A Review of Reviews: Lessons learned from comprehensive program reviews across the NOAA Fisheries science enterprise

NMFS Science Board

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA Technical Memorandum NMFS-F/SPO-216
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U.S. Department of Commerce
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National Oceanic and Atmospheric Administration
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[1] The NMFS Science Board is composed of the NMFS Chief Science Advisor and Director of Science Programs, the Director of the Office of Science and Technology (OST), the six Fisheries Science Center Directors, and the Senior Scientists for Ecosystems, Stock Assessments, and Economics. The present Science Board members who contributed to the report are Francisco Werner, Robert Foy, Jonathan Hare, Evan Howell, Kristen Koch, Doug Lipton, Jason Link, Rick Methot, Clay Porch, Michael Seki, and Kevin Werner. Ned Cyr, who was a member of the NMFS Science Board at the beginning of the review of reviews' (RoR's) writing, has since retired from federal service, and David Detlor and Jeremy Rusin served terms on the Science Board. All of these individuals are equal contributors. Stephanie Oakes' contribution to this report merits special recognition. Ms. Oakes participated in all but one of the 34 reviews, coordinated the overall review process, and co-authored many of the documents, terms of reference, communications, and national reports.

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Or online at:
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Abstract

We present a "review of reviews" (RoR) of the comprehensive five-year (2013-2017) review of the National Marine Fisheries Service (NMFS; informally known as NOAA Fisheries) science enterprise. The five-year review process was unlike any our agency had ever conducted. A total of 34 individual program reviews were conducted of our seven primary science units (six regional Science Centers and the Office of Science and Technology), one program across the science units each year: Data Collection and Management (2013), Fisheries Stock Assessment Programs (2014), Protected Species Science (2015), Ecosystem, Climate, and Habitat Science (2016), and Economics and Human Dimensions (2017). The reviews took place over approximately 125 days and included 830 combined science presentations, panel discussions, and poster sessions. Hundreds of people representing NOAA Fisheries science and 160 expert panelists were involved. Using a Strengths, Weaknesses, Opportunities, and Threats (SWOT) approach, we synthesize the information from the reviews and prioritize strategies to improve the NOAA Fisheries science enterprise. Note that while the individual reviews that commenced in 2013 could not consider impacts such as COVID-19 on our enterprise, or the increased and necessary actions on diversity, equity, and inclusion, we include a section that discusses how these events will affect the future of our science enterprise. Our scientific challenges are complex: adapting to the impacts of climate change, increasing multi-sectoral ocean uses, and developing ecosystem approaches to management, among others. As scientists, we develop tools and approaches to address these challenges. However, in addition to actions focused on our science, we identified three areas for improvement overall: attention to our workforce, organizational excellence, and engagement with our partners and stakeholders. Our RoR highlighted the need to continue to develop NOAA Fisheries science in tandem with NOAA Fisheries as a science organization.

Introduction

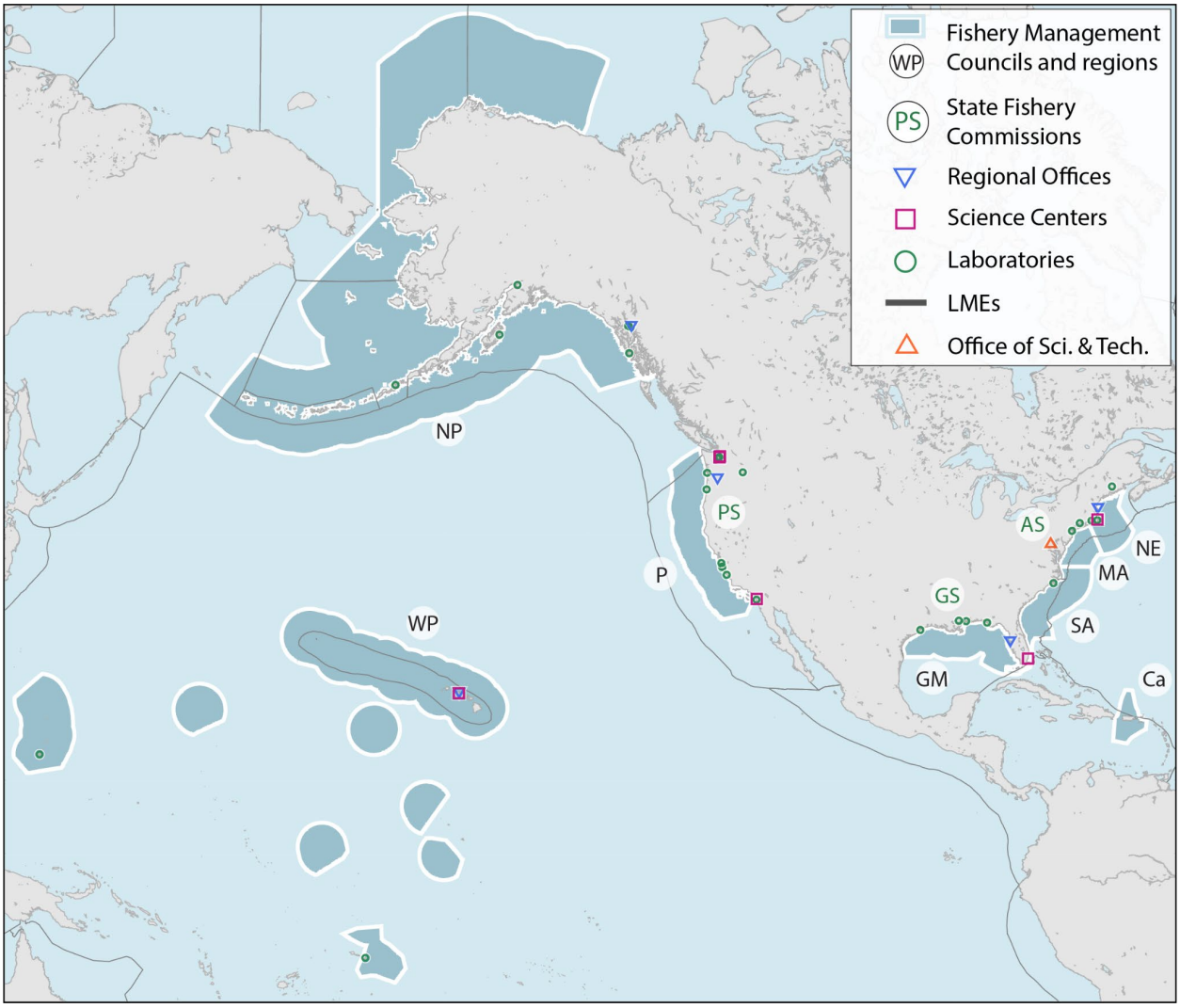
Independent peer reviews are widely used to help science-based agencies maintain and improve the quality of their scientific programs. Additionally, NOAA's Administrative Order on Research and Development (R&D), NAO 216-115A[1], provides guidance by which the R&D throughout NOAA can be continually reviewed, evaluated, and rebalanced in light of evolving mission needs. Such reviews provide scientists, administrators, and decision-makers with objective measures that are not unduly influenced by the economic, historical, cultural, and political factors that shaped the projects, programs, or institutions (Pulliam et al., 1998). Reviews can also help to increase the visibility and transparency of science programs, which may in turn help improve the agency's ability to meet legislative requirements and partners' and stakeholders' expectations (Murphy and Weiland, 2016).

NOAA Fisheries[2] is responsible for the stewardship of living marine resources and their habitats within the U.S. Economic Exclusion Zone. The agency also represents U.S. interests at international bodies and agreements including Regional Fishery Management Organizations, the Convention on the Conservation of Antarctic Marine Living Resources, the International Council for the Exploration of the Sea, and the North Pacific Marine Science Organization. The agency's mission is to provide vital services to the nation: productive and sustainable fisheries, safe sources of seafood, the recovery and conservation of protected resources, and healthy ecosystems. These services are all supported by sound science and an ecosystem-based approach to management.

The NOAA Fisheries Science enterprise includes approximately 2500 people at six regional Science Centers (SCs) and the headquarters Office of Science and Technology (OST). It has an annual appropriated budget of approximately $380M (FY 2020). The six SCs are the Pacific Islands, Alaska, Northwest, Southwest, Southeast, and Northeast. Three science and professional (ST) level Senior Scientists (for Ecosystems, Stock Assessments, and Economics) provide broad advice in their respective areas. The science enterprise reports to the Director of Scientific Programs and Chief Science Advisor for NOAA Fisheries, who in turn reports to the NOAA Assistant Administrator for Fisheries. The SCs and the OST support fisheries, protected species, habitat, aquaculture, and ecosystem-based management at five NOAA Fisheries Regional Offices: Pacific Islands, Alaska, West Coast, Southeast, and Greater Atlantic. The activities range over eleven Large Marine Ecosystems (LMEs) and include a wide array of partners, stakeholders, and collaborators related to the diverse mission (Figure 1).

[1] https://www.noaa.gov/organization/administration/nao-216-115a-research-and-development-in-noaa

[2] NOAA Fisheries, formally known as the National Marine Fisheries Service (NMFS), is an office of the National Oceanic and Atmospheric Administration within the Department of Commerce. NMFS has five Regional Offices, six Science Centers, twelve Headquarters Offices, and more than 20 laboratories around the U.S. and U.S. territories, and works with partners across the nation.


Fishery Management Councils and regions
WP
PS
State Fishery Commissions
Regional Offices
Science Centers
Laboratories
LMEs
Office of Sci. & Tech.
NP
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Peer review is an important part of marine natural resource management (Brown et al., 2020). The scientific and resource management activities of NOAA Fisheries have been reviewed previously using a variety of approaches both at the regional and national level (NRC, 1998; NEFMC[3]). Sissenwine and Rothschild[4] reviewed the NOAA Fisheries science enterprise as a whole and proposed an approach that included simultaneous reviews of similar programs across the agency with terms-of-reference designed to achieve the following ends:

- improve or create integration of NMFS science programs nationally,
- engage headquarters offices,
- enhance consistency nationally and over time, and
- assure follow-through on program review outcomes.

They also recommended a "review-of-reviews" (RoR) to synthesize the conclusions from the program reviews and to establish a foundation for implementing high-level recommendations. NOAA Fisheries agreed with these recommendations (NMFS, 2011) and instituted a coordinated series of five annual reviews (2013-2017) with the specific goals of ensuring that the science conducted by the seven primary science units (six regional SCs and OST) was well-coordinated, rigorous, relevant, effective, and optimized with respect to available resources. Expert peer reviewers from within and outside the agency were recruited independently for each of the seven science units. However, each set of reviewers was provided common terms of reference to improve integration and identify best practices, as well as identify successes and challenges within our science enterprise. The review process was open to the public and offered an opportunity for a broad dialogue with fishery management councils, fishing industry representatives, environmental non-governmental organizations, and other partners and stakeholders. In all, a total of 34 individual program reviews were conducted that covered five topical areas:

- *Data Collection and Management (2013):* evaluate scientific fishery-dependent and fishery-independent data as it relates to legal mandates (e.g., the Magnuson-Stevens Act, the Endangered Species Act, and the Marine Mammal Protection Act). The reviews included examination of NOAA ship-based surveys, cooperative research surveys, logbook and observer data, and data management and quality control.

- *Fisheries Stock Assessment Programs (2014):* evaluate fishery stock assessment programs conducted pursuant to the Magnuson-Stevens Act and comparable international agreements. The reviews generally focused less on the technical details of the stock assessment process

[3] New England Fishery Management Council. 2011. A Review of the New England Fishery Management Process, 19p. [Available at http://archive.nefmc.org/press/press_releases/2011/02_fullreport_touchstonereport.pdf]
[4] Sissenwine, Michael, and Brian Rothschild. 2011. Building Capacity of the NMFS Science Enterprise, 121 p. [Available at https://media.fisheries.noaa.gov/2021-05/Building%20%20Capacity%20of%20the%20NMFS%20Science%20Enterprise_Final.pdf]

and more on the overall program of assessment modeling approaches, the assessment review process, and assessment communication.

