NSAW14
MARVLS

PROCEEDINGS

14th National Stock Assessment Workshop and 4th Biennial Meeting of Working Group on Maturity, Assessment, Reproductive Variability, and Life Strategies

Providence, RI
May 9-11, 2023

Edited by Abigail Furnish, Sabrina Beyer, Richard McBride, Kristan Blackhart, Melissa Karp, Steve Teo, Jonathan Deroba, Kate Siegfried, Michelle Sculley, and Vladlena Gertseva

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Proceedings of the 14th National Stock Assessment Workshop and 4th Biennial Meeting of Working Group on Maturity, Assessment, Reproductive Variability, and Life Strategies

Theme: Spatial Modeling

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Executive Summary

The National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA Fisheries) held its 14th National Stock Assessment Workshop (NSAW14) from 9 to 11 May 2023 in Providence, RI. The Workshop was held jointly with the Maturity Assessment, Reproductive Variability, and Life Strategies (MARVLS) group. Over 100 participants from NOAA Fisheries science centers and headquarters attended the workshop, in addition to the participation of academic and state agency partners.

The NSAWs have two primary objectives:

1. Address an important or topical theme of common concern to all NMFS Science Centers,
2. Provide a forum for interaction between the large diversity of NMFS scientists involved in conducting stock assessments, providing management advice, and related activities.

The mission of MARVLS is to advance scientific knowledge and communicate the importance of reproductive biology in the management of marine fish.

NSAW14 focused on the topic of Spatial Modeling. MARVLS focused on recent advances and the application of reproductive ecology in fisheries management. The workshop included oral and poster presentations, as well as breakout group discussions, which were divided among four sessions.

A. A joint NSAW-MARVLS session on Advances and Applications of Spatial Life History Data
B. An NSAW Session focused on Species Distribution Modeling
C. An NSAW Session focused on Parameterizing Spatial Assessments
D. A MARVLS Session focused on Recent Advances and Studies in Reproductive Biology and Life History

These sessions provided the basis for the following conclusions and recommendations.

Recommendations

Joint NSAW-MARVLS and MARVLS

1. Continue to improve size- and age-at-maturity data for stock assessments.
2. Evaluate the frequency of spawning, which may be more or less than once per year.
3. Challenge the assumption about fish fecundity being proportional to body size.
4. Examine hypotheses about the effect of egg quality on reproductive success.
5. Investigate sex-specific traits and behaviors that can influence stock characteristics, such as size dimorphism, skewed sex ratios, and sex-specific mortality schedules.

6. Explore simulation models to determine when improved information on reproductive parameters is most useful in stock assessment models.

Species Distribution Models (SDMs)

1. SDMs have many applications within fisheries management, from evaluating and standardizing an abundance index to evaluating species distribution shifts, hotspot analysis, and others. It is important to consider how an SDM is being used because each application may have different needs and interpretations of model diagnostics.
2. SDMs hold potential for informing survey and sampling design, or potentially even filling in gaps. However, SDMs should not serve as a good substitute for developing good sampling designs. You can't model your way out of bad data! Thus, there is a need to continue to improve data collection and the quality of data.
3. Better coordination between regions is necessary to ensure that shifting distributions of species of interest are captured by overlapping surveys, so that neighboring surveys can be compared or combined.
4. Multiple diagnostics and/or plots should be considered when evaluating a model. External information needs to be considered to ensure the results make sense within the larger body of research. Also, potential sources of biases in the data collection, in the assumption of constant catchability, or the assumption of a survey covering the population's full range should be considered.
5. SDMs rely on high resolution and accurate habitat and environmental data. There is a need for improved habitat and environmental data quality and access if the hope is to expand the use of SDMs.
6. In situations where the available data are insufficient to fully estimate SDM parameters, simulated SDMs may still be useful in some applications to inform certain questions.

Parameterizing Spatial Stock Assessments

1. Stock assessments should always consider spatial approaches but strive for the most parsimonious approach available that will provide the necessary level of management advice needed.
2. When appropriate, spatial modeling can be used to highlight potential impacts (e.g., localized depletion) on stocks from a lack of spatial management as well as provide more detailed management advice. Failing to represent spatial dynamics driving stock biology could cause misleading management advice and detrimental effects on the final management decisions.
3. Ideally, stock boundaries should be based on the biology of the stock rather than political or other arbitrary lines, with allocation decisions made between political boundaries as necessary. The reality is that mismatches often exist between biological and management

units, and data availability may present challenges to developing assessments at finer spatial scales, requiring compromises from the ideal to a more pragmatic approach.
4. As with most stock assessment considerations, use of spatial modeling approaches begins with thoroughly examining the data at the highest resolution possible to try to understand the processes that could be causing observed patterns in the data.

Introduction

The 14th installment of NOAA Fisheries' National Stock Assessment Workshop (NSAW14) was hosted by the Northeast Fisheries Science Center (NEFSC) from 9 to 11 May 2023, at the Hotel Providence in Providence, RI. NOAA Fisheries holds these workshops to address important stock assessment-related themes germane to the agency's science-based sustainable fisheries management mission. The NSAWs also provide a forum for interaction and collaboration among NOAA Fisheries scientists from around the nation, particularly those who are involved in the stock assessment processes. For NSAW14, the meeting was held jointly with the Maturity Assessment, Reproductive Variability, and Life Strategies (MARVLS) group. The workshop was planned by a national steering committee (Appendix A) made up of representatives from all six NOAA Fisheries Science Centers and the Office of Science & Technology. Over 100 participants attended the NSAW/MARVLS meeting, including representatives from NOAA Fisheries headquarters and science centers, in addition to academic partners, and MARVLS members from state and other government agencies. Attendees are listed in Appendix B.

The workshop started with a one-day joint session between NSAW and MARVLS attendees, focused on studies related to fish reproduction, as well as on select topics under the sub-theme Advances and Applications of Spatial Life History Data. This session included a keynote speaker, numerous presentations, a panel discussion, and a poster session.

The key theme of the NSAW meeting focused on Spatial Modeling, with two sub-themes. One day focused on Species Distribution Modeling and included various presentations as well as breakout discussions. The second day followed a similar format and focused on Parameterizing Spatial Stock Assessments. NSAW also included keynote speakers as well as presentations on topics of national interest.

The MARVLS meeting included a one-day session focused on Recent Advances and Studies in Reproductive Biology and Life History, consisting of presentations and discussions. MARVLS attendees took a one-day field trip to the Laboratory at the NEFSC in Woods Hole, MA for a tour and hands-on session as well as more in-depth discussions and collaborative research planning.

See Appendix C for a complete agenda from the workshop and Appendix F for all presentation and poster abstracts.

Session 1: Joint NSAW/MARVLS Session

Session Overview:

The MARVLS group focuses on fish reproduction, the event that completes the cycle of life, dictates fish production, drives stock structure, and makes fisheries renewable. In fishery assessments, a key biological reference point when evaluating the status and trend of a fish population is based on its relative spawning stock biomass, which requires separating the non-spawning and spawning components of a population. Discriminating and quantifying these different population components with as much precision and with as little bias as is practical is essential to determine a stock's reproductive potential for sustainability.

Formed at a national level in 2014, MARVLS is a community of practice organized to standardize and advance how fish reproductive data and information are integrated into fishery assessment and management. It has since grown to include scientists from all six of NOAA Fisheries' science regions, as well as academic and state agency partners, and international researchers, to share best practices and expand our science capabilities. In particular, it encourages the inclusion of both biologists and modelers, working together, to deliver more and better quality data and information to stock and ecosystem assessments (https://marvls.github.io/MARVLS/index.html). It was decided that joint discussion between MARVLS and the stock assessment modelers of NSAW would be interesting and beneficial to both groups, and a full day joint session was planned.

The joint NSAW/MARVLS session began with a keynote address on "Reproductive Biology of Fish: Applications for Research, Monitoring, Assessment and Management," presented by Richard McBride (NEFSC) and co-authored by members of the MARVLS steering committee, which broke down the broad topic of reproduction into individual traits. Listed here, more or less in order from high to low availability of data, these traits are maturity, spawning frequency, fecundity (number of eggs), quality of eggs, sex ratios, and mating systems. Each trait was characterized relative to a scale indicating transition readiness: from research, to monitoring, to assessment, and to management. The presentation outlined operational successes and remaining challenges, providing an overview of examples, products, and opportunities for collaboration. The keynote was followed by multiple presentations and a panel discussion from both reproductive fish biologists and stock assessment scientists on life history data in assessments, with a particular focus on spatial elements (see Appendix F).

A common theme of the joint session was how maturity data is broadly available and widely applied to most fish stock assessments because it can be cost-effectively monitored by macroscopic characteristics such as gonad size, shape, color, etc. However, macroscopic methods are not known to be precise, and they can lead to biases when confusing a physiological maturity, similar to puberty, from a functional maturity, related to actual spawning. The use of gonad histology was recommended as a fully operational method to reduce such bias as well as to improve precision of maturity data because it offers greater resolution about the specific stages of gametogenesis. Unsurprisingly, histology is more expensive than macroscopic methods, but the question of how much it costs should be paired with the question of what problem it can solve.

Another common theme was the use of fecundity information in stock assessments and re-visiting historical assumptions that spawning stock biomass is proportional to total egg production. Fecundity data is uncommonly collected and therefore not widely used in stock assessments (with notable exceptions, such as west coast groundfish and some Atlantic stocks). If fecundity information was not collected prior to over-exploitation, it is challenging to measure the fecundity curve once larger and older fishes in a population become rare. Nonetheless, image analysis methods have advanced to an operational state that speeds up counts of eggs and therefore the estimation of individual fecundity and population-level total egg production. Increasing availability of fecundity data has led to the recognition of a disassociation between spawning stock biomass and total egg production—two measures of stock reproductive potential—when there is evidence of hyper-allometry in the relationship of maternal body size and fecundity. Hyper-allometric fecundity, a condition arising from larger fish producing disproportionally more eggs per gram of spawning biomass than smaller fish, is becoming more readily identified in fishes worldwide. The disassociating effect of hyper-allometric fecundity on biological reference points is strongest in fish populations that have experienced size and age truncation from persistent overfishing.

Panel Discussion:
The joint session ended with a panel and audience discussion to review key points. Panelists represented each of the six NOAA Fisheries science centers and the Office of Science and Technology (OST) and included scientists with expertise in fish reproductive ecology, life history, and stock assessment: Nikolai Klibansky (Southeast Fisheries Science Center, SEFSC), Derek Bolser (OST), Brad Erisman (Southwest Fisheries Science Center, SWFSC), Susanne McDermott (Alaska Fisheries Science Center, AFSC), Sabrina Beyer (University of Washington, West Coast groundfish), Jon Brodziak (Pacific Islands Fisheries Science Center, PIFSC), Jim Thorsen (AFSC), Liz Brooks (NEFSC), and Mark Wuenschel (NEFSC). They highlighted differences among regions in the way life history and reproductive information is used in fishery stock assessments. Differences include variation in monetary resources for life history and biological research (including maturity and fecundity), the varying influence of reproductive parameters on assessments, and high-priority assessment needs. For example, many west coast assessments use Total Egg Production (TEP) assessment models even though this requires not

just maturity data but fecundity information as well. Such TEP models can be more sensitive when hyper-fecundity is evident, which generated discussion as to whether it is problematic to using reference points that were formulated based on spawning stock biomass models that do not consider demographic variation in fecundity-at-age or size. There are also situations where the information on reproductive traits in assessments could be improved. Perhaps, they are out-of-date, not accounting for changing oceanographic conditions with climate change, or they do not account for a biased process such as abortive maturity that was not recognized in the historical literature. There are other situations where estimates of reproductive parameters could certainly be improved, but the effect of such changes on reducing uncertainty in the assessment model is small compared to other data sources, such as unaccounted bycatch

Recommendations

There is widespread evidence that reproductive traits in fishes can be non-stationary, thereby influenced over time or space by effects that arise from physiological (size and age of females [i.e., maternal effects]), environmental (ecophenotypic responses to changes in productivity), and genetic (stock structure, fishing-induced evolution) factors. The following recommendations provide a road map to prioritize research and monitoring of these reproductive traits, and the application of this information to assessment and management of marine fishes.

1) Continue to improve size- and age-at maturity data. There are many stocks with no reliable maturity schedule, and many other stocks whose maturity schedules are out of date and no longer accurate. When considering methodology, maturity classification benefits from using a microscopic (gonad histology) rather than a macroscopic approach, especially to distinguish between *physiological* maturity (which includes includes those that will spawn as well as fish in puberty and fish that abort a first attempt at spawning) versus *functional* maturity (those that will spawn this season, are spawning, or spawned in the past [but may be skipping this year]). Historical literature is unlikely to distinguish between these two types of maturity. Because physiological maturity typically occurs at smaller sizes and younger ages than functional maturity, it is a biased estimator that overestimates the size of the spawning stock. Such biases can be reduced by sampling as close to the spawning season as possible and by validating functional maturity classification with gonad histology.

2) Evaluate the frequency of spawning. In many stocks, not all individuals that spawned in the past continue to spawn every spawning cycle. Some species require more than one year to produce a successful clutch of eggs or offspring as part of their phenology (non-annual spawning). In others, first-time spawners may abort a clutch of developing eggs, whereas already mature fish may skip future spawning opportunities when energetically stressed. Skip spawning, in particular, overestimates a population's reproductive potential. This would be particularly problematic if it varies between years, such as if driven by environmental productivity, although no clear cases of this have been identified. Nonetheless, deviations from expected spawning cycles are becoming more apparent because more researchers are looking for the signs. Also, for batch spawners, the number of batches and therefore the length of the spawning season often increase with size or age. When spawning frequency is related to size or age, whether between or within years, the value of larger and older fish is related to population resiliency, which should be meaningful for population models and recognized by fishery policy makers.

3) Challenge the assumptions about fish fecundity. Measuring annual fecundity is difficult, and at many science centers, fecundity data are sparse, which has led to an implicit assumption that fecundity does not matter. However, stocks for which the largest and oldest fish are adequately sampled indicate that size-specific fecundity is hyper-allometric (larger fish produce more eggs than their body size alone would suggest). Hyper-allometric fecundity emphasizes the obstacles to rebuilding stocks that suffer from size and age truncation, and can complicate the estimation of productivity (the shape of the spawner/recruit relationship) when spawning output is incorrectly assumed to be identical to spawning biomass. For species with multiple stocks or for single stocks with a long time series of data, relative fecundity (# eggs/body weight) may vary considerably. Once mature, fish invest most of their surplus energy into their gametes, and we should be investing in research to demonstrate how well relative fecundity is correlated by environmental drivers. For fishes with hyper-allometric fecundity and those found in environments with high levels of variability in productivity, we would expect that total egg production is a more realistic indicator of stock reproductive success than spawning stock biomass.

4) Examine hypotheses about the effect of egg quality on reproductive success. Collaborate with partners with laboratory space for controlled experiments, such as hatcheries, or find other interdisciplinary approaches to measure and model how egg quality or other measures of reproductive success is affected by maternal or environmental effects.

5) Investigate sex-specific traits and behaviors. We need more generalizable examples of how size dimorphism between sexes, skewed sex ratios, sex-specific mortality schedules, the various forms of hermaphroditism (i.e., sequential, simultaneous), and spawning behaviors affect stock assessments.

6) Explore simulation models to determine when improved information on reproductive parameters is most useful in stock assessment models. Evaluate the implications of hyper-allometric fecundity, maternal effects, and new reproductive trait information on spawning stock biomass and, as an alternative, total egg production for setting fishing reference points and overfishing levels. Develop rules of thumb from such simulations to guide prioritization of reproductive studies across all science centers.

mortality or changing natural mortality rates. In a world of limited resources, funding for improving reproductive data competes to improve other fundamental data streams for assessment, such as age and growth information. Regardless, continued research into spatiotemporally varying life history traits, bioenergetics, and other factors influencing reproductive success will be key to better understanding and improving predictions of population dynamics as climate change increasingly impacts the physical and biological conditions in our oceans and coastal marine ecosystems.

We hope to look back at NSAW14 as a milestone event that promoted cross-disciplinary discussions to improve the generation and interpretation of reproductive data for NOAA's mission.

Session 2: Species Distribution Modeling

Session Overview:

Understanding how species are distributed in space and time and the factors that drive spatial patterns in distribution and abundance are central questions in ecology and important for species conservation and management. Species Distribution Models (SDMs) have become a common tool used to describe and predict species distributions as a function of biotic and abiotic factors, and can provide insights into species core habitat areas and impacts of both environmental and anthropogenic pressures. The session included various presentations on examples of the potential use and applications of SDMs and spatiotemporal models to answer various management questions. During breakout and plenary discussions, the challenges and limitations of SDMs were discussed, including the need for diagnostics. It is also recognized that SDMs generally require large amounts of data. At the same time, the predictive help of SDMs can potentially inform management and data collection. The conclusions and recommendations presented below are from the perspective of workshop participants, many of whom noted that they had little to no experience working with SDMs.

Breakout Discussion

Between plenary presentations, participants separated into breakout groups to discuss various questions in relation to the use of species distribution models. This section briefly describes the questions and discussions.

Session 2, Part 1:
Facilitators: LaTreese Denson, Steven Teo, Howard Townsend, Melissa Haltuch, Michelle Sculley
Rapporteurs: Amanda Hart, Angelia Miller, Samara Nehemiah, Catalina Roman, Melissa Karp

What are some important considerations when evaluating the predictive skill/performance of an SDM?

A. Consider catchability – An SDM often assumes catchability is constant in space, but it may not be, and it is difficult to parse parameters that affect catchability vs spatial distribution. Also, the environmental parameters measured and available for use within an SDM may not be the best predictors or may be correlated with other parameters that are not measured, giving a potentially false relationship.
B. Consider use of the model – Different applications (e.g., looking for an abundance index, species distribution shift analysis, or hotspot analysis) may have different needs and interpretations of the model diagnostics.

It is important to understand where the data are coming from and potential biases, including sampling design and implementation as well as any changes in the fishery that may be driving observed patterns. A solid understanding of the fishery can help reduce or understand any biases in the model, and simulations can help determine if you have the ability to estimate the parameters of interest from your data. This is especially important as species' distributions shift in response to climatological changes and may shift out of the management or survey boundaries. Ensuring that sampling in neighboring jurisdictions overlaps will help track those changes and close gaps in the range coverage.

What are the most useful metrics for measuring species distributions and range shifts (e.g., center of biomass/gravity, area occupied, distribution of abundance in space, and range boundaries)?
Center of gravity is commonly used, but this metric does not capture the spread of the population, and while changes may be attributed to climate shifts, this may not be an accurate conclusion. Area occupied or range limits can help understand the population spread.

Lessons from terrestrial SDMs that use integral difference equations such as probabilistic spatial kernel and other more mechanistic ways to understand species distributions from a SDM can help. One example is using altitude, which potentially could be extended to be used for depth in the ocean and expanded into three-dimensional SDMs.

Many of the talks use SDM/Vector Autoregressive Spatiotemporal (VAST) models to standardize/evaluate the use of data that aren't currently used in the assessment model for a variety of reasons. How do you evaluate if the new analysis solves the problems that led to the data being excluded to begin with, and if the trends in the biomass are different, how do you determine if they are more reliable than the "old" data?
What happens if you include new data and they are telling a completely different story than what you've always used? How do you know which is the "true" trend?

