Science Advisory Board

IMPROVING FISH STOCK ASSESSMENTS

A REPORT ON EMERGING STOCK ASSESSMENT TECHNOLOGIES

WITH THE ASSISTANCE OF THE SAB ECOSYSTEM SCIENCES AND MANAGEMENT WORKING GROUP

DECEMBER 17, 2019

Members of the Ecosystem Sciences and Management Working Group

Michael Castellini, Ph.D
University of Alaska Fairbanks

Robert J. Johnston, Ph.D
Clark University

Erik Chapman, Ph.D
University of New Hampshire Sea Grant

James H. Cowan, Jr., Ph.D
Louisiana State University

Selina Heppell, Ph.D
Oregon State University

Molly McCammon
Alaska Ocean Observing System

Jan Newton, Ph.D
University of Washington

Paul Edward Parnell, Ph.D
Scripps Institution of Oceanography
University of California, San Diego

Kenneth A. Rose, Ph.D
University of Maryland Center for Environmental Science

Robert Twilley, PhD
Louisiana State University and Louisiana Sea Grant

Lisa A. Wainger, Ph.D
University of Maryland Center for Environmental Science

NOAA Science Advisory Board Staff

Cynthia J. Decker, Ph.D

Caren Madsen

Introduction

Scope and background of this report

As a component of the current Two Year SAB Work Plan, in late 2018 the SAB asked the ESMWG to produce a report on Work Plan Topic 9:

> *Evaluate fisheries monitoring technologies to improve stock assessments. This evaluation should consider how to optimally balance electronic monitoring, eDNA, and other technologies…*

This task was a response to a request by NOAA to the SAB to consider technologies to increase the efficiency and accuracy of stock assessments, the potential saving of ship and personnel time in stock assessment cruises, and to explore the potential roles of future methods that are under development. During a subsequent presentation on this topic to the ESMWG, NOAA suggested that this review focus on a small set of illustrative examples of these emerging technologies, rather than a comprehensive review. The illustrative technologies proposed by NOAA were new methods for aging fish, remote observation systems using unmanned systems, and molecular (‘omics) tools. These technologies are of considerable interest to NOAA and are under active development for application to stock assessments. We emphasize that these are not the only new technologies that are potentially relevant to stock assessments within NOAA—they were chosen for emphasis in this report to illustrate the potential and issues of a much broader range of new technologies. The general themes and observations described in this report for these three illustrative technologies apply to other methods at similar levels of readiness.

As background to this ESMWG report, NOAA released a Stock Assessment Improvement Plan (SAIP) in 2018. This document emphasized that “[t]o provide the best information possible and meet the demands for increased quality and quantity of stock assessments, we must continually improve stock assessments with new developments in science and technology.” While the SAIP described many overall activities and actions taken by the Agency to meet those goals, SAB Topic 9 focused primarily on the three different tools used in this report.

This ESMWG effort also builds on another recent report of the working group. In 2016, the ESMWG produced a report on the broader issue of new technologies that could be utilized by NOAA across many different areas of research and monitoring (ESMWG, 2016). While that report covered remote systems and some molecular methods, this current report addresses more specific issues related to new technologies for fisheries stock assessment, as detailed in SAB Work Plan Topic 9.

To produce this report, the ESMWG Committee and co-chairs met with NOAA topic experts, liaisons, scientific advisors and NOAA officials via in-person meetings and multiple phone calls through late 2018 and all of 2019. In addition, ESMWG members reviewed documents related to the three case study technologies, NOAA stock assessments, and other relevant documents (e.g., documents describing general new technology readiness levels as classified by NOAA). Updates on the development of the committee work were provided by the ESMWG co-chairs to the SAB at their regular meetings in spring and summer of 2019. The draft report was revised during the fall ESMWG committee meeting in October. The draft version of the report was edited, updated and prepared for submission during October-December, 2019 to be delivered to the SAB at its December 2019 meeting.

Based on this review, the three case study technologies

- fish aging,
- remote systems, and
- molecular tools

were categorized by the ESMWG into stages of readiness using NOAA's Technology Readiness Levels (TRL) (Appendix). These levels range from 1 (experimental) to 9 (fully deployed). The ESMWG grouped these TRLs into three more general categories of readiness—near (TRL 7-8), medium (TRL 5-6) and long-term (TRL 2-3). Using these more general TRL categories, the three technologies were classified as follows:

A. **NEAR** to field deployment and in final testing stages: The example technology of new fish aging methods was placed into this category (TRL 7-8).