- *Protected Species Science (2015):* evaluate the scientific programs directed to provide information relative to the conservation and management of marine mammals, endangered or threatened wildlife, and species of concern under our jurisdiction and/or that are legally mandated (e.g., the Marine Mammal Protection Act, the Endangered Species Act).

- *Ecosystem, Climate, and Habitat Science (2016):* evaluate scientific programs directed to provide information relative to the management, protection, and restoration of resilient and productive ecosystems (including ecological, oceanographic, climate, and habitat-related processes as they are linked to living marine resource species).

- *Economics and Human Dimensions (2017):* evaluate programs that provide science advice on the socio-economic consequences of management actions, and the design of policies that maximize societal benefits from ocean and coastal ecosystems. These programs include economics and sociocultural research on commercial and recreational fisheries and fishing communities to provide information about the potential effects of fishery management options on people.

The comprehensive five-year process was unlike any our agency had ever conducted. The reviews took place over approximately 125 days and included 830 combined science presentations, panel discussions, and poster sessions. Participants included hundreds of people representing NOAA Fisheries science and 160 expert panelists, 23 of whom participated in more than one review (see Appendix 1). All the reviews, comments, and recommendations, including supporting documents, as well as our SCs', OST's and national-level responses, are available via the public links in Table 1.

The purpose of our RoR is to conduct a synthesis of the reviews and develop high-level recommendations for the NOAA Fisheries science enterprise for the coming years. This report is divided into six subsequent sections. The first section describes our approach for synthesizing information across the 34 separate reviews. The second section identifies common themes from the reviews with regard to the strengths, weaknesses, opportunities, and threats for the NOAA Fisheries science enterprise. The third section presents specific steps that NOAA Fisheries has taken in response to the reviews and identifies impediments where recommendations have not yet been addressed. The fourth section focuses on the next steps for NOAA Fisheries science and for the organization. The fifth section provides lessons learned from the process and presents high-level recommendations for the agency. The sixth section – an "Epilogue" – discusses the influence of the coronavirus pandemic and expanded diversity, equity, and inclusion focus on the future of our science enterprise.

Table 1. Weblinks to program review documents and agency responses. Note that except for the Chair's report, the external reviewers' comments are anonymous. See Appendix 2 for full web addresses of each document listed in this table.

Program Review	Organization							
	PIFSC	AFSC	NWFSC	SWFSC	SEFSC	NEFSC	OST	National Level Response
Data Collection and Management (2013)	Review	Review	Review	Review	Review	Review	Review	
	Response	Response	Response	Response	Response	Response	Response	Response
Fisheries Stock Assessment Programs (2014)	Review	Review	Review	Review	Review	Review	Review	
	Response	Response	Response	Response	Response	Response	Response	Response
Protected Species Science (2015)	Review	Review	Review	Review	Review	Review	No Program	
	Response	Response	Response	Response	Response	Response	No Program	Response
Ecosystems, Climate, and Habitat Science (2016)	Review	Review	Review	Review	Review	Review	Review	
	Response	Response	Response	Response	Response	Response	Response	Response
Economics and Human Dimensions (2017)	Review	Review	Review	Review	Review	Review	Review	
	Response	Response	Response	Response	Response	Response	Response	Response

Approach

We used a Strengths, Weaknesses, Opportunities, and Threats (SWOT) approach (Fine, 2009) to summarize the program review findings and to identify and prioritize strategies to improve the NOAA Fisheries science enterprise. Authors of this RoR revisited the program reviews written by the external review panels and the accompanying agency responses (Table 1). The RoR's components were defined by region (the program reviews for each SC/Headquarters Office were reviewed by the respective Director) and by expertise (e.g., the Data Collection and Stock Assessment program reviews were reviewed by the NOAA Fisheries Senior Scientist for Stock Assessments). The overall national level responses were reviewed by the NMFS Director of Scientific Programs and Chief Science Advisor[5]. RoR contributors answered the following 11 questions:

[5] A comment on the SWOT approach taken herein (and the results presented in the Common Themes section) is that it potentially missed analyses across our science enterprise. For instance, we did not explicitly attempt to evaluate areas where some SCs or the OST do certain things "better" than others. Exporting best practice approaches across the science enterprise is occurring implicitly, and should be an explicit metric in future reviews.

- Question 1: What 4-6 Strengths do you identify from the reviews regarding your organization?
- Question 2: What 4-6 Weaknesses do you identify from the reviews regarding your organization?
- Question 3: What 4-6 Opportunities do you identify for your organization?
- Question 4: What 4-6 Threats do you identify for your organization?
- Question 5: What were the 3 most reaffirming conclusions / recommendations from the reviews?
- Question 6: What were the 3 most surprising conclusions / recommendations from the reviews?
- Question 7: What are the top 4-6 most important steps taken thus far by your organization based on these reviews?
- Question 8: What are the top 4-6 most important steps outstanding for your organization based on these reviews?
- Question 9: What do you identify as the value of the reviews?
- Question 10: What are the 1-2 most important lessons from the reviews?
- Question 11: Taking the information developed during this RoR, what are the most consequential next steps for NOAA Fisheries?

The answers were synthesized across organizational units (SCs and headquarters) and across program areas to extract high-level conclusions regarding the value of the process, the state of NOAA Fisheries science, and high-level priorities for the next five years.

The SWOT framework was defined relative to the NOAA Fisheries science goals, which are to provide science advice in support of living marine resource management and increase scientific understanding to improve advice and management in the future. In this context, strengths are internal characteristics that support the ability of the organization to achieve these goals. Weaknesses are internal characteristics that limit the ability of the organization to achieve these goals. Opportunities are generally external to the organization, but can be internal, and can be used to enhance the ability to achieve goals. Threats are generally external conditions, but can be internal, that limit the ability of the organization to achieve goals.

Common Themes

Strengths (Q1). Seven high-level strengths were identified across the 34 program reviews (Figure 2).

- Scientists in NOAA Fisheries are dedicated and high-performing.
- People, programs, and facilities have unique capabilities that serve the NOAA Fisheries mission.
- The science produced is high quality and directly relevant to management.
- Innovative new technologies are developed and used.

- Many data collection programs are long-term (some >60 years) and broad in disciplinary coverage (from physical oceanography to fishery economics and fishing community indicators), supporting a large array of activities both inside and outside of the agency.
- Strong and diverse collaborations exist across and within the science programs.
- The organization can be strategic and is capable of change.

Weaknesses (Q2). Seven high-level weaknesses were identified.

- Limited resources (e.g., funding, ship availability, facilities) constrain operational science activities including surveys, assessments, and the provision of scientific advice to managers.
- The ability to conduct research has greatly eroded as a result of maintaining the ability to conduct operational science.[6]
- Employee morale is negatively impacted by resource and organizational constraints potentially affecting recruitment and retention.
- Science activities are "stove-piped" within programs and within regions.
- Data management remains challenging and new data collection programs are creating additional challenges.
- External communication regarding activities, results, and mission needs to be improved.
- Organizational structures and processes limit the ability of NOAA Fisheries science to be successful.

Opportunities (Q3). Eight high-level opportunities were identified that can be used as the basis to develop strategies for improving NOAA Fisheries science and for improving the ability of NOAA Fisheries science to support marine resource management.

- Increase collaborations and partnerships.
- Improve communications both internally and externally with partners and stakeholders.
- Increase use of modeling capabilities and new technologies.
- Improve data management and data accessibility.
- Implement the Ecosystem-Based Fisheries Management Road Map[7].
- Develop stronger pipelines for recruiting new people and training for people in new areas.

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[6] We use the definitions for research and for operations given in NAO-216-105B: Policy on Research and Development Transitions. Basic research is 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. Applied research is the original investigation undertaken in order to acquire new knowledge… directed primarily towards a specific, practical aim or objective. Operations are sustained, systematic, reliable, and robust mission activities with an institutional commitment to deliver specified products and services. Examples include weather and climate forecast models run on a routine basis to provide forecast guidance or seasonal outlooks, stock assessments conducted to determine changes in the abundance of fishery stocks, among others.

[7] Dennit, K. 2018. NOAA Fisheries Ecosystem-Based Fisheries Management Road Map, 50 p. [Available at https://media.fisheries.noaa.gov/dam-migration/01-120-01.pdf]

- Strategically prioritize investments in science activities balancing operational and research activities.
- Improve organizational structure and processes to better meet our mission and create efficiencies.

Threats (Q4). Eight high-level threats facing NOAA Fisheries science were identified.

- Demands for NOAA Fisheries science are increasing, both in core topic areas related to fisheries and protected species and in emerging topic areas including ecosystem-based management, offshore wind energy development, aquaculture, and climate change.
- Mission objectives are increasingly in conflict with legislation and policies, often generating competing priorities resulting from limited resources.
- There is an increasing reliance on limited duration projects and reimbursable funding to support science priorities, and increased external direction on use of funding allocations[8].
- There is an increasing reliance on external organizations to provide data and models required by NOAA Fisheries to deliver scientific advice[9].
- Trust in NOAA Fisheries science and relationships with some key stakeholders and partners needs to be improved.
- Rapidly changing ecosystems/extreme events require correspondingly rapid changes in how, what, when, and where our science is conducted.
- A general decline in societal valuation of science and evidence-based decision making is negatively affecting NOAA Fisheries science.
- Fundamental scientific questions remain unresolved, thereby limiting NOAA Fisheries' ability to accomplish the mission.

[8] NOAA Fisheries is funded mainly through direct congressional appropriations. The appropriated funds are meant to support sustained year-to-year office costs, long-term programs, and temporary research projects within NOAA Fisheries. NOAA Fisheries may also receive funds from external sources on a project basis through reimbursable agreements and other interagency mechanisms.

[9] While this could also be viewed as an opportunity (diversification of data acquisition and modeling), there needs to be a balance between collaborative partnerships and a gradual outsourcing of capabilities.

Figure 2. A summary of the Strengths, Weaknesses, Opportunities, and Threats (SWOTs) defined from a synthesis of the 34 reviews of NOAA Fisheries' science programs. Issues that were expected or reaffirming are denoted by an asterisk (*) and issues that were unexpected or surprising – either by their nature or the acceleration of their importance – are denoted by a dagger (†).

Reaffirming Conclusions (Q5). Many of the SWOTs were not unexpected and were reinforced by the program reviews. It is known that NOAA Fisheries scientists are leaders in their fields and extremely productive. The value of NOAA Fisheries research and data collection programs is also highly regarded as are the challenges to maintain these activities with declining resources, while at the same time needing to improve data processing and management systems. There is also the recognition that our science programs remain stove-piped at the regional and national levels, and that social science activities are particularly isolated from other mission activities despite humans being an integral part of marine ecosystems. Further, challenges resulting from increasing demands, conflicting mandates, and a loss of research capabilities are also known. The erosion of partner and stakeholder trust is also acknowledged and was highlighted in several of the reviews particularly related to data collection and stock assessment. NOAA Fisheries also recognizes the need and ability to plan strategically, prioritize mission objectives, and allocate resources accordingly. Finally, the importance of science partnerships and collaborations is known and there are many examples throughout NOAA Fisheries.

Surprising Conclusions (Q6). The program reviews did highlight aspects of the science enterprise that had not been previously identified as critical to the science mission. NOAA

Fisheries facilities were recognized for their locations, capabilities, and equipment. The value of each facility to the NOAA mission is often overlooked and maintaining a presence at each facility is occasionally challenging. There was also an emphasis on developing and using new technologies. There are many examples throughout the agency, but the importance of operationalizing these technologies into scientific advice was made clear, as was the importance of sharing new technologies and approaches across regions. The demand for interdisciplinary science – working across program areas and supporting ecosystem approaches – was also emphasized along with the need for an integrated vision for NOAA Fisheries science.

