



NOAA Ocean and Atmospheric Research
Ocean Acidification Program
U.S. Department of Commerce



NOAA Ocean Acidification Program 2020 REVIEW SUMMARY REPORT

September 28–30, 2020

REVIEW PANEL

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Figure 1. OA-Trifecta themes of the Ocean Acidification Program. Environmental monitoring research supports efforts that document and detect the progression of OA in the environment, biological sensitivity research characterizes and enhances our understanding of species, community, and ecosystem response, and human dimensions research investigates the impacts OA has on human communities.

Figure 2. Impact of Ocean Acidification Program scientific journal articles. A.) Non-cumulative count of other articles that have cited OAP articles per year from fiscal years 2015 through 2019. B.) OAP articles have been cited by authors affiliated with institutions in 139 countries and territories. Information and graphics developed and provided by the NOAA Library.

Table 1. Ocean Acidification Program Review Activity Areas, summary of charge to reviewers, and 2010 NOAA OA Plan Themes addressed in each Activity Area.

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Table 2. Summary of evaluation ratings by Activity Area. Evaluation ratings for quality, relevance, and performance of each Activity Area as defined by the NOAA Ocean and Atmospheric Research Program.

Table 3. Key Action Categories of recommendations. Recommendations grouped by Key Action Categories and indicated by Ocean Acidification Program-wide (OAP) or Activity Area numerical identifier (AA1, AA2, AA3, or AA4).

OVERVIEW

The National Oceanic and Atmospheric Administration (NOAA) Office of Oceanic and Atmospheric Research (OAR) conducts program reviews every five years to evaluate the quality, relevance, and performance of the activities its programs fund and how the programs decide on what types of scientific research to support. The purpose of this Ocean Acidification Program (OAP) review was to provide an external assessment of the program including its management structures and to convey program direction and priorities to external partners. This review is used for NOAA/OAR planning, helping the program progress toward its research objectives, and ensuring that OAR programs are in alignment with strategic documents, are responsive to congressional mandates, and are producing high quality and high-performance outputs. Reviewers were charged with evaluating the past five years of OAP activities from 2015 to 2019 and were asked to provide perspective and advice on how OAP and NOAA can most effectively position themselves over the next five years to tackle new challenges while leveraging existing research initiatives, partnerships, technologies, data science, and products.

Ocean Acidification (OA) research at NOAA responds to numerous legislative mandates and policy drivers. The primary OA-related legislation is the Federal Ocean Acidification Research and Monitoring Act of 2009 ([FOARAM Act](#)) that led to the formation of OAR's OAP in 2011. Under the FOARAM Act, the OAP supports research that studies the marine environment, detects changes in the ocean, improves forecast capability and drives innovative science and technological development ([2010 NOAA Ocean and Great Lakes Research Plan](#)). The FOARAM legislation and the 2010 NOAA Ocean and Great Lakes Research Plan specify that the OAP conduct research that informs sustainable use and stewardship of ocean and coastal resources as OA and other environmental changes challenge the resilience of coastal communities posing threats to vulnerable marine species. These mandates also provide directives and guidance to numerous other NOAA Programs and Laboratories participating in OA research, and do not reflect the sole responsibilities of the OAP. The scope of OAP research focuses on NOAA's mission and is generally guided by requirements and needs of other NOAA Programs such as, for example, examining impacts to economically important marine species managed by the NOAA National Marine Fisheries Service and the environments in which they live.

This external review was the first review for the OAP and the first virtual review conducted for any OAR program or laboratory. Formal virtual review meetings occurred during a three-day period from September 28 to 30, 2020. Prior to formal review meetings, four virtual meetings were conducted with OAR, OAP staff members, and review panelists to discuss the [charge to reviewers](#), logistics, evaluation metrics, additional requests for information from panel members, and [agenda](#). Three additional meetings were held with OAR, OAP, and the review panel chair to discuss organizational and logistical aspects of the virtual review. A series of four 'watch-party' meetings were also conducted one month prior to formal review meetings. During watch-party meetings 19 pre-recorded presentations (four or five, 10 to 15-minute presentations per meeting) were delivered to review panel members, OAP staff, participating principal investigators (PIs) and presenters. These presentations provided summaries and highlights of mandates, strategic plans, and tactical program planning processes; environmental, biological, and human dimension monitoring and research projects; OA data management, outreach, and education activities. Presentations were followed by discussion periods allowing for clarifying questions from panel members. Review panel members submitted any additional detailed questions in writing to OAP

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staff and received either written responses from presenters or further clarification during the formal review meetings. Approximately six weeks prior to the formal review meeting, questionnaires were emailed to 33 stakeholders across four Activity Areas (defined below) to acquire input on their perspectives, comments, and recommendations for the OAP. Twenty-six questionnaire responses were received by OAR staff and provided only to the review panel approximately two weeks prior to the formal review meeting. Aside from these questionnaire responses, all review reference materials and presentations were provided on the [OAP review website](#).

Formal review meetings commenced on September 28, 2020 with an overview presentation of NOAA Research and context for the review from the OAR Deputy Assistant Administrator for Programs and Administration, Ko Barrett, and an introduction to the OAP from the OAP Program Director, Dr. Libby Jewett. Each of four activity areas were addressed during half-day virtual meeting sessions. These sessions began with an overview of the activity area by an OAP staff member followed by an open discussion and question period including review panel members, OAP staff, participating PIs and scientists. Closed stakeholder meetings were conducted for panel members to have private discussion with stakeholders regarding each activity area, followed by closed review panel sessions for internal panel discussion and writing exercises. During stakeholder and closed panel meetings, separate concurrent meetings were conducted for NOAA Line Office staff. Each activity area session concluded with closed discussion among the review panel and core NOAA staff. Thematic activity areas for the OAP review included:

- 1) Activity Area 1: Program Scientific Priority Setting;
- 2) Activity Area 2: Research to Understand OA Vulnerability;
- 3) Activity Area 3: OA Data Management and Product Development; and
- 4) Activity Area 4: OA Education and Outreach.

Activity Area 1 (Program Scientific Priority Setting) focused on the program's ability to develop a framework to strategically identify and balance scientific priorities as an entity that facilitates and promotes research rather than executing it. Reviewers were asked to consider the success of the OAP priority decision making process in terms of responsiveness to scientific needs and mandates. The remaining OAP Activity Areas mapped to the six research themes laid out in the 2010 NOAA Ocean and Great Lakes Acidification Research Plan which include:

- Theme 1: research to develop the monitoring capacity to quantify and track OA and its impacts in open-ocean, coastal, and Great Lakes systems;
- Theme 2: assess the response of organisms to ocean and lake acidification;
- Theme 3: forecast biogeochemical and ecological responses to acidification;
- Theme 4: develop management strategies for responding and adapting to the consequences of OA from a human dimension perspective;
- Theme 5: to provide a synthesis of ocean and Great Lakes acidification data and information; and
- Theme 6: develop an engagement strategy for educational and public outreach.

Activity Area 2 (Research to Understand OA Vulnerability) focused on OAP's response to the 2010 NOAA Ocean and Great Lakes Acidification Research Plan through development of an OA monitoring network (Theme 1), research to understand species, community and ecosystem

response to OA (Theme 2), the development of biogeochemical and ecosystem models (Theme 3) and research to understand the human dimensions of OA impacts (Theme 4). The OAP recently re-framed these themes into what is called the OA-Trifecta, which is the program’s approach to integrating three spheres of research including environmental monitoring, biological sensitivity and human dimensions to more closely evaluate the intersections of these research areas with the aim of determining the vulnerability of ecosystems and human communities to OA (Figure 1). Reviewers were asked to consider the OAP’s role in fostering the development of the U.S. and Global OA observing network, supporting science to understand species, community and ecosystem response, and providing research opportunities to understand the human dimensions related to the range of stakeholder impacts to OA. Program reviewers were also asked to consider the success of OAP’s research approach, contribution to the understanding of OA science, and the impact research results have had on other NOAA Programs and the Nation.

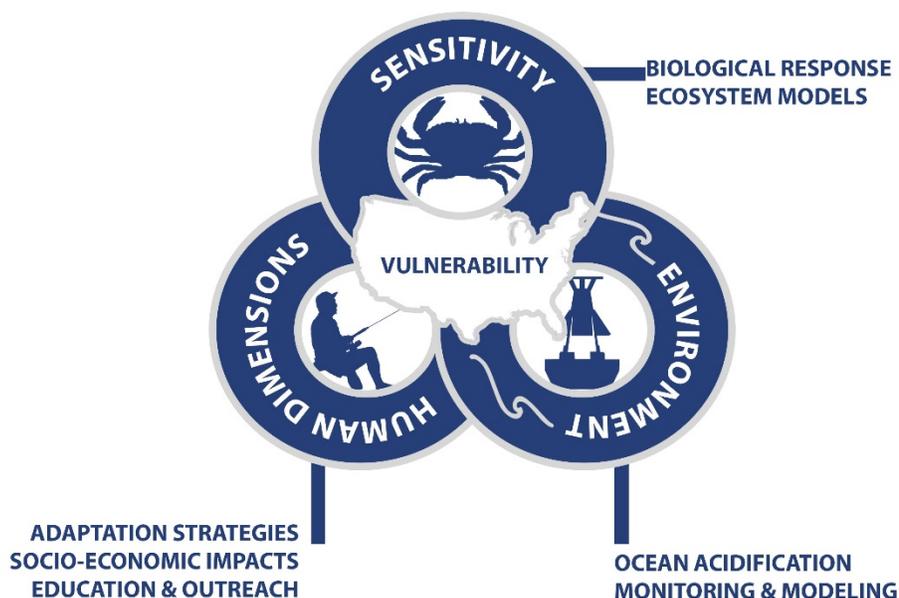


Figure 1. OA-Trifecta themes of the Ocean Acidification Program. Environmental monitoring research supports efforts that document and detect the progression of OA in the environment, biological sensitivity research characterizes and enhances our understanding of species, community, and ecosystem response, and human dimensions research investigates the impacts OA has on human communities.

Activity Area 3 (Data Management and Product Development) focused on OAP’s response to Theme 5 activities including investment of resources into development of data management plans and tools as well as data synthesis products to ensure information is findable, accessible, interoperable, and reusable (FAIR). OAP investments have supported synthesis of chemical, biogeochemical, biological and model data sets to provide products that can be used by a range of OA stakeholders. Reviewers were asked to evaluate the program’s ability to make data accessible—that is, easy to locate, relate to similar data, and obtain. As data management and information is a customer service function, the program was also evaluated on whether it

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discharges its responsibilities in a way that meets the needs of the scientific and management communities, engages partners in the sharing and dissemination of data, and develops products to share information about OA research results to broad audiences.

Activity Area 4 (Education and Communication) focused on OAP’s response to Theme 6. The OAP has invested resources and personnel in developing and strengthening OA communication and education products. In coordination with other NOAA programs and collaborators, the OAP has worked to understand and fill the needs of the OA education and communication community by working to engage local, regional, national and international audiences through innovative education and outreach programs to communicate the complex issues arising from OA and inspire action. Reviewers were asked to consider OAP’s ability to reach its target audiences and make data and information about basic OA research and results easily accessible and understandable. Reviewers were also asked to consider how OAP has built awareness of OA, inspired educators and learners, and expanded the Program through its partnerships and outreach activities. All program review Activity Areas, a summary of the charge to reviewers, and themes from the 2010 NOAA OA Strategic Plan addressed in each Activity Area are summarized in Table 1.

Table 1. Ocean Acidification Program Review Activity Areas, summary of charge to reviewers, and 2010 NOAA OA Plan Themes addressed in each Activity Area.

Activity Area 1: Program Scientific Priority Setting
<i>Evaluate success of OAP priority decision making process, responsiveness to scientific needs and mandates, and whether it leads to high quality, relevant science in an efficient way.</i>
Activity Area 2: Research to Understand OA Vulnerability
<i>Evaluate program role in fostering development of observing network, supporting OA-Trifecta science (Environment, Sensitivity, Human Dimensions), success of research approach, contributions to understanding OA science and impact of results.</i>
<ul style="list-style-type: none"> • 2010 NOAA OA Plan Themes 1, 2, 3, and 4
Activity Area 3: OA Data Management and Product Development
<i>Evaluate accessibility of information, responsiveness to need of scientific and management communities, engagement of partners in sharing and disseminating data, development of products to share information with broad audiences.</i>
<ul style="list-style-type: none"> • 2010 NOAA OA Plan Theme 5
Activity Area 4: Education and Outreach
<i>Evaluate ability to reach target audiences with easily understood and accessible information, how the program builds awareness of OA, inspires educators and learners, and expands program through partnerships and outreach activities.</i>
<ul style="list-style-type: none"> • 2010 NOAA OA Plan Theme 6

Each reviewer independently prepared written evaluations of the quality, relevance, and performance of at least one activity area. All reviewers evaluated Activity Area 3. Activity Area 2 was subdivided into the OA-Trifecta components of ‘Environment’, ‘Sensitivity’, and ‘Human Dimensions’ for more detailed reviewer evaluation, but scoring was applied to the full activity

area. Activity Area 2 findings and recommendations are reported for each of the OA-Trifecta components. Performance was evaluated within the context of two sub-categories including ‘Research Leadership and Planning’ and ‘Efficiency and Effectiveness’. Evaluation results and reviewer recommendations were compiled, but not analyzed, by the review panel chair. This report is not a consensus, but a summary of individual reviewer reports.

Program recommendations were provided for each individual activity area. Ocean Acidification Program-wide recommendations were derived from points or recommendations that arose in multiple activity areas, during the presentations, discussions, or other aspects of the review process, or in discussions during the work sessions of the review panel. Findings and recommendations are reported for the overall program and for each individual activity area.

SUMMARY OF PROGRAM-WIDE FINDINGS AND RECOMMENDATIONS

Ocean Acidification Program leadership has done an outstanding job managing a program of breadth, depth, and complexity, and successfully leveraging internal and external partnerships that have been critical to an impressive portfolio of accomplishments. Program excellence was repeatedly recognized by reviewer, program participant and stakeholder comments indicating that OAP has set the bar and serves as an example for other NOAA Programs, Laboratories, and external Federal Agency Programs. A very intensive review was required to identify and formulate recommendations (some of which were already under consideration by OAP) which is also a testament to the quality, relevance, and performance of this program. All ‘quality’, ‘relevance’, and ‘performance’ evaluation categories across all activity areas were rated ‘exceeds expectations or higher with 11 of 48 (23%) receiving a rating of ‘highest performance’ (Table 2). All ‘overall’ ratings (16 of 16) across all activity areas were ‘exceeds expectations’. No activity area received ratings of ‘satisfactory’ or ‘needs improvement’.

Key Ocean Acidification Program-wide findings, data and statistics that guided evaluation of all activity areas are summarized for each evaluation category. Recommendations are intended only as guidance for an outstanding young and growing program and do not represent deficiencies or oversights.

Seven Ocean Acidification Program-wide recommendations and thirty-one activity area recommendations were identified. Individual recommendations were numbered as Ocean Acidification Program-wide (OAP), Activity Area 1 (AA1), Activity Area 2 (AA2), Activity Area 3 (AA3), or Activity Area 4 (AA4) recommendations in report sections. All 38 recommendations mapped to eight Key Action Categories as listed in Table 3 and Appendix 1. These Key Action Categories frame recommendations that were either related or were consistently repeated across the Activity Areas.

Nine recommendations suggested development of new or more investment in existing activities and performing new assessments or evaluations. Seven recommendations suggested updating, defining, or including existing information in various reports. Ten recommendations encouraged

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continuing or enhancing existing activities. Seven recommendations indicated areas to consider or explore alternative approaches to existing activities. Five recommendations focused on internal or external engagement activities.

Table 2. Summary of evaluation ratings by Activity Area. Evaluation ratings for quality, relevance, and performance of each Activity Area as defined by the NOAA Ocean and Atmospheric Research Program.

Activity Area	Rating	Reviewer					
		1	2	3	4	5	6
Activity Area 1: Program Scientific Priority Setting	Overall	○		○			○
	Quality	○		○			●
	Relevance	○		●			●
	Performance	○		○			○
Activity Area 2: Research to Understand OA Vulnerability	Overall	○	○		○	○	
	Quality	●	●		●	○	
	Relevance	○	○		○	○	
	Performance	○	●		●	○	
Activity Area 3: OA Data Management and Product Development	Overall	○	○	○	○	○	○
	Quality	○	○	○	●	○	●
	Relevance	○	○	○	●	○	○
	Performance	○	○	○	○	○	○
Activity Area 4: Education and Outreach	Overall	○	○			○	
	Quality	○	○			○	
	Relevance	○	○			○	
	Performance	○	○			○	

● Highest Performance
 ○ Exceeds Expectations
 ○ Satisfactory
 ● Needs Improvement

Table 3. Key Action Categories of recommendations. Recommendations grouped by Key Action Categories and indicated by Ocean Acidification Program-wide (OAP) or Activity Area numerical identifier (AA1, AA2, AA3, or AA4).

1. Creating or Updating Strategic and Other Planning Documents
5 recommendations – OAP-1, AA1-1, AA1-2, AA4-1, AA4-6
2. Defining Ocean Acidification Program Responsibilities
3 recommendations – OAP-2, AA2-3, AA3-7
3. Defining, Assessing, and Enhancing Engagement with Stakeholders
8 recommendations – OAP-3, OAP-4, AA1-3, AA1-4, AA1-5, AA2-7, AA3-5, AA4-4
4. Balancing, Optimizing, and Implementing Projects Across the OA-Trifecta, Regions, and Scientific Approaches
8 recommendations – OAP-5, AA2-1, AA2-2, AA2-4, AA2-5, AA2-6, AA2-8, AA2-10
5. Tracking and Reporting Accomplishments
3 recommendations – OAP-6, AA1-6, AA2-9
6. Assessing Staffing Needs
3 recommendations – OAP-7, AA1-7, AA3-1
7. Addressing Data Management Challenges Toward Achieving FAIR Standards
4 recommendations – AA3-2, AA3-3, AA3-4, AA3-6
8. Enhancing Outreach and Communication Strategies
4 recommendations – AA4-2, AA4-3, AA4-5, AA4-7

Ocean Acidification Program-Wide Findings

Quality

The Ocean Acidification Program is widely recognized as a leader among programs within NOAA, other agencies, and the broader national and international scientific and resource management communities. This is attributable to the very high quality of their work and resulting outcomes. OAP appropriations have nearly quadrupled over the past 10 years since the program began as a direct result of the quality, relevance, and performance of their program. All ‘quality’ category ratings were ‘exceeds expectations’ or higher with six of 16 (38%) scored at ‘highest performance’ (Table 2).

There are numerous examples of high-quality outcomes from OAP activities. For example, OAP’s portfolio of supported projects is highly responsive to OAR’s strategic goal of balancing research, development, and transition of science to application and to the 2010 NOAA Ocean and Great Lakes Research Plan. Analysis of project statistics from the past 5 years indicates OAP has supported 324 projects addressing or partially addressing 60 of 89 specific tasks (67%) of the 2010 NOAA Ocean and Great Lakes Research Plan. Project distribution among the OA-Trifecta categories included 177 Environmental, 55 Sensitivity, and 77 Human Dimension projects. Project subcategories indicated 123 Monitoring, 48 Research, 30 Modeling, 24 Technology and Standards, 14 Assessments, 29 Education and Outreach, 15 Data Management, 18 Capacity Building, 22 Competitive projects, and multiple Venture investments that were reclassified into these categories. Many projects were multi-year efforts and the 2019 distribution of projects across regions was as follows: 16 National, 17 West Coast, 14 Northeast, 11 Southeast and Gulf of Mexico, 7 Pacific Islands, 1 Mid-Atlantic, 1 Florida Keys and Caribbean, 0 Arctic, 0 Great Lakes. Results from these projects have led the advancement of OA state of knowledge nationally and internationally.