Near Infrared Spectroscopy (NIRS) advances in automated otolith analyses hold promise for more accurate, faster and higher efficiency aging of fish and this technology is close to being ready for deployment. Otoliths are small calcareous bodies in the ears of fish that are used to age fish by examining layers in their structure. Typically, otolith "reading" is conducted manually by technicians counting rings on prepared otolith sections through a microscope, a time-consuming process that includes substantial measurement error for some species. Initial tests showed the NIRS techniques were promising, and methods are presently being deployed in diverse settings in order to compare results to standard methods (visual counting of otolith rings).

B. **MEDIUM** range technologies that are out of the basic research phase and beginning field testing: The example technology of remote unmanned systems (UxS) was placed into this category (TRL 5-6).

Surface drones, in-water drones and similar remote observation technologies are being field tested for their ability to detect fish and categorize the detections (counts) by species, size and other attributes. Environmental and water conditions, such as temperature and salinity, are also recorded and can provide information on habitat. These technologies use approaches such as sonar to locate and identify fish but cannot capture fish for independent species confirmation and for further analyses. While remote systems are already highly developed and deployed for environmental sensing, their use in stock assessment is at an earlier stage of development. NOAA is currently evaluating these technologies using various approaches, including test cruises and comparing remotely sensed data to trawl data.

C. At basic research level and considered **LONG-TERM** possibilities: The example technology of molecular tools were reviewed in this category (TRL 2-3).

Environmental DNA sensing (eDNA) and other molecular methods that could be used for stock assessment and fish identification are at a beginning stage of research. The field of genetic identification is expanding rapidly through medical research, and has considerable promise; but the application to fisheries fieldwork is less well developed. Although the technology is progressing rapidly, many years of testing and development will be required before these methods can be used to support stock assessments or other quantitative analyses.

Major Findings:

All of the technologies reviewed by the ESMWG have tremendous potential for enhancing current stock assessment methods. Some are more applicable to particular fisheries than others, but the potential for new directions and strategic utilization is high. Investment in research and development of these technologies offers the potential for high returns to NOAA over the medium- to long-term.

At the same time, the ESMWG's review indicated that these tools should be considered *synergistic with ongoing stock assessment methods and processes,* and cannot serve as stand-alone replacements or provide immediate solutions to time, effort, funding and ship-use constraints. That is, they can provide added value to current stock-assessment processes and could increase confidence in findings and models. For example, the molecular tools may add information about population responses to environmental and water conditions (habitat) and the drone detections might be used to evaluate fish presence and diversity in shallow waters or over sensitive habitats where trawling and other standard methods are not possible. However, the data created by some of these new techniques produce information that is substantially different from current data inputs to stock assessment and may have distinct biases that will need to be evaluated before they can be used.

As a result of different data properties, these and any other new methods will require dedicated studies comparing their results to NOAA's current best practices to ensure a high degree of integrity, reliability and credibility in stock assessments for fisheries management. As with any new data, sources of potential bias and error need to be fully evaluated. All new methods will require investment in personnel training and Quality Assurance/Quality Control (QA/QC) testing. The otolith method is a laboratory tool that provides a significant increase in QA/QC and efficiency for aging fish. In addition to the need for training and QA/QC, questions must be answered concerning how time series data on population trends and associated stock assessment modeling should be adapted to accommodate the data streams from these new technologies as they become available. These are not trivial tasks, and require dedicated analyst time to move a new technology up the TRL scale.

As new technologies come online, there may be a potential for efficiencies and cost savings in some areas. For example, the use of NIRS may soon allow much more rapid processing of otoliths for fish aging. However, cost savings from replacing NOAA research vessel time with remote sensing or molecular techniques appear unlikely in the near or intermediate term. These techniques can expand the options, efficiency and accuracy of some existing NOAA research tools and may eventually enable new questions to be addressed. As such, these new methods may hold their greatest promise in ecosystem level, multi-species stock assessments rather than as informing single-species methods. They would be particularly impactful for data-poor fisheries and highly relevant to fish species that are currently difficult to monitor using standard field sampling methods.