A threat not previously highlighted was the vulnerability of NOAA Fisheries science to declining availability of ship and aircraft resources through the Office of Marine and Aviation Operations (OMAO), as well as from other sources like fishing industry charters. This vulnerability became acute in 2019 with the unexpected decommissioning of the NOAA Ship *Hi'ialakai* and the removal of approximately 20% of the annual days at sea owing to deferred maintenance. A number of important science questions (e.g., effect of climate change on marine ecosystems, trophic interactions in a changing climate) were also identified as ones that NOAA Fisheries should investigate; the ability to conduct these studies however has been diminished by declines in personnel and the decrease in available ship and aircraft resources. A recurring recommendation in several of the program reviews was to use Management Strategy Evaluations (MSEs) as a scientific tool to test multiple potential harvest strategies, climate scenarios, and an integrated set of responses to help managers make more informed decisions in support of resource management. Finally, a societal trend for devaluing science and the scientific method was identified as a threat, much broader than – but relevant to – NOAA Fisheries.

Conclusions from Strength, Weakness, Opportunity, Threat Analysis. Complementing the science issues considered in the reviews, attention to employee morale was also identified. [Similar findings emerged from the U.S. Office of Personnel Management's Federal Employee Viewpoint Survey (FEVS)[10].] An increased emphasis on professional development was recognized as a way to partially address employee morale. There also may be a link to declining resources consistent with FEVS results, in which SC employees responded more negatively, compared to respondents within non-science mission components, when asked if they had the resources necessary to perform their jobs. Another observation that was novel – particularly across SCs – was the increased use of contractors and dependence on external grants (resulting from the increased importance of project or reimbursable funds) to meet the science needs of the agency. This pattern results in large part from the decrease in available permanent funding for core mission areas owing to rising costs, and the replacement of these funds with shorter-term, project-specific funding. This trend creates a vulnerability for the science that NOAA Fisheries provides in support of management. Improving communication was also identified as needed in most reviews, within and between SCs, as well as between the SCs and Regional Offices, and

[10] https://www.opm.gov/fevs/

SCs and external partners, stakeholders, and the public. Finally, a number of reorganizations were identified that could help streamline the SCs and encourage cross-program integration[11].

Summarizing the above data, four overarching themes emerge from the SWOT evaluation (see Figure 3):

- science-related issues,
- the people in NOAA Fisheries,
- interactions with partners and stakeholders, and
- the organization.

While the program reviews were established primarily to review the science, and a number of important observations and recommendations were made in that regard, they also made it clear that the success of NOAA Fisheries science is dependent on people, partners, stakeholders, and the organization. Viewing the analysis from this perspective will help NOAA Fisheries think strategically about improving the scientific enterprise across these four dimensions.

	Strengths	Weaknesses	Opportunities	Threats
Science	Science Products Data Collection Innovative Technologies	Loss of Research Capabilities Data Management	Science Plans Innovative Technologies Data Management & Accessibility	Changing Ecosystems Scientific Unknowns & Uncertainties
People	Dedicated Staff	Staff Morale	Staff Development	Reduction in FTEs
Partners & Stakeholders	Partnerships / Collaborations	Communications	Partnerships / Collaborations Communications	Stakeholder Trust Public Perception of Science
Organization	Facilities Strategic Capabilities	Organizational Barriers Limited Resources Stovepiped Programs	Organizational Improvements * Strategic Prioritization *	Increasing Demands Conflicting Mandates Shifts to Temporary Funding Reductions in Funding / DAS

Figure 3. Categorization of strength, weaknesses, opportunities, and threats (SWOTs) by four emergent, high-level topics: science, people, partners and stakeholders, and organization.

[11] The findings for each SWOT component emerged to the top when looking at the RoR data (i.e., the responses to the 11 questions). This approach can mask countervailing findings within FMCs. While the heterogeneity of the FMCs is lost in a high-level summary, the individual details (differences or similarities across FMCs) are available in the individual reviews and responses (see Table 1). There is power in improving NOAA Fisheries' science enterprise by further analyzing what works well in one FMC and exporting the essence of that item to other FMCs.

Science. NOAA Fisheries science is high quality and provides needed information for living marine resource managers and decision-makers. In addition, the data collection systems are world class and provide some of the most comprehensive and long-term datasets on marine ecosystems globally. While operational science products have been prioritized, the ability to conduct research has diminished as resources have decreased. Data management is a challenge and improving data management is an opportunity to find efficiencies and improve science products. Innovative technologies also provide opportunities for efficiencies and improvement in science capabilities. Yet, the data management demands for high data volume new technologies will create additional needs and challenges to incorporate the data into science products and to make data publicly available.

The largest external threat to the NMFS science enterprise is the continued need to provide useful and accurate advice in rapidly changing marine ecosystems (Payne et al., 2016). Much of the management paradigm in the U.S. is based on stationarity – a variable system around a constant mean. Climate change fundamentally equates to a non-stationary system – variable with a changing mean. Providing science in a non-stationary system presents a number of challenges (Milly et al., 2008; Busch et al., 2016). This is layered on top of existing uncertainty and unknowns related to living marine resource science (Ruckelshaus et al., 2008; Beamish and Rothschild, 2009; Lynch et al., 2018).

People. The program reviews emphasized that the people working in NOAA Fisheries are dedicated, and identified professional development as an opportunity to improve the science and elevate employee morale. A number of other actions, including more active inclusion and increased employee engagement, have been identified through the FEVS and are now ongoing practices at the SCs.

Partners and stakeholders. Partner and stakeholder trust is crucial for science to be accepted in management (Kaplan and McCay, 2004; Johnson and McCay, 2012). The reviews identified trust and public perception of science as threats. These threats can be countered through increased communication, partnerships, and collaborations. In particular, cooperative research and citizen science activities[12] have been identified as effective approaches to meeting scientific needs and increasing trust in the science produced. Increased partnerships (e.g., through Cooperative Institutes and Sea Grant) across the different regions is also an approach that has been successful and should be continued.

Organization. Organizationally, NOAA Fisheries science is at a crossroads. Demands for the agency's science are increasing. There are needs to improve and increase data collection

[12] NOAA. 2021. NOAA Citizen Science Strategy: Applying the Power of the Crowd, 9 p. [Available at: https://sciencecouncil.noaa.gov/Portals/0/Citizen%20Science%20Strategy%20_final.pdf?ver=2021-01-15-103436-693]

programs and assessments, to expand our focus in emerging areas (e.g., aquaculture, climate change, ecosystems, and offshore wind development), and to address increased interaction between mission areas (e.g., protected species and fishing). At the same time, facilities are aging, base funding is eroding, available days-at-sea are decreasing, and the number of federal employees is decreasing. Such needs must be addressed through improvements in our overall institutional and organizational excellence (e.g., redirecting some activities and programs, investing in others). Otherwise, NOAA Fisheries' ability to increase the quality and quantity of its science will remain compromised. While this assessment of NMFS' science enterprise is admittedly challenging, there are steps that can and have been taken to find ways forward.

Response to Program Reviews

Important steps taken thus far (Q7) and next steps (Q8). NOAA Fisheries has acted on most of the reviews' recommendations (Table 1), with some responses still underway. The list of actions can be divided among the themes identified above: science, people, partners and stakeholders, and organization.

Science. Based on the recommendations from Stock Assessment and Ecosystem Program reviews, NOAA Fisheries has increased the capacity for conducting MSEs in every region. Many of the reviews identified MSEs as a powerful approach for evaluating various management strategies. A strategic investment in employees to support MSEs was made for each SC. A number of MSE activities have subsequently been started and in some cases completed (e.g., Atlantic herring harvest control rule evaluation; see Deroba et al., 2019). In addition, a national, interdisciplinary coordinating committee has been established to ensure communication among regions.

Also as recommended by the program reviews, Climate Science Strategy Regional Action Plans[13] and Ecosystem-Based Fisheries Management (EBFM) Regional Implementation Plans[14] have been completed and implementation started in each region. These plans provide national and regional direction for activities to support NOAA Fisheries science in these priority areas and were developed in cooperation with regional partners. These plans identify priorities, which inform the Priority-Based Resourcing processes (also referred to as Strategic Resource Management) described below. National and regional coordination groups have also been formed and are active. A recently proposed NOAA Climate Fisheries Initiative[15] builds on these efforts and plans work across NOAA.

[13] NOAA Fisheries Climate Science Strategy Regional Action Plans. [Available at. https://www.fisheries.noaa.gov/national/climate/climate-science-strategy-regional-action-plans]
[14] NOAA Fisheries Ecosystem-Based Fishery Management Regional Implementation Plans. [Available at https://www.fisheries.noaa.gov/national/ecosystems/ecosystem-based-fishery-management-implementation-plans]
[15] NOAA Fisheries Climate and Fisheries Initiative. [Available at https://www.fisheries.noaa.gov/topic/climate-change#noaa-climate-and-fisheries-initiative]

The Stock Assessment Improvement Plan (Lynch et al., 2018) also has been completed and regional assessment prioritization has been completed in most regions. The stock assessment prioritization used national guidelines and has been implemented regionally. In some cases this prioritization effort was accompanied with a modification to stock assessment processes.

The importance of modeling and consistent, pre-evaluated analytical tools was noted in most reviews. The revision, expansion, and further development of a national fisheries modeling "toolbox" has begun. The toolbox has "drawers" for stock assessments, ecosystems, protected resources, and human dimensions. This effort seeks to draw on the innovations in each of the SCs while providing a nationally consistent approach to use of these models. An effort to establish a nationally-coordinated community stock assessment modeling framework, the Fisheries Integrated Modeling System[16] (FIMS), is also under development.

The importance of data was identified in most reviews and each SC has started recommended improvements in data collection, data processing, and database systems. New people have been hired in some regions to increase capacity and expertise, and partnerships have been developed to increase sharing of technical expertise and find operational efficiencies. As a specific example, a partnership has formed with the National Centers for Environmental Information to host acoustic and oceanographic data. Plans to expand on this partnership are proceeding. NOAA Fisheries is also developing a complete inventory of survey activities supported by the agency and has conducted a Fisheries Information Management Modernization workshop (Margolis et al., 2020) as a step toward improving the management of NOAA Fisheries data and data systems. However, some of the changes have not been made owing to resource limitations and the need to balance priorities of maintaining surveys.

Going forward, there are a number of recommendations that need continued action. A number of the reviews identified the importance of addressing emerging ecosystem and climate science needs and implementation of Ecosystem, Climate Science, and Stock Assessment Improvement plans. These issues are not going away. NOAA Fisheries will need to continue to build the science necessary to support EBFM, to address the impacts of climate change on marine resources, and to advance stock assessments (both in terms of quantity and quality). Similarly, efforts to develop and deploy new technologies and new data collection[17], processing, and management approaches will be ongoing.

Research priority recommendations stemming from the Protected Species reviews are now advanced through the agency's Protected Resources Board and Protected Species Assessment

[16] NOAA Fisheries Integrated Modeling System website. [Available at https://www.fisheries.noaa.gov/national/population-assessments/fisheries-integrated-modeling-system]
[17] NOAA Science Council Science and Technology Focus Areas website. [Available at https://sciencecouncil.noaa.gov/NOAA-Science-Technology-Focus-Areas]

Workshops. Collaborations with the Bureau of Offshore Energy Management and the U.S. Navy have expanded (e.g., Pacific Marine Assessment Partnership for Protected Species). Advanced technologies are being evaluated and operationalized for monitoring and for research. Artificial intelligence is being applied to image recognition and audio recognition (Richards et al., 2019).