When comparing newer, SDM-based analyses with the original information available, consider why the new data were originally excluded and if the problems identified originally are still a problem or if they have been improved by the new analysis. Also, different surveys and fisheries may capture different components of a stock, such as different age classes. Different trends in the index may not be a signal of inconsistency between the data. In addition, these new methods have the potential to bring in and combine different types of data that were not modeled previously. Being attentive to the potential sources of bias in each data set is important so that you can decide which you could control for and which would cause problems.

When comparing CPUE versus survey data for non-targeted species, remember that survey designs are not typically optimized for those species, so you may not be seeing the whole picture in the survey. Ultimately, you should remember that you cannot model your way out of bad data. If your data are problematic, you should try to ground-truth your data with surveys or improved data collection from fishers before you attempt to model it.

Breakout Discussion
Session 2, Part 2:
Facilitators: Francesca Forrestal, Jonathan Deroba
Rapporteurs: Challen Hyman, Peter Kuriyama

The afternoon breakout groups had two different sets of discussion questions. Half of the participants responded to the following questions.

Start with a review of the different uses of SDMs covered in the presentations (both morning and afternoon). Ask the group to then think about whether there are additional uses of SDMs in assessment and management that were not discussed.

SDMs are widely useful for fisheries research and management, and much was covered in the presentations. They are particularly useful for developing data for stock assessments like indices of abundance and age compositions. These models also facilitate comparisons between design-based and model-based approaches, aiding in the evaluation of different methodologies.

One of the advantages of SDMs is their ability to accommodate missing data and multiple data sources in a statistically consistent manner. They can be employed to validate indices included in stock assessments. Additionally, SDMs are instrumental in analyzing and predicting spatial distributions of fish species, providing valuable insights into distributional changes over time. SDMs can be valuable for estimating population trends and distributions of data-poor stocks. By leveraging relationships between common and uncommon species, SDMs can provide estimates for stocks with limited data. These models are also useful when survey designs change over time, as they can integrate data from different surveys to estimate a single mesh across the total area.

Similarly, SDMs assist in addressing data gaps in surveys and optimizing survey efforts. Climate change and changing fleet dynamics pose additional challenges, which may require adaptations to survey designs. SDMs help to provide insights into where gaps exist and guide the design of future surveys.

SDMs can also play a crucial role in essential fish habitat (EFH) and ocean planning efforts by identifying suitable habitats for various species and where these habitats overlap. They can therefore assist in the spatial management of multiple species or species complexes at the same time and may result in more efficient use of available research and management resources. However, caution should be exercised when grouping stocks and species, as doing so may mask the poor status of individual stocks within a complex.

SDMs can also be used to apportion catch and determine acceptable biological catch (ABC) for stocks without age-structured assessments. By integrating SDMs with other relevant data sources, catch allocations can be more informed and reflective of population dynamics.

How should stock structure be addressed when management units and or fishing areas do not represent biological populations?

Spatial distributions of fish populations may change over time, especially with climate change. Therefore, even if the biological basis for defining management units or fishing areas were relevant in the past, these may become outdated. However, addressing this issue may require coordination between fishery managers from fishery management bodies as well as local and national governments.

These challenges were exacerbated by transboundary stocks. For example, the assessment and management of sardine populations between the United States and Mexico highlight the challenges of managing stocks that span international boundaries. Differences in survey data and stock dynamics between different regions can also complicate management efforts. Similarly, in the Pacific Islands, expanding surveys beyond the main Hawaiian Islands to include areas like Guam and American Samoa reveals potential differences in stock structure. The International Commission for the Conservation of Atlantic Tunas (ICCAT) also faces similar issues, with movements of fish populations observed between different regions. The Gulf of Mexico presents a comparable challenge, as it is managed by multiple jurisdictions. These examples underscore the complexities associated with managing stocks that cross spatial and political boundaries and the importance of considering stock structure in management decisions.

Managers often prefer to continue managing within their established spatial extents, while scientists must convey the additional uncertainty associated with mismatches between the biology of fish populations and management boundaries. In some cases, it may be appropriate to focus on making inferences within specific spatially explicit regions where fishing activities occur, considering the dynamic nature of fish movements.

Fishermen likely adapt their fishing operations and locations to follow fish migrations, which may necessitate adjusting management borders accordingly. Additionally, in the Southeast region, relatively low gear costs suggest that watermen may be able to switch target species relatively easily if there are shifts in species ranges. This implies that flexibility in targeting different species could potentially mitigate the impacts of changing stock distributions.

One approach is to assess the entire region as a single stock but divide it into management divisions. Catch is then allocated to the respective spatial management units. However, this approach can present challenges if historical catch proportions have changed between management units over time. SDMs can provide valuable information to inform spatial catch allocations.

The best solution to address the mismatch between biological populations and management/fishing locations may be the implementation of a spatially explicit stock assessment. Such an assessment would consider the specific spatial dynamics and account for the mismatches between biological population distributions and management boundaries. This approach could provide a more accurate understanding of stock structure and inform decision-making. However, the data may not be available to support spatially explicit stock assessments.

The question was raised as to whether spatial stock assessments are necessary to address stock structure effectively. Such assessments can play a vital role in highlighting data limitations and emphasizing the need to collect spatial data, particularly for recreational fisheries. The issue of whether spatial analyses should be conducted outside or within the assessment model is a matter of consideration and depends on the specific context and available resources.

Breakout Discussion
Session 2, Part 3:
Facilitators: Shannon Calay, Brian Langseth, Maia Sosa Kapur
Rapporteurs: Matthew Smith, Abigail Tyrell, Hongguang Ma

The second question set for the afternoon breakouts focused on communicating uncertainty, understanding where SDMs can and should be inserted into the management process, and discussing the challenges to the development of SDMs in fisheries management.

How can we best communicate outputs from SDMs, specifically risk, uncertainty, and tradeoffs?

It is important to first consider the audience and how the uncertainty is going to be used in management. In considering the audience, one should also consider the uncertainties that are interesting to that audience. For instance, maybe they only care about how much of the population's distribution will be above or below a certain boundary and not uncertainty around the center of gravity estimates.

Additionally, visuals (e.g., maps) are very valuable; however, because of the simplified presentation of visual aids (i.e., that they often show central tendencies), showing uncertainty is important as well. For example, one approach could be to show values and uncertainties (e.g., standard deviations of the estimates by location or probability bounds) in separate maps. Another, simpler approach for a different audience could be to use simpler terms such as “confident” or “not confident.” It is also important to remember and explain that uncertainty from SDMs is likely an underestimate of the true uncertainty, but these models do a better job of accounting for more of the uncertainty present.

Where can/should SDMs be inserted in the fisheries management process?

SDM results can be inserted throughout the stock assessment and management process in many varied ways, but the methods should be tailored to the specific use. There is/should be a difference between operational and research uses. SDMs can be used to inform spatial boundaries, survey indices, catchability with environmental and habitat data, and assessment models (full spatial–temporal assessment models, index-based assessments), evaluate shifts in distributions across management jurisdictions, help to address allocation issues for transboundary stocks, and to stitch together disparate data sources. SDMs may also be included in projections if linked to future climate to help understand changes associated with changing ocean conditions. It was suggested that Ecosystem Socioeconomic Profiles could be a good outlet to communicate SDM outputs and illustrate how things are shifting.

What are some of the challenges to the development and use of SDMs in fisheries management?

Common barriers and challenges to more routine operational development and use of SDMs across regions included training, time, package stability, availability of data, and understanding and acceptance of outputs by end users. Lack of data at appropriate spatial resolutions is a key hindrance. While this requires further guidance and examples of how to run SDMs in more data-limited situations, it also provides a potential opportunity for

Recommendations

1. SDMs have many applications within fisheries management, from evaluating and standardizing an abundance index to evaluating species distribution shifts, hotspot analysis, and others. It is also important to consider how an SDM is being used because each application may have different needs and interpretations of model diagnostics.
2. SDMs hold potential for informing survey and sampling design or potentially even filling in gaps. However, SDMs should not serve as a good substitute for developing good sampling designs. You can't model your way out of bad data! Thus, there is a need to continue to improve data collection and the quality of data.
3. Better coordination between regions is necessary to ensure that shifting distributions of species of interest are captured by overlapping surveys, so that neighboring surveys can be compared or combined.
4. Multiple diagnostics and/or plots should be considered when evaluating a model. External information should be considered to ensure the results make sense within the larger body of research. Potential sources of biases in the data collection, in the assumption of constant catchability, or the assumption of a survey covering the population's full range should also be considered.
5. SDMs rely on high resolution and accurate habitat and environmental data. There is a need for improved habitat and environmental data quality and access if the hope is to expand the use of SDMs.
6. In situations where the available data is insufficient to fully estimate SDM parameters, simulated SDMs may still be useful in some applications to inform certain questions.

engagement and partnering with the fishing community. Industry and recreational fishers could be key partners for obtaining spatial data for informing SDM analyses (e.g., mapping red tide events in the Southeast region). Whether SDMs have been accepted by FMCs depends on the region and when they first started implementing SDM (10+ years on the U.S. West Coast and more recently in other regions). Once one FMC has adopted an approach, it then adds credibility for other councils to adopt as well.

Session 3: Parameterizing Spatial Assessments

Session Overview:

The Parameterizing Stock Assessment Session focused on the development and implementation of spatially explicit stock assessments. Presentations and discussions were largely related to providing advice on transitioning from single area to multiple area models, but other topics included demonstrations of the consequences of ignoring spatial heterogeneity, a management strategy evaluation about combining spatial assessments with spatial harvest control rules, and visualizing complex spatial data and assessment output. The challenges to developing spatially explicit stock assessments were evident in the session. Perhaps most evident were the challenges related to data, including processing data, utilizing tagging information, or finding novel data streams to inform movement rates and other spatial processes, which seemed to be a necessity for spatial assessment. Other challenges were also clear, such as those posed by transboundary issues, the interplay between conducting a spatial assessment and using it for management, and the lack of clear guidance on parameterizing (e.g., assumptions about stock structure, movement rates, growth, etc.) spatially explicit stock assessments. In addition to the suite of challenges highlighted by the session, benefits to accurate assessment and successful management were also covered, demonstrating that attempting to overcome the challenges to spatial assessment are likely worth the effort.

Dr. Daniel Goethel (AFSC) presented the session's keynote, based on work done with Dr. Aaron Berger (Northwest Fisheries Science Center, NWFSC) on developing pragmatic guidance for implementing spatial stock assessments. The presentation outlined a stepwise approach to implementing spatial stock assessments (see Goethel et al., 2023 for a full description) that include:

1. Performing a data inventory, with emphasis on novel spatially referenced data sources.
2. Developing flexible data repositories that facilitate high resolution data analysis and aggregation/disaggregation of data sources.
3. Implementing participatory processes to integrate stakeholder observations and ecological knowledge into the model development process.
4. Applying stock identification approaches to understand population structure.
5. Matching the stock assessment population structure to stock identification results ensuring that management boundaries do not constrain the science.

6. Developing conceptual spatial models that account for all known spatial dynamics.
7. Using a strategic decision point analysis with explicit justification for each spatial assumption.
8. Maintaining multiple model structures (i.e., including spatially aggregated approaches) for comparison regardless of the model used for management.
9. Simulation testing spatial models using data-conditioned operating models, especially using high-resolution frameworks (e.g., https://aaronmberger-nwfsc.github.io/Spatial-Assessment-Modeling-Workshop/index.html), to determine whether a spatial assessment is necessary, with the goal of identifying minimally complex, maximally robust management procedures.
10. Utilizing a pragmatic modeling approach, including consideration of spatially implicit models (e.g., areas-as-fleets), population of origin assessments, modeling multiple populations simultaneously to allow sharing of parameters even if connectivity is not modeled, and utilizing methods to reduce parametrization for spatially explicit models (e.g., by implementing random effects, spatial autocorrelation, and parameter sharing).
11. Ensuring reproducible workflows to allow synergistic model development and documenting code to aid in disseminating knowledge regarding spatial model development.

Dr. Goethel concluded with the thought that as the stock assessment discipline evolves, the primary need is a paradigm change in how spatial population structure is treated in assessment models. The default assumption should be to account for spatial structure unless stock identification and simulation testing suggest that the unit population assumption can provide adequate and robust management advice. As the next generation of stock assessment software is developed, the full complexity of spatial population structure should be incorporated at the outset with efficient approaches for reducing model partitions. Moreover, emphasis should be placed on developing flexible data extraction tools within reproducible workflows, which will enable sharing model development efficiencies across stock assessment communities. Implementing spatial models should be viewed as an iterative process focused on moving away from unit population assumptions using an incremental approach.

Breakout Discussion
Between plenary presentations, participants separated into breakout groups to discuss various questions in relation to parameterizing spatial stock assessments. The morning sessions included groups discussing two sets of questions. Three groups responded to these questions.

Session 3, Part 1:
Facilitators: Patrick Lynch, Dana Hanselman
Rapporteurs: Steven Teo, Dan Goethel, Howard Townsend

What types of data could be used to inform spatial structure of the stock?

A list of the types of data that might inform spatial structure is extensive: tagging data (conventional and archival), age (fishery-independent and -dependent; GIS, mapping), growth information, genetics, spatially explicit catch data, haul level catch and biological information, environmental data, morphometrics, parasite load/species, spatial residuals, otolith microchemistry (stable isotope), e-DNA, habitat distribution, larval model outputs (IBMs), and citizen science.

In application, a list of data also needs to come with other considerations. For example, different datasets will inform different aspects of spatial structure and have different utilities in stock assessment. Thus, considering how the data will be used should precede what data should be sought. Data quality is also bound to vary. Ideally, spatially informative data will cover the entire spatial domain, be collected in a standardized manner, have contrast between space and time, and come from well-designed sampling protocols. When this ideal cannot be met, efforts may be necessary to interpolate or estimate correction factors (e.g., for non-random tag mixing) through any number of modeling efforts.

What are the trade-offs between implicit (e.g., fleets as areas) and explicit approaches to account for spatial stock structure in assessment models?

Three main distinctions between implicit and explicit approaches were identified: 1) data needs, 2) ease of implementation, and 3) bias vs. precision. Generally, explicit approaches will tend to need more data. For example, a fleets-as-areas approach uses relatively standard stock assessment information, but an explicitly spatial model will likely require more data on stock structure or movement rates (e.g., tagging). The increased data needs of an explicit approach will also come with greater time demands because the new data will have to be processed and perhaps reconfigured to allow for different assessment structures to be explored (e.g., number of areas/fleets). Implicit approaches are also likely to be easier to implement, not only because data needs are lighter but also because the models used for implicit approaches (e.g., fleets-as-areas) tend to be simpler, have fewer parameters, shorter run-times, and greater stability. Implicit approaches are also more likely to align with existing management needs, whereas switching to an explicit approach may require multiple assessment cycles before the assessment and management approaches can be aligned, thus making ease of application more difficult for an explicit approach too. Understanding the trade-offs in bias versus precision between implicit and explicit approaches can be difficult. While implicit approaches are certainly biased but more precise than explicit approaches, the degree to which an explicit approach is biased depends on many factors. For example, bias in data (e.g., violations of tagging assumptions) or mis-specification in stock structure and movement rates can lead to biases as large as using implicit methods. Explicit methods do come with the advantage of the ability to consider spatially explicit stock status and can better inform localized depletion, while those considerations from an implicit approach are likely biased or non-existent.

How might movement/mixing processes (e.g., spatial foraging, migration, etc.) affect stock dynamics? What data can be used to help account for these processes in stock assessment models?

Movement affects the spatial distribution of stock productivity and sustainable harvest levels. Age (size and life-stage)-specific movement can also add greater complexity to the effects of movement. Likewise, the effect of fishing will not be homogeneous when movement or mixing occurs, especially with immigration from outside the defined spatial boundaries (i.e., demographic leakage; D. Hanselman, personal commun.), which violates a common assumption of single area stock assessments. In many situations, even basic information about movement is unavailable (e.g., walking rates of crab species). In these cases, building a conceptual model of movement and its possible effects based on ecology and life history can help bracket levels of uncertainty and be a useful point of comparison for stock assessments. Tagging may be the most useful data source for a stock assessment. Even relatively sparse tagging data or tagging collected intermittently among years can allow the estimation of movement in a stock assessment. Pop-up tags might be useful for tracking foraging areas and prey species, especially as climate change is driving directional movement. In so far as it does not complicate standardized, fishery-independent surveys, considering shifts in survey timing or some exploratory sampling outside of typical survey time frames might help track movement and disentangle the effects of movement from shifting productivity (e.g., recruitment, growth). In some cases, aspects of the species biology itself may support attempts at accounting for movement in a stock assessment. For example, in cases with strong natal homing, monitoring individual spawning areas would provide information about productivity changes of individual stock components, which may allow the estimation of movement or mixing rates at other times of the year. Ideally, however, regular tagging studies are likely the best data source. Achieving this may require revising typical funding cycles from short-term to medium- or long-term (every ~5+ years). Before embarking on costly, long-term tagging studies, however, exploratory analyses should be conducted to determine whether a spatial model is even needed, and this could become a regular term of reference for stock assessments.

Breakout Discussion
Session 3, Part 2:
Facilitators: Erin Bohaboy, Nathan Vaughan
Rapporteurs: Nikolai Klibansky, Elizabeth Gugliotti

The second set of morning questions were discussed by two other groups, and the discussion is summarized below.

When should a spatial assessment be considered? Which processes should a spatial stock assessment include (at minimum)?

The discussion participants argued that we should always consider spatial models but that their practical use will be limited by several factors. Those factors include the terms of reference set for each assessment as well as data availability. It's important to consider the expected benefit of using a spatial approach and to compile both the information in the literature for the dynamics of the stock and a data triage for the species at the stock ID level. For instance, is a "fleets-as-areas" approach sufficient to explain the spatial dynamics, or do simulation studies need to be undertaken before attempting a spatial assessment? The simulation studies could focus on whether the traditional assessment will be unreliable, biased, or provide inferior management advice if spatial dynamics are ignored. It is always possible to build really complex models, but we should be parsimonious and shrink the complexity to a reasonable level while still maintaining model performance.

What should be considered when parameterizing spatial models for different species groups, including pelagic/highly migratory, demersal, sessile species, etc.?

We should consider whether a spatial model is adding to our understanding of the stock dynamics in a way that is necessary for management advice. Which parameters are inherently spatial but do not negatively affect management advice when spatial structure is ignored? Assessment modelers should also consider whether the uncertainty in parameters across space will produce results with only a central trend and very large confidence intervals. What is the actual signal/noise ratio?

How should modeling approaches differ for species with spatial structure due to biology (i.e., differences in growth, spawning sites, etc.) and fishing (i.e., different CPUE trends, operational factors, etc.)?

