis and Monitoring Division (FRAM) completed the twenty-third in an annual series of groundfish bottom trawl surveys in 2021. The survey occurred from 20 May to 29 October 2021 and targeted the commercial groundfish resources inhabiting depths of 55 to 1,280 m (30–700 fathoms) from the area off Cape Flattery, Washington (lat 48°10′N) to the U.S.–Mexico border (lat 32°30′N) using chartered West Coast commercial trawl vessels. This ongoing series of annual surveys, conducted by FRAM since 1998, focuses on monitoring long-term trends in the distribution and abundance of West Coast groundfish, especially those species of management concern. We did not conduct sampling in 2020 due to the global COVID19 pandemic, representing the first break in the time series since it started. The 2021 survey sampled within a depth range that included both the continental shelf (55–183 m) and continental slope (183–1,280 m) using a stratified random sampling design. Because of COVID19 we modified the sampling schedule for the first half of the 2021 survey to include longer legs (11 to 18 days versus the typical 8 to 10 days) and fewer port calls (2 versus the typical 4).

In 2021, we selected 752 primary sampling sites (and associated secondary and tertiary sites) prior to the start of the survey. We allocated trawling locations according to a stratified random sampling design that divided the region into two geographic areas (north and south of Point Conception, California) and three depth zones (55–183 m, 184–549 m, 550–1,280 m). The objective was to provide a representative sample and relative numbers of the various groundfish species inhabiting each depth stratum. By selecting random stations within certain depth zones, all towable ground has an equal probability of being sampled during the survey. Thus, the method produces unbiased estimates of the relative stock size. In 2021, we completed 681 successful tows of 715 attempts (Figure 16). We obtained SIMRAD Integrated Trawl Instrumentation net mensuration data, as well as global positioning system (GPS) navigation data and bottom contact sensor data used to document performance (e.g., bottom tending) for most tows.

The survey utilized an Aberdeen-style net with a small mesh (1½″ stretched measure) liner in the codend (to retain smaller specimens) to sample fish biomass. Target duration of each tow was 15 minutes. We determined tow duration as the difference in time between touchdown and lift-off of the trawl net from the seafloor based on bottom contact sensor readings.

We sorted catches to species, aggregate, or other appropriate taxonomic level then weighed the entire catch using an electronic, motion-compensated scale. We identified a total of 567 species or families within the survey area in 2021. Although the biological sampling efforts continue to include Dover sole (*Microstomus pacificus*), shortspine thornyhead (*Sebastolobus alascanus*), longspine thornyhead (*S. altivelis*), and sablefish (*Anoplopoma fimbria*), the focus now encompasses all groundfish species of management concern (94+ species). We collected up to 100 length measurements, sex determinations, and individual weights and up to 50 age structures per haul for each species of management concern.