A rigorous and high-quality review process is consistently practiced for evaluation and selection of projects. OAP science, priorities, and goals are extremely highly regarded by international collaborators and entities. Stakeholders and PIs indicated need for some additional clarity and information on the considerations and factors used to set tactical (Prospectus level) priorities and funding allocations across regions and topical areas and on the process used to evaluate stakeholder input.

OAP funding and projects have grown considerably over the past 5 years and the number of Environment, Sensitivity, Human Dimensions, and Cross-Cutting projects has also increased. The largest portion of resources have been directed toward Environment studies to characterize the ‘chemical’ state of OA. Investments in Environment and Human Dimensions studies each increased much more substantially during the evaluation period than did Sensitivity studies, which are now the smallest resource investment in the OA-Trifecta. As knowledge foundations have increased and science has moved from basic research to transdisciplinary application, there is a growing demand for more work on Sensitivity, Human Dimensions and the data, outreach, and education activities to support the work. These demands will increasingly compete with Environment project resources. Careful rebalancing of the OA-Trifecta and expansion of external partnerships will be required to maintain [targeted] environmental monitoring while undertaking the studies needed to continue to advance understanding of sensitivity and human dimension

aspects of OA.

OAP addresses a full spectrum of scientific research evolution and progression from basic research and monitoring, multidisciplinary, interdisciplinary, integrated, to full transdisciplinary science. Some stakeholder comments indicated that project distribution and diversity is perceived as a disparate collection of work. It was clear during review that it is not, rather it is the full portfolio of work that progresses from basic research to increased levels of integration required to achieve the transdisciplinary approach needed to fully address the program OA-Trifecta goals. Additionally, it is clear that different types of transdisciplinary approaches are being applied depending on the target stakeholder (internal, external, research scientist, resource manager, policy maker). These approaches and definitions should be more clearly defined in an OAP Strategy.

In the past 5 years, OAP priority research activities and support have resulted in 217 peer-reviewed scholarly articles that have received, collectively, over 57,000 total citations; and 33% of OAP articles received more citations than 90% of other articles published in the same category and year. The OAP H-5 index is 35 and publications include authors from 34 U.S. States and 73 different countries across the globe. OAP articles appear in 27 different subject categories across 66 journals and have been cited in 3,796 other journal articles (Figure 2A) published in 781 different and interdisciplinary journals and by authors from 139 different countries (Figure 2B). OAP science is highly impactful and participating PIs are considered national and international leaders in the field.

It was recognized that there are many OAP data and information contributions that are directly incorporated into state, regional, and other stakeholder plans or directly delivered to end-users that are not captured or accounted for in journal publication lists. The accomplishments of OAP go well beyond what is evident in traditional indicators like publications. A 2017 OAP Workshop Report ([NOAA Technical Memorandum OAR-OAP 1](#)) was published but many stakeholders and participants were unaware of this report. This report is available from the NOAA Institutional Repository but is difficult to locate on the OAP website. Periodic progress reporting should continue to highlight non-published accomplishments and outcomes in addition to published work and should be highlighted to stakeholders, internal and external PIs, on the OAP website, and in future program reviews.

OAP has led the development of effective, high quality data management and communication systems, platforms, and software that support the development of OAP data and information products and serve the broader national and international science, resource management, education and outreach communities. OAP has led the development of the Ocean Acidification Data Base (OADS) in partnership with NOAA's National Centers for Environmental Information (NCEI) and in collaboration with other NOAA Programs and Laboratories such as, for example, the Global Ocean Monitoring and Observing (GOMO) Program to coordinate carbon data management. OAPs efforts have set the national and international standard for quality-controlled OA data sets that support the development of global to community level scientific, resource management, and educational products. OAP has effectively facilitated communication among the national scientific, outreach, and education communities through development and implementation of the Ocean Acidification Information Exchange (OAIE) and

numerous other outreach and education products. The OAIE is consistently expanding to include the international community.

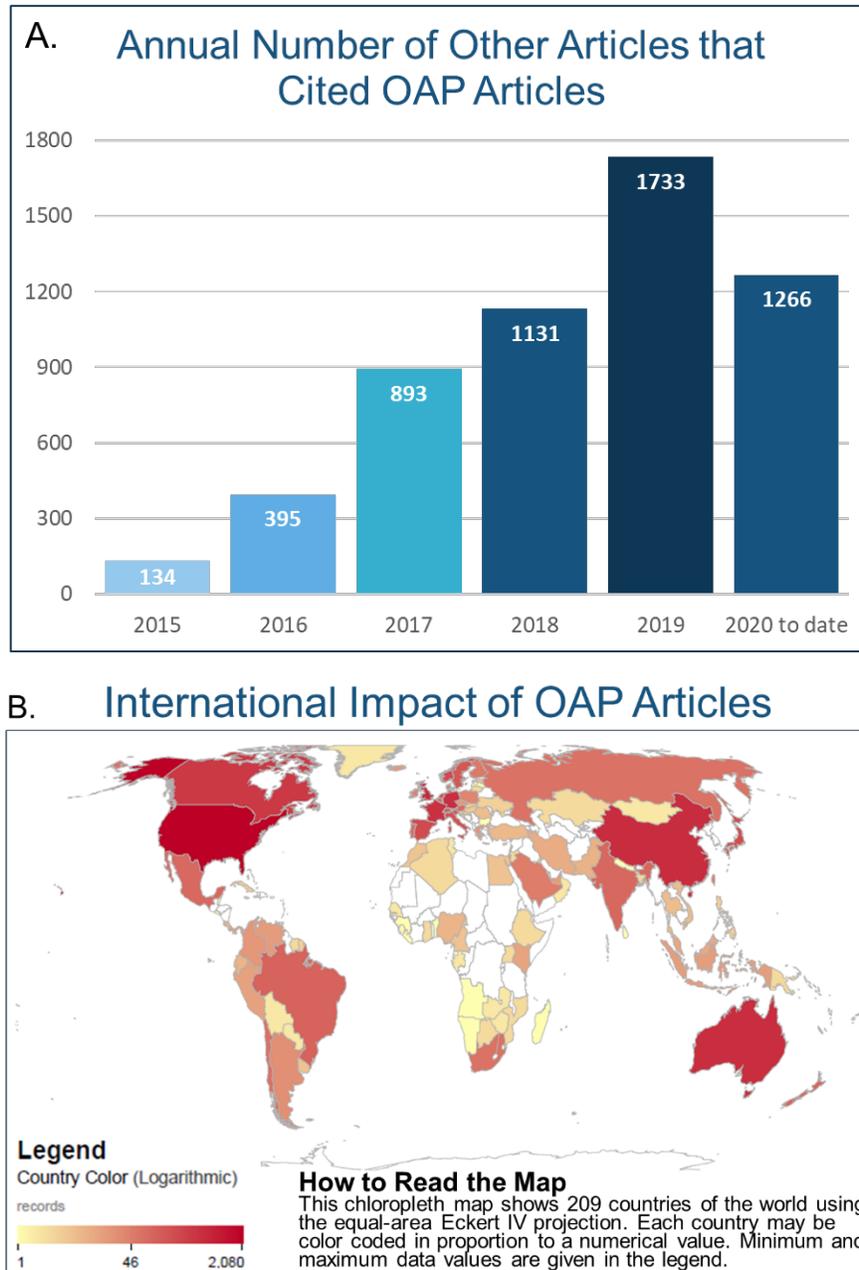


Figure 2. Impact of Ocean Acidification Program scientific journal articles. A.) Non-cumulative count of other articles that have cited OAP articles per year from fiscal years 2015 through 2019. B.) OAP articles have been cited by authors affiliated with institutions in 139 countries and territories. Information and graphics developed and provided by the NOAA Library.

Relevance

Ocean Acidification Program activities are highly relevant and responsive to guiding legislative mandates, NOAA science and strategic goals, advancing understanding of OA science and consequences, and needs of internal and external stakeholders. This is attributable to the very high degree of consideration and effort OAP leadership places on effectively gathering stakeholder input and carefully balancing stakeholder needs with National and NOAA science and strategic requirements and priority activities required to advance the state of the science. All ‘relevance’ category ratings were ‘exceeds expectations’ or higher with three of 16 (19%) scored at ‘highest performance’ (Table 2).

Ocean Acidification Program priorities and activities respond to six different but related strategic plans from congressional to program level, 16 programs and laboratories across five different NOAA Line Offices (see Table 1 of [NOAA Technical Memorandum OAR-OAP-1](#)), priorities and information needs from six Regional Coastal Acidification Networks, and many other local, state, national and international stakeholders. As a young national program that is growing, OAP activities began primarily in the Pacific Northwest and Northeast Regions and are appropriately expanding across the Nation and to island territories. OAP is carefully monitoring stakeholder needs and considering priorities and resources for expansion and evolution of the program for future work in new areas such as the Great Lakes Region. Additionally, OAP leadership has conducted 47 visits to Capitol Hill for briefings and information exchange on program activities. Analysis of activities and planning processes over the past 5 years indicates that OAP has considered, prioritized, addressed, or appropriately not addressed targets within the six strategic plans that guide their priorities including:

1. 100% of mandates, duties, reports to Congress, strategic planning and implementation activities, and general requirements of the [2009 Congressional FOARAM Act](#) have been met and delivered;
2. OAP has addressed, planned to address, or considered and provided justification for not addressing 96% of action items (97 of 101) under all seven themes of the [Interagency Working Group on Ocean Acidification 2014 Strategic Plan for Federal Research and Monitoring of Ocean Acidification](#);
3. The program is addressing or contributing to six of seven goals and enterprise objectives (100% of relevant goals and objectives); 12 of 25 key questions (100% of directly relevant questions); and is addressing 17 research, 18 development, and five transition targets within the [NOAA Research and Development 2013 – 2017 Five-Year Plan](#);
4. OAP is addressing or contributing information to seven of 12 key questions (58%) across three (of four) relevant (to OAP) goals and at least five of seven key questions (71%) across the three Enterprise Objectives within the [OAR 2014 Strategic Research Plan](#).
5. OAP is addressing or partially addressing 60 of 89 specific tasks (67%) across six themes of the [2010 NOAA Ocean and Great Lakes Research Plan](#) at the national level and within five of six regions. Those not addressed are being addressed by other entities or have been otherwise justified through the prioritization process and with consideration of available resources; thus, **100% of tasks have been considered, prioritized, addressed, or appropriately not addressed**. Regional distribution of task actions includes:
 - a. 100% of tasks (8 of 8) Nationally
 - b. 100% (8 of 8) tasks Alaska Region
 - c. 90% (18 of 20) tasks West Coast Region

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- d. 86% (6 of 7) tasks Northeast and Mid-Atlantic Region
 - e. 65% (11 of 17) tasks Pacific Islands Region
 - f. 43% (9 of 21) tasks Southeast and Gulf of Mexico Region
 - g. 0% (0 of 8) tasks Great Lakes Region
6. OAP is addressing at least 75% of actions (21 of 28) across 9 objectives and 4 goals of the [2014 NOAA OA Education and Implementation Plan](#).

Ocean acidification science requires a high degree of integration among multiple scientific disciplines required to fully characterize OA processes and impacts. Results from OAP funded activities benefit numerous natural and social science fields, resource management, economic and industry sectors such as aquaculture, commercial and recreational fisheries, blue economy initiatives, coastal recreation, tourism and related occupations. OAP has developed highly effective partnerships and collaborations that appropriately integrate scientific, resource management, policy, and industry partners needed to successfully engage in transdisciplinary OA research and optimize application and utility of scientific results. Through these partnerships OAP has successfully leveraged resources that significantly expand the reach and relevance of OAP work and science. Due to the numerous strategic plans to which OAP responds, very effective scientific and partner integration required for OA science and application, and the numerous partnership activities with other NOAA Programs and Laboratories, it was difficult to easily distinguish OAP responsibilities from other NOAA Program and Laboratory responsibilities in the six strategic documents and across the Activity Areas. Synthesis of OAP responsibilities in an OAP Strategic Plan will provide better clarity to internal and external partners and collaborators, stakeholders and participating PIs.

It was clear and understood that OAP has prioritized distribution of activities among the regions based on a national risk and vulnerability assessment (developed using primarily environmental monitoring data and limited sensitivity data from the few regions where such studies have significantly advanced understanding in this area), degree of stakeholder engagement and need, and effective and efficient use of limited resources. Regional engagement has increased over the past 5 years with program growth. While most regions are actively engaged with OAP, it was noted across the activity areas that the Southeast and Gulf of Mexico Regions were much less engaged due to the perception of low vulnerability and risk (based on OA chemistry) and low degree of stakeholder engagement. It is likely that degree of risk in these regions has a higher degree of uncertainty due to absence of sensitivity data needed to more accurately gauge risk and vulnerability. Sensitivity information is needed to better inform [and engage] stakeholders of potential risks in these regions, especially where active engagement is focused on immediate and well-understood issues such as hypoxia and harmful algal blooms (HABs). OAP has developed a solid foundation of OA knowledge over the past decade. Moving forward, as the program continues to grow, OAP should strive for greater regional balance in the distribution of ecosystems studied and co-occurring issues (e.g., HABs, marine heat waves, or MHWs) that interact with OA. OAP has already begun reaching out through workshops to HABs and hypoxia research and stakeholder communities to address multi-stressor issues. Stakeholders indicated that the Regional Coastal Acidification Networks (CANs) can be better engaged in these regions to assist with communication, distribution of information, and stakeholder engagement. No activities have been undertaken in the Great Lakes Region based on appropriate justification through evaluation of stakeholder needs and limited resources. However, the need for

engagement in the Great Lakes Region should be periodically re-evaluated.

OAP does an outstanding job serving very diverse categories of stakeholders including internal NOAA and external scientists, resource managers, formal and informal educators, policy makers, other information end-users, and subgroups of collaborator and partner stakeholders.

Stakeholders uniformly praised the program staff for their hands-on, responsive, and thoughtful approach to every activity. It is rare to find program staff who, like OAP staff, stay involved in science synthesis and knowledge generation. Stakeholders associated with all activity areas feel extremely comfortable reaching out to OAP staff and made specific note of their candor, expertise, and friendliness. It was noted by reviewers during interviews with stakeholders and program presentations that OAP results and data are getting directly applied in decision making tools, policy and resource management strategies. However, these direct and immediate applications may not be fully recognized or appreciated because they are not documented in traditional peer-reviewed publications.

Due the diversity and breadth of stakeholders (local to international), there was confusion across the activity areas from reviewers and stakeholders regarding the definition of “OAP stakeholder”, and also regarding how and which groups are prioritized to avoid potential conflicting interests. Ambiguity of the term stakeholder (particularly including internal NOAA staff as stakeholders) complicated evaluation of whether final end-user stakeholders are well understood and whether they are appropriately targeted. OAP needs to re-examine and better define stakeholder categories. A strategic assessment of stakeholders, which groups will be prioritized, the different needs of these groups, and the research approaches needed to achieve outcomes should be considered. Such an assessment will help to better target information needs; identify stakeholder subgroups being served by different data management and synthesis activities; tune outreach, education and communication efforts; and avoid potential conflicting interests.

Performance

Research leadership and planning

Ocean Acidification Program staff excellence and leadership (including their energy, dedication, and collaboration) are a key ingredient of the Ocean Acidification Program’s success. OAP is clearly achieving the high standards set by NOAA and OAR regarding goal setting, program planning and effectiveness, the OAP staff is guided by norms that go beyond what is required, and they are bringing a personal level of dedication that is apparent to every group OAP serves. All ‘performance’ category ratings were ‘exceeds expectations’ or higher with two of 16 (13%) scored at ‘highest performance’ (Table 2).

The OAP leads the development of priorities, guidance, and strategies used by other NOAA Programs and Laboratories and other Federal Agencies to guide their ocean acidification activities. Their effective leadership and planning have resulted in the numerous partnerships, collaborations, and leveraged activities (see OAP-wide Efficiency and Effectiveness section) that have been key to the broad, impactful contributions and growth of this program. These partnerships have provided flexibility and leveraged resources to expand OAP activities and advance the state of the science well beyond what could otherwise have been accomplished. The very highly effective partnership and integration of OAP activities with other NOAA Programs

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has made it difficult to clearly distinguish responsibilities among the participating NOAA Programs. This is a clear testament to the outstanding job OAP has done building collaborations, integrating science approaches, and maintaining these partnerships that should continue. Given the potential for continued OAP growth, increasing demands on resources, and numerous mandates and NOAA guidance documents to which OAP responds, OAR should assist with clearly defining the responsibilities of OAP and other NOAA Programs and Laboratories addressing OA issues.

OAP currently has a plan to develop a new OAP Strategy document. This plan is strong evidence that the program will continue to clarify and document its responsibilities, priorities, processes, and accomplishments to lead OA research and planning into the future. Stakeholders, participating scientists, and reviewers across all activity areas suggested that a strategic plan specifically for OAP is needed to consolidate OAP specific priorities, processes, and activities into a single document. Specific recommendations for content to include in a strategic plan are summarized in the OAP-wide Recommendation Section and more detailed information illustrating the need for content is provided in each Activity Area.

OAP provides numerous leadership opportunities for their staff. Their leadership is widely, internationally recognized and is illustrated through their participation in leadership positions on regional to international committees, councils, and other groups. OAP's small but incredibly effective staff have held 51 leadership positions across 36 efforts ranging from local to international and across all activity areas including:

- International leadership includes Global Ocean Acidification Observing Network (GOAON; Jewett), Ocean Acidification International Coordination Centre (OAICC; Jewett), Intergovernmental Panel on Climate Change (IPCC; Jewett, Gledhill, Busch), Interagency Working Group on Ocean Acidification (IWGOA; Jewett, Busch, Gledhill), Ocean Acidification Information Exchange (OAIE; Jewett, Gledhill, Busch, and others)
- National leadership includes White House Subcommittee on Ocean Science and Technology (SOST) representative (Jewett), US Global Change Research Program (USGCRP) Carbon Cycle Interagency Working Group (Ombres, Gledhill) and Observing Interagency Working Group (Gledhill, Ombres), North America Carbon Project (Ombres, Gledhill), Regional Coastal Acidification Networks (CANs) (Northeast - NECAN, Southeast - SOCAN, Gulf of Mexico - GCAN, Alaska - AOAN, California Current - CCAN, Mid-Atlantic – MACAN; all OAP staff), Marine Resource Advisory Council (Jewett), Olympic Coast OA Sentinel Site Steering Committee (Jewett), California Ocean Acidification and Hypoxia (OAH) Panel (Busch), Co-founder of Sharing of Ocean Acidification Resources for Communicators and Educators (SOARCE) Webinars (Mintz)
- NOAA leadership includes OAR Oceans Portfolio Steward (Jewett), OAR Senior Management Council Rep. to CRCP (Jewett), Coordinating Editors of the NOAA OA Research Plan (Jewett, Osborne), OAP Representative to NOAA Ocean Color Coordinating Group (Gledhill).

Efficiency and effectiveness

The Ocean Acidification Program efficiently executes its activities through close coordination and partnership with OAR and other NOAA Line Offices and Laboratories as indicated by the inclusive development and review process for the 3-year OAP Prospectus. OAP is continuously

improving effectiveness through inclusion of feedback from OAP PIs and scientists during OAP PI meetings and from stakeholders and external partners. OAP is highly effective at developing partnerships for efficient use and leverage of resources and processes to receive and implement feedback. OAP's example of creating leverage among other NOAA programs and offices is one that others should follow.