The group discussed this issue with respect to some real-world examples. First, Striped bass on the U.S. Atlantic coast has biologically distinct stock units that do not match with state and/or data management units. Another example is Spanish mackerel in the Gulf of Mexico. Spanish mackerel are coastal pelagics that utilize Mexican and U.S. waters. It is likely their biology and fishing mortality contain spatial differences, but without a good index for coastal pelagics, those investigations were stalled. Finally, the group discussed Atlantic cod, and those data were insufficient to conduct assessment aligned with stock ID that spanned U.S. and Canadian waters. The group discussed more of the issues with undertaking spatial modeling rather than how to model differences in biology versus fishing.

Breakout Discussion

Session 3, Part 3:

Facilitators: Katie Siegfried, Jonathan Deroba, Craig Marsh, Jeffrey Vieser, Melissa Karp

Rapporteurs: Abigail Furnish, Dana Hanselman, Benjamin Levy, Michelle Sculley, Kristan Blackhart

The goal of the afternoon breakout sessions was to engage workshop participants in small group discussions considering all of the talks and prior breakout sessions to focus on the use and value of spatial models in assessments. Specifically, participants were asked to consider "*Should we strive for spatially explicit models?*" While some workshop participants' initial response was "it depends" to this and all other questions, the consensus response was that yes, we should always consider spatial approaches but strive for the most parsimonious approach available that will provide the necessary level of management advice needed. Decisions should be data driven, evaluating changes to model performance as spatial complexity increases and adding complexity only where it is truly appropriate. Capacity (staffing, data resources, review requirements, management implementation) is another important consideration for operationalizing spatial modeling approaches, as our job is to provide regular, timely, and tactical management advice. Prioritization criteria should be based on species-specific biological factors and management priorities, as spatial models are not likely to improve management advice for all species. While spatial modeling research is useful and necessary, presenting an assessment to management partners that cannot reasonably be produced on a regular basis is likely to exacerbate the mismatch between expectations and regional assessment capacity. However, considering spatial elements is not always necessarily complex, and simpler approaches are available to utilizing spatial patterns (when present) without committing the time and resources to a fully spatial assessment model. For instance, the NEFSC uses the Scallop Area Management Simulator (SAMS) model to forecast estimates of spatially explicit biomass and guide annual management specifications.

Several related questions under this theme were also discussed by participants:

- ***What are indicators that a spatial assessment model will be beneficial (e.g., problems in model fit, tagging data showing movement, and differences in biological parameters)?***

  As with most any consideration in assessment, this begins with thoroughly examining the data at as high of a resolution as possible to try to understand the processes that could be causing observed patterns in the data. This includes reviewing the temporal scales, collection methods, management implementation, and any processing of the data that has occurred. Stock assessment scientists can then move on to looking for signs such as grouping, clustering, population shifts (e.g., change in the stock center of gravity), metapopulation structure, patterns in fishing pressure across space, or residuals in space (e.g., see abstract from Carey McGillard). Strong retrospective patterns or poor model diagnostics may also be an indication of spatial variability (although not necessarily). Another suggestion was to map age distributions, where available, although scientists must be careful about confounding biological patterns with spatial patterns of fishing pressure. Input from fishers may also be useful to indicate spatial structure is present, and further review should be pursued.

- ***How should stock boundaries be defined for assessments, reporting, and management?***

Ideally, stock boundaries should be based on the biology of the stock rather than political or other arbitrary lines, with allocation decisions made between political boundaries as necessary. The reality often is that mismatches exist between biological and management units, and management boundaries are defined under processes that can be slow to change. While well-defined management procedures can help manage discrepancies between biological and management units, these differences may cause many challenges. In theory, assessments can be conducted at finer spatial scales than the established management units, and then, the results may be scaled up to match the management areas. However, data availability for biological stock units can be a very real issue (e.g., Atlantic cod), requiring compromises from the ideal to a more pragmatic approach. Additionally, many examples of data access challenges exist

Recommendations

1. Stock assessments should always consider spatial approaches but strive for the most parsimonious approach available that will provide the necessary level of management advice needed.
2. When appropriate, spatial modeling can be used to highlight potential impacts (e.g., localized depletion) on stocks from a lack of spatial management as well as provide more detailed management advice. Failing to represent spatial dynamics driving stock biology could cause misleading management advice and detrimental effects on the final management decisions.
3. Ideally, stock boundaries should be based on the biology of the stock rather than political or other arbitrary lines, with allocation decisions made between political boundaries as necessary. The reality often is that mismatches exist between biological and management units, and data availability may present challenges to developing assessments at finer spatial scales, requiring compromises from the ideal to a more pragmatic approach.
4. As with most any consideration in assessment, the use of spatial modeling approaches begins with thoroughly examining the data at the highest resolution possible to try to understand the processes that could be causing the observed patterns in the data.

where there is misalignment of biological and management units. An emerging challenge as spatial modeling becomes more commonplace but management unit changes have not made commensurate changes is responding when assessment results indicate that one portion of the management unit is overfished (or vice versa) and managers must grapple with appropriate management actions.

- ***If the stock has spatial differences in dynamics, but the management is stock-wide, what do we gain from spatial modeling?***

  When appropriate, spatial modeling can be used to highlight potential impacts (e.g., localized depletion) on stocks from a lack of spatial management as well as provide more detailed management advice. Failing to represent spatial dynamics driving stock biology could cause misleading management advice and detrimental effects on the final management decisions. Additional benefits of utilizing spatial modeling approaches could be resolving issues with single area models or resolving complex data interactions (e.g., fleets, international). While spatial models may reduce the probability of localized depletion, spatial approaches may indicate management action is needed at a scale different from the management unit (e.g., smaller than the defined stock). Such scale mismatches can lead to very real challenges in developing and implementing an appropriate response (e.g., a rebuilding plan). Additionally, spatial approaches often can require transboundary cooperation across management boundaries, which can complicate implementation (e.g., data access, agreement on model development).

Session 4. MARVLS

4a. Gonad Histology Workshop

Instructors: Christina Conrath, Eva Schemmel, Mark Wuenschel, Emilee Tholke
Rapporteurs: Emily Slesinger, Richard McBride

The MARVLS gonad histology workshop on Monday, May 8 focused on interpreting gonad histology slides, interesting structures in ovary cross-sections, and the use of a slide scanner to process and archive slide images. MARVLS participants contributed histology images and questions for discussion and feedback. Discussions on the histology slides generally fell into two categories: 1) preserving, processing, and staining methods, and 2) what the identification and presence of atresia means in different species. Participants discussed if the presence of atresia indicated aborted maturation, fecundity regulation, or a regressing fish that had already spawned and what skip spawning looks like in various fish. Histological identification of parasites was also discussed along with whether parasites can sometimes be confused with certain types of atresia. A better review and assessment of parasites that are found in fish gonads is recommended. The group also returned to a recurring theme: in protogynous hermaphrodites, at what stage of development do sperm crypts need to be for the male to be functioning, as seminiferous tissue can advance to a stage of spermatozoa but without access to a duct structure? A more detailed description of this transition process in a good model species would be helpful. To conclude the workshop, a slide scanner used by the NEFSC group was demonstrated as a tool to digitize histology slides, more efficiently compare the same slide with multiple stains, and potentially create a large reference library. Although a significant financial investment, high quality slide scanners are a way to become fully digitized and become untethered from laboratory microscopes.

4b. MARVLS Session: Recent Advances and Studies in Reproductive Biology and Life History

Moderators: Sabrina Beyer, Suzanne McDermott, Christina Conrath, Cara Rodgvellar, Richard McBride
Rapporteurs: Ashley Pacicco, Sabrina Beyer, Eva Schemmel, Kelsey James, Sandi Neidetcher, Christina Conrath, Cara Rodgvellar

The MARVLS contributed session covered current topics in reproductive ecology relevant to the management of U.S. fisheries. Topics included atresia, general reproductive biology, best practices, and advances in novel methods (see Appendix F). The session had two open group discussions to more thoroughly explore topics and questions, and convened with invited presentations by Eva Schemmel (PIFSC) on “Open Science in the MARVLS Community” and Mark Wuenschel (NEFSC) on “Macroscopic Maturity Identification at the NOAA, Northeast Fisheries Science Center.”

The morning session speakers, Rick Rideout (Food and Agriculture Organization (FAO, Canada), Christina Conrath (AFSC), Claire Rosemond (Oregon State University, OSU), and Nikolai Klibansky (SEFSC), opened the session with presentations on atresia, skipped spawning, and how reproductive information influences stock assessment models. The ensuing first group discussion brought up questions regarding the influence of reproductive information on stock biological reference points, with agreement that the influence of reproductive information on assessment models is likely stock-specific and depends on the life history and exploitation status. Maturity-at-length (or age) information is the most widely used reproductive information in stock assessments to determine the fraction of females contributing to reproduction. Beyond maturity, other reproductive information can have varying influences on an assessment. For example, the scaling parameter of the fecundity-at-length relationship, when modeled as a power function, can influence the scale of spawning biomass, which is already often highly uncertain in stock assessments. However, the functional shape of the fecundity relationship (i.e., how strong hyper-allometric fecundity is as indicated by the exponent parameter) can influence biological reference points in heavily exploited populations and bias stock status, if not accounted for. This influence has been found in long-lived species, such as rockfishes, where high fishing levels led to size-and-age truncation of the population.

The morning discussion returned to atresia and questions about what level of atresia indicates reproductive failure of the female for the current year or some level of fecundity regulation instead. Atresia is a natural phenomena to regulate energy allocation. Increasing evidence suggests skipped spawning and fecundity downregulation are correlated with poorer ecosystem conditions, likely to influence maternal energy reserves. Best practices to categorize atresia as skipped spawning or fecundity regulation are to use information on the seasonal timing of reproduction and other indicators of development toward spawning. It was also acknowledged that fecundity regulation may be different in cold or warm environments and by spawning type, such as determinate or indeterminate batch spawning. In batch spawners, later batches may or may not be as viable, and eggs can be smaller. Fecundity and egg quality can also be influenced by maternal effects, defined as the phenotype of the mother influencing the phenotype of the progeny. Maturity, fecundity, and atresia continue to be “hot topics” in the field of fish reproductive ecology with continued interest in how these reproductive parameters are influenced by environmental and ecosystem change.

In the afternoon, Erin Reed (Cooperative Institute for Marine and Atmospheric Research, CIMAR; PIFSC), Colin Jones (International Pacific Halibut Commission, IPHC), Eva Schemmel (PIFSC), Sandi Neidetcher (AFSC), Kevin Kolmos (South Carolina Department of Natural Resources, SC DNR), and Ashley Pacicco (SEFSC, Cooperative Institute for Marine and Atmospheric Studies, CIMAS, University of Florida) presented on best practices for histological methods, species-specific reproductive biology updates, and novel approaches to determining maturity. An ensuing afternoon discussion of novel methods to identify maturity and ovarian development highlighted the benefits of less subjective and more rapid methods using Raman spectroscopy or nuclear magnetic resonance (NMR)-based metabolomics. Current drawbacks of these novel techniques include cost, specialized materials, and quality of collected tissues. However, future exploration may make new methods more efficient and cost-effective. It was noted that the presence of parasites in the ovary is of potential concern for these new techniques. Further discussion about parasites indicated a need to better identify parasites in histology images and to better understand the impact of parasites on reproduction.

Other topics of the afternoon discussion included the importance of accounting for spawning frequency in stock assessments. Whether or not a fish spawns in the current year is important information for estimating the spawning biomass, yet there remains confusion in the communication of physiological vs functional maturity of fish from biologists to stock assessment scientists. This is further complicated because the designation of maturity may differ between cold or warm species and the presence (or absence) of the cortical alveolar stage, which is typically used as an indicator of oocyte maturation. These details are confusing to stock assessment scientists who want to know which fraction of the population will spawn in the current year. Communicating simple classification schemes is best practice. In some cases, simple macroscopic maturity identification at the right time of year may suffice. Last, it was acknowledged that there is evidence of spatial variation in maturity schedules, fecundity, and also spawning success. Spatial and temporal variation in reproductive parameters is under-studied but is an important area of future research to inform spatially explicit stock assessments.

Open Science in MARVLS

Eva Schemmel (PIFSC) led a presentation on Open Science for the MARVLS community. Hesitations to open science were addressed to overcome perceived barriers. Eva provided tools and community help information to overcome these hurdles, such as the NOAA R users group and Openscapes. The MARVLS website (https://marvls.github.io/MARVLS/) and Github repository (https://github.com/MARVLS) are both tools for all MARVLS participants to share knowledge, resources, methods, and training materials for newcomers to the field. A group discussion brought up points about best practices for sharing reproductive biology and covered topics such as when and where to publish histology slides, especially sequences of gonad development. Suggestions included always publishing a sequence for new species that lack available reference material or when trying something new, such as a stain comparison. Additionally, histology plates can be published in supplementary materials of the journal or posted online at the MARVLS website to help develop a reference of sequences and other interesting findings. Supplementary histology plates and other reference materials, such as citing the staging criteria based on Brown-Peterson et al. are also a nice way to simplify and make papers more concise (a recommendation from journal editors). A question was asked about the value and feasibility of developing a histology database template to share. In response, some templates have already been made available at the SEFSC through Southeast Data Assessment and Review (SEDAR), and the NEFSC already has an automated data collection system. Databases are likely to be specific to different regions, species, and spawning types. As a follow-up, a request was made for another Open Science quarterly meeting to walk through the specifics of how to contribute to the MARVLS community for members new to Open Science and the technology.

Macroscopic Maturity Identification

Mark Wuenschel (NEFSC) presented the training materials for macroscopic maturity identification of fish collected by the NEFSC annual groundfish survey. Macroscopic identification of maturity can be useful when histological methods are unavailable and can be more reliable during certain times of the year with training. Macroscopic maturity is used to determine spawning stock biomass in some East Coast species, such as Cusk. Mark presented the universal staging scheme and examples of many species. Macroscopic identification of maturity is most difficult between immature and resting fish. Characteristics such as opaqueness of the ovarian wall can help with maturity classification. Importantly, NEFSC researchers are also trained in how to accurately identify the gonads, as the gonads are sometimes confused with fat bodies or other organs. Training at the NEFSC has helped to standardize data collection and allows for rapid inclusion of maturity information into NEFSC stock assessments.

4c. MARVLS Field Trip to Woods Hole

Organizers: Mark Wuenschel, Richard McBride, Yvonna Press, Emilee Tholke, NEFSC staff
Rapporteurs: Erin Reed, Richard McBride, Kelsey James, Joseph O'Malley, Yvonna Press

MARVLS participants traveled to the NEFSC in Woods Hole, MA on May 11th for a tour of the facilities and demonstrations of biological data collection methods. The day began with a demonstration of the autodiametric method to estimate fish fecundity. The autodiametric method involves imaging oocytes and uses open-source software (ImageJ) and a macro (contact Mark Wuenschel, NEFSC) to automate counts and measurements of oocyte diameter. The oocyte counts and diameter measurements of weighed subsamples are used to develop a species-specific calibration curve, which relates the mean oocyte diameter of a sample to an oocyte density (oocytes per gram of the ovary). Once the calibration curve is developed, the fecundity of a fish can be estimated more rapidly by 1) simply using the software to measure the mean oocyte diameter of an unweighed subsample of the gonad, 2) using the species-specific calibration curve to find the expected oocyte density, and 3) multiplying the oocyte density by the weight of the gonad to calculate fecundity. With the development and use of the calibration curve, counts of oocytes are no longer needed, thus making this method much more efficient at collecting fecundity information than traditional manual counting methods. The group discussed tips to adapt the autodiametric method to different species and which species this method is most suitable for, such as determinate spawners. The rapid collection of fecundity information is useful for stock assessments that calculate TEP (Total Egg Production) as a reference metric, as opposed to spawning biomass. The autodiametric method also aids in the efficiency of research to explore temporal and spatial variation in size–fecundity relationships and environmental drivers of variation in egg production.

The afternoon tours included an introduction to the FSCS data collection system developed at the NEFSC by Paul Kostovic (paul.kostovic@noaa.gov). The FSCS database handles all biological and environmental information collected on the NEFSC annual fishery-independent groundfish trawl survey. This includes pre-cruise survey design, on-board biological and oceanographic environmental data collection, data standardization, real-time error-checking, and post-cruise processing of biological data, such as otolith age estimation and fecundity. All biological samples are barcoded for reference. The afternoon tour also included a visit to "The Cottage," where NEFSC researchers process fish otoliths and other aging structures, such as bivalve shells, for age estimation to be used in stock assessments. The lab ages 22 fish species and clams and produces 40,000 to 100,000 age estimates a year.

The day ended with the group rotating between a hands-on fish dissection, which displayed numerous species of groundfish collected on the NEFSC trawl survey and a group reflection of the workshop. During reflection, participants highlighted appreciation for the discussion time during the MARLVS session to ask questions and to more fully explore topics in reproductive biology and application to stock assessment. Participants also appreciated the gonad histology workshop as a space to share questions, improve methods, and to standardize approaches and terminology across species and regions. Suggestions for future histology-focused workshops or quarterly seminars included abnormalities, differences between cold and warm water species, different histological stains, and more focus on males. Other topics of interest were QA/QC techniques for reproductive information, creating national online reference materials, producing a national training guide for macroscopic maturity identification, and creating center-specific “nodes,” with the idea to identify a “node” from each center to participate in activities such as creating a national training guide for macroscopic maturity observation and website updates. MARVLS participants were incredibly grateful to the team at the NEFSC for organizing this insightful field trip.