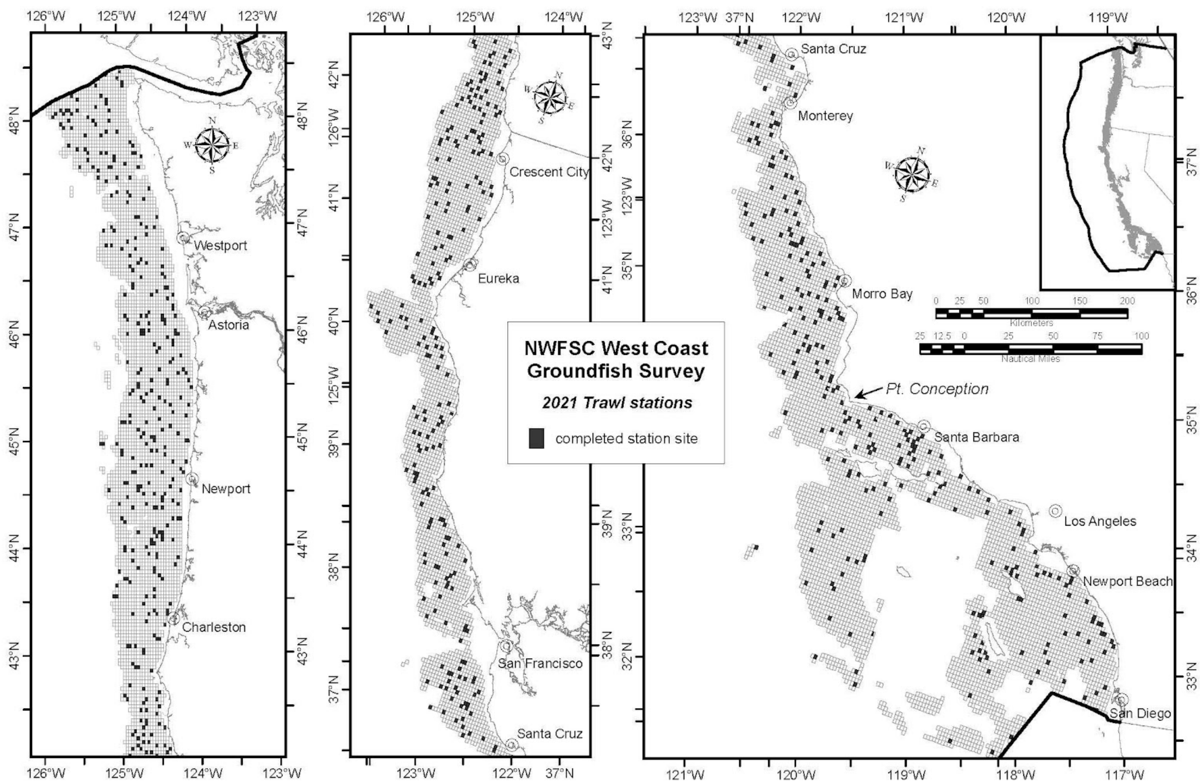

Figure 16. Chart showing extent of the 2021 West Coast groundfish bottom trawl survey and the locations of completed stations.

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D. Observer Program and Science

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2. Research

3. Observer Program Reports

E. By-catch Reduction Engineering

1. Research

a) Testing of hook sizes and appendages to reduce yelloweye rockfish bycatch in a Pacific halibut longline fishery

investigator: Mark Lomelli

In Pacific halibut longline fisheries in the eastern North Pacific Ocean bycatch of yelloweye rockfish is a concern as their stock status along the U.S. West Coast is "rebuilding" from being overfished, the southeast Alaska stock has shown a ~60% decline since at least 1994 and through 2015 where it stabilized, and the Canadian stock has been recently declared "*threatened*". In this study, we evaluated how size 16/0 and 18/0 circle hooks (QiHook brand) affect the catch efficiency of Pacific halibut and yelloweye rockfish. Further, we examined the catch efficiency of these hooks modified with a 3.1 mm stainless-steel wire appendage extending 7.6 cm from their shank at either a 45º or 90º angle (Fig. 17). We also planned to estimate hooking location probabilities for Pacific halibut and yelloweye rockfish for the hooks tested, and to test for a difference in the time of capture between Pacific halibut and yelloweye rockfish. Results showed that hook size did not significantly affect the catch efficiency of Pacific halibut or yelloweye rockfish. However, hooks with a 45º appendage angle caught significantly fewer yelloweye rockfish than hooks without an appendage, irrespective of hook size (Fig. 18). Appendage angle did not affect the catch efficiency of Pacific halibut. For both Pacific halibut and yelloweye rockfish, the most frequent hooking location was *hook through cheek*, both with and without an appendage. Time of capture of Pacific halibut and yelloweye rockfish did not differ over the duration of a set; however, the majority (75%) of individuals were caught within 2.5 hours of gear deployment. Results from our study suggest that hook appendages could have potential use in reducing catch rates on yelloweye rockfish in Pacific halibut longline fisheries, which could lead to increased fishing opportunity, more efficient Pacific halibut fisheries and less effect of fluctuations in the more productive Pacific halibut stock on fisheries that may be constrained by yelloweye rockfish. Funding for this research was provided by the NOAA Bycatch Reduction Engineering Program.