The technologies covered in this report require specialized personnel training to maximize their use. The move of new technologies into operations mode requires planning for new personnel to coincide with the technical testing schedules, so that personnel are ready to work with these methods as they are deployed. For example, utilizing and interpreting molecular methods requires biomedical, biochemical and statistical training. The use of remote sensing systems requires oceanography, engineering and quantitative analysis training. If NOAA staff are to meet these needs, then professional development, training and hiring will be required. In addition, wide scale adoption of any new technology will require associated institutional changes necessary for acceptance and implementation of data and ongoing research and development of tools to stay current. Any new data need to be available on a timely basis to be effectively used in stock assessments for informing management.

Finally, we emphasize that results from the application of these methods will likely provide information that goes beyond stock assessment and into areas of environmental assessment, ecosystem-based fisheries management, natural history and core biological information about the target species (e.g., Stat et al. 2017). For example, detailed chemical analyses of otoliths can provide information on the location of the fish at a certain age, contaminant exposure and health (Izzo et al., 2018) in addition to age. As a result, these technologies may provide information that benefits other areas of NOAA's missions.

Recommendations:

Based on these major findings focused on the three illustrative examples, the ESMWG provides the following general recommendations.

A. Although new technologies may lead to efficiencies in the medium to long-term time frames, they should not be viewed primarily as cost-saving approaches, but rather as a means to improve stock assessments and ecological monitoring moving forward. The investments required to advance and use these techniques are substantial and their application does not appear likely to result in major cost savings in the short term.

B. Before using the data from new technologies in stock assessments, NOAA will need to examine whether and how the new technologies can be linked to current stock assessment models and supporting analyses, and to what degree any new techniques enhance the stock assessments and increase the efficiency and timeliness of their preparation. For example, can these technologies enable more accurate, more rapid, more cost-effective or fundamentally different ways of assessing fishery stocks? These evaluations should consider both improvements to current, single-species stock assessments, as well as potential benefits to multi-species stock assessments, data-poor fisheries, and broader ecosystem-based fisheries management.

C. New technologies can be advanced by holding workshops with diverse experts to develop ideas for how to apply these new technologies to stock assessment. It is likely that some adjustments with the technologies and stock assessment analyses will be needed to ensure effective use of the new data. Further, the workshops could explore how these methods may provide innovative insights to benefit NOAA's fishery management and overall science mission.

D. Side-by-side dedicated comparisons between new technologies and ongoing stock assessment analyses will be needed to advance these new techniques. These comparisons will need to consider NOAA activities on-shore and at-sea. To account for environmental variability, multiple years of comparative field work and associated exploratory analyses will be required to successfully add the information generated by these new technologies to current assessment methods, while ensuring there is no disruption of the integrity, reliability and credibility of the stock assessments.

E. NOAA will need to invest in laboratory and field testing of these methods, as appropriate for the Agency's potential (present and future) applications. While basic development of molecular tools to identify DNA is mostly supported through the medical fields, studies on the application of these tools to stock assessment require NOAA support. NOAA should consider Public-Private-Partnerships (P3) to develop support for these methods in areas where the agency does not have primary responsibility or does not have sufficient in-house resources.

F. NOAA should explore the potential for workforce development, cooperative institutes, postdoctoral programs and training classes to provide current and prospective NOAA scientists training for these methods. Efforts such as these are necessary to build a future workforce with expertise in these new technologies.

G. New technologies will generate large amounts of data that will need to be organized, analyzed and interpreted. NOAA should consider how artificial intelligence, cloud computing and other approaches can be applied to process the large volumes of data that will be generated. NOAA will also need to consider provisions for (and implications of) data ownership and access, particularly when new technologies are implemented by public-private partnerships or are processed (or stored) on the cloud

Detailed background on individual technologies

The above findings and recommendations were summarized from more granular information gathered on each of the three illustrative technologies considered by the ESMWG. This information was collected from NOAA subject experts for each field (otolith analysis, UxS systems, and molecular methods). The experts were asked to present the committee with background information on each method, and its strengths and weaknesses, its TRL, and how the technology could be applied to stock assessment questions. The ESMWG also asked each expert to report on what near, medium and far term research on each technology was taking place, and how this was potentially relevant to stock assessment applications. The resulting information was supplemented by input from NOAA documents and the scientific literature on each method. The following sections summarize the conclusions drawn from this data gathering process.