Appendix A
List of Steering Committee

Name	**Affiliation**
Sabrina Beyer, *MARVLS*	University of Washington
Kristan Blackhart	Office of Science and Technology
Jonathan Deroba, *Chair*	Northeast Fisheries Science Center
Abigail Furnish, *Program Manager*	Office of Science and Technology
Vladlena Gertseva	Northwest Fisheries Science Center
Pete Hulson	Alaska Fisheries Science Center
Melissa Karp	Office of Science and Technology
Richard McBride, *MARVLS*	Northeast Fisheries Science Center
Susanne McDermott, *MARVLS*	Alaska Fisheries Science Center
Michelle Sculley	Pacific Islands Fisheries Science Center
Katie Siegfried	Southeast Fisheries Science Center
Steven Teo	Southwest Fisheries Science Center
Howard Townsend, *EBFM Liaison*	Office of Science and Technology

Appendix B: List of Attendees
* indicates attending MARVLS

Northeast Fisheries Science Center
Charles Adams
Liz Brooks
Christopher Cacciapaglia
Jui-Han Chang
Kiersten Curti
Jonathan Deroba
Kathryn Ford
Dvora Hart
Lisa Hendrickson
Dan Hennen
Alex Hansell
Andrew Jones
Chris Legault
Benjamin Levy
Chengxue Li
Brian Linton
Anna Mercer
Tim Miller
Burton Shank
Abigail Tyrell
Tara Trinko Lake
Ashley Pacicco*
Michelle Passerotti*
Yvonna Press*
Emilee Tholke*
Mark Wuenschel*
Richard McBride*

Southeast Fisheries Science Center
Lisa Ailloud
Shannon Calay
LaTreese Denson
Francesca Forrestal
Nikolai Klibansky
Amy Schueller
Kyle Shertzer
Katie Siegfried
Matthew Smith
Molly Stevens
Nathan Vaughan
Heather Moncrief-Cox*

Northwest Fisheries Science Center
Brian Langseth

Southwest Fisheries Science Center
Caitlin Allen Akselrud
Peter Kuriyama
Steven Teo
Brad Erisman*
Kelsey James*

Alaska Fisheries Science Center
Dan Goethel
Melissa Haltuch
Dana Hanselman
Maia Sosa Kapur
Craig Marsh
Carey McGilliard
Kristen Omori
James Thorson
Ben Williams
Christina Conrath*
Susanne McDermott*
Sandra Neidetcher*
Cara Rodgveller*
Emily Slesinger*

Pacific Islands Fisheries Science Center
Erin Bohaboy
Jon Brodziak
Hongguang Ma
Meg Oshima
Benjamin Richards
Michelle Sculley
Joseph O'Malley*
Erin Reed*
Eva Schemmel*

Office of Science and Technology/HQ
Kristan Blackhart
Kathryn Doering
Abigail Furnish
Elizabeth Gugliotti
Andrea Havron
Melissa Karp
Bai Li
Patrick Lynch
Richard Methot
Noriko Shoji
Christine Stawitz
Howard Townsend
Jeffrey Vieser
Melissa Yencho
Derek Bolser*
Liz Chilton*

UMass-Dartmouth
Steve Cadrin
Gavin Fay
Angelia Miller
Maria Perez
Catalina Roman

South Carolina DNR
Kevin Kolmos*
Wiley Sinkus*
Michelle Taliercio*
Catlyn Wells*
David Wyanski*

Other
Amanda Hart - Gulf of Maine Research Institute
Challen Hyman - VIMS
Samara Nehemiah - U of MD CES
Sabrina Beyer - University of Washington*
Nancy Brown-Peterson - University of S. Mississippi*
Hailey Conrad - Virginia Tech*
Rosario Dominguez-Petit - IEO-CSIC (Spain)*
Colin Jones - IPHC*
Lyndsey Lefebvre - WHOI*
Kristine Lesyna - CA DFW*
Laia Munoz Abril - DISL*
Rick Rideout - DFO (Canada)*
Claire Rosemond - Oregon State*

Appendix C: Agenda

NSAW14 MARVLS

Agenda

NOAA Fisheries will be convening NSAW14 May 8-11, 2023 at The Hotel Providence in Providence, Rhode Island. The theme is *Spatial Modeling* to evaluate and discuss the approaches to recognizing the spatial nature of fish populations. NSAW14 will also include a joint session with the 4th biennial meeting of the working group on Maturity Assessment, Reproductive Variability, and Life Strategies (MARVLS), as well as a MARVLS life history session.

May 8, Monday/Training Day*	
Morning 9:00 am-12:30 pm	• **Beginner Level TMB (Havron)** Brown University Boardroom • **Vector Autoregressive Spatio-Temporal (VAST) Model (Thorson)** RISD Gallery Room • **Introduction to Developing R Packages (Doering)** Johnson and Wales Hospitality Room

May 8, Monday/Training Day*	
Afternoon 2:00 pm-5:30 pm	• **Intermediate Level TMB (Havron)** Brown University Boardroom • **Introduction to GitHub for Project Management (Stawitz, Stevens)** RISD Gallery Room • **Automating Assessment Workflows Collaborative Session (Blackhart)** Johnson and Wales Hospitality Room • **Gonad Histology Workshop (Conrath, Schemmel, Tholke, Wuenschel)** Tilden Thurber Ballroom

Monday Training Workshops

***Workshop registration occurred during online conference registration. Workshop participants will be contacted by the instructor regarding materials and specifics of the workshop. For general questions, contact: abigail.furnish@noaa.gov**

May 9, Tuesday/Joint Day and Poster Social Main session in Tilden Thurber Ballroom Poster Social in Main Dining Room and Courtyard	
8:00	**Registration**
8:45	**Get Seated**
9:00	**Welcome**
9:15	**Jon Hare** Opening remarks
9:30	**Richard McBride (Keynote)** Reproductive Biology of Fish: Applications for Research, Monitoring, Assessment and Management
10:15	**Break (15 min)**
10:30	**Sabrina Beyer** State-dependent life history theory predicts spatial variation in the life history traits of California Current rockfishes

May 9, Tuesday/Joint Day and Poster Social Main session in Tilden Thurber Ballroom Poster Social in Main Dining Room and Courtyard	
10:50	**Emily Slesinger** Spatial differences in the northern stock of Black Sea Bass energetics and reproduction
11:10	**Rosario Domínguez-Petit** Spatial variability in life-history of *Scomber colias*, an expanding species in the East Atlantic
11:30	**Mark Wuenschel** Variation in fecundity of Winter Flounder, *Pseudopleuronectes americanus*, and Yellowtail Flounder, *Myzopsetta ferruginea*: patterns across stocks over ten years
12:00	**Lunch**
1:30	**Welcome back**
1:40	**Brad Erisman** A preliminary review of spatiotemporal patterns of spawning in the Pacific Sardine (*Sardinops sagax*) along the Pacific coast of North America in relation to population structure
2:00	**Susanne McDermott** Examining distributional shifts of spawning and feeding migrations of Pacific Cod in Alaska with Satellite popup tag
2:20	**Catlyn Wells** Exploring Spatial Reproductive Variability of Reef Fish in the Southeast, U.S.
2:40	**Break (30 min)**
3:10	**Nikolai Klibansky** Sensitivity of stock assessments in the Southeast U.S. Atlantic to reproductive life history estimates
3:30	**Amy Schueller** Estimation of selectivity in the face of time varying growth
3:50	**James Thorson** Trait-based habitat analysis: including phylogenetic-imputation of life-history strategies in joint species distribution models

May 9, Tuesday/Joint Day and Poster Social Main session in Tilden Thurber Ballroom Poster Social in Main Dining Room and Courtyard	
4:15	**Panel Discussion (moderator: Rich McBride)**
6:00-8:00	**Poster Social (Hotel)**

May 10, Wednesday/NSAW Concurrent Sessions NSAW will meet in Tilden Thurber Ballroom	
8:30	**Welcome, Get Seated**
8:45	**Kristan Blackhart** General National Updates
9:15	**Methot (Keynote)**
9:45	**Benjamin Levy** Is climate change biasing survey abundance indices? A simulation study starting point
10:00	**Christopher Cacciapaglia** Application of a vector autoregressive spatiotemporal (VAST) model to Northwest Atlantic Ocean bottom trawl data
10:15	**Derek Bolser** Spatiotemporal models facilitate fish biomass-at-age estimation with uncrewed surface vehicle acoustic sampling and non-contemporaneous compositional data
10:30	**Andrew Jones** Applying high-resolution catch and effort information to develop a novel commercial catch per unit effort index for the northern black sea bass stock
10:45	**Break (15 min)**
11:00	**Small Group Breakouts (start with 10 min intro + end with 10 minute group report out)**
12:00	**Lunch (90 min)**

May 10, Wednesday/NSAW Concurrent Sessions NSAW will meet in Tilden Thurber Ballroom	
1:30	**Welcome back**
1:45	**Abigail Tyrell** ESP Presentation/Discussion
2:15	**Christine Stawitz and/or Andrea Havron** FIMS Update
2:45	**Kristen Omori** Implementing Joint Species Distribution Models for Species Complexes to Aid Management Advice: a Case Study with Non-target Rockfish in the Gulf of Alaska
3:00	**Lisa Hendrickson** Spatiotemporal dynamics of longfin inshore squid, *Doryteuthis* (Amerigo) *pealeii*, on the Northeast U.S. shelf
3:15	**Break (15 min)**
3:30	**Breakout Discussion**
4:15	**Large group Synthesis on Topic and Breakout**
5:00	**Closing**
6:00	**Off-site social, The Malted Barley**

May 10, Wednesday/MARVLS Concurrent Sessions (continued) MARVLS will meet in Main Dining Room	
8:30	**Welcome (McBride and McDermott)**
8:40	**Rick Rideout** Changing perceptions and unanswered questions about follicular atresia

May 10, Wednesday/MARVLS Concurrent Sessions (continued) MARVLS will meet in Main Dining Room	
9:00	**Christina Conrath** Variability in maturity and skipped spawning rates of deep water rockfishes in Alaska waters
9:20	**Claire Rosemond** Black Rockfish (*Sebastes melanops*) biological and functional maturity schedules influenced by marine heat waves
9:40	**Nikolai Klibansky** Evaluating the influence of spawning dynamics, sampling design, and calculation of fecundity, through simulation modeling
10:00	**Discussion**
10:45	**Break (15 min)**
11:00	**Erin Reed** Effects of data sources and biological criteria for length-at-maturity estimates in a data limited species
11:20	**Colin Jones** Update of maturity-at-size and -age for Pacific halibut (*Hippoglossus stenolepis*) using histological analysis
11:40	**Eva Schemmel** Handling effects on identifying female reproductive status
12:00	**Lunch (90 min)**
1:30	**Welcome back**
1:40	**Sandi Neidetcher** A novel approach for determining the reproductive status of Walleye Pollock (*Gadus chalcogrammus*) using Raman spectroscopy
2:00	**Kevin Kolmos** Initial assessment of nuclear magnetic resonance-based metabolics as a tool for the identification of adult female reproductive phases

May 10, Wednesday/MARVLS Concurrent Sessions (continued) MARVLS will meet in Main Dining Room	
2:20	**Ashley Pacicco** Reproductive biology of Yellowfin Tuna (*Thunnus albacares*) in the north-central U.S. Gulf of Mexico
2:40	**Discussion**
3:15	**Break (15 min)**
3:30	**Eva Schemmel** Open Science in MARVLS
4:15	**Mark Wuenschel** Macroscopy maturity methods: overview of NEFSC classification scheme and QA/QC
5:00	**Logistics for Thursday (Wuenschel)**

May 11, Thursday/NSAW sessions NSAW will meet in Tilden Thurber Ballroom	
8:30	**Welcome, Get Seats**
8:45	**Gavin Fay (Keynote)**
9:15	**Dan Goethel (Keynote and Spatial Modeling Report Out)**
9:45	**Craig Marsh** Lessons learned for spatial model development from implementation of a tag-integrated assessment for Alaskan sablefish
10:00	**Maia Sosa Kapur** A Management Strategy Evaluation for Transboundary Sablefish (*Anoplopoma fimbria*) in the Northeast Pacific

May 11, Thursday/NSAW sessions
NSAW will meet in Tilden Thurber Ballroom

10:15	**Jonathan Deroba** Challenges in developing a spatially explicit stock assessment: a case study in applying “SPASAM” to an international spatial stock assessment experiment
10:30	**Break (15 min)**
10:45	**Dvora Hart** Effects of spatial heterogeneity of fishing mortality and life history parameters on stock-wide estimates of fishing mortality, yield and per-recruit calculations
11:00	**Carey McGilliard** The importance of accounting for spatial growth patterns in statistical catch-at-age models when sources of age data are missing, using Gulf of Alaska rex sole (*Glyptocephalus zachirus*) as an example
11:15	**Breakouts (45 min)**
12:00	**Lunch (90 min)**
1:30	**Liz Brooks** Separation Anxiety: Problems that can arise when performing separate assessments for areas that are nested
1:45	**Jon Brodziak** Visualizing Spatial Assessment Models
2:00	**Breakouts (45 min)**
2:45	**Break (15 min)**
3:00	**Kristan Blackhart** Stock Assessment Community of Practice Discussion
3:30	**Large Group Discussion**
4:00	**Closing**

May 11, Thursday/MARVLS Woods Hole Field Trip	
8:00	**Depart Hotel Providence, RI** Group transit to NEFSC, Woods Hole, MA
9:30	**Arrive at Woods Hole, MA** Sign in and welcome at Candle House (MBL- 127 Water St, Woods Hole)
10:00	**Fecundity and Histology Demos** Candle House (MBL- 127 Water St, Woods Hole)
11:30	**Lunch** On your own, in the Village
12:50	**Meet back at the Candle House**
1:00	**Lab Demos** 2 groups rotate: FSCS data collection (NEFSC- Main Bldg. 166 Water St, Woods Hole); Tour of the Cottage (Albatross St, Woods Hole)
2:30	**Break**
3:00	**Discussion and Lab Demos** 2 groups rotate: Macroscopic maturity staging; Discussion of MARVLS national products
4:30	**Depart Woods Hole, MA** Reassemble in front of Main Lab Building (166 Water St, Woods Hole)
5:30-7:00	**Group Dinner** Antonio's Restaurant (267 Coggeshall St, New Bedford, MA 02746) *antoniosnewbedford.com*

Appendix D: Description of Trainings

NSAW Training

Monday morning

Vector Autoregressive Spatio-Temporal (VAST) model, Monday morning

Instructor: James Thorson

In this course, we will briefly introduce analyses that are feasible using multivariate spatiotemporal models with associated example code. Lectures will specifically highlight abundance index standardization for stock assessment, joint species distribution models (JSDMs) for habitat assessment, and empirical orthogonal functions (EOF) for climate and ecosystem synthesis. A laboratory unit includes 30 minutes for group-based exploration, and time to discuss impressions as a group. The workshop should be sufficient for some users to run models on existing data sets, to serve as a starting point for later exploration using new data.

Introduction to Developing R packages, Monday morning

Instructor: Kathryn Doering

If you write a lot of R code but feel intimidated about turning your functions and data into a package, this course is for you! We'll discuss why turning your code into an R package is a good idea, how to do it, and some helpful tools for developing R packages. We'll work with an example, or you can bring code to turn into a package.

This class is targeted at R users who have little or no experience developing or maintaining R packages.

Beginner Level TMB, Monday morning

Instructor: Andrea Havron

This course will cover the basics of setting up a TMB model and running it in R. Topics will cover a short introduction to maximum likelihood, TMB's statistical computing framework, setting up a TMB model using C++, and running the model and exploring the output with R. There will be exercises used to practice building, running, and debugging a TMB model. The class is targeted toward people with little to no experience in TMB.

Monday afternoon

Introduction to GitHub for Project Management, Monday afternoon

Instructor: Christine Stawitz and Molly Stevens

This training will cover the basics of GitHub and how you can use it to work more effectively in teams. This is a training targeted at brand new users and will not require writing any code! You should have created a username prior to the workshop, but no local software install is required because we will only be working in the web browser. We will begin with an ice breaker, introduce Github terminology and benefits of git and GitHub, Kanban boards and Github project boards, and practice committing, pushing, and pulling. Next, we will cover branches and merge conflict resolution. We will end with a brief overview of NOAA Fisheries' specific GitHub policies.

Intermediate Level TMB, Monday afternoon

Instructor: Andrea Havron

This course explores more advanced features in TMB. Topics include dealing with parameters, uncertainty, bias correction, simulation, random effects, multivariate distributions, and sparsity. There will be exercises used to practice building and running random effects models and validating models with one-step-ahead residuals. This course assumes users have a basic understanding of how to build and run a TMB model.

Automating Assessment Workflows Collaborative Session, Monday afternoon

Facilitators: Kristan Blackhart and Kathryn Doering

Automating workflows throughout the assessment process provides myriad benefits, including streamlining, reduced possibility of error and improved reproducibility, better transparency and openness, and allowing assessment scientists the flexibility to be more responsive to emerging science needs. However, cultural, institutional, and structural hurdles make creating and implementing automated workflows challenging. This session invites regional practitioners working on or interested in developing automated workflows for the stock assessment process to join in a facilitated discussion to engage in collaborative problem solving by identifying roadblocks and needs, discussing regional methods and approaches, and sharing lessons learned.

Gonad Histology Workshop, Monday afternoon

Instructors: Christina Conrath, Eva Schemmel, Mark Wuenschel, Emilee Tholke

This training is organized by the MARVLS group and will be a hands-on workshop. During the workshop, participant slides will be reviewed and discussed. Participants will be asked to provide a PowerPoint with photographs of their slides for review. This is an opportunity to get hands-on advice about your histology work and interact and learn from other MARVLS members, and this activity helps build consistency in our interpretation of histological structures found within fish gonads.

Appendix E: National Topics

In addition to presentations focused on the workshop theme, there were additional presentations throughout the workshop focused on topics of national importance. Summaries of those presentations are included below.

General National Updates

Kristan Blackhart, National Stock Assessment Program Lead, provided updates on several national projects and initiatives related to the national stock assessment enterprise. The presentation included updates on the following topics:

- National Standards Technical Guidance: Updated guidance for National Standard 1 is being published in three phases. The guidance on carry-over and phase-in provisions was published first (Holland et al.[1]). Guidance on managing data-limited stocks with annual catch limits was published next (Macpherson et al.[2]). Finally, guidance on reference points and status determinations is still in progress; the material will be presented to Fishery Management Council (FMC) representatives at the Council Coordination Committee meeting later in May 2023, followed by distribution of the draft guidance document for FMC comment and publication anticipated by the end of 2024. Additionally, NMFS will soon announce an Advance Notice of Proposed Rulemaking for National Standards 4 (Allocations), 8 (Communities), and 9 (Bycatch). Potential updated guidance for these National Standards would be anticipated to be mainly policy focused, with limited impacts on the science enterprise.
- Stock Assessment Gap Analysis: The basis of this study was to examine NOAA Fisheries' data needs to support fish assessments by setting stock-specific targets identified by regional experts based on five primary types of assessment data inputs and then comparing those targets against current data availability. A tech memo detailing the results is in the final stages of publication preparation and anticipated to be published soon.
- DisMAP: The NOAA Fisheries Distribution Mapping and Analysis Portal (DisMAP) provides easy access to information to track and understand distributions of marine species in U.S. ecosystems, including how they change over time in response to changing ocean conditions.

Other topics briefly discussed included updates from the ecosystem modeling community, open science and openscapes, the Fisheries Integrated Toolbox, posit connect, and the Github Governance Team (NOAA accessible only).

[1] Holland, D., D. Lambert, E. Schnettler, R. Methot, M. Karp, K. Brewster-Geisz, J. Brodziak, S. Crosson, N. Farmer, K. Frens, J. Gasper, J. Hastie, P. Lynch, S. Matson, and E. Thunberg. 2020. National Standard 1 Technical Guidance for Designing, Evaluating, and Implementing Carryover and Phase-in Provisions. NOAA Tech. Memo. NMFS-F/SPO-203, 41 p.

[2] Macpherson, M., J. Cope, P. Lynch, A. Furnish, M. Karp, J. Berkson, D. Lambert, L. Brooks, S. Sagarese, K. Siegfried, E. Dick, C. Tribuzio, and D. Kobayashi. 2022. 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 DataLimited Stocks. NOAA Tech. Memo. NMFS-F/SPO-237, 33 p.

Keynote Presentation - Some Thoughts for the Fish Assessment Community

Richard Methot, NOAA Senior Scientist for Stock Assessments, presented on five themes for the assessment scientists assembled for NSAW during his keynote presentation. First was a recap of the status of the technical guidance for reference points. A particularly difficult aspect of reference points was the recognition that 25 years of regional development had resulted in quite different approaches to the use of the spawner-recruitment relationship versus proxy approaches. The guidance also covered the challenge of adapting reference points to changing environmental and ecosystem conditions. Data-limited approaches were also addressed, particularly the use of length composition data to make overfished determinations when the fishery and population has been stationary. A second and related theme was reflection on the degree to which biomass-dynamics models, statistical catch-at-age models, and data-limited composition models represent different paradigms regarding how data can inform stock status. As a community, we lack a unifying overarching paradigm regarding the different assumptions, particularly for selectivity, made in using these three approaches, yet our integrated analysis modeling must deal with those selectivity assumptions in every application. The third theme was an accolade for stock assessment products that support a highly effective science-based fishery management system. Our collective story is told well with the Stock SMART web tool, and we should find ways to augment it to be even more informative. The fourth theme highlighted the Inflation Reduction Act spending on data modernization. This provides opportunities for investing in training for reproducible workflows and treating all assessment inputs and outputs as information to be stewarded. The last theme focused on good practice guides and the value of having such documentation of our methods and procedures. This happens regionally, and there is merit in rolling it up nationally.