OAP partners and collaborates with more than 100 national and international, external and internal research and resource management groups including at least 16 other programs and laboratories across five NOAA Line Offices (National Environmental, Satellite, and Data Information Service (NESDIS); National Marine Fisheries Service (NMFS); National Ocean Service (NOS); Ocean and Atmospheric Research (OAR); and Office of Marine and Aviation Operations (OMAO), Regional Associations of the Integrated Ocean Observing System (IOOS), cooperative institutes, universities, state agencies, federal agencies, private industry and foundations. OAP data, information and other products reach well beyond these direct stakeholders to additional end-users and stakeholders that are not formally documented. Given the past rate of program growth and potential for continued growth, it is likely that OAP will need additional staff in the future to maintain their current level of productivity and effective leadership.

Ocean Acidification Program-Wide Recommendations

OAP-1. Develop an Ocean Acidification Program Strategic Plan.

OAP staff identified during review the need and their intent for development of an OAP Strategic Plan. This need was confirmed by reviewers and stakeholders, and many suggestions for content were provided. Information in this plan will help consolidate OAP priorities, responsibilities, activities, definitions and processes into a single document to more efficiently convey Program information to internal and external participants, stakeholders, and broader communities. Content suggestions specific to individual Activity Areas are described in more detail in recommendations AA1-1, AA1-2, AA4-1 and AA4-7 and are briefly summarized here:

- Consolidate, summarize and map the hierarchy of mandates, goals, objectives, actions, and tasks (and linkages among them) from the numerous strategic plans to which OAP (specifically) responds.
- Synthesize and clarify OAP responsibilities.
- Clarify and include information on program decision making processes such as strategic direction-setting and prioritization, considerations and factors used to set tactical (Prospectus level) priorities and funding allocations across regions and topical areas, processes used to evaluate stakeholder input and resolve conflicts of interest.
- Define the full scope of OAP research evolution and progression (including foundational research and monitoring, multidisciplinary, interdisciplinary, integrated, and full transdisciplinary science), anticipated outcomes, and expectations for participant engagement in each type of research project. Clearly define transdisciplinary science and variations that apply to OAP.
- Define the numerous categories of stakeholders (internal and external) to which OAP responds and serves.

OAP-2. Engage in discussion with OAR and other NOAA Programs and Laboratories to define responsibilities.

OAP has taken a leadership role in developing guidance for broader NOAA OA research and monitoring activities and in creating and maintaining very successful partnerships among NOAA programs and laboratories. OAP's leadership in both areas has been essential to achieving the high degree of integration of activities among OAP and other NOAA programs and laboratories that is required to effectively advance OA science. This successful and necessary integration of activities makes it somewhat difficult to identify OAP versus other NOAA program and laboratory responsibilities. Moving forward, it would be beneficial to more explicitly define the appropriate boundaries and overlap of OAP and other NOAA responsibilities, observational, research, and data management requirements, and portfolios. Clear definition of responsibilities will benefit current and future program planning activities and effective resource allocation. See additional details in recommendations AA2-3 and AA3-7.

OAP-3. Define and assess stakeholders and their needs.

The nature and diversity of OAP's stakeholders has evolved since the program was developed and as science has moved from fundamental research to transdisciplinary applications. Examine and clearly define OAP's diverse stakeholder groups, subgroups, and their needs. *It is understood that OAR provided the definition of stakeholder for this review; therefore, these definitions may need to be developed in consultation with OAR.* OAP could benefit from performing a strategic assessment of stakeholders. Identify which groups will be prioritized, the different needs of these groups, and the research approaches needed to achieve outcomes to continue to improve stakeholder participation, meet stakeholder needs, and clarify expectations from OAP projects and PIs for participation in OAP activities. See additional details in recommendations AA1-4, AA3-5 and AA4-4.

OAP-4. Enhance stakeholder engagement in under-invested and investigated regions.

Stakeholder engagement in some regions has been challenging. Limited engagement from stakeholders in the Southeast and Gulf of Mexico may be due to lack of sensitivity information to determine risk and vulnerability and/or focus on other environmental stressors that are perceived as more pressing such as HABs, hypoxia, and marine heat waves. OAP has begun (and should continue) improving engagement in these areas by addressing OA in the context of these multiple stressors and is encouraged to continue supporting the work needed to fully understand risk and vulnerability in these regions. Stakeholders indicated that the Regional Coastal Acidification Networks (CANs) can be better engaged, both directly and in partnership with Sea Grant, to assist with communication, distribution of information, and stakeholder engagement. OAP can provide guidance to the CANs on how to better engage within the regions to ensure local and regional priorities are being met. Periodic re-evaluation of needs, readiness, and feasibility for engagement in the Great Lakes Region should continue as resources and partnership opportunities allow. See additional details in recommendations AA1-3, AA1-5, and AA2-7.

OAP-5. Continue to re-evaluate and rebalance distribution of projects among the OA-Trifecta, regions, and scientific approaches.

Advancement of the state of OA science will require more investment in sensitivity, human dimension projects, and related data management, outreach and communication needs while

maintaining environmental monitoring, particularly in under-investigated Regions. OAP should strive for greater regional balance in the distribution of ecosystems studied and co-occurring issues (e.g., HABs, MHWs) that interact with OA. As needs for applied research increase, there will also need to be consideration of the balance that OAP is targeting with respect to fundamental, multidisciplinary, interdisciplinary, integrated, and transdisciplinary research approaches, and clear guidance on expected outcomes for each approach and engagement/roles/responsibilities of project participants. See additional information on specific implementation suggestions in recommendations AA2-1, AA2-2, AA2-4, AA2-5, AA2-6, AA2-8 and AA2-10.

OAP-6. Consider ways to track or document accomplishments that are not recorded in peer-reviewed publications.

OAP has an outstanding portfolio of peer-reviewed journal articles that illustrates its many accomplishments. However, OAP has many other accomplishments that are not documented in journal publications that should be recognized and similarly documented. For example, results and data are getting directly applied in decision making and resource management tools; many education, outreach, and communication tools have been developed and are highly utilized in formal and informal educational activities; numerous capacity building activities have advanced national and international OA science interest and participation. OAP is encouraged to continue periodic reporting of accomplishments including those that are not published in journals. See additional details in recommendations AA1-6 and AA2-9.

OAP-7. Assess current and future staffing needs.

The OAP has a small (seven permanent staff members and three temporary positions) but highly effective staff. This small team has done an outstanding job effectively and efficiently leading and managing an incredibly successful program. OAP has implemented creative approaches to ensure adequate human resources through developing and successfully leveraging shared staff positions with other OAR programs and labs, internships, and fellowship positions. Human resources are currently adequate to meet program management needs. However, additional staff resources are likely needed in the near-term to support rapidly growing data management needs, expedite delivery of OAP data and products, and to increase focus on communications. Given the rate of program growth and potential for continued growth, it is likely that OAP will need additional staff in the future to maintain their current level of productivity. *The review team understands that this discussion is a regular part of OAP to OAR communications.* Assessment of staffing should consider current and future needs and roles for additional permanent, shared, and temporary staff members required to maintain the balance and workload of core program activities and shared program activities. See additional details in recommendations AA1-7, AA3-1, AA3-3, and AA4-5.

FINDINGS AND RECOMMENDATIONS BY ACTIVITY AREA

Activity Area 1: Program Scientific Priority Setting

Quality

Review of all aspects of the OAP Program including responses from stakeholder questionnaires indicates that the OAP priority setting process is leading to the highest quality science. The scientific priority setting process is very well-considered, well-defined, planned, and implemented. The quality of OAP's work (both funded, and programmatic) is widely judged exceptional and a model for other programs to emulate. The quality, relevance, performance and success of this program are also illustrated by the impressive growth of program activities, budget, and number of internal and external partners who have reached out to OAP for collaboration. The priority setting process has undoubtedly contributed to the considerable growth of the OAP budget since the program's inception. Examples of very high-quality outcomes from the scientific priority setting process described in the OAP Program-Wide Findings section and summarized below include:

- a diverse portfolio of projects, activities, and publications that are highly impactful and responsive to congressional NOAA, OAR and external stakeholder mandates, goals, key questions, and objectives that balance research, development, and transition of science to application;
- highly successful collaborations and partnerships that effectively leverage resources to grow program activities;
- OAP staff leadership activities that support NOAA and the broader National and International science communities.

Outstanding effort is made to incorporate scientific and stakeholder input from diverse participants, groups, and from local to international communities. Program staff reevaluate inputs and priorities admirably and frequently. Transparency of process is also outstanding, and stakeholders indicated OAP provides a higher degree of transparency than most other federal agency programs. Stakeholders and PIs indicated a need for some additional clarity and information on the considerations and factors used to set tactical (prospectus level) priorities and funding allocations across regions and topical areas and on the process used to evaluate stakeholder input. OAP currently has a plan to develop a new OAP Strategy document which is strong evidence that the program will continue to improve and document its already strong processes and lead OA research and planning into the future. Stakeholder, PIs, and reviewers all suggested that a strategic plan specifically for OAP is needed to consolidate OAP specific priorities, processes, and activities into a single document.

OAP is clearly forward thinking and understands the short and long-term challenges it faces. OAP produced a detailed report of national, regional, and international OAP progress, lessons learned, gaps, and future endeavors in the NOAA OAP Summary of the 2017 PI Meeting (NOAA Technical Memorandum OAR-OAP-1) and have prioritized activities to address these challenges in all activity areas as documented in the 2020 to 2029 NOAA OA Research Plan. Periodic progress reports should continue to highlight non-published accomplishments and outcomes in addition to published work. Some stakeholders were unaware of the 2017 OAP progress report. Such publications should be highlighted to stakeholders, on the OAP website,

and in future Program reviews.

Numerous stakeholders indicated that OAP has done an outstanding job managing a program of this breadth, depth, and complexity with a very high degree of transparency, serves as a model and has set the bar for other programs and labs in OAR and across other Federal agencies.

Specific examples of comments are summarized below:

- The quality of OAP work is exceptional, laying important groundwork for National and International OA research, education, and capacity building efforts.
- OAP investments reflect a comprehensive and well-balanced program with an impressive geographic expanse that leverages the regional expertise, observing, experimental, and modeling resources and infrastructure of multiple NOAA labs.
- Highly effective in leveraging important partnerships with NOAA laboratories, academic partners, other agencies and organizations, and international partners.
- Spearheaded by OAP, the NOAA Ocean Acidification Working Group (NOAWG) is one of the most effective cross-line office collaborations in NOAA.
- OAP Program is highly effective at developing ways to receive and implement feedback from researchers and stakeholders.
- OAP has thoughtful consideration in development and execution of funding opportunities valuing the input from stakeholders and is well-aware of research needs across the country.
- The review process for OAP funding competition is fair and efficiently executed to ensure adequate review and feedback.
- Outstanding job of funding high-quality research and projects, having built a community of researchers that would not exist without the work of OAP.
- Very thoughtful, transparent, and inclusive in development of strategic priorities and funding.
- OAP uses the highest standards of review for their extramural research projects.

Relevance

The OAP is highly responsive to governing documents, funded researchers, and downstream stakeholders. Their work is highly relevant to illustrating the local and global implications of ocean acidification, both at a basic research level and an applied resource management user level. Due to the numerous strategic plans to which OAP responds and numerous partnership activities with other NOAA Programs and Laboratories, it was difficult to easily identify what are OAP responsibilities versus other NOAA Program and Laboratory responsibilities in many of these documents. Synthesis of OAP responsibilities in an OAP Strategic Plan will provide better clarity to partners, stakeholders and participating PIs.

The framing of the OA-Trifecta approach – observing/understanding/predicting the environment, measuring/understanding responses of organisms & ecosystems, and multifaceted human dimensions – all in service of understanding and addressing vulnerability to OA, has further solidified the relevance of OAP science. It is also key to their priority-setting process. Attention to the OA-Trifecta in the context of scientific priority setting has, for example, informed the composition of the competitive funding portfolio and led to an increase in resources directed to sensitivity; social science, education, and outreach; and synthesis projects. OAP funded science results and data are being incorporated into resource management, regulation, and policy

documents at the state, national, and international levels. These impactful accomplishments may not be fully documented.

OAP addresses a full spectrum of scientific approaches from basic research and monitoring, multidisciplinary, interdisciplinary, and integrated, to full transdisciplinary science. Some stakeholder comments indicated that this is perceived as a disparate collection of work. It was clear during review that it is not, rather it is the full portfolio of work that progresses from basic research to increased levels of integration required to achieve the transdisciplinary approach needed to fully address the Program OA-Trifecta goal. Additionally, it is clear that different types of transdisciplinary approaches are being applied depending on the target stakeholder. These approaches and definitions should be more clearly defined in an OAP strategy.

OAP is highly effective at gathering input from diverse stakeholder groups for development of priorities and activities. The most recent NOAA Ocean and Great Lakes Research Plan: 2020-2029 includes technical contributions from several external academic and international institutions. Stakeholders encouraged OAP to continue developing creative methods for collecting input and communicating what options are available to stakeholders for direct communication with the program to ensure input from ‘less vocal’ members of the community. There was some confusion regarding categories of stakeholders (internal versus external). A strategic assessment of stakeholders, which groups will be prioritized, the different needs of these groups, and the research approaches needed to achieve outcomes would be helpful due to the diversity (internal and external scientists and information end-users, stakeholders of collaborators and partners) and breadth (local to international) of stakeholders and potential for conflicting interests. A more nuanced view will help OAP serve each subgroup of stakeholders even better.

Numerous stakeholders indicated that OAP has done an excellent job of gathering stakeholder input and meeting the needs of stakeholders. Specific comments are summarized below:

- OAP Program is highly effective at developing ways to receive and implement feedback from researchers and stakeholders.
- Impressively employs vast strategies to access stakeholders from the International science community down to community members living on the coast.
- Some improvement can be made with respect to communicating better with CANs that have not been as engaged for input.
- OAP scientific priorities and activities are highly relevant. OAP is more advanced than other NOAA programs when it comes to relevance to end users, stakeholders, and partners.

Performance

Research leadership and planning

OAP is firmly and effectively established as the Nation’s leading Ocean Acidification Program through outstanding performance of their staff as leaders of the national, international, and NOAA ocean acidification communities. OAP staff have done an outstanding job working together effectively to develop an impressive portfolio of accomplishments (See OAP-wide Findings Section). Personal engagement and commitment of staff, a key component of overall performance, is exceptional.

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Participating staff and scientists have held 51 scientific leadership positions nationally and internationally across 36 different efforts. Examples of international leadership have included but are not limited to GOAON, OAICC, and IPCC. OAP provides leadership and direction for development of scientific priorities for all NOAA Programs engaged in OA science and has led the development of the NOAA-wide OA strategic plans which guide all NOAA OA research, monitoring, data management, education and outreach activities. OAP leads all other U.S. Federal agencies of the Interagency Working Group on Ocean Acidification (IWG-OA) and in the development and implementation of the U.S. Federal OA Strategic plan which guides all Federal Agency OA activities, and provides guidance to academic, resource management, industrial and other communities across the nation and internationally. Additional leadership accomplishments are listed under the ‘OAP-wide Findings - Performance’ Section.

OAP has skillfully and effectively led the IWG-OA. Some agencies aren’t as invested as NOAA which may present risk to collaborative activities; and NOAA’s challenge is to encourage them to engage more wholeheartedly. Reviewers and stakeholders indicated that greater balance needs to be achieved in terms of regional engagement and suggested more support for CANs and using NOAA regional entities like Sea Grant more heavily can be a way to achieve this.

The OAP has clearly defined and documented management, scientific, technological, and policy objectives and rationale for funding key activities and projects through leadership of and/or contribution to multiple OA and broader NOAA strategic plans. However, this information is currently distributed among six different strategic plans ranging from Congressional to NOAA Program levels. It seems the “guiding principles” that OAP leadership is bringing to the program are slightly more ambitious than strictly necessary to fulfill OAR goals; the comprehensive attention and examples associated with each guiding principle is an indicator that staff are deeply committed and gives another reason why this program is so successful. OAP and the broader NOAA, scientific, and stakeholder communities would benefit from development of an OAP strategic plan. Recommendations for information to include in such a plan are described in the Activity Area 1 Recommendations Section. OAR should assist with clearly defining responsibilities of OAP and other OAR Programs and Laboratories addressing OA issues.

The OAP conducts an extensive and transparent planning process to set scientific priorities in response to numerous guiding documents and input from stakeholders, producing the OAP prospectus every three years. OAP identifies its priorities through careful consideration of and adherence to congressional and NOAA mandates, requirements and strategies. NOAA and national priorities are considered through OAP formal collaboration with other federal agencies, NOAA Program leadership, internal and external stakeholders, and the OA and broader marine science communities. Examples include but are not limited to IWG-OA leadership and planning processes, NOAA Executive Oversight Board Engagement, leadership of NOAWG planning activities, direct and frequent engagement with other OAR and broader NOAA Programs and Laboratories as the OAR Oceans Portfolio Steward and OAR Senior Management Council Representative to CRCP, leadership and involvement in numerous and diverse stakeholder engagement meetings, and other creative mechanisms for receiving community comment and feedback such as the OAIE. Additionally, OAP has made clear that there has been as much thought put into what not to fund as what to fund. There are high-level statements in the IWG-

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OA implementation plan that clearly identify what NOAA is not doing and why.

OAP engages the scientific community in determining the state of the science, identifying gaps, determining needed approaches for moving scientific understanding forward and answering scientific questions of national relevance, and in prioritizing tasks. Regular PI meetings are conducted to gather input, external scientists are included in development of NOAA OA strategic plans (see for example co-authors of the [2020-2029 NOAA OA Research Plan](#)), and three OAP-led community meetings or workshops have been conducted in the past five years. Next steps and future endeavors are based on scientific advancement, priority needs, and careful consideration of feasibility and readiness. Planning (e.g., IWG-OA and NOAA OA Plan) and accomplishments (e.g., 2017 OAP PI Meeting Summary) documents clearly indicate forward thinking and future planning by explicating describing future challenges and next steps to address them. Other NOAA Programs are engaged in review of the OAP Prospectus including budgeting.

As a result of a carefully executed planning process and its transparency, the rationale for their decisions is quite clear. Some stakeholders argued that it's not always clear why something did not become a priority, and it was noted that the OAP prospectus is only available to NOAA staff. While it is likely not necessary for the program to enumerate and justify every non-decision, it may be helpful to further consider and communicate with external stakeholders and participants; for instance, researchers not currently funded by the program, and/or interests in regions that are not currently well resourced. There is a need for OAP to more formally communicate its point of view and protocols on conflicts of interest (COIs), decision-making and priority setting. This will make the program even more transparent and will serve as a reference for other programs seeking to achieve a similar level of transparency and rapport with the groups it serves (see Activity Area 4 for more detail).

The program has rigorous and effective evaluation processes for its activities that are clearly documented within notices of funding opportunities, charges to review committees, and descriptions of meeting activities and outcomes. Transition of work to application is evident in the progression and accumulation of knowledge and results from basic research to transdisciplinary science application as indicated by the distribution of funded projects. The process for ending or transitioning projects is based on reviews and evaluations but is not explicitly stated in planning documents.

OAP management shows effective inward and forward thinking, self-evaluation, and community input to identify challenges, lessons learned, gaps, and areas of improvement to continually improve their processes. Stakeholders indicate that OAP leadership is very introspective in terms of thinking about how they can improve processes. This information is communicated by OAP management both internally and externally and documented in NOAA OA Strategic Plans and the OAP 2017 PI Meeting Report. The 3-year Prospectus provides the opportunity and flexibility to respond to changes in direction and processes more rapidly than 5 to 10-year strategic plan guidance. There is a disconnect in timing between the 3-year prospectus and 5-year strategic plan that should be considered and either formalized or modified. This timing offset could prove to be either an advantage or disadvantage. Institutional guidance from OAR and other NOAA Line Offices on the roles and responsibilities of other NOAA Programs and Laboratories may help

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OAP refine and improve their strategic and implementation planning processes.