Near Term TRL 7-8: Modern methods in fish aging through otolith analysis.

NOAA technical presentation: Dr. Tom Helser (NOAA, AFSC)

A fundamental aspect of age-structured stock assessment is aging the fish that are captured during stock-assessment cruises. This is regularly carried out through the laboratory analyses of the otoliths that are removed from the fish. Otoliths are small, calcareous bodies in the ears of fish that are created in layers through time. The layers appear as rings in the otolith when sectioned and examined using microscopy. Using essentially the same methods as in aging tree rings, NOAA technicians prepare an otolith by slicing it and counting the rings. This is carried out in duplicate by two different technicians to correct for individual variation in counting results. A highly skilled technician can count 30 preparations a day. NOAA has a backlog of thousands of otoliths waiting to be counted and an individual cruise can add hundreds more.

The calcareous layers in the otoliths are separated by an organic matrix of proteins. In the new method, Near Infrared Spectroscopy (NIRS) energizes the organic layers with infrared energy and then analyzes the ensuing vibrations of the matrix. With one scan, the entire otolith can be read and a statistical model of the number of rings/matrices is produced. Using a well-established mathematical tool to categorize the scan (Fourier transformation; FT), an age is estimated based on the number of rings/matrices (Wedding et al. 2014, Helser et al. 2018). Using this method, over 300 otoliths can be scanned/day. FT-NIRS provides rapid age estimation with good precision, and greater than 800% efficiency compared to optical counting methods. Further, subjectivity is reduced and repeatability increased as compared with traditional aging methods.

Correlation tests show R values of over 0.95 between manual microscopy and FT-NIRS aging methods (Benson et al., 2019). FT-NIRS aging is faster and has a higher repeatability than manual methods, but FT-NIRS also requires technicians with advanced methods training. FT-NIRS may not be necessary or cost-efficient for small fisheries or where current methods are readily applied.

NOAA is currently investing in FT-NIRS and its utilization on stock assessment cruises. Their next steps are to use the data to produce stock assessments using both visual counting and NIRS methods for aging fish. FT-NIRS aging is at a very high TRL and data can be readily utilized in current stock-assessment methods. FT-NIRS aging offers reduced time, effort and costs in the preparation and counting of the otolith rings.

Medium Term: Remote systems. TRL 5-6

NOAA technical presentation: Christian Meinig, PMEL

The 2016 ESMWG new technologies report covered the use of remote systems in a broad sense. This Topic 9 report specifically addresses autonomous surface vehicles that sail on the surface and may have direct stock assessment applications. In this case, we reviewed a system made by the company Sail-Drones™; however, the concepts apply broadly (see Moody et al. 2017). Surface unmanned systems are a component of greater UxS systems, where the term "UxS" is defined as aerial, underwater and other unmanned vehicle platforms.

Surface UxS drones can be directed to both near-shore and off-shore sites that are hard to access with ships. UxS systems can be at sea for long time periods and also used to "pre-survey" sites that will be later be sampled by ships. They can repeatedly survey small areas over time to quantify temporal and spatial variability.

NOAA is investing in equipment, personnel, laboratory and ship time to test and deploy remote observation tools. NOAA has laid out a plan for:

(1) Platform Design and Integration,

(2) Operations and Field Testing,

(3) Data collection and Validation,

(4) Research Missions, and

(5) Transition to Operations.

Test cruises and comparative work with Sail-Drones™ have been components of the California hake surveys, the Chukchi sea Arctic cod surveys and fur seal studies in the Bering Sea. Many stocks are data-poor and remote systems could be used to monitor these stocks without utilizing research ship cruises. Only about 50% of all managed stocks are assessed using ships, and UxS systems could reach some of the unassessed fisheries. Also, the data for many assessments are lacking in water and ocean conditions that cannot be trawled or sampled easily (too shallow, rocky bottoms, sensitive habitat). In such cases, remote systems using UxS methods, underwater systems, sonar, remote cameras and video may provide a means to gather data that would otherwise be unavailable to stock assessors.