Incorporating Ecosystem Data into Stock Assessments Using the Ecosystem and Socioeconomic Profile Framework: Case Studies from Alaska and the Northeast

Abigail Tyrell (NEFSC) gave a presentation on collaborative work with Kalei Shotwell (AFSC) and Scott Large (NEFSC) to further develop and operationalize Ecosystem and Socioeconomic Profiles (ESPs). ESPs offer a flexible framework to assess and monitor ecosystem information within the stock assessment process. The ESP process includes: 1) review of literature and research priorities for the stock; 2) development of conceptual models outlining major drivers on the stock; 3) creating, selecting, and analyzing relevant indicators; and 4) reporting scientific advice. Indicators inform stock advice through four pathways, including providing context, supporting model assumptions, informing model parameters, and providing model covariates. ESPs are updated within the stock assessment cycle to provide timely advice.

Ms. Tyrell then went on to detail two ESP implementation case studies. Alaska ESPs began in response to requests to revamp the ecosystem considerations of stock assessment and fishery evaluation reports. First produced in 2017, the sablefish ESP provided support for reducing initially large but uncertain recruitment estimates. ESPs have subsequently been developed for six other Alaskan stocks and are integrated into annual stock assessment processes. In the Northeast, ESPs began as an effort to incorporate ecosystem information from routine reporting into single stock advice, supported by a required research track stock assessment Term of Reference addressing ecosystem and climate influences. The first Northeast ESP was recently completed for bluefish, with ESPs in progress for three additional species. ESPs are a next generation stock assessment tool to proactively respond to our rapidly changing climate. Leveraging the success in the two disparate stock assessment processes in Alaska and the Northeast, the project leads hope to facilitate the expansion of ESPs to all six science centers.

The Fisheries Integrated Modeling System Update

Christine Stawitz, Fisheries Integrated Modeling System (FIMS) Project Lead, provided an update on FIMS development for workshop participants. FIMS is software designed and architected to support next-generation fisheries stock assessment, ecosystem, and socioeconomic modeling. Developed as a modular modeling system to provide flexibility and extensibility, FIMS is delivered as an R package with compiled C++ code and made available via the open source platform Github. An operational beta version of FIMS is anticipated to be released publicly later this year, followed by regional pilot studies before moving on to the second phase of development. While FIMS will not be ready for operational assessment use for another 1 to 2 years, early feedback on the software is welcome.

Discussion on Building a NOAA Fisheries Stock Assessment Community of Practice

Kristan Blackhart, National Stock Assessment Program Lead, facilitated a brief plenary discussion building out a NOAA Fisheries stock assessment community of practice (CoP). A more formalized assessment CoP could be a way to support staff and assessment programs as they deal with multiple challenges, including flat budgets, staff attrition, emerging/increasing requirements and increasing stakeholder demands, and a burnout crisis. A CoP could also support diversity, equity, and inclusion efforts by encouraging full participation and contributions across all community members, strengthening our science by including a range of different perspectives by inviting debate. A key contribution of an assessment CoP would be providing a potential venue for developing and cataloging assessment “good practices.” Many building blocks already exist to support an NOAA Fisheries assessment CoP (e.g., National Stock Assessment Workshops, Fisheries Integrated Toolbox, etc.), but fully formalizing a CoP would require both buy-in from the community and support (resources) to maintain it.

Appendix F: Presentation and Poster Abstracts

Session: Joint NSAW-MARVLS Session on Advances and Applications of Spatial Life History Data

Keynote: Reproductive biology of fish: Applications for research, monitoring, assessment and management. By R. S. McBride, S. Beyer, C. Conrath, J. Field, M. Head, N. Klibansky, K. Kolmos, B. Linton, S. McDermott, S. Neidetcher, J. M. O’Malley, A. Pacicco, E. Schemmel, P. Spencer, C. Rodgveller, and M. Wuenschel

NOAA Fisheries’ MARVLS (Maturity Assessment Reproductive Variability and Life Strategies) working group originated as a journal club at the Alaska Fisheries Science Center (AFSC) and held its first national workshop at the AFSC laboratory in Seattle in 2014. Subsequent, biennial workshops occurred at the SWFSC laboratory in La Jolla (2016) and the SEFSC laboratory in Panama City (2018). This year's, 2023, joint meeting with NSAW (National Stock Assessment Workshop), originally scheduled for 2020, was postponed due to the SARS-CoV-2 pandemic. In response, in 2021, we started a quarterly webinar series that features special topics. Our mission is to advance the science of reproductive biology and its use in the assessment and management of marine fish and invertebrates. Our workshops are designed to share best practices regarding descriptive, experimental, and modeling approaches used in fisheries research, monitoring, assessment, and management. Across all six science centers, we investigate a broad suite of exploited marine species—distributed from tropical to boreal systems in both the Atlantic and Pacific oceans—in terms of data types (e.g., maturity, spawning frequency, and fecundity), sexuality (gonochores, hermaphrodites), reproductive modes (benthic egg layers, pelagic broadcast spawners, and live bearers), and energetic strategies (capital and income breeders). Although NOAA-centric, we welcome international, other U.S. federal, state, academic, NGO, and student scientists who work on common issues, many in direct partnership with NOAA Fisheries. This talk outlines the scope of our interests, describing the research and operational challenges associated with reproductive studies when applied to stock assessment and management. Specifically, we translate the insider jargon, highlight some of the opportunities for progress through collaboration, and invite everyone to join the discussion.

State-dependent life history theory predicts spatial variation in the life history traits of California Current rockfishes. By Sabrina G. Beyer, John C. Field, Marc Mangel, Chris J. Harvey, and Suzanne H. Alonzo

Life history traits of live-bearing rockfish (*Sebastes* spp.) vary by latitude in the California Current Ecosystem. This includes inter- and intra-specific spatial variation in how often females reproduce. Most produce a single brood during a reproductive season, but some reproduce more often (called multiple brooding). Multiple brooding is most common in the south and is likely due to different environmental conditions there. This includes warmer temperatures, weaker seasonality, and lower ocean productivity. An incomplete understanding of spatial variation in the frequency of reproduction hampers efforts to accurately assess individual fecundity and stock reproductive potential. Here, we develop a state-dependent life history model using stochastic dynamic programming and bioenergetics to better understand spatial variation and how phenotypic plasticity in life history traits is adaptive and can be expected. This approach mathematically explains adaptive reproductive behaviors, including the potential for skipped spawning, multiple brooding, and variable fecundity, given the environment and a female's state (age, length, and energy reserves). We find a single brood reproductive strategy in the north is adaptive to cope with strong seasonality and the need to survive a winter period of poor food resources causing net energy loss. Multiple brooding in the south is adaptive when seasonality is weaker, temperatures warmer, and after a female has reached a near maximum size. However, due to lower ocean productivity in the south, females are expected to be smaller with smaller-sized broods and thus have much less lifetime fecundity, despite multiple brooding. We compare model predictions to field and laboratory observations.

Spatial differences in the northern stock of black sea bass energetics and reproduction. By Emily Slesinger, Kiernan Bates, Mark Wuenschel, Olaf Jensen, and Grace Saba

Ocean warming is leading to poleward range shifts for many fish species potentially influencing spatial intraspecific differences in life history from historic to current locations of higher biomass. The Northern stock of black sea bass (*Centropristis striata*) inhabits the U.S. Northeast continental shelf (Cape Hatteras, NC–Gulf of Maine) and has experienced a recent northward distribution expansion. To assess spatial differences in energetics and reproduction, black sea bass were collected across this distribution and throughout their spawning season (April–October) during 2018 and 2019. Metrics related to spawning phenology, spawning output, and energetic allocation were analyzed in dissected gonad, liver, and muscle tissues. Unlike male fish, female fish both invested more energy into liver and gonad tissues and exhibited regional differences in energetic values. Broadly, black sea bass in the northern portion of their distribution had lower energetic values both in somatic stores and toward gonadal development than the fish in the southern portion of the distribution. These energetic differences may have led to the observed lower reproductive output from fish in northern portions of the distribution. Additionally, black sea bass spawning season length decreased from south to north. Overall, during the years studied, we found significant spatial variation in energetic constraints that may have affected reproductive output and success. These results have important implications for recruitment success in black sea bass spawning in locations representing their historic vs. current centers of biomass and provide insight into the complexity of managing species with broad distributions and recent range expansions.

Spatial variability in the life-history of *Scomber colias*, an expanding species in the East Atlantic. By Rosario Domínguez-Petit, María Rosario Navarro, Marta Cousido-Rocha, Jorge Tornero, Fernando Ramos, Alba Jurado-Ruzafa, Cristina Nunes, Carmen Hernández, Andreia V. Silva, and Jorge Landa

Atlantic chub mackerel is a pelagic species present in the Atlantic Ocean that in recent decades has expanded northwards in the East Atlantic. Fish samples were collected in scientific surveys and commercial catches between 2011 and 2019. We analyzed the latitudinal variation of the biological parameters (age, length, weight, and condition), as well as the length-weight relationship, maturity-at-length, spawning season onset and duration, and growth pattern, parameters, and performance index in five geographical areas (from south to north): the Canary Islands, Gulf of Cadiz, W Portuguese coast, NW Spanish coast, and Cantabrian Sea. Influence of the SST on fish length was modeled as a potential driver of geographical variability. In general, biological parameters increased progressively northwards, while the spawning season was delayed and prolonged with increasing latitude, from January in the Canary Islands to May-August in the Cantabrian Sea, when SST was between 15º and 19ºC. Despite *S. colias* growth was faster in the northern areas, the strength of cohorts was similar along its distribution. SST influenced both length and growth. Deviance of the geographical pattern of some biological parameters in the Gulf of Cadiz, suggests that it could be a hinge or mixing zone between Atlantic African, Mediterranean and Atlantic Iberian population components.

Variation in fecundity of winter flounder, *Pseudopleuronectes americanus*, and yellowtail flounder, *Myzopsetta ferruginea*: Patterns across stocks over ten years. By Mark J. Wuenschel, Emilee Tholke, Yvonna Press, W. David McElroy, and Richard S. McBride

Annual fecundity estimates in marine fishes have been limited for most species due in part to the challenges of traditional methods; however, recent advances in image analysis have facilitated fecundity estimation. Ongoing monitoring of potential annual fecundity (PAF) in winter and yellowtail flounder across multiple stocks (Gulf of Maine, Georges Bank, and Southern New England/Mid-Atlantic) provides a rich dataset to explore scaling in the fecundity–size relationship in addition to spatial and temporal variation in annual fecundity. Both species exhibited significant hyperallometric scaling of fecundity vs. weight; larger females produce disproportionally more eggs than smaller females. We modeled annual fecundity as a function of fish size, liver size, relative condition (Kn), and the mean oocyte diameter for these two species with different reproductive strategies (total vs. batch spawning) using generalized additive models (GAMs). Spatial and temporal effects were assessed as factors across three stock areas over a ten-year period (2010-2019). As expected, fish size, condition metrics (Kn and liver size), and mean oocyte diameter (which served as a proxy for time before spawning) explained significant portions of variation in potential annual fecundity. For both species, GAMs also indicated significant spatial and temporal effects, as well as the interactions between them suggesting regional level forcing that has varied through time. Observed variation in reproductive output across stocks, species, and years provides empirical data to propose and test hypotheses related to "upstream" regulation of fecundity (via environmental drivers and productivity) and "downstream" effects on population replenishment and recruitment.

A preliminary review of spatiotemporal patterns of spawning in the Pacific Sardine (*Sardinops sagax*) along the Pacific coast of North America in relation to population structure. By Brad Erisman, Matthew Craig, Barbara Muhling, and Andrew Thompson

The Pacific Sardine (*Sardinops sagax*) is currently managed under the assumption of two subpopulations along the Pacific coast of North America, based on a suite of biological criteria (e.g., vertebral counts, blood groups, tagging, growth) proposed by several historical studies. Among these is a study by Marr[3], who hypothesized that spatiotemporal differences in spawning and migration patterns maintain geographic separation and promote reproductive isolation between two subpopulations. Marr's hypothesis was based on his interpretation of previous studies by Ahlstrom who analyzed data from monthly surveys off California and Baja California during the 1950s to describe spatiotemporal patterns of spawning in Pacific Sardine. In response to renewed interests in population and stock structure in Pacific Sardine, we conducted a critical review of Marr's hypothesis by re-examining the findings of Ahlstrom viewed through the lens of current theories and understanding on the life history and reproductive ecology of clupeoid fishes. Upon doing so, we found that Ahlstrom's results do not support the conclusion of isolated spawning centers indicative of separate subpopulations. Rather, Ahlstrom's studies showed a relatively continuous distribution of spawning from southern Baja California to central

[3] Marr, J.C. 1960. The causes of major variations in the catch of the pacific sardine *Sardinops caerulea* (Girard). Pages 667-791 in H. Rosa, Jr. and G. Murphy, editors. Proceedings of the world scientific meeting on the biology of sardine and related species. Food and Agricultural Organization of the United Nations, Rome.

California with annual variations in the spatial and temporal distribution of spawning in response to regional environmental conditions. Here, we summarize Ahlstrom's findings and more recent studies of spawning in Pacific Sardine, which collectively support the existence of a single population along the Pacific coast.

Examining distributional shifts of spawning and feeding migrations of Pacific cod in Alaska with Satellite popup tags. By Susanne McDermott, Julie Nielsen, Charlotte Levy, Kimberly Rand, and Liz Dawson

Pacific cod (*Gadus macrocephalus*) is a key component of the Eastern Bering Sea ecosystem. Warming in recent years has resulted in dramatic shifts in the distribution of Pacific cod in Alaskan waters. This research represents a collaborative effort between the Alaska Fisheries Science Center groundfish assessment program, Aleutian East Borough, Pacific cod harvesters, and Norton Sound Economic Development Corporation and tribal partners. Particular concerns include a northward shift in distribution of Pacific cod from the Eastern Bering Sea to the Northern Bering Sea and seasonal movement between the Gulf of Alaska and Bering Sea management areas. This study examines the changes in seasonal distribution patterns, specifically spawning and feeding migrations, with Satellite popup tags. These tags provide information on the location of the fish at time of popup as well as light, temperature, and depth data. We estimate movement paths with a hidden Markov model (HMM) that enables us to reconstruct the travel paths of individual fish and produce monthly maps of tagged cod distributions. Results from tags released in the summer in the Northern Bering Sea show that fish migrated south to spawn in previously observed spawning locations of the Eastern Bering Sea, suggesting that the Northern Bering Sea summer population is a northward expansion of Eastern Bering Sea and Gulf of Alaska Pacific cod stocks. Results from tags released in the winter in the Western Gulf of Alaska indicate that a high percentage may move north into the Bering Sea for the summer, with tagged fish migrating into the Northern Bering sea, Russia, and the Chukchi Sea during the summer months. These northward shifts in Pacific cod distribution and the seasonal movement across management boundaries pose challenges for stock assessment, and results from this study have provided valuable information for spatial management of Pacific cod stocks.

Exploring spatial reproductive variability of reef fish in the Southeast, US. By Catlyn Wells, Walter Bubley, Tracey Smart, Kevin Kolmos, and Gorka Sancho

Red snapper (*Lutjanus campechanus*) are an important species both recreationally and commercially in the Southeast United States. Currently, there are regulations in place to minimize fishing pressure on these species with additional deep-water marine protected areas (MPAs) and spawning special management zones (sSMZs) that are meant to protect bottom habitat and fish within their boundaries. However, these protected areas are not the only habitats utilized, nor do they fully eliminate fishing practices within their boundaries. The question we aim to answer is, do adult fish spawn where they live, or do they move to new areas to spawn? A comprehensive characterization of adult female distribution and seasonal spawning female distribution throughout the region would greatly improve our understanding of habitat utilization. Differences in these distributions would indicate spatial and temporal changes in habitat utilization and potential preferences with associated environmental variables. For this study, we utilized fishery-independent data from 2010-2019 to determine the location of spawning hot spots and overall adult distributions from Cape Hatteras, NC to St. Lucie Inlet, FL. Boosted regression tree analysis (BRT) was used to explain complex relationships between explanatory variables and fish presence/abundance. The final BRT models include different combinations of explanatory variable influence for fish presence and abundance as well as for adult females and spawning adult females. These results will fill knowledge gaps regarding the reproduction and distribution of adult reef fish off the Southeast U.S. and influence management decisions relating to the protection of the spawning areas of these valuable fisheries.

Sensitivity of stock assessments in the Southeast U.S. Atlantic to reproductive life history estimates. By Nikolai Klibansky

Reproductive life history traits are often incorporated into stock assessment models as fixed values based on empirical estimates. The degree to which variation in those estimates affects stock assessment results can be evaluated with sensitivity analysis. We evaluated the sensitivity of stock assessments of several demersal and pelagic fish species in the Southeast US Atlantic, to reproductive life history traits, such as maturity, sex ratio, time of peak spawning, batch fecundity, and spawning frequency. We considered the effects of these varying traits on MSY and SPR-based benchmarks, which are both used in the Southeast region. This analysis provides a unique look at sensitivity to reproductive estimates across models and species to help gain an understanding of which reproductive traits are most in need of further study. This research should be of interest to stock assessment analysts and reproductive biologists alike, working together to improve management advice.

Estimation of selectivity in the face of time varying growth. By Amy M. Schueller and Peter Kuriyama

Many fish species have spatial patterns in growth, as well as patterns in growth over time. Spatially and temporally varying growth is especially important for forage fish species who exhibit rapid growth and are important prey species. Life history information is important for stock assessments but is often considered constant over both space and time. Additionally, life history information is often intertwined with estimation of other important stock assessment parameters like selectivity. Our objectives were to determine under what conditions spatially and temporally varying growth forms should be accounted for in a stock assessment and to determine the extent to which selectivity can be well estimated in situations where growth data are spatially and temporally varying. An age-structured stock assessment model was paired with a simulation model to compare true and estimated values of growth, selectivity, and reference points for a generalized forage fish stock. The operating model had both time-varying, cohort-specific growth and time-varying selectivity due to seasonal migrations. We evaluated the ability to correctly estimate both time-varying components under three data scenarios: low, medium, and high age composition qualities and sample sizes. Additionally, we evaluated the impact of misspecification (e.g., the estimation model estimating constant growth and selectivity) on reference points and forecast biomass values. Determining the best approaches to accommodate spatially and temporally varying growth will help to improve stock assessment outcomes and the resultant management.