Partners and Stakeholders. NOAA Fisheries continues to strengthen relationships with partners and stakeholders, including increased emphasis on science-related collaborations. SCs are actively engaged in the NOAA Cooperative Institute program, which are academic and non-profit research institutions that conduct research to support NOAA's Mission Goals and Strategic Plan. Each SC has an affiliated Cooperative Institute and many of these have been re-competed during 2017-2021, which allows topics raised in the program reviews to be included in the Cooperative Institute work plans. SCs are also actively engaging in industry partnerships around the country. These partnerships have been encouraged at all levels and are specific to certain topics and regions. For example, chartering for-hire and commercial vessels, testing new reporting methods (e.g., cellular VMS units, electronic logbooks, etc.), and new certification of state recreational fisheries surveys, among others. Similarly, non-governmental organizations are playing a greater role in the marine research landscape and SCs are looking at new ways to work with them on priority needs.

The NOAA Fisheries science enterprise has increased and diversified its communication strategies partially in response to the program reviews, e.g., via the Marine Resource Education Program (MREP)[18]. NOAA Fisheries has centralized its outgoing communications through subscriber-based electronic document delivery (govdelivery)[19]. Many SCs are also active on social media including Facebook (e.g., AFSC[20]) and Twitter (@NOAAFisheries). The use of videos (Virtual Ecosystem Viewer[21]) and infographics (example from Fisheries of the United States[22]) to communicate is also becoming more common. There has also been more effort to engage in listening sessions and panel discussions, which engender more two-way communications. These additional activities are occurring simultaneously with traditional scientific communication techniques including workshops, conferences, reports, and peer-reviewed publications.

Similar to the need to continue to improve science, the need to continue to improve relationships with partners and stakeholders is also recognized. Much of the emphasis has been on research

[18] Gulf of Maine Research Institute Marine Resources Education Program (MREP) website. [Available at https://www.gmri.org/projects/marine-resource-education-program-mrep/]
[19] NOAA Fisheries Electronic Document Delivery sign up. [Available at https://public.govdelivery.com/accounts/USNOAAFISHERIES/subscriber/new?preferences=true#tab1]
[20] AFSC Facebook page. Available at https://www.facebook.com/NOAAFisheriesAK/
[21] NOAA Fisheries Virtual Ecosystem Scenario Viewer (VES-V). [Available at https://www.fisheries.noaa.gov/resource/tool-app/virtual-ecosystem-scenario-viewer-ves-v]
[22] NOAA Fisheries' Fisheries of the United States Infographics. [Available at https://www.fisheries.noaa.gov/national/sustainable-fisheries/fisheries-united-states#infographics]

partners (e.g., universities) and management partners (e.g., Regional Offices, Fishery Management Councils). Communication efforts and work with industry partners needs increased emphasis. These activities should focus on increasing trust with partners and stakeholders, which was one of the threats identified.

People. NOAA Fisheries continues its efforts to address employee morale using the FEVS as one of its primary performance metrics over time. The reviews' recommendation to support training activities for new and current scientists in high priority areas is being implemented; it is also being broadened to all job categories in the agency. NOAA Fisheries is also continuing involvement in the NMFS-Sea Grant Fellowship and continuing the Quantitative Ecology and Socioeconomics Training (QUEST[23]) program. Training opportunities for current scientists include the National Stock Assessment Workshop and the Protected Species Assessment Workshop. Each region is devoting more resources to professional development, mentoring, and temporary details.

Organization. The reviews recommended strengthening Annual Priority-Based Resourcing/ Strategic Resource Management and in fiscal year 2018, all SCs began implementing a priority-based resourcing process for annual budget planning. This effort prioritizes operational science that supports scientific advice for management and has identified areas where increased efficiencies could reduce costs (e.g., electronic-based data entry replacing paper-based data entry). Continued use of these prioritization processes will be required to address the resource challenges that the agency faces. The program reviews indicated that core science activities are now at risk due to funding constraints; prioritization and seeking efficiencies have limited utility when evaluating all high priority, highly efficient programs, especially given NOAA Fisheries' multifaceted mission.

Based in part on the program reviews, NOAA Fisheries developed Regional Strategic Plans[24] that combine science and management activities conducted in each of the five regions (the Northwest and Southwest Fisheries Science Center have a joint regional strategic plan with the West Coast Regional Office). All SCs have strategic plans but the reviews pointed out the regional plans would improve the link between science and management. The Regional Strategic Plans were developed with input from regional management partners including the Fishery Management Councils and Marine Fisheries Commission thereby strengthening regional management-related partnerships. These plans will also strengthen the alignment between science and management in each of the five regions.

[23] NOAA Fisheries' Quantitative Ecology and Socioeconomics Training (QUEST) Program website. [Available at https://www.fisheries.noaa.gov/content/quantitative-ecology-and-socioeconomics-training-quest-program]
[24] NOAA Fisheries Strategic Plans website. [Available at https://www.fisheries.noaa.gov/resource/document/noaa-fisheries-strategic-plans]

Recommended reorganizations for some of the SCs have been initiated and in some cases completed. The purpose of the efforts have been to improve coordination among program areas. The recommendations related to reorganizations were specific to specific SCs and their programs, and not at the national level. As an example, in the Northeast Fisheries Science Center, the Atlantic Salmon team was moved to the protected species group to better align science activities conducted in support of the Endangered Species Act. Reorganizations are also underway in the Southeast Fisheries Science Center to align the organization around programs rather than geography.

The recommended strengthening of the Annual Priority Based Resourcing/Strategic Resource Management has largely been completed. However, there is growing recognition that annual planning in a changing system (e.g., budget, environment) and complex mission (e.g., fisheries, wildlife, ecosystems) can lead to negative, unintended consequences (e.g., reduction of research capabilities, polarization of people and effort). The development of Regional Strategic Plans should provide a framework for annual planning. In addition, the need for multi-annual planning and more strategic decision-making is recognized.

Lessons Learned / Next Steps

Value of the reviews (Q9). To summarize, we need to ask the question, were the five years of intensive and quite time-consuming program reviews worth it? The answer is an unequivocal "yes". We learned a great deal, much of which we would not have known without the extensive set of reviews. The reviews also gave us the opportunity to summarize our science enterprise for ourselves, our partners, and our stakeholders, and to have our scientific enterprise reviewed by external experts in a public and transparent format. The main message from the reviews is that NOAA Fisheries science is world-class and the people working for NOAA Fisheries are dedicated and experienced. In this sense, the reviews were successful in reaffirming the quality and value of NOAA Fisheries science.

The next question is would we do five consecutive years of programmatic reviews again? Probably not in the immediate future. The five annual reviews were comprehensive and served an important purpose. Future reviews should build on what we have learned and be structured to capture evolving needs and questions. The salient point: based on what we learned, we took action and redirected efforts to improve and enhance the science conducted by NOAA Fisheries. That said, given the numerous recommendations provided across all reviews (Table 1), coupled to an environment with evolving priorities and significant resource challenges, we triaged our responses with some already implemented (see Response to Reviews above), some underway, and others deferred. Continued evaluations and assessments of our enterprise will tell how successful we have been in addressing the highest priority recommendations (Haas et al., 2019).

The program reviews occurred during a challenging time for NOAA Fisheries science, with declining budgets, a decreasing workforce, needs for reorganization, and increasing demands for science. The reviews pointed to the need to "increase resources", "hire additional people", and "do more". We don't disagree: NOAA Fisheries' mission supports important national resources and management programs that are successful in large part because of the investment in science. That said, the reviews also challenged us as leaders of the NOAA Fisheries science enterprise to emphasize four aspects of our mission: improving the culture of science for advice across the agency, systematic and strategic prioritization of all our science programs, strategies for developing and enhancing resources, and consistently messaging the benefits of the science executed by our people. There are of course important local and regional actions, but at the national level identifying these four key areas was of great value. Thus, completing this RoR has served as a unifying step for the agency's science enterprise.

Going forward, other forms of reviews are possible: regional reviews of science and management programs based on the Regional Strategic Plans (e.g., reviews of Fisheries Science Centers and their partner Regional Offices), or reviews of specific programs (e.g., of the NMFS Climate Science Strategy) across organizational units. Such targeted reviews could evaluate the ability of coupled science-management enterprises to meet the NOAA Fisheries mission. Other types of reviews are Laboratory Science reviews conducted by other line Offices, e.g., the Oceanic and Atmospheric Research's 2021 Chemical Sciences Laboratory[25] review.

NOAA Fisheries' R&D is on schedule for its next review[26] with the formulation of its charge underway. The review will build on the 2013-2017 program reviews and this RoR, and will evaluate fundamental components and the operation of our science enterprise. Recommendations will need to interweave the future of our scientific mission, our human/workforce proficiency, our institutional structures, and our ability to incorporate new technologies and methods of analyses, so that we can continue to provide sound scientific advice.

Organization/ People - Most important lessons (Q10) and consequential next steps (Q11). Many of the lessons learned are generic and can apply to many medium to large-sized science organizations, and/or natural resource management agencies. A clear message was the central role that the well-being and greater inclusion of people plays in the success of our enterprise. Increased attention on this is needed in the organization, particularly regarding employee morale and engagement. This has also been emphasized in recent FEVS results.

[25] NOAA OAR's 2021 Chemical Sciences Laboratory Review website. [Available at https://csl.noaa.gov/reviews/2021]

[26] From NAO-216-115A Section 5.08: Evaluation of NOAA's R&D activities will include regular, independent peer reviews performed at least every five years. These reviews shall assess R&D activities for quality of the science, as well as how well the activities meet NOAA's mission needs and/or requirements (i.e., relevance and performance).

A second organizational conclusion is learning how to conduct and provide science where the need is increasing and resources are decreasing. The need for science is discussed below. The resources needed for science require organization-wide consideration. NOAA Fisheries must articulate how the scientific capacity to support the agency's mission is being challenged. During the reviews, the loss of research capacity was noted. For example, from 1996 to 2008, NOAA Fisheries participated in the jointly funded National Science Foundation – National Oceanic and Atmospheric Administration's Global Ocean Ecosystems Dynamics (GLOBEC) Program with projects in the Northwest Atlantic, Northeast Pacific, and Antarctica (Fogarty and Powell, 2002). NOAA Fisheries committed people, laboratories, sea-days, and funding support to this tens-of-millions-of-dollars effort with the goal of understanding how physical processes influence marine ecosystem dynamics in order to predict the response of the ecosystem and the stability of its food web to climate change (Turner et al., 2013). In recent years, NOAA Fisheries' ability to engage in large-scale research related to fisheries and protected species has diminished. The decline in research activities has been accelerated by the prioritization processes that we developed – in part – in response to these reviews. As resources continue to decline and costs continue to rise, the high-priority, operational science activities (e.g., surveys, data collection, and stock assessments) are now at risk. We need to clearly articulate this risk in our evolving prioritization processes.

Part of rethinking our prioritization processes is developing a clear understanding of how much NOAA Fisheries should invest in future-focused, or forward looking, science. The mainstay of NOAA Fisheries science is operational – conducted with the specific goal to support marine resource management in the near-term. These activities are "high-priority" in our prioritization processes. The need for future-focused science is clear: to understand and solve emerging challenges to our mission, e.g., climate change, multisector ocean use, and working within socio-ecological systems. These future-focused issues can be viewed as (i) in competition for resources with the core operational science activities, or (ii) fundamental to being successful in our mission. NOAA Fisheries needs to address this apparent conflict, find a proper balance, and communicate the importance of science to inform decision making.