Remote systems operate in a fundamentally different manner than ship-based surveys, and as a result, have different data output and sources of uncertainty. They move more slowly than large ships, which limits the area that they can cover unless sufficient autonomous systems are deployed. They must either use telemetry to transmit data, or store data on-board for later analysis, each of which has engineering challenges. Moreover, they are more vulnerable to destruction, for example during storms or interactions with the public. Despite these limitations, these systems offer potential advantages over some current approaches because they have the capacity to sample in shallow water and to correlate fish abundance with *in situ* water conditions at multiple locations in real time, and may be less disruptive to fish schooling behavior than large ships. They may further complement research ship data because they can potentially be deployed with shorter mobilization time to capture ephemeral events. However, the data that they provide on environmental conditions and their interpretation of location and types of fish species present requires validation and will not be able to be inserted directly into assessment models without substantial additional research. Even with extensive deployment, UxS systems are unlikely to remove the need for trawl surveys and ship-based acoustic surveys. To be used in assessment models, correlation studies will be needed with trawling methods, and stock assessment model parameters may need to be re-estimated as UxS methods are adopted.

Full deployment of surface drones or similar tools is likely to require specialized expertise to conduct research and development and for ongoing operation and maintenance because the equipment and techniques are evolving rapidly. Changes can be expected in equipment (e.g., computer microcontrollers), software and communication systems. To avoid bearing the full cost burden of development, operation and maintenance of a small fleet of such systems, NOAA may want to consider Public-Private-partnerships to take advantage of economies of scale. Existing companies that have been working with NOAA demonstrate that purchasing services for platforms and ocean sensor systems is a feasible alternative to in-house development. Given the rate of technological development in this field, NOAA may benefit from working with companies dedicated to systems development.

Long Term: ‘Omics and molecular methods. 5-10 years. TRL 2-3

NOAA technical presentation: Dr. Kelly Goodwin, OAR, AOML, SWFSC

NOAA is preparing an ‘Omics Strategy that includes a large suite of molecular tools for scientific research questions. ‘Omics refers to biochemical concepts that include genomics (the study of genetic patterns), proteomics that examines what proteins are created under various genetic models, and metabolomics that studies how animals and plants utilize their genetic and protein capabilities to alter their metabolism. The key to the use of ‘Omics for this ESMWG report is that animals moving through a body of water shed off DNA (from skin, slime, fecal matter, etc). This DNA can be extracted from a water sample and identified. That is, it is possible to determine that fish of species X swam through a body of water. This is called “eDNA” and mean environmental DNA as opposed to extracting DNA from the organism directly, such as with whale-biopsies to identify individuals. The field of eDNA is expanding rapidly in life sciences from asking whether species occupy a niche where they have never been seen, to if their presence has seasonal patterns. Some of the advantages of using this method include: Nondestructive sampling (no nets, trawls, biopsy); better reach (polar, deep, fragile); and more comprehensive species information (microbes to mammals) (Lacoursière-Roussel et al., 2016)

Many challenges and questions must be addressed before ‘Omics approaches can be applied for stock assessment purposes (Hansen et al. 2018). In the ocean, questions about the lifetime or persistence of the eDNA in a water sample must be considered. For example, when did this species of whale swim through this mass of water? The issue of where did the water sample move over the lifetime of the eDNA and how to best remove the high microbial DNA signal which swamps vertebrate eDNA are basic questions that must be studied. Other questions relate to relationships between the quantity of eDNA found in the water (e.g., for particular fish species) and the attributes of the source populations (e.g., abundance, biomass, age structure, etc.). The binary nature of such data (presence or absence) render them insensitive to trend detection. This might limit the usefulness of eDNA to very specific questions at the current stage of development. Additional questions and challenges relate to how autonomous vehicles and sensors might be used to collect samples for eDNA analyses.

The application of eDNA and molecular tools to stock assessment will require answers to these and other basic application questions. However, they are extremely powerful biochemical methods, and hold the promise of obtaining species-specific details of presence and absence beyond our current abilities. This general method holds promise and potential for many other uses beyond stock assessment. For example, these methods could potentially be used to identify spawning areas, characterize changes in the distribution of stocks, and provide other information relevant to broader understanding of coastal and marine ecosystems.