Efficiency and effectiveness

The OAP program is organized and managed in a manner that has optimized the planning and execution of its activities and includes the support of creativity. The effectiveness of program organization and management is best illustrated by OAP's sustained program growth, successful partnerships and collaborations, requests for OAP leadership, outstanding portfolio and impact of accomplishments, and very high degree of responsiveness to mandates, NOAA requirements, and stakeholder needs. In addition to funding and facilitating excellent science on its own, the OAP has done an outstanding job leveraging other NOAA resources, programs, and personnel in support of its mission and serves as a model for NOAA with respect to integration across laboratories (e.g., Pacific Marine Environmental Laboratory [PMEL], Atlantic Oceanographic and Meteorological Laboratory [AOML]) and programs (e.g., Global Ocean Monitoring and Observation [GOMO], Sea Grant, Climate Program Office [CPO]). OAP has been recognized by stakeholders as the model for and hallmark of effective partnerships with 16 NOAA programs, laboratories, and science centers across five NOAA line offices that have leveraged \$34M of funding from other NOAA entities to complement the five-year \$46M budget of OAP providing an additional 74% of funding for OA activities relative to the OAP budget. Effective, creative OAP partnerships, collaborations, and leveraging have expanded the breadth, impact, and application of OAP supported science, and have substantially advanced the state of OA knowledge well beyond what could have been accomplished without OAP's establishment and leadership of these partnerships.

As a result of program leadership and management, OAP has effectively addressed, partially addressed, or contributed to (on average) approximately 83% of all mandates, goals, objectives, key questions, and tasks set forth in the six strategic plans to which it responds (see 'OAP-wide Relevance' Section). OAP has rigorously considered, accounted for, and justified the activities it is not undertaking with appropriate reasons ranging from 'being addressed by other entities', 'limited resources' (funding or capability) and advancement of priority science within the limitations of resources. Thus, 100% of actions have been appropriately considered and justified. OAP has submitted all required reports in a timely manner including the 2009 Congressional FOARAM Act required submission of the 2014 IWG-OA Strategic Plan, 2016 Implementation Plan, five Biennial Progress Reports to Congress, and has recently submitted the new five-year IWG-OA Strategic Plan for review. OAP is well-aware of its immediate and future challenges and has taken a very proactive approach to identifying, strategizing, and documenting actions to address these challenges.

Human resources are currently adequate to meet program management needs. The OAP program has seven permanent staff members and supports three rotating positions through internships and fellowships. This small team has truly done an outstanding job working together effectively and efficiently to lead the development of an incredibly successful OAP Program. OAP has implemented creative approaches to ensuring adequate human resources through developing and successfully leveraging shared staff positions with other OAR programs and labs, internships, and fellowship positions. OAP has provided numerous professional development opportunities for all its staff members by encouraging participation in leadership positions in the broader OA and scientific community, through the shared program positions allowing staff members to

develop cross-program knowledge and networking, and intern and fellowship positions that provide invaluable professional experience for young career individuals.

Given the rate of program growth and potential for continued growth, it is likely that OAP will need additional staff to maintain their current level of productivity. Additional resources may be required in the future to expand staff to maintain the balance and workload of this lean but effective team. Given that staff are shared from programs or labs that receive funding from OAP, clear information on how OAP avoids conflicts of interest with respect to decision making should be documented.

The program is organized and managed to ensure diversity and inclusion in its workforce. However, this is a recognized challenge that extends beyond NOAA to the broader scientific and STEM communities. OAP is engaging in workforce development activities (educational, intern fellowship opportunities) with this in mind to improve in this area.

Numerous stakeholders indicated that OAP has done an outstanding job managing this Program, and that OAP serves as a model for other Programs and Labs in OAR and across other Federal agencies. Specific comments are summarized below:

- Excellent management team that executes their program efficiently and effectively to ensure they are meeting programmatic priorities and mission with a high caliber of integrity.
- Other NOAA programs would benefit from looking at how OAP develops partnerships with other line offices at NOAA to leverage and pool investments for an outsized impact.
- OAP is the poster child for partnerships at NOAA.
- Partnerships is a hallmark of the OAP program.
- OAP performance is excellent at meeting OA research and information needs of the Nation.
- The team has demonstrated excellent ability to execute and deliver with a transparent and thoughtful approach and to leverage other programs and organizations.

Recommendations

AA1-1. Develop and consider suggestions for information to include in an Ocean Acidification Program Strategic Plan.

The OAP has clearly defined and documented management, scientific, technological, and policy objectives and rationale for funding key activities and projects through leadership of and/or contribution to multiple OA and broader NOAA strategic plans. However, this information is currently distributed among six different strategic plans ranging from Congressional to NOAA Program levels making it difficult to cross-walk and understand the full scope and responsibilities of the OAP. This information is clear to OAP staff and became clear to reviewers during an in-depth review of the full program, but it does not appear to be generally well-understood by many program participants and stakeholders. Additional needs for information related to program processes were identified by stakeholders and reviewers. OAP is encouraged to consolidate information on guiding mandates and NOAA requirements, program responsibilities, activities, definitions and processes into an OAP Strategic Plan to more efficiently convey program information both internally to NOAA and to external participants, agencies, and institutions. Suggestions on specific content to consider include:

- a. **Consolidate, summarize and map the hierarchy of mandates, goals, objectives, actions, and tasks (and linkages among them) from the numerous strategic plans to which OAP (specifically) responds.** Consolidating this information in a ‘digestible’ format will help clarify OAP’s responsibilities, provide context for prioritization particularly for external participants and stakeholders, and will highlight the relevance of OAP. Appendix 1 of the 2017 Principal Investigator’s Meeting (for example) summarizes specific activities OAP addressed from the 2010 NOAA OA Plan, but does not articulate the responsibilities of other NOAA programs. Similar information is difficult to summarize and cross-walk from the other NOAA and OAR strategic plans. This is especially important given the new, more comprehensive NOAA Oceans and Great Lakes Research Plan for OA. *OAR Program should assist with clarifying responsibilities of OAP versus other NOAA programs and laboratories. Institutional guidance from OAR and other NOAA Line Offices on the roles and responsibilities of other NOAA Programs and Laboratories may help OAP refine and improve their strategic and implementation planning processes.*
- b. **Clarify and document factors and considerations used to set tactical priorities, project and funding distributions.** Full review of all program elements and documents indicates the data, considerations, and justifications used by OAP for both long-term (strategic) and short-term (tactical) priority setting. However, this information is distributed across many documents, presentations, statistical analyses, etc. The process for setting priorities and the transparency of that process are excellent; and the outcomes of that process are also very clear in the products and progress. What is less clear to both internal and external participants are the considerations and factors that set the tactical priorities and determine the distribution of funding by region and topical area.
- c. **Clarify and summarize the process used to evaluate and prioritize stakeholder input.** It is also unclear as to how stakeholder input is evaluated and prioritized particularly with the potential for conflicting requests from diverse audiences and geographic locations.
- d. **Clearly define the categories of internal and external stakeholders and stakeholder subgroups to which OAP responds and serves.** Clarify roles of stakeholder categories in the program’s priority setting process, and what types of activities and products target these specific categories.
- e. **Clarify roles and procedures for shared and temporary staff.** OAP has established creative solutions to staffing needs through positions that are shared with other NOAA programs and laboratories and through internships and fellowships. These positions serve as excellent employee development and workforce capacity-building opportunities. Indicate how conflicts of interest are avoided for shared staff whose NOAA labs/programs receive funding from OAP. Consider and describe the feasibility and role of temporary staff in maintaining and growing program functions.
- f. **Describe the process and considerations used for ending or transitioning projects.** The process for evaluating and selecting proposed project activities is clear and transparent. OAP indicated evaluations are also used to determine project discontinuations or transitions. However, project participants indicated a need for additional guidance and information on the process used to end or transition projects.
- g. **Provide clear definitions of the full spectrum of OAP science.** Define science approaches undertaken and required to achieve the transdisciplinary (TD) approach and

outcomes (from basic research, multi-, interdisciplinary, integrated, to full transdisciplinary). Explain that to achieve the OA-Trifecta, a progression from basic research to increased levels of integrated science toward achieving transdisciplinary research is required. Also, the TD label is being applied to what may be considered different approaches/categories of TD science and this is related to the type of stakeholders/participants involved (scientists as stakeholders, resource managers as stakeholders, public as stakeholders). This is appropriate but also needs to be defined clearly.

- h. Clearly define the terms adaptation and mitigation.** Stakeholders noted that different entities appear to be using different definitions.

AA1-2. Consider and formalize the timing for updates to short and long-term planning documents.

There is potentially a disconnect between the 3-year prospectus and 5-yr review period. Consider the advantages (e.g., provides flexibility to shift directions/address emerging issues and allows for time to prepare program review materials) and disadvantages (may need to get through 2 complete 3-yr cycles for more robust reporting on outcomes that guide 5-year strategic planning).

AA1-3. Continue developing creative and alternative methods for collecting stakeholder input.

It was noted that formal stakeholder input to OAP occurs primarily during in-person stakeholder and OA PI meetings. Several stakeholders also noted the dedication, willingness, and responsiveness of OAP staff to stay engaged with direct (person to person) communications with stakeholders. Some concern was expressed that broader stakeholder input may be limited in formal meetings due to less input from ‘less vocal’ members of the community, limitations on ability of participants to attend, or lack of input from potential stakeholders not directly involved in OAP activities. The OAIE is an excellent example of an alternative method for collecting stakeholder input. OAP should continue to consider and communicate other alternative methods and options to stakeholders for direct communication with the OAP. This could include, for example, having virtual community meetings so those who are not able to travel can attend, which could increase stakeholder participation.

AA1-4. Perform a strategic assessment of stakeholders.

Identify which stakeholder groups will be prioritized, the different needs of these groups, and the research approaches needed to achieve outcomes to continue to improve stakeholder participation, meet stakeholder needs, and clarify expectations from OAP projects and PIs for participation in OAP activities.

AA1-5. Continue to enhance communications and engagement with the Regional Coastal Acidification Networks.

Some of the Coastal Acidification Networks are well engaged and others are not. Continue to engage the Coastal Acidification Networks both directly and in partnership with Sea Grant offices. OAP can provide guidance to CANs (based on lessons learned from those regions with effective CAN engagement) on how to better engage within regions to ensure local and regional priorities are being met.

AA1-6. Continue periodic synthesis and reporting of OAP progress and accomplishments.

It is clear OAP has many accomplishments that are not documented in journal publications including information platforms, outreach and educational materials, citations in state, regional, and other stakeholder plans, among others. NOAA Technical Memorandum OAR-OAP-1 (the 2017 NOAA PI Meeting Summary Report) is an excellent summary of OAP progress and accomplishments and an example for future reporting documents. Reports of accomplishments will help document the full scope of OAP progress and impact and can greatly facilitate future program reviews. The periodicity of these reports could be timed with either renewal of an OAP strategic plan or with the 3-year Prospectus.

AA1-7. Continue creative solutions to future staffing needs. Given the growth trajectory of OAP over the past 5 years and anticipated growth in future years, consider and plan for future staffing needs to maintain level of performance (the balance between being “lean and mean”, and not overtaxed). Shared program positions have worked very well, and this is a good, creative solution to supporting program growth. Additional resources and permanent positions may be required to maintain long-term functions of temporary staff and program productivity in the future. Continue engaging in workforce development activities (educational, intern fellowship opportunities) and identifying other opportunities that will improve diversity and inclusion in the NOAA and OAP workforce.

Activity Area 2: Research to Understand Vulnerability

ENVIRONMENT

Quality

The NOAA OAP environmental monitoring efforts are both extensive and high quality. Environmental data collection has, to date, been the single largest investment of the program in terms of resources, which seems reasonable because it informs the range of exposures and future scenarios to be investigated in sensitivity and vulnerability studies. The Program focused initially on the measurement of relevant ocean CO₂ system variables (pH, pCO₂, inorganic carbon and alkalinity) along with ancillary physical, chemical and biological variables. More recent efforts have expanded to identifying targeted biological indicators of sensitivity. Moving forward, additional consideration will likely need to be invested in evaluating and implementing routine biological indicators.

The environmental monitoring effort spans a range of different sampling strategies and platforms including regional ship-based surveys, mooring-based time series and targeted sampling of coral reefs in conjunction with the NOS national Coral Reef Conservation Program (CRCP). The program has successfully created and leveraged an observational network (the NOAA OA Observing Network, or NOA-ON) involving partnerships with IOOS, priorities guidance from the regional coastal acidification networks (CANs), National Marine Sanctuaries (NMS), and other stakeholders. These partnerships have greatly expanded the capabilities and volume of data collection and extend sampling into near shore regions inaccessible through routine survey by NOAA ships.

The quality of the seawater chemistry and other data collected by the NOAA OAP is widely

recognized as world-class. The individual elements of the observing program provide perspective particularly on ocean variability. For example, the moorings provide high-frequency time-series but for surface properties and only for local conditions while the regional ship-surveys provide geographic and depth information but can only be conducted infrequently. Modeling and forecasting components are being developed to augment the field data, and a relatively small investment in technology development is preparing OAP for new observing platform and sensors approaches.

Relevance

Environmental data on variations in seawater chemical properties are critical for the other two components of Activity Area 2 related to organism and ecosystem sensitivity to ocean acidification and human dimensions of ocean acidification. NOAA OAP has strong capability to conduct comprehensive environmental monitoring efforts that support research and related ocean acidification efforts across the NOAA line offices, NOAA Sea Grant and external stakeholders in the ocean science community, industry, state and local governments and other stakeholders. The OAP environmental modeling investments also contribute to larger-scale NOAA OAR strategic goals and OAR Oceans portfolio elements and complement well the global-scale carbon observing elements of the OAR Global Ocean Monitoring and Observing (GOMO) program. At a national level, NOAA OAP observing elements are highly responsive to the relevant parts of the 2009 FOARAM Act and contribute to and facilitate efforts by other federal agencies as coordinated by the Interagency Ocean Acidification Working Group and to the Interagency Carbon Cycle Working Group.

Performance

Research Leadership and Planning

Overall, the NOAA OAP is doing an excellent job in carrying out the environmental monitoring effort and managing the diverse collection of internal and external researcher elements and partnerships. All observing systems have limitations, but overall the OAP should be complimented for creating over the past decade a much more detailed and sophisticated picture of seawater CO₂ system variability in coastal ocean waters around the U.S.

Efficiency and Effectiveness

The observational data produced by the OAP is guiding the biological experimental and human dimensions research elements of OAP Activity Area 2. The OAP program office also deserves considerable recognition for the successful development and support of the numerous partnerships that greatly enhance observational capabilities.

Recommendations

AA2-1. Continue leveraging partnerships and research results to strategically prioritize research activities.

There will be increasing demands for targeted environmental monitoring as the OAP moves forward, and the costs of environmental monitoring will not likely decrease sufficiently to cover these demands with current resources. The OAP needs to be strategic in its investments, continuing to leverage existing partnerships and building new partnerships as possible. The OAP has initiated studies on how to best optimize sampling strategies, and the results of these studies

will help guide future investment decisions. The results from standard observational sampling strategy experiments designed in terms of best capturing chemical variability will complement more expert-opinion driven observing priorities developed and built on information on the biological sensitivity of organisms and habitats.

AA2-2. Continue to optimize OAP monitoring to characterize impacts to ecosystems and humans.

As knowledge and understanding grow, the geography of the OAP monitoring element should be optimized adaptively to best characterize ecosystem dynamics and impacts on human dimension as well as providing information in a timely fashion to a diverse range of stakeholders. Near-term challenges include addressing the growing obsolescence of Moored Autonomous pCO₂ (MAPCO₂) sensor systems and exploiting observing platforms that will fill in time/space gaps in the current observing system. Current gaps in the OAP observing network, such as in the Great Lakes region, will need to be reevaluated with time depending on the needs of potential new stakeholders.

AA2-3. Engage in discussion with OAR and other NOAA Programs to clearly define OAP's observation and research responsibilities.

Project distribution and resource investments indicate OAP's primary focus has been environmental observation with other NOAA programs primarily responsible for species and ecosystem studies. OAP effectively leverages numerous NOAA programs and laboratories in partnerships to accomplish this work. It is important for OAP and OAR to clearly define responsibilities and limitations for programs and laboratories participating in OA activities. Additionally, clarification of monitoring responsibilities among OAP NOAA partners would also be beneficial. For example, the OAP and GOMO program need to continue to cooperate to determine the appropriate boundaries and overlap of their observational requirements and portfolios.

SENSIVITY

Quality

Based on review of papers and datasets developed and published with OAP support, as well as bibliographic metrics summarizing those products, the program supports extremely high quality and well-cited research. Many of the OAP's funded investigators (internal and external) and staff serve as leaders internationally, nationally and locally, performing leadership roles in basic research, large synthetic reviews, regional CAN activities, international networks, and as conveners or moderators of important scientific meetings and conference sessions.

How the quality of work supported by OAP compares to that of other programs is difficult to assess given that OAR has only recently begun to conduct program evaluations, and this is the first review for OAP. OAR and often NOAA appear to value the intellectual freedom of their staff more so than many other agencies. OAP is no exception to this and, in its research funding activities, has demonstrated openness to credible but varying perspectives about ocean acidification and the research needed to address it.

Relevance

OAP's environmental measurement activities are at the highest performance level, based on review of publications and data, but also on feedback from the participating science stakeholders. One area of modest concern is the continuing reference to the Pacific Northwest by funded investigators as an area of highest priority for OA research. Given the general sense from stakeholders that the US Southeast, Gulf of Mexico, Mid-Atlantic, and the rest of the world's coastal oceans are under-studied relative to the Pacific Northwest, and therefore are experiencing unknown risks, this continues to create misunderstanding. Geographic distribution of research and monitoring investments by other federal programs have been and will continue to be profoundly affected by such statements made by scientists or picked up from media outlets.

The US Southeast, Gulf of Mexico (GOM), and the Great Lakes come up as exemplary areas where “absence of evidence” is potentially being misinterpreted as “evidence of absence.” There has not been enough sensitivity research to fully determine risks and vulnerability and provide evidence to stakeholders for their assessment of that risk. There is likely not enough data and information on species response to clearly define potential human impacts. The OAP already has an excellent track record of seeking early input and responding to early concerns about overemphasis on the Pacific Northwest, as demonstrated by its increased investment in other areas. It was clear from discussion with OAP staff during the review that the importance of geographical sampling bias is recognized; reviewers are confident that similar portfolio adjustments will be made for areas where sampling gaps persist. However, this may require departure from the stakeholder-driven approach, at least temporarily. This is because the absence of basic biological or ecological response information from gap areas may be what's limiting stakeholder interest and impeding OAP's efforts to find partners. It is understood that OAP must respond to needs of NOAA fisheries, and much of the species response work is driven by that connection. Ability to engage in species response research has been heavily reliant on willingness of regional fisheries offices to engage and clear requests from stakeholders. There is a legacy effect from NOAA's historical emphasis on fisheries, leading to emphasis on specific regions that will be a challenge to overcome.

The New 2020-2029 NOAA Ocean and Great Lake Research Plan clearly indicates more focus on approaching OA in the context of multiple stressors and associations (hypoxia, HABs). This is essential for moving OA forward particularly in the Southeast (SE), Mid-Atlantic (MA), and Gulf of Mexico (GOM) regions where risk and vulnerability are less well defined (lack of coastal data and species response data), and stakeholders are more difficult to engage due to their attention on what they perceive as more immediate problems. It was noted and encouraging that OAP is working to better engage SE, MA, GOM regions through Sea Grant, and to address OA in the multi-stressor context. Stakeholders, program participants and reviewers agreed this is a good way forward.