The program reviews also recognized a healthy tension of a national mission with large regional differences in specific issues. This creates challenges for national approaches and consistent prioritization of issues, yet several national efforts were recommended and applauded by the program reviews (EBFM Roadmap, Climate Science Strategy, Stock Assessment Improvement Plan). The tension between regional and national programs will persist and we need to work to maintain a healthy balance between the two. The program-specific science-to-management reviews identified above (e.g., a review of Climate Science in NOAA Fisheries, a review of Pacific Salmon recovery programs) could be used to deliberately evaluate the balance between regional and national roles.

We also recognize the need to evolve our workplaces to embrace more collaborative and openly learning cultures (Holling and Meffe, 1996; Shrum et al., 2007). What do we mean by this? Historically, our leadership approaches defined priorities and problems, directed planning, and identified solutions. Many organizations, particularly government organizations that need to answer to the Administration and Congressional priorities and be responsive to constituents, operate "top-down". However, this should not be exclusive of developing collaborative and inclusive approaches that foster team building, sharing of knowledge and information, valuing diverse views and input, and encouraging discussion of alternative priorities and approaches to deliver our mission. A learning organization is skilled at creating, acquiring, transferring, and acting on new knowledge (Garwin, 1993). Part of this shift in institutional leadership needs to define career pathways for scientists interested in contributing to the NOAA Fisheries mission, as well as recruiting and retaining talent. While progress has been made in evolving our culture (e.g., establishment of Employee Action Teams, within Center cross-Divisional teams, joint strategic planning between Science Centers and Regional Offices, and others), continued and deliberate efforts are needed.

Finally, it is interesting that the reviews brought up limitations in some aspects of the functioning of NOAA's administrative procedures. Some of the issues raised in the reviews include increased administrative requirements on scientific positions and increased costs related to contracting and hiring without perceived increases in the quality of service. Achieving a balance in the cost of support functions with decreasing resources available for the mission are concerning and suggest program reviews of administrative functions, e.g., Operations, Management and Information (OMI) offices, could be valuable across the agency to evaluate performance and make recommendations for improvement.

Science - Most important lessons (Q10) and consequential next steps (Q11). The present set of program reviews represent another plank in the rationale for Ecosystem Approaches to Management, a future-focused issue. The mission is expanding, not shifting. Operational science needs – surveys, sample and data collection, and assessments – are increasing, not decreasing. Other mission areas are growing, e.g., aquaculture, multi-sector ocean uses, habitat conservation and restoration, and climate science. The reviews were clear that NOAA Fisheries needs to take a systematic view of living marine resource management, in light of climate change, changing ocean ecosystems, and growing ocean use. Yet transitioning to accommodate an ecosystem approach in an organization and management system developed around single species and single sectors is challenging. We need to address this challenge more deliberately.

Related to the need for Ecosystem Approaches to Management, all the reviews emphasized that links need to be strengthened across disciplines and regions. This relates to the prior point about developing a collaborative organizational culture and emphasizes the need for interdisciplinary science that studies ecosystems as a whole, including humans (i.e., socio-ecological systems). This transition is not easy, as interdisciplinary efforts by their nature are difficult, messy, and

atypical compared to traditional disciplinary efforts, but despite these difficulties, we need to be more integrative and interdisciplinary.

The program reviews also identified a number of new technologies and approaches that NOAA Fisheries should embrace. We recognize the value of new technologies to science and have supported strategic initiatives in image recognition, such as Video and Image Analytics for a Marine Environment (VIAME) (Richards et al., 2019) and surveying in non-trawlable areas. Recently NOAA Fisheries supported Strategic Initiatives in genomics and Fourier transform near-infrared spectroscopy for aging otoliths (Helser et al., 2019). NOAA has also identified new science and technologies as focus areas emphasizing uncrewed systems[27], artificial intelligence[28], 'omics[29], citizen science, and cloud computing[30]. These new science and technology areas are part of a future-focused vision discussed above. One caveat, with which NOAA Fisheries has experience, is that developing new technologies and then including them in operational science is harder than it seems. Learning from the need to prioritize limited resources and from stewarding some of the world's longest marine ecosystem time series, there should be a strong business case for developing new technologies, ability to maintain the integrity of time series, and a plan for supporting research-to-operations (R2O) and research to applications (R2X).

As for new approaches, the reviews identified the value of MSEs, an area in which NOAA Fisheries has invested. This has initiated conversations with our management partners and is developing a new category of scientific support for management (Deroba et al., 2019). Similarly, the development of approaches to examine the effect of climate change on living marine resources promises to be quite valuable and is already of high interest to our management partners. The development of Climate Integrated Modeling from physical to human sciences also is providing a new category of scientific support for management, one that explicitly includes changing climate conditions (Hollowed et al., 2020). These activities are a component of a future-focused science agenda.

Stakeholders, Partners and Collaboration - Most important lessons (Q10) and consequential next steps (Q11). NOAA Fisheries needs to increase collaborative science efforts and needs to include partners and stakeholders in the scientific process (Hare, 2020). There are numerous ongoing activities and existing structures for these types of collaborative efforts (e.g., Take-Reduction Teams, Stock Assessment Working Groups, cooperative research projects). While the terms co-

[27] NOAA. 2020. NOAA Uncrewed Systems Strategy: Maximizing Value for Science-based Mission Support, 12 p. [Available at [https://sciencecouncil.noaa.gov/LinkClick.aspx?fileticket=ZTSJagQ-IIk%3d&portalid=0]
[28] NOAA. 2020. NOAA's Artificial Intelligence Strategy: Analytics for Next-Generation Earth Science, 8 p. [Available at https://sciencecouncil.noaa.gov/Portals/0/2020%20AI%20Strategy.pdf?ver=2020-09-17-150016-857]
[29] NOAA. 2020. NOAA's 'Omics Strategy: Strategic Application of Transformational Tools, 8 p. [Available at https://sciencecouncil.noaa.gov/Portals/0/2020%20Omics%20Strategy.pdf?ver=2020-09-17-150026-760]
[30] NOAA. 2020. NOAA's Cloud Strategy: Maximizing the Value of NOAA's Cloud Services, 12 p. [Available at https://sciencecouncil.noaa.gov/Portals/0/2020%20Cloud%20Strategy.pdf?ver=2020-09-17-150020-887]

learning, co-production, and adaptive management are becoming mainstream, the reviews clearly recommend that NOAA Fisheries continue to advance these concepts. The recognition of the importance of co-production is not unique to marine resource management and applies much more broadly (Norström et al., 2020). Several of the reviews pointed out one of the strengths of fisheries management is the involvement of stakeholders in decision-making (see Dell'Apa et al., 2012) and the concept of co-learning, co-production, and adaptive management are also a component of ecosystem approaches to management (Link, 2010).

Collaboration also has other benefits, including additional resources and scientific expertise. NOAA Fisheries is invested in NOAA Cooperative Institutes and works to varying degrees with state Sea Grant programs and specific university collaborators. These types of activities should continue to be encouraged at the national and regional level. The transition in organizational culture discussed above is a critical element to increasing collaborations *writ large*.

A final piece is the need for improved internal and external communications. In a collaborative culture, communication is multidirectional. As an organization, NOAA Fisheries has a largely unidirectional communication style – organizing and communicating outward. The inward communications are presently uneven. A consequential step we can take to improve relationships with our stakeholders and partners is to develop a multipronged communication plan that provides for a range of engagement from the sharing of information to the co-production of science products. In this process, information is produced consistent with stakeholder and partner needs and interests (industry, community, public, etc.).

2021 Epilogue

Much of this "Review of Reviews" was conducted before the renewed reevaluation of discrimination in American society and before the major disruption caused by the coronavirus pandemic (Severe Acute Respiratory Syndrome Coronavirus 2 or SARS-CoV-2; hereafter COVID-19). These two landmark events are related to some of the lessons learned during the program reviews.

Evidence of discrimination and the continued need to improve diversity, equity, and inclusion in the U.S. workforce is deeply distressing and has caused fundamental reevaluation of our guiding principles. As a U.S. institution, NOAA Fisheries should reflect society at-large. We have a strong equal employment opportunity[31] ethic and clear organizational statements as to the importance of diversity, equity, and inclusion[32]. That said, we need to do more to increase diversity within our organization and to make our organization more inclusive of the unique

[31] NOAA Policy Statement on Equal Employment Opportunity. [Available at https://www.noaa.gov/organization/inclusion-and-civil-rights/policy-statement-on-equal-employment-opportunity]
[32] NOAA Policy Statement on Diversity and Inclusion. [Available at https://www.noaa.gov/organization/inclusion-and-civil-rights/noaa-policy-statement-on-diversity-and-inclusion]

attributes of all team members (NOAA Fisheries[33]). The value of diversity and equity to science is well documented (Johnson et al., 2016). Thus, we need to create and recruit from diverse applicant pools for positions in NOAA Fisheries. To have diverse applicant pools, we need to work with academic institutions at all levels, especially colleges and universities, in developing and supporting diversity in science, technology, engineering, and mathematics. NOAA supports regional and disciplinary programs focused on specific parts of the educational system (e.g., Partnership Education Program[34], Cooperative Science Centers[35], NMFS-Sea Grant Doctoral Fellowships[36]), but NOAA Fisheries does not yet have a coordinated effort to develop the skills that the agency will need in the future nor to promote diversity in the development of those skills. In addition, in our efforts to promote a collaborative, learning culture, we need to ensure that the culture is inclusive of a diversity of individual perspectives and backgrounds. Some would argue that this is implicit in a collaborative culture, but it is necessary to be explicit and to take action directly aimed at increasing diversity and inclusivity.

As a result of the health and safety precautions required due to the COVID-19 pandemic, our scientific activities have been directly impacted, with most surveys and field data collection programs in 2020 cancelled or postponed (Link et al., 2021). NOAA Fisheries now must meet its mission with less rather than more data, as called for by most of the program reviews. In one sense this will drive innovation (e.g., Saildrones deployed in the Bering Sea[37]) and in another sense it will degrade the quality of scientific advice, at least in the short term. The COVID-19 pandemic has underscored that increasing our capacity for rapid innovation (a recommendation in the 2013 Data Collection program review) is essential if we are to prioritize new ways of collecting and managing data in face of current and future challenges (Link et al., 2021).

Our transition to a collaborative, learning culture is made even more important by the pandemic. The number of challenges arising as a result of COVID-19 is overwhelming. Allowing all individuals in the organization to learn together and identify and solve problems has been a strength. Traditional crisis management calls for a strong command-and-control approach. But distributed crisis management requires a much more collaborative approach because there is little to no experience with many of the challenges we face (Moynihan, 2008). Limiting ideas and direction to a few leaders will greatly limit our ability to adapt and respond. At the same time, an

[33] NOAA Fisheries Diversity and Inclusion website. [Available at https://www.fisheries.noaa.gov/topic/careers-more#diversity-&-inclusion]
[34] The Woods Hole Partnership Education Program (PEP) website. [Available at https://www.woodsholediversity.org/pep/]
[35] NOAA Office of Education Jose E. Serrano Educational Partnership Program with Minority Serving Institutions (EPP/MSI)-EPP/MSI Cooperative Science Centers website. [Available at https://www.noaa.gov/office-education/epp-msi/csc]
[36] NMFS-Sea Grant Joint Fellowship Program website. [Available at https://seagrant.noaa.gov/NMFS-SG-Fellowship]
[37] NOAA Fisheries. 2020. Autonomous Vehicles Help Scientists Estimate Fish Abundance While Protecting Human Health and Safety. [Available at https://www.fisheries.noaa.gov/feature-story/autonomous-vehicles-help-scientists-estimate-fish-abundance-while-protecting-human]

uncoordinated and uneven response is also not productive and further impairs equity and inclusion during a national crisis, underscoring the importance of a collaborative, well-coordinated approach. This is an opportunity to advance an ecosystem approach as we understand the effects of COVID-19 on our science, management, and the communities we serve.