Trait-based habitat analysis: Including phylogenetic-imputation of life-history strategies in joint species distribution models. By James Thorson, Cheryl L. Barnes, Jennifer S. Bigman, Sarah T. Friedman, Romain Frelat, Aurore A. Maureaud, Janelle L. Morano, Bastien Mérigot, Maria Lourdes D. Palomares, Malin L. Pinsky, Samantha A. Price, and Peter Wainwright

Traits (including life-history parameters, morphometrics, diet, and reproductive characteristics) are essential to predict community responses to environmental conditions under global change. Traits measurements are not available for all species, and missing continuous traits can be imputed based on evolutionary relatedness and trait covariance. Here, we extend FishLife by (1) specifying covariance among traits as a structural equation model (SEM) and (2) incorporating covariance among both continuous and categorical traits. We fit this to 33 variables representing life history, reproductive, morphological, and behavioral traits for all >32,000 described fishes worldwide. Results suggest that one degree Celsius increase in habitat is associated with an average 3.5% increase in natural mortality (including a 1.4% indirect impact that acts via temperature effects on the growth coefficient) and an average 3.0% decrease in fecundity (via indirect impacts on maximum age and length). Similarly, species distribution models (SDM) are widely used to relate species occurrence and density to local environmental conditions, and often include a spatially correlated variable to account for spatial patterns in residuals. Ecologists have extended SDMs to include spatially varying coefficients (SVCs), where the response to a given covariate varies smoothly over space and time. We quickly review ecological contexts where SVCs can improve the interpretability and descriptive power from SDMs. We then use the Vector Autoregressive Spatio-Temporal (VAST) model to fit a trait-based multispecies SDM to data from the Gulf of Alaska. Results highlight the role of body size and temperature in spatial community assembly in the Gulf of Alaska.

Session: Species Distribution Modeling

Is climate change biasing survey abundance indices? A simulation study starting point. By Benjamin Levy, Christopher M. Legault, Elizabeth N. Brooks, and Timothy J. Miller

Stock assessments use abundance estimates derived from stratified random bottom trawl data. To accurately represent true abundance, catches of a species must contain a low enough noise level to allow for a discernible pattern, and all strata in which the population exists should be sampled. These assumptions might be violated given enough noise in the sampling process and/or climate change causing a population to move into previously uninhabited strata. Using the R package MixFishSim, we have developed data-driven spatial models for Yellowtail Flounder, Cod, and Haddock on Georges Bank to allow examination of these assumptions through simulation. Movement rates combine species-specific static habitat preferences with temperature tolerances. Habitat preferences were derived from niche models relating bottom trawl catches to environmental covariates. A repeating yearly temperature pattern produces repeating spatial biomass distributions in a given week, while a temperature gradient that increases on average over time results in spatial preferences that evolve throughout a given simulation. We examined several temperature scenarios and population trends to create simulated spatial time series datasets for each species. We then conduct stratified random sampling on model output and compare abundance estimates using the stratified mean to those using a common model-based approach that allows inclusion of environmental covariates (VAST). Our focus is on the ability of contemporary indexing methods to track population trends under shifting spatial preferences. Results highlight conditions that can result in biased indexing estimates and demonstrate the value of including spatial covariates in abundance estimates.

Application of a vector autoregressive spatiotemporal (VAST) model to Northwest Atlantic Ocean bottom trawl data. By Christopher Cacciapaglia, Elizabeth N. Brooks, and Charles F. Adams

Biomass indices for four species with differences in life history, spatial extent, proportion of zero observations, biomass trajectory, and stock status were modeled using the Vector Autoregressive Spatio Temporal (VAST) model. We iteratively tested model settings following a workflow developed to find the best model for each stock, where "best" was determined from AIC, an R2 score between model estimates and samples, and quantified deviation from design-based approaches. Biomass indices from the best VAST model had good agreement with design-based indices in three of the species. We found that model fit tended to asymptote around 1000 knots for all species and that the generalized gamma error distribution with a logit link was the best model for two of the species, and the gamma error distribution with log link was the best model for the other two. In general, both the AIC and R2 statistic performed well as model selection tools in the simulation; however, on occasion they point to a model with estimates far too large, a known issue. Comparing model output quantitatively to the design-based approach could help select the best model when AIC or R2 were inappropriate. Simulation self-tests were performed from the best model and fitted with several estimation models to determine robustness of the model selection tools in recovering the specifications of the original model, and additional visualizations for spatial residuals and clustering are introduced to aid interpretation of model fit and highlight latent spatial components.

Spatiotemporal models facilitate fish biomass-at-age estimation with uncrewed surface vehicle acoustic sampling and non-contemporaneous compositional data. By Derek G. Bolser, Aaron Berger, Dezhang Chu, Jim Hastie, Julia Clemons, and Lorenzo Ciannelli

The use of acoustic data collected by uncrewed surface vehicles (USVs) for generating biomass-at-age indices used in fisheries stock assessments is limited by the need for contemporaneous biological (e.g., age) data. To address this limitation, we generated age composition data for Pacific Hake (*Merluccius productus;* "hake") using a vector-autoregressive spatio-temporal (VAST) model fit to a combination of fishery-dependent data and a non-target fishery-independent bottom trawl dataset. Estimated age compositions were then compared to age compositions from midwater trawls in the formal hake acoustic-trawl survey (ATS). Both compositional datasets were paired with acoustic data collected by Saildrones (in 2019) and a fishery survey vessel (FSV; 9 years between 2003-2019) to estimate hake biomass-at-age. Our approach to generate compositional data performed well in areas where both fishery-dependent and non-target fishery-independent data were available (within 3% of proportion at age class in ATS midwater trawls in 2019, 9% across years). However, in areas where only non-target fishery-independent data were available, VAST-estimated age compositions did not provide better predictions than a simple time series average. The 2019 total biomass estimate from VAST-estimated compositions paired with saildrone acoustics was 23% lower than the formal hake ATS estimate. The discrepancy between acoustic data from USV and FSV was the primary driver of overall differences in biomass estimates (15-fold), much larger than the uncertainty arising from our approach of generating age compositions. When differences in acoustic data between FSVs and USVs can be better explained, similar approaches could provide useful age-based indices of abundance for stock assessment.

Applying high-resolution catch and effort information to develop a novel commercial catch per unit effort index for the northern black sea bass stock. By Andrew W. Jones, Anna M. Mercer, and Kiersten L. Curti

Despite the availability of a significant amount of fishery-dependent data from the northeastern U.S. and the interest of stakeholders in using it, these data are not frequently employed to create indices for stock assessments in the region. To demonstrate the potential of these data, we developed a catch per unit effort (CPUE) index for the northern black sea bass (*Centropristis striata*) stock, which is currently the subject of a research track stock assessment. By combining data from two extensive fishery-dependent data sets, the Northeast Fisheries Science Center (NEFSC)'s Study Fleet Program and the Northeast Fisheries Observer Program, we created a generalized additive model-based catch rate standardization that incorporates important spatial, ecological, and economic factors. Our index was spatially specific, with individual models fitted for each region within the stock, and high-resolution spatial information was utilized to develop covariates for the index standardization. To evaluate the resulting index, we compared it to a recreational CPUE central to the stock assessment and the NEFSC's bottom trawl survey index. The comparisons revealed a high degree of correspondence between these indices, demonstrating the potential utility of this type of product. This work illustrates how utilizing these high-resolution fishery-dependent data sets can enhance our scientific understanding of a species' abundance and provides an example of effectively integrating the insights of fishermen into a stock assessment.

Implementing joint species distribution models for species complexes to aid management advice: A case study with non-target rockfish in the Gulf of Alaska. By Kristen L. Omori, Cindy Tribuzio, Chris Lunsford, and Pat Malecha

Non-target species are a challenge to manage, given data paucity when estimating population trends and attempting to avoid the species becoming a "choke" stock. Non-target species are often inadequately sampled in fishery-dependent catch or fishery-independent survey data. Moreover, data sources commonly suggest conflicting spatiotemporal trends, which make identification of shifts in species' distribution or composition difficult. Oftentimes, non-target species are grouped into species complexes, which aim to assign species based on similar patterns in life history, exploitation, or distribution. Therefore, understanding how species respond to environmental or anthropogenic perturbations is necessary to develop robust management advice and adaptive complex groupings. The ability to implement species distribution models for non-target species can be a novel aid for management by improving identification of population trends and distributional shifts. The Gulf of Alaska non-target rockfish complex is a useful case study, where a variety of species are assessed and managed as a complex but mismatches in observed spatial distributions exist among species and between the survey and fishery catches. We explore potential distributional and species composition shifts using quantitative methods, including a joint species distribution model (i.e., VAST). Preliminary results indicate that multispecies distribution models can provide species interactions and overlap as well as spatiotemporal mapping. Additionally, these spatial models can be a useful management tool to identify changing distributions, apportion quota to management areas, and monitor hotspots of non-target species in fisheries' catch.

Spatiotemporal dynamics of longfin inshore squid, *Doryteuthis* (Amerigo) *pealeii*, on the Northeast U.S. shelf. By Lisa C. Hendrickson and Charles F. Adams

A VAST model was used to investigate the spatiotemporal dynamics of longfin inshore squid, *Doryteuthis* (Amerigo) *pealeii*, recruits and pre-recruits on the Northeast U.S. shelf to inform stock assessments. The species inhabits deep water along the shelf edge during winter/spring but is found shelf-wide during summer/fall in the Mid-Atlantic region. VAST runs were conducted using Northeast Fisheries Science Center spring and fall bottom trawl survey data for 1992–2021. The center of gravity varied without trend during the spring and fall for both recruits and pre-recruits in both time series. Effective area occupied varied without trend during the spring and fall in the early part of the time series for both recruits and pre-recruits. However, there was a large spike in effective area occupied during the spring of 2012, corresponding with the warmest shelf temperatures on record. Effective area occupied generally increased during the later part of the fall time series. Adding environmental covariates improved some of the model fits. For example, including bottom temperature and bottom salinity to the later part of the time series greatly improved the spring model fits, but during the fall, this was only true for bottom temperature. A spatial collocation analysis was done with butterfish (*Peprilus triacanthus*) because the longfin squid fishery is subject to closures based on a butterfish discard mortality cap.

Session: MARVLS Session Focused on Life History

Changing perceptions and unanswered questions about follicular atresia. By R. M. Rideout, R. S. McBride, M. J. Wuenschel, C. L. Conrath, D. M. Wyanski, E. Schemmel, N. Brown-Peterson, R. Dominguez-Petit, and D. Garabana

Follicular atresia, the process by which oocytes deteriorate and are reabsorbed by the ovary, is a well-recognized process in the reproductive cycle of fishes. For ecologists that study reproductive potential, atresia is often associated with negative connotations due to its role in reduced egg production and/or skipped spawning. Here, we emphasize the need to recognize atresia as a vital process in the ovaries of fish, helping to facilitate a crucial balance between reproductive investment and the energy required for survival and other vital life functions. It also plays a major role in transitioning the ovary following spawning to prepare it for subsequent development in the next reproductive cycle. Although atresia is an important topic in fields of research ranging from medicine to fisheries ecology, many of the same unresolved questions/issues in atresia research have persisted for 20 years or more. Here, we outline, and when appropriate try to resolve, some of these issues, including inconsistencies in terminology, how to interpret elevated levels of atresia in relation to differential egg development/spawning strategies, difficulties in distinguishing between high levels of fecundity downregulation via atresia vs. skipped spawning, and how fixation and processing issues can influence the identification of atretic follicles. In addition, we highlight other modes of oocyte degeneration other than the classic mode of follicular atresia.

Variability in maturity and skipped spawning rates of deep water rockfishes in Alaska waters. By Christina Conrath and Pete Hulson

Skipped spawning has been documented in many species of rockfishes in Alaska waters. A fish that has skipped spawning is known to be physiologically mature but has no reproductive output for the year. The incorporation of data from these fishes into maturity ogives can therefore be problematic. Reproductive parameters, especially maturity at length or age estimates, directly influence estimates of stock biomass for these federally managed fish species. Parameters like maturity and skipped spawning rates can vary over different temporal scales, and a better understanding of how and why these parameters change will aid in the management of these species. The length at maturity and skipped spawning rates of two deep water rockfish were compared between two reproductive years, 2010 and 2016. Maturity rates for both the rougheye rockfish, *Sebastes aleutianus,* and shortraker rockfish, *S. borealis*, were not significantly different. Skipped spawning rates were significantly lower for the 2016 reproductive year for both rougheye rockfish (2010 = 37.4%, 2016 = 21.8%, $P < 0.001$) and shortraker rockfish (2010 = 60.0%, 2016 = 47.0%, $P < 0.001$) and were significantly related to fish length for both species ($P < 0.001$ for both). Rates of skipped spawning in rockfish species appear to be dynamic and likely vary according to environmental conditions. This study also provides evidence of the increased productivity of larger, older females within rockfish populations.

Black Rockfish (*Sebastes melanops*) biological and functional maturity schedules influenced by marine heat waves. By R. Claire Rosemond, Melissa A. Head, and Scott A. Heppell

The California Current Ecosystem (CCE) is highly dynamic, driven not only by natural climate oscillations and seasonal upwelling but also by anthropogenic, directional climate change. Anomalous events such as marine heat waves may modulate fish individual performance and long-term productivity of managed fish populations. The influence of oceanographic conditions on vital rates of fish populations is increasingly being included in stock assessment models, particularly for species in the CCE. Our study investigates how marine heat waves influence Black Rockfish (*Sebastes melanops*) biological versus functional maturity schedules. Functional maturity accounts for the occurrence of abortive maturation and skipped spawning rates, which may be driven by environmental stress. Ovary samples were collected from 900 Black Rockfish caught on recreational fishing charters off the coast of Oregon from 2014 to 2021. Ovaries were histologically assessed for stage of maturity and prevalence of atresia. We evaluated size at biological maturity and functional maturity of female Black Rockfish during a period that included years with marine heat waves and non-anomalous years. Quantifying the influence of temperature-driven variability on maturity schedules of Black Rockfish will allow stock assessment scientists to incorporate this environmental variability into the assessment process when calculating metrics used to manage the fishery and in developing ecosystem-based fishery management plans.

Evaluating the influence of spawning dynamics, sampling design, and calculation of fecundity through simulation modeling. By Nikolai Klibansky and Kyle W. Shertzer

Including fecundity information in stock assessment models to characterize the spawning stock may be better than using spawning stock biomass if the data quality is sufficient. In this research, we simulated the reproductive dynamics of red snapper (*Lutjanus campechanus*), and we evaluated current methods of estimating annual fecundity and subsequent effects on biological reference points. Estimates of fishery and stock status were generally robust to variations in annual fecundity estimates. However, estimates of annual fecundity and subsequently the stock size reference point were biased high due to the simple standard method of measuring spawning season duration. To address this bias, we explored several alternative methods of estimating spawning season duration and identified one method that removed most of this bias. Increasing sampling or changing the temporal sampling pattern did not resolve the issue. Using the improved method, estimation of the stock size reference point was robust to decreased sampling but not to biased estimates of spawning indicator duration. Improved methods developed here can resolve bias in estimates of spawning duration but would not resolve bias in estimates of spawning fraction. Past estimates using standard calculations of spawning period duration probably overestimate population fecundity, perhaps to a large degree. The results of this work can help researchers evaluate potential bias in current fecundity estimates and help steer research toward the most efficient methods.

Effects of data sources and biological criteria for length-at-maturity estimates in a data limited species. By Erin M. Reed, Nancy J. Brown-Peterson, Edward E. DeMartini, and Allen H. Andrews

Reproductive characteristics of a fish stock provide important tools for assessing population health. The timing of length-at-maturity is a potential indicator of change in exploited fish populations, but when criteria for determining maturity classifications for the estimation of L_{50} are inconsistent, it is difficult to accurately assess change over time and space. *Etelis coruscans* is a commercially important, deep-water eteline snapper found throughout the Indo-Pacific, but its fishery is data-limited in the Hawaiian Islands. The present study describes length-specific female reproductive characteristics of this slow-growing and late-maturing species. We explored six maturity classification criteria based on a functionally mature (vitellogenic oocytes and capable of spawning within the season of collection) or physiologically mature (gonadotropin-dependent maturation) designation. Of these classifications, the largest and therefore the most conservative estimate of L_{50} was for functional maturity using specimens collected during the spawning period, September–December (L_{50F} = 65.8 cm). The other criteria resulted in progressively smaller values as we incorporated additional reproductive phases; the smallest was for physiological maturity using fish collected year-round (L_{50PY}= 50.0 cm). All estimates were smaller than previous reports for this species. Both functional and physiological maturity are valid for estimating length-at-maturity but can yield drastically different estimates based on the reproductive phases selected as mature or immature. The development of reproductive indicators (i.e., length-at-maturity and spawning period) is more unreliable in fish that grow relatively slowly, are late-maturing, and whose catches span a wide size range, if inconsistent maturity classification criteria are executed over time and space.

Update of maturity-at-size and -age for Pacific halibut (*Hippoglossus stenolepis)* using histological analysis. By Colin L. Jones and Josep V. Planas

Each year, the fishery-independent setline survey (FISS) collects biological data on the maturity of female Pacific halibut that are used in the stock assessment to estimate spawning stock biomass. Currently used estimates of maturity-at-age using macroscopic visual criteria collected in the FISS indicate that the age at which 50% of female Pacific halibut are sexually mature is 11.6 years on average. However, female maturity schedules have not been revised in recent years and may be outdated. In addition, the currently used macroscopic visual criteria used to score female maturity in the field have an undetermined level of uncertainty and need to be contrasted with more accurate microscopic (i.e., histological) criteria. In previous studies examining the annual reproductive cycle of Pacific halibut, it was determined that the time when gonad samples can be collected on the FISS (June–August) is an appropriate temporal window during which Pacific halibut females that are developing toward the spawning-capable reproductive phase can be identified as mature for stock assessment purposes. In 2022, the IPHC Secretariat has initiated studies to revise maturity schedules through histological characterization of maturity throughout the distribution range of Pacific halibut in the northeastern Pacific Ocean, including the U.S. West Coast, British Columbia, Gulf of Alaska, Bering Sea, and Aleutian Islands. A total of 1,025 ovarian samples were collected on the FISS coastwide. Maturity ogives will be generated by size and age, as well as potential updates to our current macroscopic visual criteria used in the field.

Handling effects on identifying female reproductive status. By Eva Schemmel and Nancy J. Brown-Peterson

Postmortem ovarian tissue degradation from handling effects, such as delays in preservation, can lead to inaccurate reproductive assessments. Therefore, it is important to understand the differences between these handling effects and natural ovarian atresia. Seven treatments of various holding temperatures and times to preservation were applied to whole fish and extracted ovaries of tropical deepwater snappers (*Pristipomoides filamentosus, P. auricilla,* and *Etelis carbunculus*). Handling effects for extracted ovaries were observed at 12 hr at room temperature and 48 hr iced or refrigerated for both whole fish and extracted ovaries. A clear histological indicator of postmortem degradation was a breakdown of ooplasm organelles at the oocyte periphery, which we observed in vitellogenic and cortical alveolar oocytes. The effect on primary growth oocytes was less clear across all treatments. Effects on post-ovulatory follicles (POFS), a primary indicator of prior spawning, were more discernible after 96 hrs on ice or refrigeration; however, the ability to detect POFs with increased time to preservation depended on the POF stage. Freezing gonad tissue resulted in drastic changes to oocyte shape and morphology. The ability to accurately assess reproductive phase with various handling effects will likely depend on the level of expertise of the researcher and prior knowledge of the handling effects. Therefore, it is advised that 1) freezing ovaries should be avoided where possible and that 2) gonad tissue should be preserved immediately and no later than 48 hr post-capture.