In the U.S. Southeast, it appears that the institutional capacity exists to conduct biological/ecological response research but has not been fully engaged. Also, with its higher alkalinity source watersheds, GOM and especially the arid systems along its coast may provide unique opportunities for comparison with more temperate systems. One stakeholder questionnaire indicated concern that the mid-Atlantic is also being under-sampled relative to the variability existing in that region.

An additional area of modest concern relates to extrapolation of cellular and organismal sensitivity to untested ecological scales (i.e., populations, food webs, ecosystems). As an analogy, such an approach would require as much caution as predicting the state of the seawater carbonate system from measurements of only one parameter. Large “what if” modeling efforts such as ecosystem vulnerability assessments are valuable to stakeholders and should continue as scoping exercises or as iterations in adaptive management. There are concerns that key assumptions underlying ecological extrapolations are not being propagated forward into statements of assessment uncertainty. In particular, the need to understand how a biological effect on, for example, an early life stage scales up to a mixed-age population was identified in the 2014 IWG-OA strategic plan as a key unknown. Populations are the arenas where gene pools are altered or extinguished by environmental change and are often the unit of focus in legislative protections and stock assessment mandates. Yet, ecological models being used in ecosystem assessments do not capture adaptation, nor do they incorporate the modern synthesis view of ecosystems as adaptive nonequilibrium states with shifting functional structure. This is okay, if there is improvement in the way models are presented and interpreted. Whether these ecological uncertainties are OAP’s responsibility to address, given OAR’s more traditional emphasis on environmental measurements, is a question likely beyond the scope of this review; however, open acknowledgment of the issue and formal, up-front expression of uncertainty in these modeling and assessment efforts is needed.

Although the research community has far to go on the problem of ecological extrapolations, both the discussion with staff during the review and the published literature indicate that the OAP and its funded investigators have already put considerable thought into it. Multiple papers in the early part of the review period identified key knowledge gaps like the one discussed above, in addition to concerns about multiple stressors and differing life stage responses. These include Mathis et al. (2015), Gobler and Baumann (2016), Punt et al. (2016), Busch et al. (2015), and Hodgson et al (2016). The assumptions were identified in those papers as either major limitations in their respective analyses or as subjects for future work. These gaps continue to be pointed out by OAP-funded investigators (e.g., Saba et al. 2019, Neuman et al. 2018), suggesting that progress has been modest. Through partnerships, the OAP staff have worked hard on this issue and provided meta-analytic evaluations of sensitivity (Busch and McElhany 2016) that are now being used by others in exciting Atlantis-based ecosystem vulnerability assessments, but the assumption that biological sensitivity is predictive of population sensitivity persists in ways that need to be more obvious to users of vulnerability assessments. To be sure, this is another tall order, since it is not merely a communication issue. Propagation of ecological uncertainty requires rigorous study and methods, but some of these already exist in other environmental fields.

The above gaps and approaches to ecological risk are not at all unique to the OAP’s work. They are pervasive in environmental science and they will likely persist in OA science if the necessary involvement of biogeochemists and chemical oceanographers isn’t somehow balanced by other perspectives. The OAP-funded work on pteropods (Bednarsek et al. 2014-2019) stands out as a shining exception and example of how to address scaling gaps, not just within the OA world, but in environmental science more broadly. More work like theirs would help to address these scaling gaps between environmental measurements, lab experiments and regional vulnerability.

It has taken a lot of time and care, and many top-notch papers to get where they are, so the appearance of a diminishing OAP investment in sensitivity research, relative to other parts of the trifecta, suggests the need for either reconsideration or clarification of program intent. As more species indicators are identified in other regions, OAP should work closely with the regions toward standardization for their use.

Performance

Research Leadership and Planning

Based on reviewers' experiences with OAP, observations of interactions with experts and stakeholders, and on stakeholder input provided during this review, program leadership is extremely accessible to experts and stakeholders and responsive to their input. Over the years of its existence, the program has adapted and adjusted to new events and discoveries. When issues are identified by stakeholders, program leadership and staff adopt a cooperative, problem-solving posture. When working on reports to Congress and on other mandated materials and plans that rely on input from experts outside of OAP, program staff maintain high expectations, but also reach out frequently to offer assistance for addressing roadblocks, refining charges, etc. They have an extremely enthusiastic, cooperative and open approach at all stages.

The program's funded investigators have an excellent record of publication. Through other efforts such as the CANs and mini-grant programs, the program provides leadership but also facilitates development of new leaders and programs.

Efficiency and Effectiveness

Funded investigators actively engage in partnerships and many appear to leverage opportunities with other programs and investigators. One indicator of this is the long list of publications that involve authors from multiple institutions.

Integration of OAP-funded research with other OAR programs was difficult to address due to unfamiliarity with the OAR administrative landscape. However, it is likely that integration will become increasingly necessary as the distributed nature of OA, the enormous sampling challenge in the inner coastal areas, and OA's interaction with other forms of environmental change become more clear. One example of good integration is the biological sampling that Bednarsek et al. are adding to sampling trips in the Pacific Northwest as indicated during Activity Area video presentation discussions. That biological sampling appears to be funded by other OAR programs and serves as a great example of the much-needed integration of 'environment' and 'sensitivity' components of the OA-Trifecta.

Recommendations

AA2-4. Develop and implement an approach to improving utility of species response data in ecological scaling studies.

The OAP should work toward decisions about how to handle large unknowns in the meaning of laboratory response data. The major alternatives are 1) accept, acknowledge, and communicate the effect of the ecological unknowns on higher scale uncertainty envelopes; 2) allocate some of the increased vulnerability funding to quantify these unknowns; or 3) rebalance the OA Trifecta funding to increase investment in the sensitivity area. If the unknowns are to be addressed rather than merely quantified and communicated, emphasis should be on ecological scaling studies

(more observations and experiments, fewer models) and other issues that complicate the assumed relationships (e.g., adaptation and acclimation). Grear et al. (2020) is one example of item number 1, and involved OAP-funded investigators, but there are other examples as well, especially from other fields. Studies of in situ response and acclimation in shellfish include Thomsen et al. (2017), Leung et al. (2017), and Grear et al (2020). As already noted, the OAP-funded work by Bednarsek and others is another excellent example, but there needs to be much more like that work if forecasting is to include ecological responses at any scale above that used in laboratory studies (i.e., individuals of a specific life stage). Any divestment whatsoever from environmental observing is not suggested. Rather, the beauty of the Bednarsek work is that it has moved toward inclusion of pteropod biology indicators within the environmental observing program, but with solid underpinning in the basic biology and ecology.

AA2-5. Consider creative approaches for implementing future larger scale ecosystem studies.

Engage the broader OA community and other agencies in discussions and consideration of creative approaches to pursuing larger scale ecosystem experiments that are needed to better inform models. This is not OAP's or NOAA's responsibility alone, and the answer is not clear as to how it can be accomplished with limited funding across agencies, other entities and, perhaps, limited bandwidth. Integrated chemical/biological studies have depended heavily on academic colleagues. Continued discussions and collaboration with MBON to pursue work in this area is encouraged.

AA2-6. Invest in under-sampled regions to better inform risk and vulnerability.

The OAP should also continue to seek opportunities for investment in regions that are under sampled in terms of environmental measurements or biological sensitivity. The threshold for defining “relevant” environmental change 1) should be determined by biological/ecological sensitivities; 2) should inform environmental observing; 3); and may be lower (i.e., higher sensitivity) in regions with lower background variability during recent evolutionary history. There are numerous academic and other external institutions that have the capacity and expertise to perform the sensitivity research needed to improve understanding of risk and vulnerability in the SE and GOM regions. OAP may consider more external support/collaboration with external labs and academia where NMF response is slow to help move science forward in these areas. There is also existing NOAA infrastructure and labs at AOML that are equipped and capable of these studies that could be more fully engaged. Consider re-engaging/check-in with stakeholders from Great Lakes to determine readiness, potential, and need for moving activities forward in that region. The answer may be no, but this will provide updated information and justification for not addressing that region.

HUMAN DIMENSIONS

Quality

OAP is the only OA research entity that has so explicitly coupled environment, ecosystem, and human elements. This is well aligned with NOAA's overall mission and is helping break down disciplinary silos between natural and social sciences. OAP's inclusion of social science is leading the way internationally as an example of how to fully integrate marine environmental studies. Engaging social scientists remains challenging across the broader science community

which in some cases may be due to concerns about the social equity implications of market-based environmental decision-making. OAP funded research with communities on Washington's Olympic Peninsula is an excellent effort illustrating those concerns. OAP is taking an active approach to encourage engagement of social scientists and economists through discussion with the Office of Economists, NMS, and Woods Hole Oceanographic Institution (WHOI) due to limited response from other NOAA contacts.

OAP has greatly increased funding to human dimensions projects in the most recent funding cycle. There has been recognition that the greater amount of expertise for human dimensions work lies outside of NOAA, and this has been reflected in funding going to external projects. Funded PIs represent national leaders in their fields.

Relevance

Human dimensions studies have received increased prioritization in the 2020 NOAA Ocean and Great Lakes Acidification Research Plan as a critical aspect of OA research; and it is now a specific component of the OAP research OA-Trifecta. Human dimensions are being appropriately addressed, building on the foundational environmental and biological sensitivity data. Stakeholders are engaged through community OA Workshops to develop priorities.

Projects address a wide range of human dimensions, including:

- a) Synthesis of OA data to assess where vulnerabilities exist or are emerging;
- b) Data products (i.e. forecasts/nowcasts) to assist stakeholders with decision-making in multiple geographic regions (e.g., shellfish hatcheries in the Chesapeake; fisheries managers in the Bering Sea);
- c) Assessment of vulnerabilities of human communities (including social, economic, and cultural aspects) to OA;
- d) Identification of tipping points/thresholds to help resource managers with decision-making.

It was noted by reviewers that OAP results and data are getting directly applied in decision making tools, policy and resource management strategies. However, these direct and immediate applications may not be fully recognized or appreciated because they are not documented in traditional peer-reviewed publications.

The leverage OAP undertakes with other NOAA areas gives it an advantage particularly in assessing the end-to-end impacts of OA on the marine ecosystem and human users. However, a disadvantage is that this can skew the OA marine ecosystem research a little far towards commercially valuable/managed species. There is a basic research need to also understand the impacts of OA on forage/prey species which could be enhanced to good effect for future predictive capability.

Performance

Research Leadership and Planning

Human dimensions projects align with the defined tasks from Theme 4 of the 2010 NOAA Ocean and Great Lakes Acidification Research Plan. With the development of the OA-Trifecta, Human Dimensions has taken on greater importance in the OAP science portfolio, and recent notices of funding opportunities (NOFOs) have highlighted the human dimension research needs

(e.g., OCA Thresholds NOFO with NOS, Regional Vulnerability Assessments).

Human dimensions projects have increased in the most recent funding cycle (FY18-20), and Program-funded researchers are making OA-relevant information available to stakeholders (e.g., the Chesapeake Bay Nowcast/Forecast; Wrathall’s Geo-visualization Tool for the Pacific Northwest). Greater regional balance needs to be achieved in the distribution of ecosystems studied and co-occurring issues (e.g., HABs, MHWs) that interact with OA.

Efficiency and Effectiveness

OAP is very effective at carrying out plans made in this activity area. From 2015-2020, 77 OAP-funded projects included elements related to human dimensions (socio-economic models, education, capacity, data products & tools). Successive years have broadened the work in ways that more fully help achieve overall goals.

OAP is helping to connect scientists from different disciplines (i.e. natural and social sciences) during the OAP Community Workshops; however, the expected interaction could be more clearly defined in NOFOs. One stakeholder noted that the “NOAA OAR Climate Program Office has evolved to encourage transdisciplinary research, a more complex approach that attempts to unify frameworks beyond disciplinary perspectives, compared to a multidisciplinary approach encouraged by the OAP”. As OAP review materials indicate, OAP already encourages and supports transdisciplinary research (for example, recent work engaging tribes on the Olympic Peninsula); thus, it is clear there are misunderstandings by PIs and other participants regarding transdisciplinary and multidisciplinary science approaches and how OAP is engaging in either one.

OAP is leveraging relationships with external PIs to make the most of investments and effectively execute human dimensions projects. A recent example that OAP work is affecting management decisions is the use of OA data in Alaska fisheries stock assessments – a very important step toward human dimensions application.

Recommendations

AA2-7. Enhance stakeholder engagement in Southeast and Gulf of Mexico.

There is an apparent lack of external-to-NOAA stakeholder engagement in this region, potentially due to other environmental stressors that are more pressing including HABs and hypoxia. OAP has already identified this issue in the 2020 NOAA Ocean and Great Lakes Acidification Plan. Stakeholder engagement in this region may need to be focused on multiple stressors and it was noted that OAP is working toward this approach with their recent HABs workshop and partnership with Sea Grant for student fellowship grants. As stakeholder needs are largely driving research priorities, this lack of engagement has been used as rationale for the lower amount of funding for biological sensitivity projects in this region. Perhaps OAP can directly assist scientists in this region to connect with potential stakeholders.

AA2-8. Provide clarity and guidance on targeted research approaches for project participants.

There may need to be some clarity moving forward as to the balance that OAP is targeting with respect to fundamental, multidisciplinary, interdisciplinary, integrated versus transdisciplinary

research approaches – including clear language as to what OAP will not fund and expects other agencies to fund. Additional guidance regarding the expected type of research approach and, thus, relationship among participants from different disciplines could be included in future NOFOs. Natural and social scientists are often not used to working together and may benefit greatly from such guidance from OAP so that human dimensions projects can be productive and effective immediately upon receiving funding instead of requiring a ‘ramp up’ period while the team gets used to working together. Further guidance may be required from OAP on how to target budget reductions for [especially multidisciplinary to transdisciplinary] projects requested to reduce budgets. OAP may consider developing a training presentation or webinar that funded teams can use to facilitate their interactions.

AA2-9. Consider ways to document non-published and externally published accomplishments.

OAP results and data are getting directly applied in decision making tools, and OAP should get credit for the high impact, immediate application aspects of their Program data and work that is not evident in publications. It is clear data and information are being included in resource management and adaptation strategies (as indicated during review presentations), but unless reported directly by the stakeholder agency, this information is not widely available, tracked, or known by others. This information should be tracked, documented, and better show-cased (perhaps as a website section of links to non-peer reviewed accomplishments).

AA2-10. Continue efforts to better engage social scientists.

OAP has actively tried to engage social scientists and economists from the Office of Economists and NMS and continued conversations are encouraged moving forward. OAP has also reached out to WHOI social scientists due to limited response from other NOAA contacts. OAR may be able to help with these communications. OAP is continuing to seek better ways to link natural and social scientists through workshops and NOFOs and are encouraged to continue with these efforts.

Activity Area 3: Data Management and Product Development

Quality

Data management was recognized as a great strength of OAP, which has set the standard for many other federal programs. A diverse group of stakeholders agreed that OAP was a leader in the area of data management. OAP has made a major contribution to developing an OA data management system through support of a data management project (Ocean Acidification Data Stewardship, or OADS) operated within NOAA’s National Centers for Environmental Information for all of NOAA and the broader scientific community. The NOAA OAP data management effort is addressing to some degree all main elements needed for a high-quality data management system. The data management team is working together with research PIs jointly on data quality assessment and quality control issues and has in place systems for data capture, storage, accessibility, and archiving. OAP’s data synthesis efforts are internationally well-regarded and highly cited. OAP is supporting development of easy-to-use metadata collection applications which helps ensure a higher-quality, more complete data product is submitted by PI’s. OAP is actively involved in creating best practices guidance for PI’s and in translating data

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into actionable knowledge.

OAP has contributed to the archiving of the historical Carbon Dioxide Information Analysis Center (CDIAC) ocean carbon data which is no longer supported by Department of Energy (DOE) but remains extremely important for the global ocean science community. Attention needs to be paid to make sure OAP isn't shouldering too much of the carbon cycle monitoring portfolio on behalf of other NOAA areas. The CDIAC data rescue activity was important, but a candid conversation needs to happen between CPO, OAP, GOMO and OAR to ensure that OAP responsibilities are appropriately balanced with respect to oversight and transition of NOAA's ocean carbon cycle data to the NOAA Ocean Carbon Data System (OCADS).

Measures of success are evident through development and community use of data products at coastal, regional, national and global levels as indicated in OAP publication records. OAP data are currently downloaded at a rate of 3000 records per day on average, indicating high usage of data. OAP is supporting the standardization of metadata, providing DOIs, standardizing quality assurance/quality control (QA/QC), and using controlled vocabularies. These actions create higher-quality datasets and will improve findability, accessibility, interoperability, and reusability (FAIR data) by a broader community.

OAP and partnering programs recognize that there is still much work to be done moving into the future to fully achieve FAIR data goals. It was noted by stakeholders that NCEI has for many years been an archive where data were secure for the long term but neither findable nor accessible. OAP is leading the charge to change that. OAP's investments in data management and particularly in synthesis products are increasing, to good effect.

Several reviewers indicated high confidence in quality assurance and management of OA data through OAP-supported programs. Some reviewers noted the OAP understood the importance of data QA and management early on and took steps to incorporate them. One reviewer identified the OAP as being among the few NOAA programs that "steps up" with funding for data management. Other reviewers indicated that OAP's efforts in this realm have raised the bar for all of OAR. The OAP was also commended for reaching out to data experts and partners for input regarding needs and priorities. However, this was contrasted with what was described as a more passive approach to distribution of data products to stakeholders. One reviewer commented that "the collection and delivery of environmental data by the OAP, and most of NOAA, for that matter, is far superior to anything I have seen from any other organization, inside or outside of the U.S. Government".

Despite the unanimously positive reviews by stakeholders in the questionnaires and closed sessions, there were a few constructive criticisms. These included concerns about discoverability and accessibility of data. Data accessibility issues were primarily attributed to the time lag between data collection and data publication as a result of the time required for QA review. Mooring data used by one stakeholder, for example, are presently available through 2017, but not later. It was suggested that preliminary, pre-QA data could be released for consumption by the public or by program partners and should not rely on peer-to-peer requests. One very supportive stakeholder described ongoing difficulty obtaining data from the Chesapeake Bay buoy. Multiple reviewers discussed the challenge this creates for

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development of real time forecast capability. The planned “live fire” exercise mentioned by OAP staff (a potential workshop to explore data discovery with stakeholders) elicited productive discussion during the review as an excellent start for identifying and addressing discoverability and indicated that OAP is already charting a course to address these issues.

It was noted that a more consistent system may be required moving forward for PIs to clearly delineate what potential data sets may be generated as part of their research rather than depending on PI submission and data capture after the fact. Also, more consistent implementation of a data management policy is needed in terms of what data needs to be submitted, when data will be submitted after collection, and what measures OAP managers have to enforce the data management policy. As with many data management efforts, the rules and treatment of synthetic data products and model products was less clear.

Regarding data synthesis products, feedback from one stakeholder in this activity area, as well as comments made for Activity Area 4 suggest a need for more data synthesis products, including products targeted to shellfish stakeholders. Regional data synthesis (e.g., Gledhill et al. 2015) was identified by specific stakeholders as especially useful. Relatedly, more thought and input are probably needed for identifying potential users of data synthesis products.

There was also discussion about whether the final users (i.e., stakeholders) are well understood and whether they are appropriately targeted. This was complicated by ambiguity of the term “stakeholder” during the review itself.