The COVID-19 pandemic also showed NOAA Fisheries that a different approach to work is possible. In March 2020, NOAA transitioned to a mandatory telework status and, as of this writing (July 2021), most people are still teleworking. We now should ask "What is the role of telework and remote work in the future and what are our actual facility requirements to achieve our mission?" Certainly, our facilities need to provide space for laboratory work and for the staging and de-staging of field work. But how much office space we will need and how our facilities should be used in the future are important questions that we now need to address. In addition, the rapid shift to telework shows the efficacy of virtual work, the importance of information technology in every aspect of our work, and technology's essential role in ensuring continuity of mission in face of future catastrophic events. We should build upon these successes for the future of our work environment.

A final point is that all of us have a tremendous amount of respect and deep appreciation for the people who work for NOAA Fisheries. The program reviews identified the excellence and commitment of these people. Throughout the pandemic, we have seen everyone continue to work toward the mission, while enduring professional and personal hardships that were unthinkable during the program reviews. This serves as a reminder that the most important part of NOAA Fisheries and the top priority for future actions are the people in the agency.

Summary

The set of 34 program reviews is distinguished by the programmatic and national scale and the emphasis on scientific rigor. The willingness to be examined, study the reviews, and implement changes in response to the recommendations is founded within the central tenets of science. The reviews were undertaken recognizing that NOAA Fisheries must provide the best science available to inform living marine resources management. The issues connected to our mission are far-reaching and valuable economically and culturally. This best scientific information available needs to withstand the scrutiny of stakeholders, and the public-at-large. Acknowledging that there are areas in need of improvement is part of the scientific process and reflects NOAA Fisheries' credibility as a preeminent scientific organization.

In addition to the specific comments offered in the individual reviews (Table 1), we identified four areas for overall improvement: science, people, organization, and engagement with partners and stakeholders. It is worth highlighting again that while the program reviews addressed our

science, a clear and consistent message was the need to improve NOAA Fisheries as an organization, as was the need to increase the support of our people, and strengthen our relationships with partners and stakeholders. Our scientific challenges are complex, including adapting to climate change, increasing multi-sectoral ocean uses, and developing ecosystem approaches to management. As scientists, we were trained to address these challenges. The NOAA Fisheries of the future presents people, organizational, and relationship opportunities and challenges of a different sort – challenges that are common across many science and mission agencies. Our review of reviews – the RoR – has highlighted the need to continue to develop NOAA Fisheries science in tandem with NOAA Fisheries as a science organization.

References

Beamish, R.J., and B.J. Rothschild (eds.). 2009. The future of fisheries science in North America. Fish and Fisheries, Vol. 31, 736 p. Springer Science & Business Media.

Brown, S.K., M. Shivlani, R.F. Koeneke, D. Agnew, J. Byrd, M. Cryer, C. Dichmont, D. Die, W. Michaels, K. Reid, J. Rice, H. Sparholt, and J. Weinberg. 2020. Patterns and practices in fisheries assessment peer review systems. Marine Policy, vol. 17, article 103880, 11 p. https://doi.org/10.1016/j.marpol.2020.103880

Busch, D.S., R. Griffis, J. Link, K. Abrams, J. Baker, R.E. Brainard, M. Ford, J.A. Hare, A. Himes-Cornell, A. Hollowed, N.J. Mantua, S. McClatchie, M. McClure, M.W. Nelson, K. Osgood, J.O. Peterson, M. Rust, V. Saba, M.F. Sigler, S. Sykora-Bodie, C. Toole, E. Thunberg, R.S. Waples, and R. Merrick. 2016. Climate science strategy of the US National Marine Fisheries Service, Marine Policy 74:58-67. https://doi.org/10.1016/j.marpol.2016.09.001

Dell'Apa, A., L. Schiavinato, and R.A. Rulifson. 2012. The Magnuson–Stevens act (1976) and its reauthorizations: Failure or success for the implementation of fishery sustainability and management in the US? Marine Policy 36(3):673-680.

Deroba, J.J., S.K. Gaichas, M.Y. Lee, R.G. Feeney, D. Boelke, and B.J. Irwin. 2019. The dream and the reality: meeting decision-making time frames while incorporating ecosystem and economic models into management strategy evaluation. Canadian Journal of Aquatic & Fisheries Science, 76(7): 1112-1133.

Fine, L. 2009. The SWOT Analysis: Using your Strength to overcome Weaknesses, Using Opportunities to overcome Threats, 78 p. CreateSpace Independent Publishing Platform.

Fogarty, M.J., and T.M. Powell. 2002. An overview of the US GLOBEC program. Oceanography 15(2):4–12. https://doi.org/10.5670/oceanog.2002.17

Garwin, D.A. 1993. Building a learning organization. Harvard Business Review 71(4):73-91.

Haas, B., M. Haward, J. McGee, and A. Fleming. 2019. The influence of performance reviews on regional fisheries management organizations. ICES Journal of Marine Science 76(7):2082-2089.

Hare, J.A. 2020. Ten lessons from the frontlines of science in support of fisheries management. *ICES* Journal of Marine Science 77(3):870-877.

Helser, T.E., I. Benson, J. Erickson, J. Healy, C. Kastelle, and J.A. Short. 2019. 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 Aquatic & Fisheries Science 76(5):780-789.

Holling, C.S. and G.K. Meffe. 1996. Command and control and the pathology of natural resource management. Conservation Biology 10(2):328-337.

Hollowed, A.B., K.K. Holsman, A.C. Haynie, A.J. Hermann, A.E. Punt, K. Aydin, J.N. Ianelli, S. Kasperski, W. Cheng, A. Faig, K.A. Kearney, J.C.P Reum, P. Spencer, I. Spies, W. Stockhausen, C.S. Szuwalski, G.A. Whitehouse, and T.K. Wilderbuer. 2020. Integrated modeling to evaluate climate change impacts on coupled social-ecological systems in Alaska. Frontiers in Marine Science 6:775. https://doi.org/10.3389/fmars.2019.00775

Johnson, A., M.J. Huggans, D. Siegfried, and L. Braxton. 2016. Strategies for increasing diversity in the ocean science workforce through mentoring. Oceanography 29(1):46-54.

Johnson, T.R., and B.J. McCay. 2012. Trading expertise: The rise and demise of an industry/government committee on survey trawl design. Maritime Studies 11(1):14.

Kaplan, I.M., and B.J. McCay. 2004. Cooperative research, co-management and the social dimension of fisheries science and management. Marine Policy 28(3):257-258.

Kelley, E. (ed.). 2016. Large marine ecosystems of the world: an annotated bibliography. NOAA Tech. Memo. NMFS-F/SPO-167, 94 p. [Available at https://spo.nmfs.noaa.gov/sites/default/files/TM167.pdf]

Link, J. 2010. Ecosystem-based fisheries management: confronting tradeoffs, 207 p. Cambridge University Press.

Link, J.S., F. Werner, K. Werner, J. Walter, M. Strom, M. Seki, F. Schwing, J. Rusin, C. Porch, K. Osgood, K. Moline, R. Methot, P. Lynch, D. Lipton, K. Koch, E. Howell, J. A. Hare, R. Foy, D. Detlor, L. Desfosse, J. Crofts, and N. Cabana. 2021. A NOAA Fisheries science perspective on the conditions during and post COVID-19: Challenges, observations, and some possible solutions, or why the future is upon us. Canadian Journal of Aquatic & Fisheries Science 78:1–12. https://doi.org/10.1139/cjfas-2020-0346.

Lynch, P.D., R.D. Methot, and J.S. Link. 2018. Implementing a next generation stock assessment enterprise. An update to the NOAA fisheries stock assessment improvement plan. NOAA Tech. Memo. NMFS-F/SPO-183, 127 p. [Available at https://spo.nmfs.noaa.gov/content/tech-memo/SAIP2018]

Margolis, Sarah, Alan Lowther, Lisa Peterson, Frank Schwing, and Karen Sender. 2020. Fisheries Information Management Modernization Workshop. NOAA Tech. Memo. NMFS-F/SPO-204, 85 p. [Available at https://spo.nmfs.noaa.gov/content/tech-memo/fisheries-information-management-modernization-workshop]

Milly, P.C., J. Betancourt, M. Falkenmark, R.M. Hirsch, Z.W. Kundzewicz, D.P. Lettenmaier, and R.J. Stouffer. 2008. Stationarity is dead: Whither water management? Science 319:573-574.

Moynihan, D.P. 2008. Learning under uncertainty: Networks in crisis management. Public Administration Review 68(2):350-365.

Murphy, D.D., and P.S. Weiland. 2016. Guidance on the use of best available science under the US Endangered Species Act. Environmental Management 58(1):1-14. https://doi.org/10.1007/s00267-016-0697-z

NMFS. 2011. NMFS Response to Contract Report: "Building Capacity of the NMFS Science Enterprise,"12 p. [Available at https://media.fisheries.noaa.gov/2021-05/NMFS%20Response%20to%20Sissenwine%20and%20Rothschild_Final.pdf]

Norström, A.V., C. Cvitanovic, M.F. Löf, et al. 2020. Principles for knowledge co-production in sustainability research. Nature Sustainability 3:182–190. https://doi.org/10.1038/s41893-019-0448-2

NRC [National Research Council]. 1998. Improving Fish Stock Assessments, 177 p. National Academy Press. Washington, D.C.

Payne, M.R., M. Barange, W.W.L Cheung, B.R. MacKenzie, H.P. Batchelder, X. Cormon, T.D. Eddy, J.A. Fernandes, A.B. Hollowed, M.C. Jones, J.S. Link, P. Neubauer, I. Ortiz, A.M. Queirós, and J.R. Paula. 2016. Uncertainties in projecting climate-change impacts in marine

ecosystems. ICES Journal of Marine Science 73(5): 1272–1282. https://doi.org/10.1093/icesjms/fsv231

Pulliam, H.R., M.E. Soulé, and D.M. Waller. 1998. Independent scientific review in natural resource management. Conservation Biology 12(2):268-270.

Richards B.L., O. Beijbom, M.D. Campbell, M.E. Clarke, G. Cutter, M. Dawkins, D. Edgington, D.R. Hart, M.C. Hill, A. Hoogs, D. Kriegman, E.E. Moreland, T.A. Oliver, W.L. Michaels, M. Piacentino, A.K. Rollo, C. Thompson, F. Wallace, I.D. Williams, and K. Williams. 2019. Automated Analysis of Underwater Imagery: Accomplishments, Products, and Vision. NOAA Tech. Memo. NOAA-TM-NMFS-PIFSC-83, 59 p. https://doi.org/10.25923/0cwf-4714

Ruckelshaus, M., T. Klinger, N. Knowlton, and D.P. DeMaster. 2008. Marine ecosystem-based management in practice: scientific and governance challenges. BioScience 58(1):53-63.

Shrum, W., J. Genuth, and I. Chompalov. 2007. Structures of scientific collaboration 296 p. MIT Press.

Turner, E., D.B. Haidvogel, E.E. Hofmann, H.P. Batchelder, M.J. Fogarty, and T. Powell. 2013. US GLOBEC: Program goals, approaches, and advances. Oceanography 26(4):12-21.

Appendix 1 - List of Program Reviewers 2013–2017

Reviewers in italics served on more than one review panel.