A novel approach for determining the reproductive status of walleye pollock (*Gadus chalcogrammus*) using Raman spectroscopy. By Sandi Neidetcher, Morgan Arrington, Thomas E. Helser, Esther Goldstein, and Irina Benson

Knowledge of reproductive status of fishes is essential to stock assessment estimates for the reproductive potential of a stock, which are used in calculating biological reference points in fisheries management. Efforts to incorporate this information into stock assessment models require either macroscopic evaluation (visual inspection) that is inherently subjective and can lead to high uncertainty and bias or histological analysis, which is most accurate but extremely time-intensive and costly. These challenges often result in limitations on the frequency of data collection and the quantity of available data. Here, we explore a novel approach, Raman spectroscopy, for rapidly differentiating the reproductive status of Gulf of Alaska walleye pollock (*Gadus chalcogrammus*) ovaries based on oocyte molecular composition. Partial least squares–linear discriminant models of Raman spectra from histologically staged ovaries accurately differentiate non-yolked ovaries from yolk stage ovaries (99% accuracy; AUC of .99). Non-yolk stages including mature-non-developing and spent ovaries were further differentiated from immature ovaries (93% accuracy; AUC of .98). Raman spectra of vitellogenic oocytes, including prespawning stage with coalescence and spawning stage with hydration, in the fingerprint region (200-1800 cm^{-1}) and high frequency region (2600-3250 cm^{-1}) were differentiated (79-86 % accuracy; AUC of .90–99) due to variation in relative quantities of proteins and lipids. The rapid approach using Raman spectroscopy to identify the reproductive status of walleye pollock from ovaries may hold potential to substantially increase key biological data available to inform the ecology and management of walleye pollock.

Initial assessment of nuclear magnetic resonance-based metabolomics as a tool for the identification of adult female reproductive phases. By Kevin Kolmos, Aaron Watson, and Fabio Casu

Accurate assessments of reproductive phases within a population are essential for developing reproductive parameters and estimating reproductive potential in fish stock assessments. What if there was a way to determine reproductive phase without the use of traditional gonad histological methods? We are currently working on the development of a novel analytical approach to differentiate female reproductive phases in fish populations. Specifically, we applied high-resolution molecular technology, Nuclear Magnetic Resonance (NMR)-based metabolomics, to generate metabolic profiles of adult females in various phases of reproduction. We evaluated samples from one species of interest in the U.S. South Atlantic: Vermilion Snapper (*Rhomboplites aurorubens*). The physiological and hormonal changes occurring within the gonad during oocyte development and spawning can significantly alter metabolic profiles. NMR-based metabolomics coupled with gonad histological interpretation can identify specific metabolic “fingerprints” as well as quantify potential biomarkers, which would clearly differentiate adult female reproductive phases. Our preliminary results show that the metabolite profiles of four ovarian reproductive phases (regenerating, vitellogenic, early oocyte maturation, hydration) were significantly different from each other, thus demonstrating that NMR metabolomics has the potential to clearly differentiate ovaries at different phases of reproductive development.

Reproductive biology of yellowfin tuna (*Thunnus albacares*) in the northcentral U.S. Gulf of Mexico. By Ashley E. Pacicco, Nancy J. Brown-Peterson, Debra J. Murie, Robert J. Allman, Derke Snodgrass, and James S. Franks

The reproductive biology of yellowfin tuna (*Thunnus albacares*) was investigated from 1135 females collected throughout 2000–2017 in the northcentral U.S. Gulf of Mexico predominately from recreational anglers fishing off the Mississippi River (93%). Histological evidence showed that peak spawning occurred from May to August, with the highest mean GSI value observed in May 1.52%. The upper and lower 95% confidence intervals among length at 50% maturity (L_{50}) estimates had the largest degree of separation between the physiological (cortical alveoli, L_{50} = 1002 ± 7.18 mm CFL) and functional maturity thresholds (primary or secondary vitellogenesis; L_{50} = 1071 ± 4.89 mm CFL), indicating that the physiological maturity threshold should be used with caution as it may underestimate L_{50}. Using the postovulatory follicle (POF) method, the minimum spawning interval was estimated during peak spawning months for all functionally mature females at 2.10 days, with a minimum of 17.30% daily spawning. Batch fecundity estimates for 24 females was linearly related to size and ranged from 37,956 to 6.2 million eggs per batch. These data allow for U.S. GOM reproductive parameter estimates to be incorporated, for the first time, into future Atlantic yellowfin tuna stock assessments done by the International Commission for the Conservation of Atlantic Tunas.

Session: Parameterizing Spatial Assessments

Lessons learned for spatial model development from implementation of a tag-integrated assessment for Alaskan sablefish. By Craig Marsh, Daniel Goethel, Aaron Berger, Katy Echave, Pete Hulson, and Ben Williams

Developing a spatially explicit stock assessment model is complex, requiring identification of primary spatial dynamics and appropriate assumptions. Given the dearth of spatial assessment applications, documenting and disseminating the model development process can be helpful for highlighting lessons learned to aid future spatial applications. The development of a spatially explicit assessment model for Alaskan Sablefish (*Anoplopoma fimbria*), covering the Gulf of Alaska, Bering Sea, and Aleutian Islands regions, provides a unique case study to illustrate how the spatial modeling process can be approached. Alaskan Sablefish represent a highly mobile, data rich population with a dedicated longline survey and over 40 years of tag releases and recaptures. Currently a single, panmictic population is modeled with quotas apportioned to management areas based on area-specific survey biomass. However, significant ontogenetic spatial heterogeneity exists in the population distribution resulting from age-based habitat preferences and migration patterns. We document the development of a spatially explicit assessment model for Alaskan sablefish, including fine-scale data analysis, model decision points, diagnostics, simulation analysis, and final implementation. Although not complete, the model development process provides a first attempt at utilizing good practices (e.g., as outlined by the Center for Advancement of Population Assessment Methodology, CAPAM) for spatial assessments. Similarly, we provide a useful template for transparent and reproducible workflows that can aid in sharing both successes and failures in implementing spatial models, which are rarely documented yet likely to be valuable to assessment practitioners confronted with complex spatiotemporal dynamics.

A management strategy evaluation for transboundary sablefish (*Anoplopoma fimbria*) in the Northeast Pacific. By M. Kapur, M. Haltuch, A. Berger, B. Connors, K. Fenske, D. Goethel, D. Hanselman, L. Rogers, and A. E. Punt

Sablefish (*Anoplopoma fimbria*) of the northeast Pacific support a highly mobile, valuable fishery resource worth over $112 million USD that employs 8% of the harvesting workforce in Alaska alone. Scientific management of sablefish is currently based on three regional assessments (Alaska, British Columbia and the US west coast) by the National Oceanic and Atmospheric Administration (NOAA-US) and the Department of Fisheries and Oceans (DFO – Canada). Recent work has shown sablefish to be genetically mixed across the range, tagging studies have confirmed high movement rates, and there is range wide synchrony in biomass trends, including declines and subsequent stock increases during the last decade. These observations led scientists to consider whether evaluating the stock as a spatially structured population might reveal transboundary dynamics and/or improve management outcomes at the regional scale. We developed a management strategy evaluation (MSE) with the collaboration of stakeholders and scientists from the three regions. This effort synthesized demographic information (growth, maturity, and movement) and held stakeholder workshops to determine management strategies and performance metrics. The MSE consists of an operating model to represent spatial dynamics, delay-difference estimation model(s) to test management strategies involving various spatial stratifications, and harvest control rules (HCRs). We found that the "status quo" management paradigm (three separate areas, blind to movement, individual region-specific HCRs) led to undesirable management outcomes. However, there were several management procedures with only minor model differences from the status quo that avoided these outcomes, including accounting for movement and applying consistent HCRs across management regions. This work serves as an example of stakeholder-informed MSE and illustrates the value of how incremental changes towards spatially structured management procedures can meet biological and economic fishery objectives for this transboundary stock.

Challenges in developing a spatially explicit stock assessment: A case study in applying "SPASAM" to an international spatial stock assessment experiment. By Jonathan J. Deroba and Brian Langseth

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′×5′ 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. While useful for explorations, reducing dimensionality led to poorer diagnostics and model stability, especially under heterogeneity in fleet dynamics. 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.

Effects of spatial heterogeneity of fishing mortality and life history parameters on stock-wide estimates of fishing mortality, yield, and per-recruit calculations. By Dvora Hart

Most stock assessment models are based on the assumption that all individuals of the same age (and/or size) have the same rate of fishing and natural mortality as well as other life history characteristics. In reality, fishing mortality and life history parameters often vary spatially. This talk will present qualitative methods for understanding and estimating the bias that can be induced by spatial heterogeneity on mortality rates, selectivity, yield, and per recruit calculations.

The importance of accounting for spatial growth patterns in statistical catch-at-age models when sources of age data are missing, using Gulf of Alaska rex sole (*Glyptocephalus zachirus*) as an example. By Carey McGilliard

Most stock assessments are single-area models, though research shows that single-area models can lead to biased estimates of reference points when spatial heterogeneity exists in fishing mortality and movement is limited among areas. However, the literature suggests that a large amount of data may be needed to support the estimation of additional parameters in multi-area models. Therefore, single-area models continue to be the norm for species with missing data sources or sparse data. One such case was the Gulf of Alaska (GOA) rex sole assessment, where survey biomass, length, and age data and fishery length data were available, but fishery age data were missing. Historically, this was a statistical catch-at-age model yielding estimates of $F_{40\%} > 1$. The addition of newly aged fishery age data led to a major shift in the estimated fishery selectivity and a much lower $F_{40\%}$ but led to major mismatches in fits to length and age data. An exploration of spatial life history data showed that fish in the Eastern GOA grew to a smaller maximum length than fish in the Western-Central GOA. Two-area models for GOA rex sole, estimating growth separately in each region, with and without the fishery age data led to estimates of reference points similar to those of the single-area model with fishery age data included and largely resolved mismatches in fits to length and age data. These results highlight the importance of accounting for spatial life history and fishing patterns in assessment models when key data sources are missing because conflicts between data sources are missed.

Separation anxiety: Problems that can arise when performing separate assessments for areas that are nested. By Elizabeth N. Brooks

Stock structure discussions often separate scientists into "lumpers" or "splitters," depending on their affinity to aggregate or subdivide. Conclusive data to resolve stock structure is hard to come by, leaving ample room for interpretation and debate. When a species is distributed across international boundaries (or any adjacent jurisdictions such as state versus federal or state versus state), the biological challenges are augmented with political ones. Differences in fleet characteristics, regulatory framework, species valuation, risk tolerance, and scientific capacity can lead to different perspectives of how the stock or stock components should be assessed and managed. In the Northeast United States, three transboundary stocks on Georges Bank are jointly managed by the U.S. and Canada: cod (*Gadus morhua*), haddock (*Melanogrammus aegelfinus*), and yellowtail flounder (*Limanda ferruginea*). For haddock and cod, two different stock areas (one nested within the other) are assessed and used for management advice: i) a transboundary stock unit restricted to the NE corner of Georges Bank; and ii) a domestic stock unit that covers all of Georges Bank. Assessment methods and assumptions were initially the same for both the domestic and transboundary stock areas, but as retrospective patterns emerged and new benchmarks were conducted, divergence in model methodology and assumptions led to divergence in abundance estimates, reference points, and catch advice. In this talk, I will focus on haddock and trace the evolution of these divergences and the associated anxiety from the lack of alignment between the two assessment frameworks. The resolution to divergent separate assessments will not be achieved with an exhaustive spatial modeling exercise. Aligning management objectives that satisfy the sustainability and economic mandates of both countries is a necessary step and should precede the costly investment of spatial modeling.

Visualizing spatial assessment models. By Jon Brodziak

Stock assessment models are an important part of the fishery management process, helping to inform decision-makers on current stock status and probable future outcomes. Understanding the structure of models is important for building a credible assessment and optimizing parameters. Every assessment analyst knows the importance of visualizing model diagnostics, results, and associated uncertainty metrics for conveying conservation information effectively. Visualizing assessment model structure can improve the flow of information. In this paper, we show how graphs and hypergraphs can provide a concise, intuitive, and natural way to characterize model structure. This is particularly true for spatially structured models which have higher dimensionality than single-area models and is also true for ensemble models. Hypergraphs are particularly appropriate for showing the polyadic structural features of spatial assessment models. In this case, hyperedges represent areas, while nodes represent entities, such as population attributes or fishing fleets. We provide several examples of visualizing spatial assessment models and submit that augmenting assessment information with graph-based representations of model structure is worth the time cost.

Poster Session

Updating the standardized terminology for reproductive development. By Susan K. Lowerre-Barbieri, Nancy J. Brown-Peterson, David M. Wyanski, Heather Moncrief-Cox, Kevin Kolmos, Hayden Menendez, Beverly Barnett, and Claudia Friess

The Brown-Peterson et al. publication[4] helped to standardize reproductive development terminology for fishes over the past 12 years. Here, we address improvements to the terminology to help integrate reproductive data into stock assessments. We propose a new early developing phase to allow identification of gonadal recrudescence and entry into the spawning season, defined by the appearance of cortical alveolar oocytes or primary spermatocytes. The former developing phase will now be known as late developing and in females includes the presence of any stage of vitellogenic oocyte but no postovulatory follicles (POF). The late developing phase in males includes all stages of spermatogenesis but no spermatozoa in the lumens of lobules. The spawning-capable phase has been replaced with a new spawning phase that has several subphases which allow temporal definition of spawning. For females, these subphases are imminent (oocytes undergoing early oocyte maturation), active (late oocyte maturation, hydration), and recent (presence of POF). For males, subphases are based on the appearance of the germinal epithelium (GE): early GE (active spermatogenesis, continuous GE at terminal end of all lobules) and late GE (reduced spermatogenesis, discontinuous GE at terminal end of some lobules, anastomosing lobules). The definitions of regressing and regenerating phases are unchanged. The sex transition phase for hermaphroditic species has two subphases, early and late transition. This presentation will provide photomicrographs of each phase for two commonly used histological methodologies: paraffin blocks stained with hematoxylin and eosin (H&E) and plastic blocks stained with Periodic Acid Schiff's reagent (PAS).

Gulf of Mexico red snapper research track lessons learned so far. By LaTreese S. Denson, Matthew Smith, and Katie Siegfried

Red snapper (*Lutjanus campechanus*) are a highly sought after species in the Gulf of Mexico (GOM), in both the commercial and recreational sectors. Red snapper are managed by the GOM Fisheries Management Council and have been assessed by the Southeast Fisheries Science Center (SEFSC) for almost 40 years. In 2018, the SEFSC began the implementation of the Research Track Assessment structure to create a robust analytical tool (e.g., an assessment model) for species with no previous assessment or those for which new data sources and/or modeling procedures are available. The first research track completed by the SEFSC was for Gulf of Mexico Scamp (Southeast Data Assessment and Review - SEDAR 68), which had never been assessed before. With some setbacks due to COVID-19, the research track began in June 2019 and ended in August 2022. The Red snapper research track began in 2020 with the data workshop taking place in May of 2022. The assessment team had its first assessment webinar in September 2022 and its fifth assessment webinar in February 2023. Although a base assessment

[4] Brown-Peterson, N.J., D. M. Wyanski, F. Saborido-Rey, B.J. Macewicz, and S.K. Lowerre-Barbieri. 2011. A Standard Terminology for Describing Reproductive Development in Fishes. Marine and Coastal Fisheries 3(1): 52-70. https://doi.org/10.1080/19425120.2011.555724

model is still in development, the red snapper research track assessment team has learned considerable lessons during the process that may benefit research track processes of the future, particularly those with such a complex and controversial management history as red snapper. Lessons learned so far include setting realistic expectations for stakeholders by discussing specific aspects of the tool that can be updated in a reasonable period, early on in the process. Without reasonable expectations, it is impossible to balance the wants and needs of stakeholders, the inclusion of the best available science through research, and the resources available at the SEFSC (i.e., person hours and computational time). Using our experiences with the red snapper research track, the assessment team aims to discuss issues that have arisen during the process and provide words of caution for future research tracks.

Does climate-integrated stock assessment improve management? An American plaice example. By Amanda R. Hart, Lisa Kerr, and Timothy J. Miller

Climate impacts on marine species are widely acknowledged, but they are rarely incorporated directly into management advice. Climate-integrated stock assessment models provide a pathway to link spatiotemporal ecosystem drivers with population dynamics. However, the proposed benefits of this approach have not always been realized. We used the Woods Hole Assessment Model (WHAM) to develop assessment models with and without environmental covariates influencing aspects of stock dynamics, and we tested their performance using Management Strategy Evaluation. American plaice were used as a case study because they have known changes in productivity and a demonstrated shift in distribution in response to ocean warming that are not explicitly accounted for in the current stock assessment. The strength of environmental drivers on recruitment and catchability were varied across simulations to identify possible thresholds for environmental change, past which climate-integrated assessment models are more likely to result in differential management advice. Our results explore methods to incorporate physical–biological links in single-species stock assessments and explore the long-term consequences for management under climate change.

Exploration of variations in length-at-age to inform the stock structure of Pacific sardine (*Sardinops sagax*) off the U.S. West Coast. By Kelsey James and Brad Erisman

Pacific sardine (*Sardinops sagax*) is an economically important forage fish in the eastern North Pacific. Three stocks that seasonally migrate have been suggested by several historical studies based on multiple criteria (e.g., tagging data, blood groups, vertebral counts, isolated spawning centers, and growth rates). The delineation of these stocks for U.S. fisheries management has recently received renewed attention. Regional length-at-age is included as a criterion to separate stocks based on one study's observed bimodality in length compositions of certain year classes and differences in maximum predicted length (L_{inf}) from measurements of growth increments of scales. High variability of length-at-age within regions was one source of uncertainty of the historical study. Due to the renewed discussion of Pacific sardine stock structure, we seek to revisit whether length-at-age is a viable criterion to inform stock structure. We will use Pacific sardine otoliths from the California Current Ecosystem Survey from 2004–2021 to examine temporal and geographic differences in length-at-age. The dataset includes over 9000 otoliths representing the full size and age range of Pacific sardine from Spring and Summer surveys that extend from Canada to Mexico. The temporal and geographic range of this dataset is large. Therefore, time (year and season), survey extent, and environmental factors must be accounted for when examining variability in length-at-age. Following other studies with similar goals, we propose using the first derivative of the spatial smoothing term of a generalized additive model to detect potential spatial structure in length-at-age within and among Pacific Sardine stocks.