Since the majority of eDNA basic research is funded through medical research (unrelated to fisheries), NOAA will likely need to fund research that adapts these techniques to NOAA-relevant questions. It might be most effective to enter into long-term collaborations with the medical field to utilize their technology, and then invest in the transfer of this technology to fisheries applications.

The new and large amounts of data that ‘Omics can provide different forms of data that must be analyzed and summarized to be integrated into stock assessment models, and could require substantial changes to those models. Given current capabilities, eDNA may complement research ship data collection with presence/absence information on rare or cryptic species. It must also be recognized that ‘Omics techniques are currently better able to address some types of questions than others. For example, current eDNA approaches might be better suited for use within occupancy models which can apply the presence / absence data to generate species richness findings. They might be less suited to analyses of biodiversity (richness weighted by number of individuals of each species) or estimates of abundance or biomass.

As with the other technologies discussed in this report, there will be a need for NOAA professional and workforce development to best utilize research tools and modeling efforts using ‘Omics data. Biochemists, molecular biologists, engineers and model experts will need to be part of the NOAA workforce to move this field into the future. This development could involve detailing people in other federal agencies to NOAA, in order to share relevant knowledge and laboratory techniques.

Conclusion

To make use of emerging technologies, NOAA will need to investigate how these and other new methods could be useful to validate, expand and provide new possibilities for improving, and possible reducing the costs and effort, of stock assessment analyses. However, given the levels of readiness of the techniques themselves and the ability of stock assessment models to accept new types of data, many technologies do not appear ready to replace current approaches on a wide scale. In the near-term, they could be useful for broad Ecosystem Based Fisheries Management (EFBM) efforts and might be especially useful in data-poor fisheries. All use will require trained personnel. The techniques clearly hold potential for new scientific developments beyond stock assessments and could open up new research directions for NOAA.

Appendix: NOAA readiness levels.

NAO 216-105B: POLICY ON RESEARCH AND DEVELOPMENT TRANSITIONS

https://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-105B.html

Readiness Levels (RLs): A systematic project metric/measurement system that supports assessments of the maturity of R&D projects from research to operation, application, commercial product or service, or other use and allows the consistent comparison of maturity between different types of R&D projects. (Note: NOAA RL's are similar to Technology Readiness Levels developed by NASA and embody the same concept for quantifying the maturity of research). A project achieves a readiness level once it has accomplished all elements described within a readiness level. A program may include projects at different RLs depending on the goals of each project.

a. RL 1: Basic research, experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view. Basic research can be oriented or directed towards some broad fields of general interest, with the explicit goal of a range of future applications.
b. RL 2: Applied research, original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective. Applied research is undertaken either to determine possible uses for the findings of basic research, or to determine new methods or ways of achieving specific and predetermined objectives.

c. RL 3: Proof-of-concept for system, process, product, service, or tool; this can be considered an early phase of experimental development; feasibility studies may be included.
d. RL 4: Successful evaluation of system, subsystem, process, product, service, or tool in a laboratory or other experimental environment; this can be considered an intermediate phase of development.
e. RL 5: Successful evaluation of system, subsystem process, product, service, or tool in relevant environment through testing and prototyping; this can be considered the final stage of development before demonstration begins.
f. RL 6: Demonstration of a prototype system, subsystem, process, product, service, or tool in relevant or test environment (potential demonstrated).
g. RL 7: Prototype system, process, product, service or tool demonstrated in an operational or other relevant environment (functionality demonstrated in near-real world environment; subsystem components fully integrated into system).
h. RL 8: Finalized system, process, product, service or tool tested, and shown to operate or function as expected within user's environment; user training and documentation completed; operator or user approval given.
i. RL 9: System, process, product, service or tool deployed and used routinely

References:

ESMWG 2016 report on Technology

https://sab.noaa.gov/sites/SAB/Meetings/2016%20Documents/November%202016%20Documents/Emerging%20Technologies%20Report_final%20with%20title%20page.pdf

NOAA Stock Assessment Improvement Plan

Lynch, P. D., R. D. Methot, and J. S. Link (eds.). 2018. Implementing a Next Generation Stock Assessment Enterprise. An Update to the NOAA Fisheries Stock Assessment Improvement Plan. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/ SPO-183, 127 p. doi: 10.7755/TMSPO.183 Available online at https://spo.nmfs.noaa.gov/content/tech-memo/SAIP2018.