2013 Data Collection and Management

AFSC

Rich Ferrero	U.S. Geological Survey
George Hunt	University of Washington
Terry Quinn	University of Alaska
John Stein	NOAA/NMFS Northwest Fisheries Science Center
Jim Nance	NOAA/NMFS Southeast Fisheries Science Center
Amy Holman	NOAA National Ocean Service

NEFSC

Jon Helge Vølstad	Institute of Marine Research, Norway
Paul Fernandes	University of Aberdeen, UK
Rick Stanley	Department of Fisheries and Oceans, Canada
David Somerton	NOAA/NMFS Alaska Fisheries Science Center
Beth Turner	NOAA National Ocean Service
Joseph E. Hightower	U.S. Geological Survey

NWFSC

Robert J. Rosenbauer	U.S. Geological Survey, Menlo Park, California
Andrew Cooper	Simon Fraser University, Vancouver, Canada
Don Gunderson	University of Washington
James Ianelli	NOAA/NMFS Alaska Fisheries Science Center
Steven Katz	NOAA/NMFS Channel Islands Marine Sanctuary
Russell Nelson	NOAA/NMFS Alaska Fisheries Science Center (retired)

OST

Stephen Bartone	Gulf of Mexico Fishery Management Council (retired)
Jack Dunigan	NOAA/NOS/NMFS, Atlantic States Marine Fisheries Commission (retired)
Michael Hinton	Inter-American Tropical Tuna Commission
Steve Jordan	Environmental Protection Agency
Bonnie Ponwith	NOAA/NMFS Southeast Fisheries Science Center
Ed Waters	Gentner Consulting Group

PIFSC

Gordon Tribble	U.S. Geological Survey
Craig MacDonald	NOAA Stellwagen Bank National Marine Sanctuary
Dave Colpo	Pacific States Marine Fisheries Commission
Steve Martell	International Pacific Halibut Commission
Joseph E. Powers	Louisiana State University
Steve Turner	NOAA/NMFS Southeast Fisheries Science Center
Cisco Werner	NOAA/NMFS Southwest Fisheries Science Center

SEFSC

Cecil Jennings	U.S. Geological Survey/University of Georgia
Robert Ahrens	University of Florida
Andrew Cooper	Simon Fraser University, Vancouver, Canada

Wendy Gabriel	NOAA/NMFS Northeast Fisheries Science Center
Mark Monaco	NOAA National Ocean Service

SWFSC

Donna Schroeder	Bureau of Ocean Energy Management
Rick Deriso	Inter-American Tropical Tuna Commission
Larry Jacobson	NOAA/NMFS Northeast Fisheries Science Center
Sam Pooley	NOAA/NMFS Pacific Islands Fisheries Science Center
Chris Sabine	NOAA/OAR Pacific Marine Environmental Laboratory

2014 Stock Assessment Programs

AFSC

Bruce Leaman	International Pacific Halibut Commission
Bill Clark	International Pacific Halibut Commission (retired)
David Fluharty	University of Washington
Paul Rago	Northeast Fisheries Science Center
Christopher Sabine	NOAA/OAR Pacific Marine Environmental Laboratory
John Stein	NOAA/NMFS Northwest Fisheries Science Center

NEFSC

John Armor	NOAA National Ocean Service
Mark Dickey-Collas	International Council for Exploration of the Sea
Patricia Livingston	NOAA/NMFS Alaska Fisheries Science Center
Gunnar Stefansson	University of Iceland
Jon Helge Vølstad	Institute of Marine Research, Norway
Stephen Walsh	Department of Fisheries and Oceans, Canada

NWFSC

Richard Ferrero	U.S. Geological Survey
Louis Botsford	University of California, Davis
Andrew Cooper	Simon Fraser University, Vancouver, Canada
James Ianelli	NOAA/NMFS Alaska Fisheries Science Center
Genevieve Nesslag	Atlantic States Marine Fisheries Commission
Ian Stewart	International Pacific Halibut Commission

OST

Jack Dunnigan	NOAA NOS/NMFS, Atlantic States Marine Fisheries Commission (retired)
Mark Dickey-Collas	International Council for the Exploration of the Sea
Mary Erickson	National Centers for Coastal and Ocean Science
Pat Livingston	NOAA/NMFS, Alaska Fisheries Science Center
Bob O'Boyle	Beta Scientific Consulting, Inc.

PIFSC

Steve Murawski	University of South Florida
Yong Chen	University of Maine, Orono
Steve Martell	International Pacific Halibut Commission
Keith Criddle	University of Alaska, Fairbanks at Juneau
Cisco Werner	NOAA/NMFS Southwest Fisheries Science Center

SEFSC

Michael Hansen	U.S. Geological Survey - Great Lakes Science Center

Ewen Bell	UK Center for Environment, Fisheries and Aquaculture Science
Joe Hightower	NC State University, Cooperative Fish and Wildlife Research Unit
Bob Atlas	NOAA OAR Atlantic Oceanographic and Meteorological Lab.
Bill Karp	NOAA/NMFS Northeast Fisheries Science Center

SWFSC

Dan Howard	Sanctuary Superintendent, Cordell Bank NMS, NOAA NOS
Anne Hollowed	NOAA/NMFS Alaska Fisheries Science Center
Samuel Pooley	NOAA/NMFS Pacific Islands Fisheries Science Center
Jake Schweigert	Department of Fisheries and Oceans, Canada (retired)
Nathan Taylor	Department of Fisheries and Oceans, Canada

2015 Protected Species Science

AFSC

Jim Harvey	Moss Landing Marine Laboratory
Laura Cowen	University of Victoria
Mike Simpkins	NOAA/NMFS Northeast Fisheries Science Center
John Stein	NOAA/NMFS Northwest Fisheries Science Center
Mike Tillman	NOAA/NMFS Southwest Fisheries Science Center (retired)

NEFSC

Daryl J. Boness	Senior Scientist, Smithsonian (retired)
Jamie Gibson	Department of Fisheries and Oceans, Canada
Garry Stenson	Department of Fisheries and Oceans, Canada
Robin S. Waples	NOAA/NMFS Northwest Fisheries Science Center

NWFSC

Daniel Schindler	University of Washington
David Hankin	Humboldt State University
Jennifer Ruesink	University of Washington
Anke Mueller-Solger	U.S. Geological Survey
John Kocik	NOAA/NMFS Northeast Fisheries Science Center
Ken Currens	Northwest Indian Fisheries Commission

OST

N/A

PIFSC

David Helweg	U.S. Geological Survey, Pacific Islands Climate Science Center
Douglas DeMaster	NOAA/NMFS Alaska Fisheries Science Center
Jim Estes	Long Marine Laboratory, University of California at Santa Cruz
Frank Paladino	Indiana-Purdue University
Robin Waples	NOAA/NMFS Northwest Fisheries Science Center

SEFSC

Bill Kendall	USGS Colorado Cooperative Fish and Wildlife Research Unit
Selina Heppell	Oregon State University
Tim Ragan	Marine Mammal Commission (retired)
Gustavo Goni	NOAA OAR, Atlantic Oceanographic and Meteorological Lab.
Lisa Ballance	NOAA/NMFS Southwest Fisheries Science Center

SWFSC

Frances Gulland	The Marine Mammal Center, U.S.
Scott Baker	Oregon State University
Phil Clapham	NOAA/NMFS Alaska Fisheries Science Center
Selina Heppell	Oregon State University
Bonnie Ponwith	NOAA/NMFS Southeast Fisheries Science Center
Lorenzo Rojas-Bracho	Coordinación de Investigación y Conservación de Mamíferos Marinos, INECC, C/O CICESE, Ensenada, México

2016 Ecosystem, Climate, Habitat Science

AFSC

Beth Turner	NOAA National Ocean Service
Manuel Barange	Plymouth Laboratory, UK
Mike Dagg	Louisiana Universities Marine Consortium (retired)
Beth Fulton	Commonwealth Scientific and Industrial Research Org., Australia
Sarah Gaichas	NOAA/NMFS Northeast Fisheries Science Center
Mike Seki	NOAA/NMFS Pacific Islands Fisheries Science Center

NEFSC

Charles Stock	NOAA/OAR Geophysical Fluid Dynamics Laboratory
Cisco Werner	NOAA/NMFS Fisheries Southwest Fisheries Science Center
Jeremy Collie	Graduate School of Oceanography, University of Rhode Island
Jon Helge Volstad	Institute of Marine Research, Norway
Simon Jennings	Center for Environment, Fisheries, and Aquaculture Science, UK

NWFSC

David Fluharty	University of Washington
Beth Fulton	CSIRO, Hobart, Tasmania, Australia
Sarah Gaichas	NOAA /NMFS Northeast Fisheries Science Center
Ian Perry	Department of Fisheries and Oceans, Canada
Ellen Pikitch	Stonybrook University, Stonybrook, NY

OST

David Fluharty	University of Washington
Mark Dickey-Collas	International Council for the Exploration of the Sea
Michael Seki	NOAA/NMFS Pacific Islands Fisheries Science Center
Michael Sigler	NOAA/NMFS Alaska Fisheries Science Center
Christopher Sabine	NOAA/OAR Pacific Marine Environmental Laboratory

PIFSC

Jo-Ann Leong	Hawai‘i Institute of Marine Biology
Michael Fogarty	NOAA/NMFS Northeast Fisheries Science Center
Cisco Werner	NOAA/NMFS Southwest Fisheries Science Center
Chris Kelble	NOAA/OAR Atlantic Oceanographic & Meteorological Laboratory

Anne Cohen	Woods Hole Oceanographic Institution
Jeff Drazen	University of Hawai'i

SEFSC

Jake Rice	Department of Fisheries and Oceans, Canada (emeritus)
Peter Ortner	Univ. of Miami Rosenstiel School of Mar. & Atmosph. Sci. (emeritus)
Charles Birkeland	Univ. of Hawai'i, Hawaii Cooperative Fisheries Res. Unit (emeritus)
Albert Hermann	NOAA/OAR Pacific Marine Environmental Lab / JISAO
Jon Hare	NOAA/NMFS Northeast Fisheries Science Center

SWFSC

Robin Webb	NOAA/OAR Physical Sciences Laboratory
Dan Costa	University of California, Santa Cruz
Éva Plagányi-Lloyd	Commonwealth Scientific and Industrial Research Org., Australia
Jeff Polovina	NOAA/NMFS Pacific Islands Fisheries Science Center
Eileen Hofmann	Old Dominion University
Doug DeMaster	NOAA/NMFS Alaska Fisheries Science Center

2017 Economics and Human Dimensions

AFSC

Ralph Townsend	University of Alaska - Anchorage
Vic Adamowicz	University of Alberta
Ben Muse	NOAA/NMFS Alaska Regional Office (retired)
Patrica M. Clay	NOAA/NMFS Northeast Fisheries Science Center
Bonnie Ponwith	NOAA/NMFS Southeast Fisheries Science Center

NEFSC

Theo Brainerd	NOAA/NMFS Southeast Fisheries Science Center
Theresa Goedeke	NOAA National Ocean Service
Mike Orbach	Duke University
Kathleen Segerson	University of Connecticut
Tracy Yandle	Emory University

NWFSC

James N. Sanchirico	University of California, Davis
Steve Freese	NOAA/NMFS West Coast Regional Office (retired)
Robert J. Johnston	Clark University
Arielle Levine	San Diego State University
Scott Steinback	NOAA/NMFS Northeast Fisheries Science Center

OST

John Whitehead	Appalachian State University
J*ames Sanchirico*	University of California, Davis
Richard B. Robins, Jr.	Mid-Atlantic Fishery Management Council Chairman (retired)
Emily Menashes	NOAA/NMFS Office of Sustainable Fisheries
Theresa L. Goedeke	NOAA National Ocean Service

PIFSC

Sherry Larkin	University of Florida
Ron Felthoven	NOAA/NMFS Alaska Fisheries Science Center

Kirsten Oleson	University of Hawai'i
Melissa Poe	University of Washington Sea Grant
Christopher Hawkins	Coastlines Group, LLC

SEFSC

Lee Anderson	College of Earth, Ocean and Env., University of Delaware (emeritus)
Shirley Fiske	Department of Anthropology, University of Maryland
Timothy Haab	Dept. of Agricultural, Env. & Developmental Econ., Ohio State University
Eric Thunberg	NOAA/NMFS Northeast Fisheries Science Center
Rebecca Lent	Executive Director, Marine Mammal Commission