One reviewer noted that this Activity Area encompasses disparate aims including data management and support of data synthesis products. Pre-review presentations, which were of very high quality, were primarily regarding the latter. Data management aspects came into focus through the stakeholder questionnaires and during the review itself. OAP’s efforts in both areas are highly regarded.

Relevance

Data quality assessment, management, discoverability, and accessibility are highly relevant to the overall mission of the NOAA OAP, NOAA OAR, other national and stakeholder needs. There is no doubt that data management is an essential element of the OAP, and that a successful effort touches on the success of all other elements from research to education and outreach. Data management was an important part of the 2010 NOAA Ocean and Great Lakes Acidification Plan, but at that point, each region proposed a different means of data management. OAP has and is continuing to consolidate and improve data management at a level that is on track to be the gold standard for the Nation’s OA data. OAP encourages early input from stakeholders so data products meet needs. A [Research to Product Development Best Practices](#) guide for transitioning research outputs to applications and operations was developed at the 2018 OA Research to Product Development Workshop. OAP’s data synthesis efforts are providing significant contributions to OA and carbon cycle research.

Much effort and funding are going into development of operational models and stakeholder tools. These will require real time/near real time access to data. There should be consideration of an approach to make data (e.g., buoy) available near-real time and consideration of how to

maintain/update operational products while continuing research activities. Some stakeholders expressed a desire for faster (near real-time) access to data, even if not fully QA/QC'd. This would enable more timely production of forecasts. Modelers who would like to access real time data from OAP time series find the time it takes for raw data to be QA/QC'd is too slow for their model validation needs. In some cases, real-time data are purported to be available but are, in fact, only presented as graphs that are updated in real-time and display values upon cursor roll-over rather than access to raw numerical data sets. There were recommendations from stakeholders (who should be engaged in future discussion) on how this might be accomplished, and other NOAA program (IOOS and NWS) that can be consulted as OAP moves toward these activities in the future.

It is important to clarify who the stakeholders are for this activity area. Reviewers noted they did not hear directly from any stakeholders using data products defined by OAP as 'strategic information for stakeholders, managers, and industry created in a way that is fit for the purpose'. Instead, the stakeholder group for this activity area consisted of those who were either involved in data management or in development of data products. It would have been useful to have feedback on use patterns and utility of mega-synthesis products outside of the scientific community such as use of forecasts by hatcheries in the Pacific Northwest or Chesapeake Bay. Additionally, it is unclear who exactly are the stakeholder subgroups being served by different data management and synthesis activities; there are internal NOAA audiences (e.g., other scientists), external audiences (ranging from other scientists to daily coastal resource users) and each has slightly different needs and expectations. Further clarification on which stakeholders are using raw data products and data synthesis products is needed.

Performance

Research Leadership and Planning

OAP is playing well above its weight in the area of data management (in particular) and in product development. A stakeholder noted, "Compared to how things move at the federal level, OAP [data management and product development] is moving at warp speed." OAP's sustained investment to this activity area is unusual and precedent-setting. Strategic investments, partnering, and leveraging of other resources are, as in other areas of OAP, important components of its success. OAP is very effectively leveraging partnerships with other NOAA areas and other activities internationally (e.g. GOAON) to manage and synthesize data, and, in collaboration with NCEI is turning OA data management into a customer-oriented service. An additional positive activity to note in terms of the NOAA OAP data management effort includes supporting (in collaboration with GOMO) the transition of CDIAC data to NCEI including funding to maintain and integrate CDIAC data with new carbon data acquisition. Overall it appears most data are captured into the management system and are being archived. The data management team are also well connected with modern data management practices such as effort to create uniform data ontologies. Reviewers noted that even when a stakeholder brought up data management services they wished were better or even just different, they qualified such statements by saying that OAP was exceeding expectations or that OAP data management is the best they have used. Recommendations for improvement are either very ambitious goals (recognizing the FAIR standard has yet to be fully attained by anyone in ocean science) or not entirely within OAP's control (e.g., they are in the purview of labs, researchers, or require larger investments from other programs of NOAA).

The program is making OA data available to those who need it. It is obvious that datasets are downloaded on a regular basis (as indicated by download statistics) and use of real-time data has, to date, been accommodated through individual agreements. It is unclear how frequently data products for industry, resource managers, and other stakeholders outside of the science research community are used. For example, reviewers learned that OA data was recently used for the first time in a fisheries stock assessment in Alaska. It is clear through discussion with stakeholders, review presentations, and news highlights that OAP data and information is being incorporated into policy (e.g., Washington State) and resource management strategies and tools. However, it is difficult to quantify such uses of OAP data and information products that are not documented in standard peer-reviewed publications. An upcoming (and well-anticipated by OAP) challenge is how to effectively incorporate biological data into the data management system; to help address this, some interface between NCEI and other repositories like PANGAEA might be necessary but may be difficult to develop.

Efficiency and Effectiveness

The most significant performance issue appears to be the timely delivery, accessibility, and discoverability of data products. As noted above, OAP's approach in these areas appears to be more passive than their active efforts to ensure high quality data and metadata. This is the correct order of priorities, but it now seems to be time to invest in shortening the turnaround time for data publication and distribution. Based on review discussion, the primary factor seems to be availability of resources and staff time for QA work prior to data release. Consideration should be given to when and where it makes sense to host pre-QA data. Based on the stakeholder input, there remain some significant issues regarding the data discovery stage. Effort needs to be made to create a transparent system where users are guided to the appropriate data sets without requiring individuals to know about the presence of particular data sets in advance.

QA/QC of data is a bottleneck that needs to be solved; increasing staffing is a partial solution, as is increasing automated data checking capabilities. Investments are needed in solving this bottleneck and serving data users sooner. Another issue is with the availability of near-real time data. The available graphic display tools are insufficient for some data users, and access to near-real time data should be generally available rather than limited to individual requests. Note that the issues and responsibilities of near-real time data cross the boundary between research PIs and the data management group. The availability of near-real time data does not preclude parallel efforts in data quality control to produce the highest quality data for delay data release.

Recommendations

AA3-1. Evaluate staff and resource needs for data management and product development.

The OAP data management effort has ramped up relatively quickly and must deal with a large range of different data types and sources. Investment in this area should be continued as it is setting a precedent within NOAA for program support of big-picture (regional, national, and global research, modeling, and resource management) activities. For the size of the data management and product development effort, the program may potentially be under resourced, depending on only the work of a few key individuals. Stakeholders recognized that data management is different from modeling and synthesis. There are currently capacity and resources to address OA data management. However, including modeling and synthesis in data

management will require staff and resources that are currently unavailable. Moving forward, the data needs of the program will only grow both in terms of data volume and the data needs (discoverability and accessibility) of a growing stakeholder base, many of whom in industry and the public may not be sophisticated data users. **OAP could benefit from developing a process to routinely evaluate potential weaknesses, staffing, and resource needs in the data management effort.** OAP is encouraged to continue their strong partnerships and resource leveraging across and outside of NOAA to assist with addressing resource needs. OAP is also encouraged to continue supporting regional-scale data synthesis products through better engagement with the CANs that can help tailor products for regional information needs.

AA3-2. Seek to shorten the time between data collection and data publication.

Funding opportunities already require timely data delivery by funded external investigators, but publication/availability still lags considerably. It is unclear whether similar requirements exist for internal investigators. But in both cases, the QA/QC process seems to be a bottleneck. Consider greater investment of resources or other creative solutions to expedite the QA/QC process.

AA3-3. Explore solutions for making real-time data publicly available.

Real-time data is currently being used by a limited number of partners who have individually negotiated access to that data from NOAA labs. However, real-time data is not generally available to all users. As real-time forecast models and resource management tools are increasing in demand, it is likely that development and maintenance of these products will need to be outsourced to external entities for long term maintenance and updates. A future challenge for OAP will be to find ways to make OAP monitoring data (from buoys, etc.) available to better fulfill FAIR requirements. There is potential for collaboration and discussion with IOOS and NWS for development of approaches and solutions to operational activities and data/product requirements as OAP moves in this direction in future years. IOOS may also be able to provide more assistance with development of region-specific products. Other recommendations from stakeholders and reviewers included:

- Serve near-real-time data to technical users (e.g., model developers, synthesis product creators) with appropriate QA/QC flags and metadata; this may require adding staff.
- Lean more on automated QA/QC or changing the data-providing culture to allow temporary use of provisional data.
- Clarify among the PI and stakeholder communities that there is a distinct difference between real-time data that is required by modelers and data products derived from real-time data that are updated in real-time data.
- Continue to work to make monitoring data available to scientific users in the form they need on the time frame they want. Preliminary or “raw” data that are not fully QA/QC’d can be flagged as such. Continue to work to match provision of data & products to stakeholder needs: some want raw data, some want plots.

AA3-4. Engage stakeholders for solutions to data discoverability and consider development of a user guide to data access.

OAP is encouraged to continue “live fire” exercises to identify data discoverability and accessibility issues. Continue to keep up the good work toward the goal of FAIR data. Stakeholders offered good suggestions for ways forward to improve data discoverability and potential ways forward for broader real-time data access. OAP is encouraged to reach out to the

data management stakeholder panel group from this review perhaps through a workshop as they move forward with these aspects of data management. OAP may consider development of a user guide to data access targeted at various groups of stakeholders. A closer examination of which stakeholders are using which data and information may be needed to inform development of a user guide. Other reviewer and stakeholder recommendations included:

- As a growth opportunity (recommended by a stakeholder) consider a federated data discovery solution based on platforms already available (ERDDAP) that can greatly enhance the data access and data discovery of OAP supported data over and above what NCEI provides.
- Improve announcements to data-using stakeholders about what products are available and advances in data availability and storage to improve active distribution of information.
- Make effort to steer clear of the constantly shifting landscape of web pages and hypertext links (used for other NOAA resources such as basic tides and currents, historical SST info, and El Nino calculations) that may confuse repeat users. Avoiding this for OA data will require a delicate trade-off between improving discoverability and maintaining a stable internet landscape.

AA3-5. Clearly define stakeholder subgroups and their data management and product needs.

Refine and resolve the meaning of “stakeholder” so that data products and syntheses can be appropriately developed, targeted, disseminated, discovered, and accessed. Clarify which OAP stakeholder subgroups depend on which data management services and product development activities and ensure that their needs are being fully served (through interviews, panel discussions, open comment periods on planned activities, etc.).

AA3-6. Continue efforts in collaboration with NOAA programs and IWGOA to improve interoperability of data.

Interoperability of data is recognized as an enormous challenge moving forward, as is defining interactions and responsibilities among participants in data management. OAP is clearly taking a leadership role in working with internal programs and external agencies to improve interoperability and is encouraged to continue this effort.

AA3-7. Engage in discussion with OAR and other NOAA Programs to clearly define data management responsibilities.

OAP has taken a leadership role in creating and maintaining very successful partnerships among NOAA program and laboratories that have been essential to development of effective OA data management. As with other activity areas, there needs to be good clarity (and discussion with OAR) on what is OAP’s responsibility and expectations versus other OAR and NOAA program responsibilities with respect to data management, synthesis and product development, and the degree of separation that should exist between Carbon and OA Programs.

Activity Area 4: Education and Outreach

Quality

OAP supports multiple high-quality, far-reaching education and communication activities, including the OA information exchange (OAIE), graduate student fellowships, mini-grants, SOARCE webinars, and funding to the regional CANs with admirable expansion over time across the country (e.g., mini-grant projects, SOARCE) and the world (e.g., OAIE). SOARCE webinars and OAIE are nearly one-of-a-kind offerings and significantly contribute to the broader OA community by increasing knowledge, fostering community connections, aiding accessibility of OA expertise for a wider non-scientist audience.

The OAIE is a particularly effective tool for members of the national and international OA community to connect and share information and experiences. Users span a broad range of backgrounds and interests in OA and include industry members, resource managers, educators, and others. A high percentage of users are actively participating in discussions. The OAIE has a robust evaluation procedure in place to track its use and reach.

Mini-grants also have an appropriate evaluation process that has led to OAP increasing funding to the mini-grants in the second cycle. Stakeholders indicated a need for a better mechanism to provide feedback to the OAP program to communicate successes of mini-grants and more discussion with the OAP program on how to continue successful work. This may happen through the review of mini-grants that is recommended below. It was noted by reviewers that there is no evaluation procedure for SOARCE webinars. Webinar evaluation could take many forms. Some SOARCE webinars include polls during the lecture to help speakers gauge the audience's level of understanding; perhaps that capability could be expanded to more formally (and randomly) solicit pre- and post-webinar feedback on effectiveness from audience members. A small steering group could periodically evaluate webinar content (topics, complexity, regional breadth, diversity of audiences and presenters, audience-provided effectiveness metrics). And download/user metrics of archived webinars could be followed over time. These metrics would help gauge whether SOARCE webinars are effectively serving their intended audiences, which topics are most useful, and how they "age" over time as a permanent resource.

Staff dedication and involvement are visible to all who engage with the program and are a critical part of the overall high-quality work of the program. Outreach and education products from OAP are popular and frequently referred to and shared by members of the broader OA community (educators, local leaders, etc.). Education and communication activities, like all of OAP, leverage resources to develop products far beyond the OAP investment.

Relevance

OAP education, outreach and communication activities are guided by and respond to the 2010 NOAA Ocean and Great Lakes Research Plan, the FOARAM Act, NOAA OAR's outreach and education goals, and the OAP Education Implementation Plan. OAP outreach and education activities address the needs of OAP stakeholders, identified as part of the program initiation, and target audiences (e.g., teachers, community groups, information users) are engaged at the outset to help shape and implement activities.

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OAP does an amazing job serving a vast array of different stakeholders, but these different groups could be more clearly defined to improve communication. OAP stakeholders can include scientists at OAR laboratories using OAP data to support their research or development of data products, other NOAA scientists creating data products or education and communication products, resource managers, industry members, or state-level commissions. Clarity on who these different stakeholders are and what their needs are would help highlight the exceptional work that OAP is doing on many fronts. Clearly defining and targeting current stakeholder/audience subgroups will help steer future products toward maximum utility. The stakeholder/audience subgroups that OAP serves have very likely shifted since the program began. Clarification of stakeholder groups will facilitate evaluation of which stakeholders are using data products and how those data products can be improved.

Activities under this Activity Area are often cross-cutting, linked to research activities, and are serving the science research community in addition to formal and informal educators; for example, the Oyster CSI project educates and engages students, but also provides information on biological sensitivity. Results from OAP research are being used to inform the fishery management process in at least one fishery now; efforts such as “ecosystem report cards” etc. are helping integrate OAP results into decision-relevant information.

Stakeholders from many areas (i.e. educators, industry members, scientists) are engaged in OAP education and communication activities. OAP Communication resources are highly utilized. Website traffic has dramatically increased from 1200 visitors in 2015 to 7100 visitors in September of 2020, the SOARCE and CAN webinar series have had over 7000 participants, and 79% of OAIE members are active on the site. OAP effectively collaborates and leverages funding and partnerships with CANs, Sea Grant Offices, and other NOAA programs and external collaborators to implement and disseminate outreach/education products and ensure a broad range of stakeholders are reached.

This OAIE platform is an extraordinary tool for members of the OA community to share ideas and experiences, make connections, and build collaborations. However, by nature of requiring users to create a membership profile, the OAIE reach is limited to those who opt to sign up and join. Member only access to OAIE information may also limit discovery through web-browsing and requests for membership by (especially) non-scientist stakeholders. This means that potential users and stakeholders who are seeking information about OA may not benefit at all from the OAIE community.

Performance

Research Leadership and Planning

The OAP program is a world leader in establishing best practices, disseminating information, and leading international OA outreach and education coordination efforts. Support for outreach/education activities is well explained in strategic and implementation documents and thoughtfully granted. Activities have been appropriately evaluated and priorities are clearly outlined (especially in the outreach and education implementation plan). With limited financial investment in this area, OAP nonetheless demonstrated how important this activity area is by hiring a coordinator to lead the Education and Outreach efforts, providing OAP with appropriate leadership in this activity area. Collaboration with the CANs are a major aspect of this activity

area with respect to identifying stakeholder needs. OAP provides some financial support to the CANs, but perhaps more importantly, provides an OAP staff member to serve on each CAN Steering Committee. This helps tie the CANs together and provides national leadership for the CANs' regional efforts. A common theme in the stakeholder session for this activity area was the very accessible and attentive OAP office staff. All members of the office are known to groups around the country by name and often travel to different regions to lend support and leadership to regional efforts (i.e. State level OA commissions, Maine Ocean and Coastal Acidification Partnership (MOCA), etc.)

Stakeholders and reviewers commented that the range of OAP stakeholders has grown over the years and OAP can't be everything to everyone. As noted elsewhere, OAP needs to re-examine and better define categories of program "stakeholders" to better tune outreach and education efforts to their needs. Stakeholder fatigue was recognized as challenge to maintaining effective engagement. OAP is addressing stakeholder fatigue by working to insert information where it is already being consumed by stakeholders (fisheries, HABs, CANs, Sea Grant etc.). It will be a challenge to continue to find creative ways to avoid it and it must keep it on the radar. OAP is encouraged to continue their effort in this area.

Efficiency and Effectiveness

Program staffing appears to have grown appropriately through time as budget, partnerships, and other duties have also grown. As OAP continues to grow, it will be appropriate to add additional staff to maintain effective leadership. OAP leadership has paid close attention to keeping program overhead costs low, to maximize the impact of other activities. OAP is exceptionally effective at creating partnerships to leverage and extend the reach of their work across NOAA and outside of the agency and is leveraging resources and partnerships with internal (e.g., Sea Grant, NOS, etc.) and external (academic researchers) entities to achieve maximum results. The very engaged program leadership is constantly involved in assessment/reassessment of current developments and effectively addresses opportunities and needs within the scope of the (well written and comprehensive) strategic and implementation plans. OAP clearly holds education and communication to very high standards, but this area of the investment portfolio could be expanded to broaden the reach.

Stakeholders indicated that the Regional Coastal Acidification Networks (CANs) can be better engaged to assist with communication and distribution of information. OAP may consider incorporating updates from the OAP Communications Coordinator to CAN coordinators during CAN meetings on newly available information or may alternatively consider newsletters as a platform for sharing new information updates which can easily be forwarded to networks for rapid communication and distribution. It was recognized that OAP is working to improve communications with CANs through Sea Grant grants and fellowships to build workforce capacity in outreach and education areas.

The OAP website is how the program presents itself to the outside world and how many stakeholders seek content, so its design is extremely important in the overall communication effort. Quantity of materials has expanded over time such that improved indexing, archival, and cross-linking is needed, as part of an overall website refresh to improve accessibility to all the great OAP content. Stakeholders commented that the OAP website is not easy to navigate and it

is difficult to find specific education products. This discussion was not comprehensive of everything that could be improved, but included comments that it is hard to find specific content, it is challenging to share a link to a specific SOARCE webinar, there is excessive scrolling needed, the CANs (a very important part of OAP) are somewhat hidden, the menu bar takes up too much of the screen, and additional sub-navigation may help locate information.

OAP should continue its thoughtful approach to outreach and education over the next 5 years, broadening it in key ways outlined in the ‘Recommendations’ section. OAP support for outreach and education activities has grown admirably since the start of the program. SOARCE webinars, mini-grants, and partnerships among OAP staff and other NOAA and non-NOAA offices have all been very effective at creating a broad base of outreach/education materials and making them available to the public. Activities are very carefully selected and supported.

Recommendations

AA4-1. Update the NOAA OA Education Implementation plan.