Near Infrared Spectroscopy and otolith chemistry

Benson, I., T. E. Helser, J. Erickson, J. Healy, C. Kastelle, and J. Short. Fourier Transform Near-Infrared (Ft-Nir) Spectroscopy Ageing of Eastern Bering Sea Walleye Pollock (*Gadus chalcogrammus*) Otoliths. In: Helser, T. E., I. M. Benson, and B. K. Barnett (eds). 2019. *Proceedings of the Research Workshop on the Rapid Estimation of Fish Age Using Fourier Transform Near-Infrared Spectroscopy (FT-NIRS)*. AFSC Processed Rep. 2019-06, 195 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Campana, S.E., Thorrold, S.R., Jones, C.M., Günther, D., Tubrett, M., Longerich, H., Jackson, S., Halden, N.M., Kalish, J.M., Piccoli, P. and De Pontual, H., 1997. Comparison of accuracy, precision, and sensitivity in elemental assays of fish otoliths using the electron microprobe, proton-induced X-ray emission, and laser ablation inductively coupled plasma mass spectrometry. *Canadian Journal of Fisheries and Aquatic Sciences*, *54*(9), pp.2068-2079.

Dauphin, Y. and Dufour, E., 2003. Composition and properties of the soluble organic matrix of the otolith of a marine fish: Gadus morhua Linne, 1758 (Teleostei, Gadidae). *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, *134*(3), pp.551-561.

Helser, T.E., Benson, I., Erickson, J., Healy, J., Kastelle, C. and Short, J.A., 2018. A transformative approach to ageing fish otoliths using Fourier transform near infrared spectroscopy: a case study of eastern Bering Sea walleye pollock (*Gadus chalcogrammus*). *Canadian Journal of Fisheries and Aquatic Sciences, 76(5)*, pp.780-789.

Izzo, C, Reis-Santos, P, and Gillanders, BM. Otolith chemistry does not just reflect environmental conditions: A meta-analytic evaluation. 2018. *Fish and Fisheries*, *19*, pp. 441–454. https://doi.org/10.1111/faf.12264

Rigby, C.L., Wedding, B.B., Grauf, S. and Simpfendorfer, C.A., 2014. The utility of near infrared spectroscopy for age estimation of deepwater sharks. *Deep Sea Research Part I: Oceanographic Research Papers*, *94*, pp.184-194.

Robins J.B., Wedding, B.B., Wright C., Grauf S., Sellin M., Fowler A., Saunders T. and Newman S., 2015. *Department of Agriculture, Fisheries and Forestry*, Revolutionising Fish Ageing: Using Near Infrared Spectroscopy to Age Fish. Brisbane, April, 2015. CC BY 3.0. 114 p.

Wedding, B.B., Forrest, A.J., Wright, C., Grauf, S., Exley, P. and Poole, S.E., 2014. A novel method for the age estimation of Saddletail snapper (Lutjanus malabaricus) using Fourier Transform-near infrared (FT-NIR) spectroscopy. *Marine and Freshwater Research*, *65*(10), pp.894-900.

Remote observation systems

Levine, M. and De Robertis, A., 2019. Don’t work too hard: Subsampling leads to efficient analysis of large acoustic datasets. *Fisheries Research*, *219*, p.105323.

Lowerre-Barbieri, S.K., Kays, R. Thorson, J.T., and Wikelski, M. The ocean’s movescape: fisheries management in the bio-logging decade (2018–2028), *ICES Journal of Marine Science*, Volume 76, Issue 2, March-April 2019, Pages 477–488, https://doi.org/10.1093/icesjms/fsy211

Mordy, C.W., Cokelet, E.D., De Robertis, A., Jenkins, R., Kuhn, C.E., Lawrence-Slavas, N., Berchok, C.L., Crance, J.L., Sterling, J.T., Cross, J.N. and Stabeno, P.J., 2017. Advances in ecosystem research: Saildrone surveys of oceanography, fish, and marine mammals in the Bering Sea. *Oceanography*, *30*(2), pp.113-115. https://www.jstor.org/stable/26201857?seq=1#page_scan_tab_contents

Newman, L., Heil, P., Trebilco, R., Katsumata, K., Constable, A.J., van Wijk, E., Assmann, K., Beja, J., Bricher, P., Coleman, R. and Costa, D., 2019. Delivering sustained, coordinated and integrated observations of the Southern Ocean for global impact. *Frontiers in Marine Science*, *6*, p.433.