Evidence of density-dependent, time-varying processes in Pacific sardine stock assessments. By Peter Kuriyama, Kevin Piner, Hui-Hua Lee, Kevin Hill, Paul Crone, Steve L. H. Teo, and Juan Zwolinski

The factors that drive Pacific sardine (*Sardinops sagax*) dynamics are not well understood. Sardines have large population fluctuations and likely have a number of time-varying biological processes, such as movement and growth. These factors pose challenges to both stock assessments and studies that infer environmental relationships from stock assessment output. Here, we develop a stock assessment approach that synthesizes all data previously used in assessments to first estimate growth and its temporal variation and second relate the output to environmental time series. The first goal is to evaluate the degree of biological complexity supported by the data. The most complex assessment configuration estimates time-varying age-based selectivity (as a proxy for sardine movement) and a form of time-varying growth (either cohort-specific or annually varying). The simplest assessment configuration has constant selectivity and time-invariant growth. The second goal is to relate the output from the best fitting model to environmental time series (such as sea surface temperature and Pacific Decadal Oscillation) that have been hypothesized to drive sardine dynamics. The model with time-varying age-based selectivity and cohort-specific growth best fit the data. Cohort growth deviations seemed to be density-dependent, as they were significantly negatively correlated with age 1+ biomass. Recruitment success, from the best fit model, was significantly positively correlated with combined summer and spring PDO ($r = 0.76$) and annual sea surface temperature ($r = 0.45$), among other covariates. While this is a statistical rather than mechanistic relationship, the results can inform the configurations and inclusion of environmental effects in future stock assessments.

A histological investigation of size at maturity for white seabass (*Atractoscion nobilis*). By Miranda Haggerty, Kristine Lesyna, Scott Aalbers, and Chuck Valle

White Seabass (*Atractoscion nobilis*) are a popular target of sport and commercial fisheries throughout much of California, with the majority of catch occurring off southern California. They are the largest sciaenid or croaker species found in the state and range from Magdalena Bay, Mexico to as far north as Juneau, Alaska during warm water events. White Seabass are multiple batch spawners, with an extended spawning season from March to September that peaks in May and June. The current minimum size limit of 28 inches is based on the macroscopic maturity of just 33 southern California females from 1930, necessitating a current maturity to be reassessed histologically from a larger sample size while incorporating considerations for spatial variability. White seabass gonad samples from 139 females, ranging in size from 23–54 inches (584–1371 mm) total length were collected during the 2017–2022 spawning seasons across southern California for comparison against 253 samples collected from the San Francisco Bay area. A combination of macroscopic and histological criteria were used to assign females to one of six reproductive phases: immature, developing, spawning capable, actively spawning, spent, and resting. Using these phases, length at maturity curves were developed for physiological, functional, and spawning maturity. Preliminary results suggest that white seabass functionally mature at a larger length than previously indicated, which may have implications toward the improved management of this valuable marine resource.

Evaluating offshore wind impacts to the Northeast bottom trawl survey using a spatiotemporal generalized linear mixed model. By Angelia Miller, Gavin Fay, Catalina Roman, Philip Politis, Andrew Lipsky, Catherine Foley, and Kathryn Ford

Offshore wind energy development is occurring throughout the northeast large marine ecosystem and will interact with the National Marine Fisheries Service (NMFS) Northeast Fisheries Science Center's (NEFSC) multispecies bottom trawl survey, which has been conducted biannually, every fall and spring, along the United States' northeast continental shelf since 1963 and 1968 for the fall and spring survey, respectively. It is expected that offshore wind energy development will impose four types of impacts on survey operations and downstream data products such as stock abundance indices (Hare et al.[5]). Here, we consider the preclusion of trawling effort within the wind areas, one of the four identified impacts, and how resulting changes in stock abundance indices will directly affect fisheries management advice. We present a methodology to calculate and compare indices of abundance for summer flounder (*Paralichthys dentatus*) with and without wind preclusion. Using available survey data, we fit and test the predictive performance of a spatiotemporal generalized linear mixed effect model (GLMM) for summer flounder distribution. We then simulate data for survey catches that differed in terms of whether tows were precluded by wind energy areas or not, calculate an index of abundance, and compare them to indices calculated from historical data, with and without wind area preclusion. Preliminary results suggest annual estimates of relative abundance with wind preclusion and survey effort reduction are lower than those calculated without preclusion, suggesting that proposed and impending wind development areas have higher mean catch rates. Future applications of this model include examining changes to survey catches associated with wind preclusion.

Imaging of histologically prepared gonad sections for maturity assessment and preservation. By Heather E. Moncrief-Cox and Robert J. Allman

Microscopic reproductive phase assignment for maturity determination in teleosts requires review of the entire histologically prepared gonad section, typically a costly and time-intensive process. The preservation of archived histology slides is a priority due to the risk of stain degradation and slide breakage over time. Digital imaging of slides is a way to create a backup of archived slides, in addition to providing the ability to annotate areas of interest for reference and to share images with collaborators. However, a major limitation has been the ability to obtain representative images with a wide field of view containing the entire section and sufficient magnification, which can result in multiple images needed of each slide.

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[5] Hare, J. A., B. J. Blythe, K. H. Ford, B. R. Hooker, B. R. Jensen, A. Lipsky, C. Nachman, L. Pfeiffer, M. Rasser, and K. Renshaw. 2022. NOAA Fisheries and BOEM federal survey mitigation implementation strategy—Northeast U.S. region. NOAA, NMFS, Silver Spring, MD.

Gulf of Mexico Red Snapper, *Lutjanus campechanus*, biological samples have been collected by the NOAA Fisheries Southeast Fisheries Science Center, Panama City laboratory for over 30 years, resulting in an archive of over 9,500 reproductive tissue histology slides. As a means to preserve this archive and as a rapid method to assign maturity stage to older tissue samples using digital images based on Brown-Peterson et al. (2011), a Motic EasyScan One slide scanner was purchased, which is capable of whole-slide imaging at high resolution and magnification. We present here the methods developed for implementation of this project, including software set-up, file naming and storage structure, and review process.

Variation in reproductive characteristics of red snapper (*Lutjanus campechanus*) in the northcentral Gulf of Mexico. By Laia Juliana Munoz and Sean P. Powers

The Red snapper *Lutjanus campechanus* is an inhabitant of the rocky and muddy environments with an important role in reef areas. Due to intense fishing pressure, the species is considered vulnerable to overfishing and hence is a species that is almost continually assessed in the Gulf of Mexico and South Atlantic. A routine recommendation from stock assessment is the need for updated reproductive parameters. Given the increased focus on more regional, state focused management, greater spatial resolution in these parameters will be needed. In an effort to provide this information for the northcentral Gulf of Mexico, we have begun a multi-year study to update the reproductive status (sexual maturity size, spawning season, and reproductive status by age cohorts) of red snapper in the Gulf of Mexico using histological information. Specimens have been collected from fisheries-dependent sources (fishing tournaments) as well as fisheries-independent surveys. Comparisons between Red Snapper occupying artificial reefs and natural hard bottom will be conducted among depth strata. Additionally, we will estimate fecundity and age as well as fecundity with length and weight relationships. The information collected will assist scientists in investigating how reproductive parameters vary as a function of age and habitat. Comparisons with previous studies will allow us to evaluate the temporal and spatial patterns of variability in these important metrics.

Evaluation of histology stains to determine gonadal cellular characteristics related to maturity and spawning. By Yvonna Press, Mark J. Wuenschel, Emilee Tholke, and Richard S. McBride

Gonad histology offers a microscopic window into the reproductive dynamics of fish and provides a more detailed look into the reproductive behaviors and traits of fish by revealing cellular characteristics before, during, and after the spawning period. Since 2010, we have used Schiff's Mallory Trichrome (SMT) stain, which highlights post ovulatory follicles (POF), a critical character in determining recent/prior spawning of individuals. At the time, the cost of this stain was only marginally (25%) more expensive than the standard hematoxylin and eosin (H&E) stain. Recent substantial increases in cost compelled us to explore more cost effective stains for our routine sampling. We compared the appearance of several traits using four different stains (H&E, Toluidine Blue, Periodic acid Schiff [PAS], and SMT) for three Atlantic fishery species (yellowtail flounder, haddock, and Atlantic herring). We selected 10 individuals from each species that had key cellular characteristics (e.g., POFs, atresia, early oogenesis). In addition, we include archived slides of round scad stained with H&E, PAS plus Metanil Yellow (PAS/MY), and Thionin. Each slide was scanned using the Grundium Ocus and analyzed using the Aperio Image Scope software. A standardized datasheet was developed to record the presence of histological features and confidence in their interpretation (e.g., High, Med, Low), as well as annotated images of each sample. Both qualitative and quantitative metrics are compiled and summarized across all readers. Preliminary results outline how an optimal staining approach depends on the species and purpose of the investigation.

Unexpected observations of rodlet cells in the gonads of Greenland halibut (*Reinhardtius hippoglossoides*) help solve a century-old mystery. By S. A. Smith, R. M. Rideout, Y. Wang, P. R. Arun, F. Aylward, R. Jensen, J. C. Wolf, and D. D. Kuhn

Rodlet cells are found only in teleost fish. The unique occurrence of these cells has been known for over 100 years, and though there has been much speculation during this time about their origin and function, there is no definitive confirmation of their true nature. They are most commonly found in low numbers in epithelial layers of the digestive tract, gills, or other organs that have some level of exposure to the external environment. However, their occurrence in a particular species or tissue has generally not been predictable. The surprising discovery of extremely dense aggregations of rodlet cells in the gonads of Greenland halibut during routine reproductive studies provided a unique opportunity to resolve the true origin and function of rodlet cells. In particular, dense aggregations of rodlet cells were noted to be present in nearly 100% of immature testes in this species. Therefore, in order to isolate and sequence rodlet cells, 12 immature Greenland halibut were collected during research vessel surveys by Fisheries and Oceans Canada. Testes were removed by gross dissection and rapidly frozen at sea on dry ice. Frozen sections were used to identify tissues with large aggregates of rodlet cells, which were subsequently used for laser capture microscopy and RNA isolation. RNA sequence data provide irrefutable evidence that rodlet cells are endemic in origin and provide novel insight into the role of these cells in teleost fish.

Estimating population abundance at a site in the open ocean. By Kyle W. Shertzer, Nathan M. Bacheler, William E. Pine III, Brendan J. Runde, Jeffrey A. Buckel, Paul J. Rudershausen, Robin T. Cheshire, and Jamie H. MacMahan

For populations in open systems, abundance estimates from tagging data can be highly uncertain or biased as a result of unaccounted movement. In this study, we developed a novel approach to estimate the abundance of an open population by pairing two models, each utilizing distinct types of tagging data. Using data from telemetry tags, we infer movement rates to and from the study site with a Markovian transition model allowing for an environmental effect. Then, using data from conventional passive tags, we apply a Lincoln-Petersen abundance estimator modified to account for mortality and movement. The model was implemented within a Bayesian framework to data on gray triggerfish (*Balistes capriscus*) tagged in the Atlantic Ocean off North Carolina, USA. For this open population, we estimated site abundance to be approximately 1000 fish (~2000 fish km^{-2}) and additionally found evidence for an effect of hurricanes on movement. The general approach may be useful for fisheries, wildlife, and other ecological studies utilizing multiple tag types, particularly for estimating the site abundance of an open population.

Utilizing a focalized hydro-stream to separate oocytes for fecundity estimates in *Balistes capriscus*. By Wiley Sinkus, Kevin Kolmos, and David Wyanski

Fecundity is an important reproductive parameter in determining the reproductive potential in fisheries stock assessments. Knowing how many eggs are produced by the spawning stock biomass allows managers to better estimate the number of new recruits to the fishery. The traditional process for assessing fecundity involves taking a subsample of gonad tissue from a gonad of known weight, separating oocytes of a specific diameter from all other oocytes/connective tissue using forceps, counting the oocytes manually, and extrapolating out to the weight of the whole gonad. This process is tedious and time consuming, especially for a demersal egg laying species like *Balistes capriscus*, which produce smaller diameter mature oocytes unlike larger hydrated oocytes found in broadcast spawning reef fish. Our lab modified a technique developed by Erik Lang and Christopher Levron at the Louisiana Department of Wildlife and Fisheries, where a fan-shaped stream of water was passed over the sample in a sieve. Using this method, paired with microscopic image analysis software, we were able to greatly reduce the time required to prepare and count fecundity samples from *B. capriscus*, reducing work time by 75%. We plan to develop this technique for various sized oocytes and apply the technique to a range of managed fish species in our region.

Life history assessment of cusk (*Brosme brosme*), a data-poor species, in U.S. waters. By McElroy, W. David, Emilee K. Tholke, Mark J. Wuenschel, and Eric Robillard

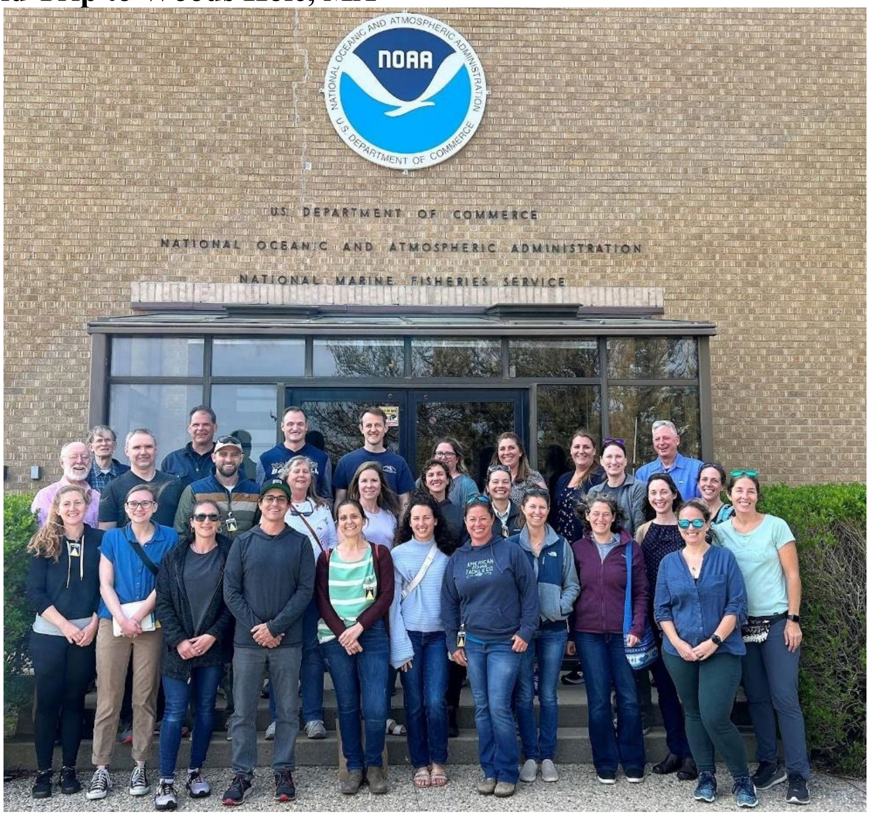
Cusk, *Brosme brosme*, are fished across the northern Atlantic Ocean, but even basic biological data is limited in part by the deep and difficult to sample structured habitats they prefer. We sampled fish from a variety of sources across the Gulf of Maine to provide comprehensive life history information (age and size at maturity, fecundity, sex ratio, growth) for this data-poor species considered by NOAA Fisheries as a species of concern. Gonad histology and %GSI data indicated peak spawning in late spring (May-June) with limited spawning activity into summer. The histologically derived L_{50} for female maturity was 39.5 cm TL. Fecundity varied from 0.25 to 4 million oocytes, with a positive allometry versus size indicating larger females have proportionally higher fecundity than smaller females. Male cusk had unusually low gonadal investment for a gadiform, and males of all sizes examined (down to 21 cm) had spermatozoa present. Male maturity was equivocal even when the relative proportions of sperm stages was quantified through image analysis of gonad histology; further anatomical and physiological study of small males is required to assess functional maturity in male cusk. The sex ratio at length indicated more males at larger sizes, and males had faster growth and larger size-at-age than females. Condition patterns also suggested lower condition for females than males after spawning, and generally less variable condition for males. Gonadal investment, relative condition, and growth patterns all suggest differences in energy allocation between the sexes. This data-poor species has an uncertain stock status in US waters, therefore the results of the current work provides critical information to its management.

A simple procedure for examining the influence of sample distribution on growth parameter estimation. By Derek G. Bolser, Arnaud Grüss, Mark A. Lopez, Erin M. Reed, Ismael Mascareñas-Osorio, and Brad E. Erisman

Effort to collect samples from scarce size and age classes comes at the cost of other sampling needs, so understanding the impact of additional samples on derived quantities is critical for resource prioritization. Here, we present a simple procedure for understanding the influence of unbalanced sample distribution: adding simulated observations to a raw dataset such that the number of samples at age is equal and comparing derived quantities from the raw dataset with those from the dataset bolstered by simulated observations. We conducted a case study with Gulf Corvina (*Cynoscion othonopterus*) to illustrate this procedure. Several growth models were fit to length-at-age data, then spawning-stock-biomass-per-recruit (SSBPR) and yield-per-recruit (YPR) models were fit to understand if differences in growth parameters influenced fishery assessments. The flexible Schnute-Richards (SR) model displayed the most pronounced differences, as it described a biphasic growth pattern when fit to the raw dataset and an asymptotic growth pattern when fit to the dataset bolstered by simulated observations. The commonly used von Bertalanffy growth model (VBGM) exhibited an 11% difference in k and a 4% difference in L_∞ when the two datasets were compared. These differences had a small impact on per-recruit quantities (1% Δ YPR/YPR_{max}, 1% Δ SSBPR/$SSBPR_{natural}$). Differences in SR parameters had a larger impact (9% Δ YPR/YPR_{max}, 13% Δ SSBPR/$SSBPR_{natural}$). Given the effect sizes we estimated, we suggest this procedure as a sensitivity analysis in comparative growth studies (e.g., examining regional differences or temporal changes in growth) as sample distribution may differ between datasets.

Appendix G: Group Photos

MARVLS Field Trip to Woods Hole, MA



MARVLS participants visited the NMFS-NEFSC Woods Hole Lab on 11 May 2023. Back row (l-r): D. Wyanski (SC-DNR), J. O'Malley (PIFSC), K. Kolmos (SC-DNR), C. Jones (IPHC), C. Conrath (AFSC), Y. Press (NEFSC [IBSS]), K. James (SWFSC), and M. Wuenschel (NEFSC). Next row: R. McBride (NEFSC), R. Rideout (DFO), W. Sinkus (SC-DNR), N. Brown-Peterson, E. Tholke (NEFSC [IBSS]), C. Rosemond (OSU), L. Munoz Abril (DISL), M. Passerotti (NEFSC), and L. Lefebvre (WHOI). Front row: K. Lesyna (DCFW), H. Conrad (VT), A. Pacicco (SEFSC [CIMAS]), B. Erisman (SWFSC), R. Dominguez-Petit (IEO-CSIC [Spain]), C. Wells (SC-DNR), M. Taliercio (SC-DNR), E. Reed (PIFSC), C. Rodgeveller (AFSC), S. Beyer (UW), H. Moncrief-Cox (SEFSC [CIMAS]), and E. Schemmel (PIFSC). Not pictured: N. Klibansky (SEFSC), B. Linton (NEFSC), S. McDermott (AFSC), S. Neidetcher (AFSC), and E. Slesinger (AFSC-OSU).

NSAW Group Picture