As the OAP develops their own strategic plan, update the Education and Communication Implementation Plan. The new plan should also lay out communications goals and principles (see below), include a refreshed view of OAP’s stakeholders (see below), and re-formulate the Outreach and Education Activity Area as a cross-cutting effort. The existing outreach and education plan provided a robust foundation for the outreach and education work OAP does, heavily emphasizing work with educators, and many future outreach/education activities will naturally continue to serve mainly formal and informal educators. However, outreach and education are inseparably tied to communications, and they also reach beyond educators. For example, even data sharing is a type of outreach and communication work. The refreshed outreach/education plan needs to consider the full breadth of audiences, their needs, and how OAP activities serve their needs, and critically, how OAP is pushing that information out to them. Moreover, the stakeholder subgroups served by OAP have evolved, and as OAP refreshes its understanding of its stakeholders and their needs (see below), the outreach/education plan will necessarily need refreshing too. The plan should include an upfront diversity, equity, and inclusion (DEI) statement, as was suggested in the stakeholder meeting. The updated plan can improve education and communication strategy by reflecting on which aspects of the current plan have been most successful. Additionally, efforts should be made to ensure education and communication products are accessible to those with disabilities.

AA4-2. Consider public accessibility to some OAIE content to increase interest in membership.

The OAIE is a central forum for outreach/education across the OA community, and it should continue to be cultivated over the next 5 years. The OAIE receives consistent praise as a forum for supporting connections across the community and offering quick responses to obscure questions. OAP’s approach to developing it has been thoughtful, evidence-driven, and inclusive. The OAIE has also been embraced by the international community and has provided a good deal of knowledge transfer from well-established OA scientific efforts to newly established activities, especially in developing countries. A reviewer suggested opening some OAIE posts to the public to “lure” in people more peripheral to the OA community; perhaps this strategy could work well for discussions of how OA intersects with other ocean issues, such as heat waves, harmful algal blooms, hypoxia, or discussions that relate to a specific industry. Other suggestions included

having discussions open for anyone to view (but not contribute to without membership) to increase the usefulness of the OAIE to those who may not wish to create an account but could benefit from quickly reading a discussion. A compromise could be to make key discussions open and ‘Google-searchable’ so that stakeholders may be lured in by Google results.

AA4-3. Update the OAP website to make content and information more ‘discoverable’.

Some stakeholders noted that the OAP website isn’t serving their needs, because they can’t easily find and share key products. Since the OAP’s offerings have broadened so much over the life of the program, the products can no longer be offered in a simple way, but the website should provide a straightforward portal to finding everything under the OAP umbrella. Products need to be indexed and searchable in a number of ways (e.g., by date, technical level, subject, region, etc.; perhaps OAIE themes and interest areas could be informative about useful indexing terms) to allow users to more easily find and share what they need. Although feedback on this activity area from stakeholders focused mainly on accessibility of webinars and reports, data users could also use a better road map on where to find various OAP-related data products. Suggestions for organization included having sub-navigation leading to categories of products and information. Website redesign must take into account accessibility for users of all abilities and search engine optimization. Website redesign must also incorporate insights gained from metrics about website traffic to current OAP sites; different types of users will have different information needs and different levels of determination in digging them out. As the welcome mat for OAP, the OAP website needs to serve all the stakeholder subgroups OAP is charged with serving, more so than any other product OAP creates. OAP staff indicated they are performing an analysis for determining how website visitors are finding info and who is using what pages. OAP is encouraged to use results from that analysis to tune content on pages to focus on who (audience) is looking at the pages in a similar manner to how they are already doing this on Facebook, Instagram, and Twitter. Additionally, consider creation of web navigation tuned to audiences that are targeted for different categories of information (students, teachers, etc.).

AA4-4. Examine and clearly define OAP’s diverse stakeholder groups, subgroups, and their needs.

It is time for OAP to refresh its understanding of who its stakeholders are. There is no single type of stakeholder, and for a program like OAP that works so closely with local resource managers, the scientific community, high-level elected officials, and even local educators, this is doubly true. As a result, there is a diversity of audiences that OAP serves, and there is insufficient clarity about who these audiences are, what they need, and how they need it. Moreover, in keeping with efforts across STEM to improve diversity of those served, OAP needs to examine how they are serving information to these groups. A diversity, equity, and inclusion improvement plan should be included as part of the overall education/outreach plan refresh.

AA4-5. Evaluate all education and outreach activities including communication.

There is a robust evaluation cycle in place for mini-grant-funded education and outreach activities, and a very good protocol in place for improving the OAIE through a steering committee and evidence-based decision-making about site improvements. It’s important to recognize that communications to internal and external stakeholders about OAP activities is a type of outreach, as are OAP activities such as developing partnerships and data dissemination. Data discoverability by users is tightly connected to communication by OAP, either by

announcements of what's available or a well-designed website. There should be a similarly robust evaluation cycle in place for other education, outreach, and communication activities beyond mini-grants and the OAIE. As noted above, this could be captured in a revised outreach/education/communication plan and supported by regular monitoring of metrics. These could include things like website and media metrics, monitored in conjunction with NOAA's Communications office and metrics showing who is being served by different activities (e.g., affiliation, role, experience level of SOARCE webinar attendees or specialized events like OA week). Education/outreach goals should be set and measured that are associated with other areas of OAP besides the activities that serve mainly educators. Attention to the education/outreach/communications "metadata" associated with OAP activities (visitor types, topics of interest, etc.) that fall outside the education/outreach plan may also help identify where a broader audience could be served. Adding a partial or full-time staff member focused on communications may be necessary in the near-future to support a more intentional focus on disseminating information.

AA4-6. Include information on program decision-making processes in future strategic plans.

OAP is currently extraordinarily transparent and candid about its decision making and achievements to some stakeholder subgroups, but a more rigorous communications approach will improve transparency and serve a wider array of stakeholders. The panel heard from stakeholders that OAP's annual community meetings and other NOAA-wide and science-community-wide activities are some of the most common times when OAP staff provide information on decision making and direction-setting within the program. However, that can unintentionally exclude individuals who miss gatherings. Several stakeholders also expressed a desire for increased transparency about program decision making, ways in which conflicts of interest are handled, and strategic direction-setting, and OAP is encouraged to include descriptions of these processes in an OAP Strategic plan and updated Education and Outreach plan. Additional guidance should be provided to mini-grant recipients on how best to communicate successes to OAP and how to engage in discussions with OAP regarding continuation of successful efforts.

AA4-7. Consider an approach for more active communication and delivery of information to stakeholders.

OAP is actively engaging the stakeholder community for input into data and product needs. However, communication of research results and information to stakeholders seems to be generally passive. OAP might consider if there is a need to develop an approach for active delivery of information to stakeholders where appropriate as part of the transdisciplinary science approach (co-production of information for outcome driven science). There is a difference between notifying a stakeholder of availability, and actively delivering information and there may be appropriate instances for both approaches. Stakeholders interviewed felt that a periodic email newsletter could offer a good solution. A monthly or bimonthly roundup of announcements, relevant links, and current events would be appreciated by stakeholders and is used to good effect by other similar programs (e.g., IOOS, OCB). OAP is already doing some of this with the Pier2Peer newsletter, but a regular program-wide "push" of information would be useful as the program grows, and regular personal contact between each member of the community and a NOAA OAP staff member becomes less possible. An email update can be easily forwarded by recipients to other external groups to grow the reach of OAP information.

SUMMARY OF RECOMMENDATIONS BY ACTIVITY AREA

Ocean Acidification Program-Wide Recommendations

OAP-1. Develop an Ocean Acidification Program Strategic Plan.

OAP staff identified during review the need and their intent for development of an OAP Strategic Plan. This need was confirmed by reviewers and stakeholders, and many suggestions for content were provided. Information in this plan will help consolidate OAP priorities, responsibilities, activities, definitions and processes into a single document to more efficiently convey Program information to internal and external participants, stakeholders, and broader communities. Content suggestions specific to individual Activity Areas are described in more detail in recommendations AA1-1, AA1-2, AA4-1 and AA4-7 and are briefly summarized here:

- Consolidate, summarize and map the hierarchy of mandates, goals, objectives, actions, and tasks (and linkages among them) from the numerous strategic plans to which OAP (specifically) responds.
- Synthesize and clarify OAP responsibilities.
- Clarify and include information on program decision making processes such as strategic direction-setting and prioritization, considerations and factors used to set tactical (Prospectus level) priorities and funding allocations across regions and topical areas, processes used to evaluate stakeholder input and resolve conflicts of interest.
- Define the full scope of OAP research evolution and progression (including foundational research and monitoring, multidisciplinary, interdisciplinary, integrated, and full transdisciplinary science), anticipated outcomes, and expectations for participant engagement in each type of research project. Clearly define transdisciplinary science and variations that apply to OAP.
- Define the numerous categories of stakeholders (internal and external) to which OAP responds and serves.

OAP-2. Engage in discussion with OAR and other NOAA Programs and Laboratories to define responsibilities.

OAP has taken a leadership role in developing guidance for broader NOAA OA research and monitoring activities and in creating and maintaining very successful partnerships among NOAA programs and laboratories. OAP's leadership in both areas has been essential to achieving the high degree of integration of activities among OAP and other NOAA programs and laboratories that is required to effectively advance OA science. This successful and necessary integration of activities makes it somewhat difficult to identify OAP versus other NOAA program and laboratory responsibilities. Moving forward, it would be beneficial to more explicitly define the appropriate boundaries and overlap of OAP and other NOAA responsibilities, observational, research, and data management requirements, and portfolios. Clear definition of responsibilities will benefit current and future program planning activities and effective resource allocation. See additional details in recommendations AA2-3 and AA3-7.

OAP-3. Define and assess stakeholders and their needs.

The nature and diversity of OAP's stakeholders has evolved since the program was developed and as science has moved from fundamental research to transdisciplinary applications. Examine and clearly define OAP's diverse stakeholder groups, subgroups, and their needs. *It is*

understood that OAR provided the definition of stakeholder for this review; therefore, these definitions may need to be developed in consultation with OAR. OAP could benefit from performing a strategic assessment of stakeholders. Identify which groups will be prioritized, the different needs of these groups, and the research approaches needed to achieve outcomes to continue to improve stakeholder participation, meet stakeholder needs, and clarify expectations from OAP projects and PIs for participation in OAP activities. See additional details in recommendations AA1-4, AA3-5 and AA4-4.

OAP-4. Enhance stakeholder engagement in under-invested and investigated regions.

Stakeholder engagement in some regions has been challenging. Limited engagement from stakeholders in the Southeast and Gulf of Mexico may be due to lack of sensitivity information to determine risk and vulnerability and/or focus on other environmental stressors that are perceived as more pressing such as HABs, hypoxia, and marine heat waves. OAP has begun (and should continue) improving engagement in these areas by addressing OA in the context of these multiple stressors and is encouraged to continue supporting the work needed to fully understand risk and vulnerability in these regions. Stakeholders indicated that the Regional Coastal Acidification Networks (CANs) can be better engaged, both directly and in partnership with Sea Grant, to assist with communication, distribution of information, and stakeholder engagement. OAP can provide guidance to the CANs on how to better engage within the regions to ensure local and regional priorities are being met. Periodic re-evaluation of needs, readiness, and feasibility for engagement in the Great Lakes Region should continue as resources and partnership opportunities allow. See additional details in recommendations AA1-3, AA1-5, and AA2-7.

OAP-5. Continue to re-evaluate and rebalance distribution of projects among the OA-Trifecta, regions, and scientific approaches.

Advancement of the state of OA science will require more investment in sensitivity, human dimension projects, and related data management, outreach and communication needs while maintaining environmental monitoring, particularly in under-investigated Regions. OAP should strive for greater regional balance in the distribution of ecosystems studied and co-occurring issues (e.g., HABs, MHWs) that interact with OA. As needs for applied research increase, there will also need to be consideration of the balance that OAP is targeting with respect to fundamental, multidisciplinary, interdisciplinary, integrated, and transdisciplinary research approaches, and clear guidance on expected outcomes for each approach and engagement/roles/responsibilities of project participants. See additional information on specific implementation suggestions in recommendations AA2-1, AA2-2, AA2-4, AA2-5, AA2-6, AA2-8 and AA2-10.

OAP-6. Consider ways to track or document accomplishments that are not recorded in peer-reviewed publications.

OAP has an outstanding portfolio of peer-reviewed journal articles that illustrates its many accomplishments. However, OAP has many other accomplishments that are not documented in journal publications that should be recognized and similarly documented. For example, results and data are getting directly applied in decision making and resource management tools; many education, outreach, and communication tools have been developed and are highly utilized in formal and informal educational activities; numerous capacity building activities have advanced

national and international OA science interest and participation. OAP is encouraged to continue periodic reporting of accomplishments including those that are not published in journals. See additional details in recommendations AA1-6 and AA2-9.

OAP-7. Assess current and future staffing needs.

The OAP has a small (seven permanent staff members and three temporary positions) but highly effective staff. This small team has done an outstanding job effectively and efficiently leading and managing an incredibly successful program. OAP has implemented creative approaches to ensure adequate human resources through developing and successfully leveraging shared staff positions with other OAR programs and labs, internships, and fellowship positions. Human resources are currently adequate to meet program management needs. However, additional staff resources are likely needed in the near-term to support rapidly growing data management needs, expedite delivery of OAP data and products, and to increase focus on communications. Given the rate of program growth and potential for continued growth, it is likely that OAP will need additional staff in the future to maintain their current level of productivity. *The review team understands that this discussion is a regular part of OAP to OAR communications.* Assessment of staffing should consider current and future needs and roles for additional permanent, shared, and temporary staff members required to maintain the balance and workload of core program activities and shared program activities. See additional details in recommendations AA1-7, AA3-1, AA3-3, and AA4-5.

Activity Area 1: Scientific Priority Setting Recommendations

AA1-1. Develop and consider suggestions for information to include in an Ocean Acidification Program Strategic Plan.

The OAP has clearly defined and documented management, scientific, technological, and policy objectives and rationale for funding key activities and projects through leadership of and/or contribution to multiple OA and broader NOAA strategic plans. However, this information is currently distributed among six different strategic plans ranging from Congressional to NOAA Program levels making it difficult to cross-walk and understand the full scope and responsibilities of the OAP. This information became clear to reviewers during an in-depth review of the full program but does not appear to be generally well-understood by many program participants and stakeholders. Additional needs for information related to program processes were identified by stakeholders and reviewers. OAP is encouraged to consolidate information on guiding mandates and NOAA requirements, program responsibilities, activities, definitions and processes into an OAP Strategic Plan to more efficiently convey program information both internally to NOAA and to external participants, agencies, and institutions. Suggestions on specific content to consider include:

- a. **Consolidate, summarize and map the hierarchy of mandates, goals, objectives, actions, and tasks (and linkages among them) from the numerous strategic plans to which OAP (specifically) responds.** Consolidating this information in a ‘digestible’ format will help clarify OAP’s responsibilities, provide context for prioritization particularly for external participants and stakeholders, and will highlight the relevance of OAP. Appendix 1 of the 2017 Principal Investigator’s Meeting (for example) summarizes specific activities OAP addressed from the 2010 NOAA OA Plan, but does not articulate

the responsibilities of other NOAA programs. Similar information is difficult to summarize and cross-walk from the other NOAA and OAR strategic plans. This is especially important given the new, more comprehensive NOAA Oceans and Great Lakes Research Plan for OA. *OAR Program should assist with clarifying responsibilities of OAP versus other NOAA programs and laboratories. Institutional guidance from OAR and other NOAA Line Offices on the roles and responsibilities of other NOAA Programs and Laboratories may help OAP refine and improve their strategic and implementation planning processes.*

- b. **Clarify and document factors and considerations used to set tactical priorities, project and funding distributions.** Full review of all program elements and documents indicates the data, considerations, and justifications used by OAP for both long-term (strategic) and short-term (tactical) priority setting. However, this information is distributed across many documents, presentations, statistical analyses, etc. The process for setting priorities and the transparency of that process are excellent; and the outcomes of that process are also very clear in the products and progress. What is less clear to both internal and external participants are the considerations and factors that set the tactical priorities and determine the distribution of funding by region and topical area.
- c. **Clarify and summarize the process used to evaluate and prioritize stakeholder input.** It is also unclear as to how stakeholder input is evaluated and prioritized particularly with the potential for conflicting requests from diverse audiences and geographic locations.
- d. **Clearly define the categories of internal and external stakeholders and stakeholder subgroups to which OAP responds and serves.** Clarify roles of stakeholder categories in the program's priority setting process, and what types of activities and products target these specific categories.
- e. **Clarify roles and procedures for shared and temporary staff.** OAP has established creative solutions to staffing needs through positions that are shared with other NOAA programs and laboratories and through internships and fellowships. These positions serve as excellent employee development and workforce capacity-building opportunities. Indicate how conflicts of interest are avoided for shared staff whose NOAA labs/programs receive funding from OAP. Consider and describe the feasibility and role of temporary staff in maintaining and growing program functions.
- f. **Describe the process and considerations used for ending or transitioning projects.** The process for evaluating and selecting proposed project activities is clear and transparent. OAP indicated evaluations are also used to determine project discontinuations or transitions. However, project participants indicated a need for additional guidance and information on the process used to end or transition projects.
- g. **Provide clear definitions of the full spectrum of OAP science.** Define science approaches undertaken and required to achieve the transdisciplinary (TD) approach and outcomes (from basic research, multi-, interdisciplinary, integrated, to full transdisciplinary). Explain that to achieve the OA-Trifecta, a progression from basic research to increased levels of integrated science toward achieving transdisciplinary research is required. Also, the TD definition is being applied to what may be considered different approaches/categories of TD science and this is related to type of stakeholders/participants involved (scientists as stakeholders, resource managers as stakeholders, public as stakeholders). This is appropriate but also needs to be defined

clearly.

- h. Clearly define the terms adaptation and mitigation.** Stakeholders noted that different entities appear to be using different definitions.

AA1-2. Consider and formalize the timing for updates to short and long-term planning documents.

There is potentially a disconnect between the 3-year prospectus and 5-yr review period. Consider the advantages (e.g., provides flexibility to shift directions/address emerging issues and allows for time to prepare program review materials) and disadvantages (may need to get through 2 complete 3-yr cycles for more robust reporting on outcomes that guide 5-year strategic planning).

AA1-3. Continue developing creative and alternative methods for collecting stakeholder input.

It was noted that formal stakeholder input to OAP occurs primarily during in-person stakeholder and OA PI meetings. Several stakeholders also noted the dedication, willingness, and responsiveness of OAP staff to stay engaged with direct (person to person) communications with stakeholders. Some concern was expressed that broader stakeholder input may be limited in formal meetings due to less input from ‘less vocal’ members of the community, limitations on ability of participants to attend, or lack of input from potential stakeholders not directly involved in OAP activities. The OAIE is an excellent example of an alternative method for collecting stakeholder input. OAP should continue to consider and communicate other alternative methods and options to stakeholders for direct communication with the OAP. This could include, for example, having virtual community meetings so those who are not able to travel can attend, which could increase stakeholder participation.

AA1-4. Perform a strategic assessment of stakeholders.

Identify which stakeholder groups will be prioritized, the different needs of these groups, and the research approaches needed to achieve outcomes to continue to improve stakeholder participation, meet stakeholder needs, and clarify expectations from OAP projects and PIs for participation in OAP activities.

AA1-5. Continue to enhance communications and engagement with the Regional Coastal Acidification Networks.

Some of the Coastal Acidification Networks are well engaged and others are not. Continue to engage the Coastal Acidification Networks both directly and in partnership with Sea Grant offices. OAP can provide guidance to CANs (based on lessons learned from those regions with effective CAN engagement) on how to better engage within regions to ensure local and regional priorities are being met.

AA1-6. Continue periodic synthesis and reporting of OAP progress and accomplishments.