Stierhoff, K.L., Zwolinski, J.P. and Demer, D.A., 2019. Distribution, biomass, and demography of coastal pelagic fishes in the California Current Ecosystem during summer 2018 based on acoustic-trawl sampling. NOAA technical memorandum NMFS SWFSC, La Jolla, CA ; 613. p.81.

eDNA

Bayer, S.R., Countway, P.D. and Wahle, R.A., 2019. Developing an eDNA toolkit to quantify broadcast spawning events of the sea scallop *Placopecten magellanicus*: moving beyond fertilization assays. *Marine Ecology Progress Series*, *621*, pp.127-141.

Hansen, B.K., Bekkevold, D., Clausen, L.W. and Nielsen, E.E., 2018. The sceptical optimist: challenges and perspectives for the application of environmental DNA in marine fisheries. *Fish and Fisheries*, *19*(5), pp.751-768.

Lacoursière-Roussel, A., Côté, G., Leclerc, V. and Bernatchez, L., 2016. Quantifying relative fish abundance with eDNA: a promising tool for fisheries management. *Journal of Applied Ecology*, *53*(4), pp.1148-1157.

Lacoursière-Roussel, A., Rosabal, M. and Bernatchez, L., 2016. Estimating fish abundance and biomass from eDNA concentrations: variability among capture methods and environmental conditions. *Molecular Ecology Resources*, *16*(6), pp.1401-1414.

Sassoubre, L.M., Yamahara, K.M., Gardner, L.D., Block, B.A. and Boehm, A.B., 2016. Quantification of environmental DNA (eDNA) shedding and decay rates for three marine fish. *Environmental science & technology*, *50*(19), pp.10456-10464.

Stat, M., Huggett, M.J., Bernasconi, R. et al., 2017. Ecosystem biomonitoring with eDNA: metabarcoding across the tree of life in a tropical marine environment. *Scientific Reports*, *7, 12240*, pp. 1-11. doi:10.1038/s41598-017-12501-5

AI

Bradley, D., Merrifield, M., Miller, K.M., Lomonico, S., Wilson, J.R. and Gleason, M.G., 2019. Opportunities to improve fisheries management through innovative technology and advanced data systems. *Fish and Fisheries*, *20*(3), pp.564-583.

Chen, S.H., Jakeman, A.J. and Norton, J.P., 2008. Artificial intelligence techniques: an introduction to their use for modelling environmental systems. *Mathematics and computers in simulation*, *78*(2-3), pp.379-400.

Malde, K., Handegard, N.O., Eikvil, L. and Salberg, A.B., 2019. Machine intelligence and the data-driven future of marine science. *ICES Journal of Marine Science*. pp 1-12. https://doi.org/10.1093/icesjms/fsz057

National Research Council. 2015. Robust Methods for the Analysis of Images and Videos for Fisheries Stock Assessment: Summary of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/18986.

O'Neill, F. G., Feekings, J. P., Fryer, R. J., Fauconnet, L., and Afonso, P., 2019. Discard avoidance by improving fishing gear selectivity: helping the industry help themselves. In S. Uhlmann, C. Ulrich, & S. Kennely (Eds.), *The European Landing Obligation : Reducing discards in complex, multi-species multi-jurisdictional fisheries*. pp. 279-296. Springer Open. https://doi.org/10.1007/978-3-030-03308-8_14

Probst, W.N., 2019. How emerging data technologies can increase trust and transparency in fisheries. *ICES Journal of Marine Science*. pp. 1-9. https://doi.org/10.1093/icesjms/fsz036

Uranga, J., Arrizabalaga, H., Boyra, G., Hernandez, M.C., Goñi, N., Arregui, I., Fernandes, J.A., Yurramendi, Y. and Santiago, J., 2017. Detecting the presence-absence of bluefin tuna by automated analysis of medium-range sonars on fishing vessels. *PloS one*, *12*(2), p.e0171382.