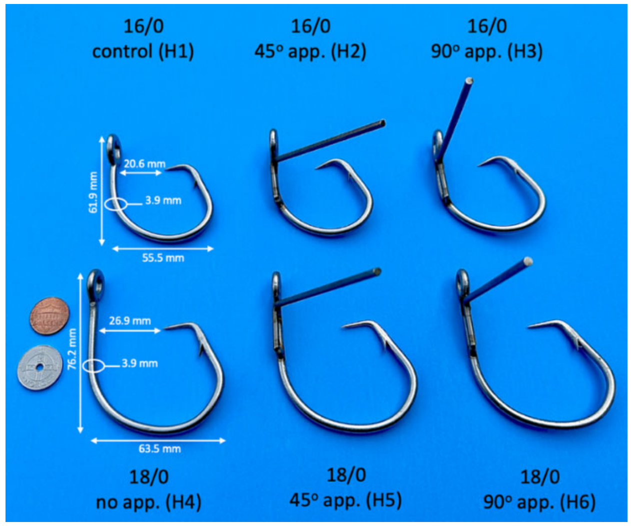

Figure 17. Image of the control hook (H1) and the five experimental hooks (H2-H6) examined. app. = appendage. Scale: Diameter of the Norwegian 1 krone displayed is 21 mm, diameter of the United States 1 cent displayed is 19 mm.

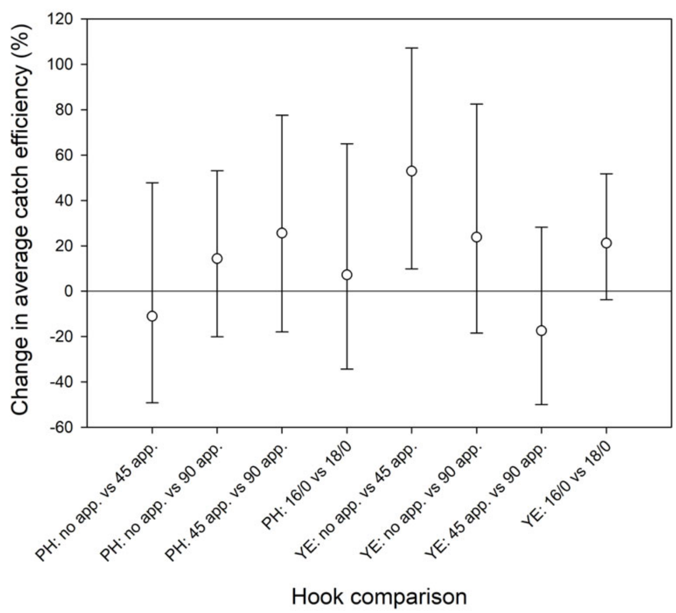

Figure 18. Change in average catch efficiency (%) between hooks with no appendage, 45° appendage, and 90° appendage. Open circles depict the mean value. Vertical lines are 95% CLs. PH = Pacific halibut; YE = yelloweye rockfish; app. = appendage.

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

b) Artificial illumination of trawl gear components to reduce Pacific halibut bycatch in West Coast bottom trawl fishery

investigator: Mark Lomelli

This study used catch comparison and catch ratio sampling and analyses techniques to determine if catches of Pacific halibut and groundfishes differ between illuminated and non-illuminated high-rise bottom trawls. In a collaborative effort, our research team worked in the U.S. West Coast groundfish bottom trawl fishery where Pacific halibut are a prohibited species barring their post capture retention. CPUE (by weight) and length data were collected on species of commercial importance. Biological data (e.g., length-weight relationships, somatic fat content, and blood samples to look at physiological stress indicators glucose, lactate, cortisol) on Pacific halibut was also collected to see if physiological condition could be related to their ability to avoid trawl capture (these analyses are currently occurring). Preliminary length-integrated analysis results show the illuminated trawls on average caught fewer Pacific halibut than the non-illuminated trawls as well as fewer sablefish, Dover sole, and petrale sole. However, these catch reductions were not statistically significant. The Length-dependent analysis for these species is currently occurring. In addition to the potential application of project results to fishery management, this research is contributing to the Master of Science degree of a student enrolled in the School of Marine Science - Fisheries Science concentration at the Virginia Institute of Marine Science. Funding for this research was provided by the NOAA Bycatch Reduction Engineering Program.

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

Recent publications

Larsen, R.B., Herrmann, B., Sistiaga, M., Brinkhof, J., Cerbule, K., Grimaldo, E., Lomeli, M.J.M. 2022. Effect of the Nordmøre grid bar spacing on size selectivity, catch efficiency and bycatch of the Barents Sea Northern shrimp fishery. PLOS ONE. 17(12): e0277788.

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Jacobsen, N.S., K.N. Marshall, A.M. Berger, C. Grandin, and I.G. Taylor. 2022. Climate-mediated stock redistribution causes increased risk and challenges for fisheries management. ICES Journal of Marine Science, 2022, 79, 1120–1132 DOI: 10.1093/icesjms/fsac029
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