SWFSC

Sam G. Pooley	University of Hawaii
Jeff Michael	University of the Pacific
Kenneth McConnell	University of Maryland
Olivier Thebaud	IFREMER, Maritime Economics Unit, UMR AMURE, France
Lisa Colburn	NOAA/NMFS Northeast Fisheries Science Center

Appendix 2 - List of full web addresses for documents in Table 2

Data Collection and Management (2013):

PIFSC:
Review: https://media.fisheries.noaa.gov/2021-05/PIFSC%20MSRA%20data%20review%20summary%20reports%202013.pdf
Response: https://media.fisheries.noaa.gov/2021-05/PIFSC_External%20Review%20Response%202013.pdf

AFSC:
Review: https://media.fisheries.noaa.gov/2021-05/AFSC%20program%20review%20summary%20report%202013.pdf
Response: https://media.fisheries.noaa.gov/2021-05/FD%20FI%20Program%20Review%20AFSC%20Response%20Final%202013.pdf

NWFSC:
Review: https://media.fisheries.noaa.gov/2021-05/Combined_Panel_Final_Report-NWFSC_Data_Review_2013.pdf
Response: https://media.fisheries.noaa.gov/2021-05/NWFSC_PrgmRevResp2013_Final.pdf

SWFSC:
Review: https://media.fisheries.noaa.gov/2021-05/SWFSC_Summary_and_Individual_Reports%202013.pdf
Response: https://media.fisheries.noaa.gov/2021-05/SWFSC_ExternalReviewResponse_Final_19Dec13.pdf

SEFSC:
Review: https://media.fisheries.noaa.gov/2021-05/SEFSC%20Data%20Peer%20Reviewer%27s%20Reports_June%202013.pdf
Response: https://media.fisheries.noaa.gov/2021-05/SEFSC_Data%20Peer%20Review_2013.pdf

NEFSC:
Review: https://media.fisheries.noaa.gov/2021-05/NEFSC_Peer%20Review%20Summary%20Report%202013.pdf
Response: https://media.fisheries.noaa.gov/2021-05/NEFSCDirectorsMemo2013.pdf

OST:
Review: https://media.fisheries.noaa.gov/2020-10/ST%202013%20Review%20of%20the%20FINs%20-%20Compiled%20Results.pdf
Response: https://media.fisheries.noaa.gov/2021-05/ST%20FINs%20Review%20Response%202013-%20Final.pdf

National Level:
Response: https://media.fisheries.noaa.gov/2021-05/NationalProgramReviewResponse_2013_Final.pdf

Fisheries Stock Assessment Programs (2014):

PIFSC:
Review: https://media.fisheries.noaa.gov/2021-05/2014%20PIFSC%20Stock%20Assessment%20review%20reports.pdf
Response: https://media.fisheries.noaa.gov/2021-05/2014%20PIFSC_External%20Review%20Response_FINAL.pdf

AFSC:
Review: https://media.fisheries.noaa.gov/2021-05/Report%20of%20the%20Review%20Panel%20for%20AFSC%20Assessment%20Science%20Program%20-%20Final%2003312014.pdf
Response: https://media.fisheries.noaa.gov/2021-05/AFSC_program_review_summary_response%202014.pdf

NWFSC:
Review: https://media.fisheries.noaa.gov/2021-05/NWFSC_Assessment_Program_Review_Reports_2014_Final_July3_2014.pdf
Response: https://media.fisheries.noaa.gov/2021-05/2014%20NWC%20SA%20Prg%20Rev%20Response%20_FINAL.pdf?null

SWFSC:
Review: https://media.fisheries.noaa.gov/2021-05/SWFSC_MSRA_SA_Program_Review_PanelReport_FINAL_8Aug2014.pdf
Response: https://media.fisheries.noaa.gov/2021-05/SWCenter_Response_13Nov2014_FINAL.pdf

SEFSC:
Review: https://media.fisheries.noaa.gov/2021-05/SEFSC%20Panel%20Report%202014%20-%20Chair.pdf
Response: https://media.fisheries.noaa.gov/2021-05/SEFSC_StockAssessmentPeerReviewResponse2014.pdf

NEFSC:
Review: https://media.fisheries.noaa.gov/2021-05/NEC%202014%20Stock%20Assessment%20Program%20Review%20reports.pdf
Response: https://media.fisheries.noaa.gov/2021-05/nefsc-directors-memo-2014-program-review.pdf

OST:
Review: https://media.fisheries.noaa.gov/2021-05/ST%20FY14%20Stock%20Assessment%20Program%20Review%20-%20Compiled%20reviewer%20reports.pdf?null
Response: https://media.fisheries.noaa.gov/2021-05/ST%20FY14%20Program%20Review%20Response_Final.pdf

National Level:
Response: https://media.fisheries.noaa.gov/2021-05/NationalProgramReviewResponse_2014_final.pdf

Protected Species Science (2015):

PIFSC:
Review: https://media.fisheries.noaa.gov/2021-05/Chair%E2%80%99s%20Summary%20PIFSC%20PRS%20Program%20Review%2013Aug15.pdf
Response: https://media.fisheries.noaa.gov/2021-05/2015%20PIFSC_External%20Review%20Response_FINAL%204Nov15.pdf

AFSC:
Review: https://media.fisheries.noaa.gov/2021-05/AFSC%202015%20Panel%20Summary_final.pdf
Response: https://media.fisheries.noaa.gov/2021-05/AFSC_program_review_summary_response%202015.pdf

NWFSC:
Review: https://media.fisheries.noaa.gov/2021-05/2015%20WC%20Marine%20Mammal%20and%20Turtle%20Review%20Reports.pdf
Response: https://media.fisheries.noaa.gov/2021-05/West%20Coast%20Centers%20Protected%20Fish%20review%20response%20Aug%207%202015.pdf

SWFSC:
Review: https://media.fisheries.noaa.gov/2021-05/2015%20WC%20Marine%20Mammal%20and%20Turtle%20Review%20Reports_0.pdf
Response: https://media.fisheries.noaa.gov/2021-05/Response%20-%20SW%26NWFSCs%20Science%20Review%20of%20M%20Mammals%20%26%20Turtles_FINAL%20Oct%2015.pdf

SEFSC:
Review: https://media.fisheries.noaa.gov/2021-05/2015%20SEFSC%20Protected%20Species%20Program%20Review%20Reports.pdf
Response: https://media.fisheries.noaa.gov/2021-05/SEFSC_Protected%20Species%20Peer%20Review%20Response_2015.pdf

NEFSC:
Review: https://media.fisheries.noaa.gov/2021-05/2015%20NEFSC%20Protected%20Species%20Program%20Review%20Report.pdf
Response: https://media.fisheries.noaa.gov/2021-05/2015%20NEFSC%20Directors%20Response%20final.pdf

OST:
Review: No program
Response: No program

National Level:
Response: https://media.fisheries.noaa.gov/2021-05/NationalProgramReviewResponse_protected%20species_2015_Final.pdf

Ecosystems, Climate, and Habitat Science (2016):

PIFSC:
Review: https://media.fisheries.noaa.gov/2021-05/PIFSC%202016%20Ecosystem%20Science%20Program%20Review%20Report.pdf
Response: https://media.fisheries.noaa.gov/2021-05/ecosystem_science_program_review_2016_pifsc_response_esd_final-mps.pdf

AFSC:
Review: https://media.fisheries.noaa.gov/2021-05/AFSC%202016%20Ecosystem%20Program%20Review%20Panelist%20Reports.pdf
Response: https://media.fisheries.noaa.gov/2021-05/AFSC_program_review_summary_response%202016.pdf

NWFSC:
Review: https://media.fisheries.noaa.gov/2021-05/NWFSC%20Ecosystem%20Panel%20Report%2025%20July%202016.pdf
Response: https://media.fisheries.noaa.gov/2021-05/NWFSC%27s%20Review%20of%20Ecosystem%20Science%202016-%20Response%20to%20Panelists%27%20Comments%20and%20Suggestions.pdf

SWFSC:
Review: https://media.fisheries.noaa.gov/2021-05/Ecosystem_Science_Review_SWFSC_Response_Reports_21Sept2016.pdf
Response: https://media.fisheries.noaa.gov/2021-05/Ecosystem_Science_Review_SWFSC_Response_Reports_21Sept2016.pdf

SEFSC:
Review: https://media.fisheries.noaa.gov/2021-05/2016%20SEFSC%20Ecosystem%20Science%20Review%20Reports.pdf
Response: https://media.fisheries.noaa.gov/2021-05/SEFSC_Ecosystem%20Peer%20Review%20Response_2016.pdf

NEFSC:
Review: https://media.fisheries.noaa.gov/2021-05/NEFSC%202016%20EcoReview%20Chair%20and%20Reviewers%20Reports.pdf
Response: https://media.fisheries.noaa.gov/2021-05/EDAB_2016_Ecosystem_Review_Response.pdf

OST:
Review: https://media.fisheries.noaa.gov/2021-05/ST%20FY16%20Ecosystem%20Science%20Program%20Review%20-%20Compiled%20Reviewer%20Reports.pdf
Response: https://media.fisheries.noaa.gov/2021-05/ST%20FY16%20Program%20Review%20Response_Final.pdf

National Level:
Response: https://media.fisheries.noaa.gov/2021-05/NationalProgramReviewResponse_2016_final.pdf

Economics and Human Dimensions (2017):

PIFSC:
Review: https://media.fisheries.noaa.gov/2021-05/PIFSC%202017_EconHD_ExtRev_FullPanelReports.pdf?null
Response: https://media.fisheries.noaa.gov/2021-05/2017-econ-hd-program-review-pifsc-response.pdf?null

AFSC:
Review: https://media.fisheries.noaa.gov/2021-05/AFSC%202017%20Review_Panel_Summary_Report.pdf?null
Response: https://media.fisheries.noaa.gov/2021-05/AFSC_Review_Summary_Response_2017.pdf?null

NWFSC:
Review: https://media.fisheries.noaa.gov/2021-05/NWFSC%202017%20Chair%20Summary%20and%20Panel%20Reviews%20NOAA%20Northwest%20Science%20Economics%20%26%20Human%20Dimen%20%281%29.pdf?null
Response: https://media.fisheries.noaa.gov/2021-05/NWFSC%20Economics%20%26%20Human%20Dimensions%20Science%20Program%20Review%20Response%20-%201-31-18.pdf?null

SWFSC:
Review: https://media.fisheries.noaa.gov/2021-05/SWFSC%202017_EconReview_PanelReport.pdf?null
Response: https://media.fisheries.noaa.gov/2021-05/SWFSC_Response_12Feb18_FINAL.pdf?null

SEFSC:
Review: https://media.fisheries.noaa.gov/2021-05/SEFSC%202017%20Economic%20and%20Human%20Dimensions%20Reviewer%20Reports.pdf?null
Response: https://media.fisheries.noaa.gov/2021-05/SEFSC_Economics%20and%20Human%20Dimensions%20Program%20Review%20Response_2017.pdf?null

NEFSC:
Review: https://media.fisheries.noaa.gov/2021-05/NEFSC%202017_Peer%20Review%20Summary%20Report.pdf?null
Response: https://media.fisheries.noaa.gov/2021-05/NEFSC_SSB_ReviewResponse_Sep11%202017.pdf?null

OST:
Review: https://media.fisheries.noaa.gov/2021-05/NMFS%20ST5%202017%20Program%20Review.pdf
Response: https://media.fisheries.noaa.gov/2021-05/ST%20FY17%20Economics%20%26%20Human%20Dimensions%20Program%20Review%20Response.pdf

National Level:
Response:
https://media.fisheries.noaa.gov/dam-migration/nationaleconprogramreviewresponse2017_final.pdf