It is clear OAP has many accomplishments that are not documented in journal publications including information platforms, outreach and educational materials, citations in state, regional, and other stakeholder plans, among others. NOAA Technical Memorandum OAR-OAP-1 (the 2017 NOAA PI Meeting Summary Report) is an excellent summary of OAP progress and accomplishments and an example for future reporting documents. Reports of accomplishments will help document the full scope of OAP progress and impact and can greatly facilitate future

program reviews. The periodicity of these reports could be timed with either renewal of an OAP strategic plan or with the 3-year Prospectus.

AA1-7. Continue creative solutions to future staffing needs. Given the growth trajectory of OAP over the past 5 years and anticipated growth in future years, consider and plan for future staffing needs to maintain level of performance (the balance between being “lean and mean”, and not overtaxed). Shared program positions have worked very well, and this is a good, creative solution to supporting program growth. Additional resources and permanent positions may be required to maintain long-term functions of temporary staff and program productivity in the future. Continue engaging in workforce development activities (educational, intern fellowship opportunities) and identifying other opportunities that will improve diversity and inclusion in the NOAA and OAP workforce.

Activity Area 2: Research to Understand Vulnerability Recommendations

AA2-1. Continue leveraging partnerships and research results to strategically prioritize research activities.

There will be increasing demands for targeted environmental monitoring as the OAP moves forward, and the costs of environmental monitoring will not likely decrease sufficiently to cover these demands with current resources. The OAP needs to be strategic in its investments, continuing to leverage existing partnerships and building new partnerships as possible. The OAP has initiated studies on how to best optimize sampling strategies, and the results of these studies will help guide future investment decisions. The results from standard observational sampling strategy experiments designed in terms of best capturing chemical variability will complement more expert-opinion driven observing priorities developed and built on information on the biological sensitivity of organisms and habitats.

AA2-2. Continue to optimize OAP monitoring to characterize impacts to ecosystems and humans.

As knowledge and understanding grow, the geography of the OAP monitoring element should be optimized adaptively to best characterize ecosystem dynamics and impacts on human dimension as well as providing information in a timely fashion to a diverse range of stakeholders. Near-term challenges include addressing the growing obsolescence of Moored Autonomous pCO₂ (MAPCO₂) sensor systems and exploiting observing platforms that will fill in time/space gaps in the current observing system. Current gaps in the OAP observing network, such as in the Great Lakes region, will need to be reevaluated with time depending on the needs of potential new stakeholders.

AA2-3. Engage in discussion with OAR and other NOAA Programs to clearly define OAP’s observation and research responsibilities.

Project distribution and resource investments indicate OAP’s primary focus has been environmental observation with other NOAA programs primarily responsible for species and ecosystem studies. OAP effectively leverages numerous NOAA programs and laboratories in partnerships to accomplish this work. It is important for OAP and OAR to clearly define responsibilities and limitations for programs and laboratories participating in OA activities.

Additionally, clarification of monitoring responsibilities among OAP NOAA partners would also be beneficial. For example, the OAP and GOMO program need to continue to cooperate to determine the appropriate boundaries and overlap of their observational requirements and portfolios.

AA2-4. Develop and implement an approach to improving utility of species response data in ecological scaling studies.

The OAP should work toward decisions about how to handle large unknowns in the meaning of laboratory response data. The major alternatives are 1) accept, acknowledge, and communicate the effect of the ecological unknowns on higher scale uncertainty envelopes; 2) allocate some of the increased vulnerability funding to quantify these unknowns; or 3) rebalance the OA Trifecta funding to increase investment in the sensitivity area. If the unknowns are to be addressed rather than merely quantified and communicated, emphasis should be on ecological scaling studies (more observations and experiments, fewer models) and other issues that complicate the assumed relationships (e.g., adaptation and acclimation). Gear et al. (2020) is one example of item number 1, and involved OAP-funded investigators, but there are other examples as well, especially from other fields. Studies of in situ response and acclimation in shellfish include Thomsen et al. (2017), Leung et al. (2017), and Gear et al (2020). As already noted, the OAP-funded work by Bednarsek and others is another excellent example, but there needs to be much more like that work if forecasting is to include ecological responses at any scale above that used in laboratory studies (i.e., individuals of a specific life stage). Any divestment whatsoever from environmental observing is not suggested. Rather, the beauty of the Bednarsek work is that it has moved toward inclusion of pteropod biology indicators within the environmental observing program, but with solid underpinning in the basic biology and ecology.

AA2-5. Consider creative approaches for implementing future larger scale ecosystem studies.

Engage the broader OA community and other agencies in discussions and consideration of creative approaches to pursuing larger scale ecosystem experiments that are needed to better inform models. This is not OAP's or NOAA's responsibility alone, and the answer is not clear as to how it can be accomplished with limited funding across agencies, other entities and, perhaps, limited bandwidth. Integrated chemical/biological studies have depended heavily on academic colleagues. Continued discussions and collaboration with MBON to pursue work in this area is encouraged.

AA2-6. Invest in under-sampled regions to better inform risk and vulnerability.

The OAP should also continue to seek opportunities for investment in regions that are under sampled in terms of environmental measurements or biological sensitivity. The threshold for defining “relevant” environmental change 1) should be determined by biological/ecological sensitivities; 2) should inform environmental observing; 3); and may be lower (i.e., higher sensitivity) in regions with lower background variability during recent evolutionary history. There are numerous academic and other external institutions that have the capacity and expertise to perform the sensitivity research needed to improve understanding of risk and vulnerability in the SE and GOM regions. OAP may consider more external support/collaboration with external labs and academia where NMF response is slow to help move science forward in these areas. There is also existing NOAA infrastructure and labs at AOML that are equipped and capable of

these studies that could be more fully engaged. Consider re-engaging/check-in with stakeholders from Great Lakes to determine readiness, potential, and need for moving activities forward in that region. The answer may be no, but this will provide updated information and justification for not addressing that region.

AA2-7. Enhance stakeholder engagement in Southeast and Gulf of Mexico.

There is an apparent lack of external-to-NOAA stakeholder engagement in this region, potentially due to other environmental stressors that are more pressing including HABs and hypoxia. OAP has already identified this issue in the 2020 NOAA Ocean and Great Lakes Acidification Plan. Stakeholder engagement in this region may need to be focused on multiple stressors and it was noted that OAP is working toward this approach with their recent HABs workshop and partnership with Sea Grant for student fellowship grants. As stakeholder needs are largely driving research priorities, this lack of engagement has been used as rationale for the lower amount of funding for biological sensitivity projects in this region. Perhaps OAP can directly assist scientists in this region to connect with potential stakeholders.

AA2-8. Provide clarity and guidance on targeted research approaches for project participants.

There may need to be some clarity moving forward as to the balance that OAP is targeting with respect to fundamental, multidisciplinary, interdisciplinary, integrated versus transdisciplinary research approaches – including clear language as to what OAP will not fund and expects other agencies to fund. Additional guidance regarding the expected type of research approach and, thus, relationship among participants from different disciplines could be included in future NOFOs. Natural and social scientists are often not used to working together and may benefit greatly from such guidance from OAP so that human dimensions projects can be productive and effective immediately upon receiving funding instead of requiring a ‘ramp up’ period while the team gets used to working together. Further guidance may be required from OAP on how to target budget reductions for [especially multidisciplinary to transdisciplinary] projects requested to reduce budgets. OAP may consider developing a training presentation or webinar that funded teams can use to facilitate their interactions.

AA2-9. Consider ways to document non-published and externally published accomplishments.

OAP results and data are getting directly applied in decision making tools, and OAP should get credit for the high impact, immediate application aspects of their Program data and work that is not evident in publications. It is clear data and information are being included in resource management and adaptation strategies (as indicated during review presentations), but unless reported directly by the stakeholder agency, this information is not widely available, tracked, or known by others. This information should be tracked, documented, and better show-cased (perhaps as a website section of links to non-peer reviewed accomplishments).

AA2-10. Continue efforts to better engage social scientists.

OAP has actively tried to engage social scientists and economists from the Office of Economists and NMS and continued conversations are encouraged moving forward. OAP has also reached out to WHOI social scientists due to limited response from other NOAA contacts. OAR may be able to help with these communications. OAP is continuing to seek better ways to link natural

and social scientists through workshops and NOFOs and are encouraged to continue with these efforts.

Activity Area 3: Data Management and Product Development Recommendations

AA3-1. Evaluate staff and resource needs for data management and product development.

The OAP data management effort has ramped up relatively quickly and must deal with a large range of different data types and sources. Investment in this area should be continued as it is setting a precedent within NOAA for program support of big-picture (regional, national, and global research, modeling, and resource management) activities. For the size of the data management and product development effort, the program may potentially be under resourced, depending on only the work of a few key individuals. Stakeholders recognized that data management is different from modeling and synthesis. There are currently capacity and resources to address OA data management. However, including modeling and synthesis in data management will require staff and resources that are currently unavailable. Moving forward, the data needs of the program will only grow both in terms of data volume and the data needs (discoverability and accessibility) of a growing stakeholder base, many of whom in industry and the public may not be sophisticated data users. **OAP could benefit from developing a process to routinely evaluate potential weaknesses, staffing, and resource needs in the data management effort.** OAP is encouraged to continue their strong partnerships and resource leveraging across and outside of NOAA to assist with addressing resource needs. OAP is also encouraged to continue supporting regional-scale data synthesis products through better engagement with the CANs that can help tailor products for regional information needs.

AA3-2. Seek to shorten the time between data collection and data publication.

Funding opportunities already require timely data delivery by funded external investigators, but publication/availability still lags considerably. It is unclear whether similar requirements exist for internal investigators. But in both cases, the QA/QC process seems to be a bottleneck. Consider greater investment of resources or other creative solutions to expedite the QA/QC process.

AA3-3. Explore solutions for making real-time data publicly available.

Real-time data is currently being used by a limited number of partners who have individually negotiated access to that data from NOAA labs. However, real-time data is not generally available to all users. As real-time forecast models and resource management tools are increasing in demand, it is likely that development and maintenance of these products will need to be outsourced to external entities for long term maintenance and updates. A future challenge for OAP will be to find ways to make OAP monitoring data (from buoys, etc.) available to better fulfill FAIR requirements. There is potential for collaboration and discussion with IOOS and NWS for development of approaches and solutions to operational activities and data/product requirements as OAP moves in this direction in future years. IOOS may also be able to provide more assistance with development of region-specific products. Other recommendations from stakeholders and reviewers included:

- Serve near-real-time data to technical users (e.g., model developers, synthesis product creators) with appropriate QA/QC flags and metadata; this may require adding staff.

- Lean more on automated QA/QC or changing the data-providing culture to allow temporary use of provisional data.
- Clarify among the PI and stakeholder communities that there is a distinct difference between real-time data that is required by modelers and data products derived from real-time data that are updated in real-time data.
- Continue to work to make monitoring data available to scientific users in the form they need on the time frame they want. Preliminary or “raw” data that are not fully QA/QC’d can be flagged as such. Continue to work to match provision of data & products to stakeholder needs: some want raw data, some want plots.

AA3-4. Engage stakeholders for solutions to data discoverability and consider development of a user guide to data access.

OAP is encouraged to continue “live fire” exercises to identify data discoverability and accessibility issues. Continue to keep up the good work toward the goal of FAIR data.

Stakeholders offered good suggestions for ways forward to improve data discoverability and potential ways forward for broader real-time data access. OAP is encouraged to reach out to the data management stakeholder panel group from this review perhaps through a workshop as they move forward with these aspects of data management. OAP may consider development of a user guide to data access targeted at various groups of stakeholders. A closer examination of which stakeholders are using which data and information may be needed to inform development of a user guide. Other reviewer and stakeholder recommendations included:

- As a growth opportunity (recommended by a stakeholder) consider a federated data discovery solution based on platforms already available (ERDDAP) that can greatly enhance the data access and data discovery of OAP supported data over and above what NCEI provides.
- Improve announcements to data-using stakeholders about what products are available and advances in data availability and storage to improve active distribution of information.
- Make effort to steer clear of the constantly shifting landscape of web pages hypertext links (used for other NOAA resources such as basic tides and currents, historical SST info, and El Nino calculations) that may confuse repeat users. Avoiding this for OA data will require a delicate trade-off between improving discoverability and maintaining a stable landscape.

AA3-5. Clearly define stakeholder subgroups and their data management and product needs.

Refine and resolve the meaning of “stakeholder” so that data products and syntheses can be appropriately developed, targeted, disseminated, discovered, and accessed. Clarify which OAP stakeholder subgroups depend on which data management services and product development activities and ensure that their needs are being fully served (through interviews, panel discussions, open comment periods on planned activities, etc.).

AA3-6. Continue efforts in collaboration with NOAA programs and IWGOA to improve interoperability of data.

Interoperability of data is recognized as an enormous challenge moving forward, as is defining interactions and responsibilities among participants in data management. OAP is clearly taking a leadership role in working with internal programs and external agencies to improve

interoperability and is encouraged to continue this effort.

AA3-7. Engage in discussion with OAR and other NOAA Programs to clearly define data management responsibilities.

OAP has taken a leadership role in creating and maintaining very successful partnerships among NOAA program and laboratories that have been essential to development of effective OA data management. As with other activity areas, there needs to be good clarity (and discussion with OAR) on what is OAP’s responsibility and expectations versus other OAR and NOAA program responsibilities with respect to data management, synthesis and product development, and the degree of separation that should exist between Carbon and OA Programs.

Activity Area 4: Outreach and Education Recommendations

AA4-1. Update the NOAA OA Education Implementation plan.

As the OAP develops their own strategic plan, update the Education and Communication Implementation Plan. The new plan should also lay out communications goals and principles (see below), include a refreshed view of OAP’s stakeholders (see below), and re-formulate the Outreach and Education Activity Area as a cross-cutting effort. The existing outreach and education plan provided a robust foundation for the outreach and education work OAP does, heavily emphasizing work with educators, and many future outreach/education activities will naturally continue to serve mainly formal and informal educators. However, outreach and education are inseparably tied to communications, and they also reach beyond educators. For example, even data sharing is a type of outreach and communication work. The refreshed outreach/education plan needs to consider the full breadth of audiences, their needs, and how OAP activities serve their needs, and critically, how OAP is pushing that information out to them. Moreover, the stakeholder subgroups served by OAP have evolved, and as OAP refreshes its understanding of its stakeholders and their needs (see below), the outreach/education plan will necessarily need refreshing too. The plan should include an upfront diversity, equity, and inclusion (DEI) statement, as was suggested in the stakeholder meeting. The updated plan can improve education and communication strategy by reflecting on which aspects of the current plan have been most successful. Additionally, efforts should be made to ensure education and communication products are accessible to those with disabilities.

AA4-2. Consider public accessibility to some OAIE content to increase interest in membership.

The OAIE is a central forum for outreach/education across the OA community, and it should continue to be cultivated over the next 5 years. The OAIE receives consistent praise as a forum for supporting connections across the community and offering quick responses to obscure questions. OAP’s approach to developing it has been thoughtful, evidence-driven, and inclusive. The OAIE has also been embraced by the international community and has provided a good deal of knowledge transfer from well-established OA scientific efforts to newly established activities, especially in developing countries. A reviewer suggested opening some OAIE posts to the public to “lure” in people more peripheral to the OA community; perhaps this strategy could work well for discussions of how OA intersects with other ocean issues, such as heat waves, harmful algal blooms, hypoxia, or discussions that relate to a specific industry. Other suggestions included having discussions open for anyone to view (but not contribute to without membership) to

increase the usefulness of the OAIE to those who may not wish to create an account but could benefit from quickly reading a discussion. A compromise could be to make key discussions open and ‘Google-searchable’ so that stakeholders may be lured in by Google results.

AA4-3. Update the OAP website to make content and information more ‘discoverable’.

Some stakeholders noted that the OAP website isn’t serving their needs, because they can’t easily find and share key products. Since the OAP’s offerings have broadened so much over the life of the program, the products can no longer be offered in a simple way, but the website should provide a straightforward portal to finding everything under the OAP umbrella. Products need to be indexed and searchable in a number of ways (e.g., by date, technical level, subject, region, etc.; perhaps OAIE themes and interest areas could be informative about useful indexing terms) to allow users to more easily find and share what they need. Although feedback on this activity area from stakeholders focused mainly on accessibility of webinars and reports, data users could also use a better road map on where to find various OAP-related data products. Suggestions for organization included having sub-navigation leading to categories of products and information. Website redesign must take into account accessibility for users of all abilities and search engine optimization. Website redesign must also incorporate insights gained from metrics about website traffic to current OAP sites; different types of users will have different information needs and different levels of determination in digging them out. As the welcome mat for OAP, the OAP website needs to serve all the stakeholder subgroups OAP is charged with serving, more so than any other product OAP creates. OAP staff indicated they are performing an analysis for determining how website visitors are finding info and who is using what pages. OAP is encouraged to use results from that analysis to tune content on pages to focus on who (audience) is looking at the pages in a similar manner to how they are already doing this on Facebook, Instagram, and Twitter. Additionally, consider creation of web navigation tuned to audiences that are targeted for different categories of information (students, teachers, etc.).

AA4-4. Examine and clearly define OAP’s diverse stakeholder groups, subgroups, and their needs.

It is time for OAP to refresh its understanding of who its stakeholders are. There is no single type of stakeholder, and for a program like OAP that works so closely with local resource managers, the scientific community, high-level elected officials, and even local educators, this is doubly true. As a result, there is a diversity of audiences that OAP serves, and there is insufficient clarity about who these audiences are, what they need, and how they need it. Moreover, in keeping with efforts across STEM to improve diversity of those served, OAP needs to examine how they are serving information to these groups. A diversity, equity, and inclusion improvement plan should be included as part of the overall education/outreach plan refresh.

AA4-5. Evaluate all education and outreach activities including communication.

There is a robust evaluation cycle in place for mini-grant-funded education and outreach activities, and a very good protocol in place for improving the OAIE through a steering committee and evidence-based decision-making about site improvements. It’s important to recognize that communications to internal and external stakeholders about OAP activities is a type of outreach, as are OAP activities such as developing partnerships and data dissemination. Data discoverability by users is tightly connected to communication by OAP, either by announcements of what’s available or a well-designed website. There should be a similarly

robust evaluation cycle in place for other education, outreach, and communication activities beyond mini-grants and the OAIE. As noted above, this could be captured in a revised outreach/education/communication plan and supported by regular monitoring of metrics. These could include things like website and media metrics, monitored in conjunction with NOAA's Communications office and metrics showing who is being served by different activities (e.g., affiliation, role, experience level of SOARCE webinar attendees or specialized events like OA week). Education/outreach goals should be set and measured that are associated with other areas of OAP besides the activities that serve mainly educators. Attention to the education/outreach/communications "metadata" associated with OAP activities (visitor types, topics of interest, etc.) that fall outside the education/outreach plan may also help identify where a broader audience could be served. Adding a partial or full-time staff member focused on communications may be necessary in the near-future to support a more intentional focus on disseminating information.

AA4-6. Include information on program decision-making processes in future strategic plans.

OAP is currently extraordinarily transparent and candid about its decision making and achievements to some stakeholder subgroups, but a more rigorous communications approach will improve transparency and serve a wider array of stakeholders. The panel heard from stakeholders that OAP's annual community meetings and other NOAA-wide and science-community-wide activities are some of the most common times when OAP staff provide information on decision making and direction-setting within the program. However, that can unintentionally exclude individuals who miss gatherings. Several stakeholders also expressed a desire for increased transparency about program decision making, ways in which conflicts of interest are handled, and strategic direction-setting, and OAP is encouraged to include descriptions of these processes in an OAP Strategic plan and updated Education and Outreach plan. Additional guidance should be provided to mini-grant recipients on how best to communicate successes to OAP and how to engage in discussions with OAP regarding continuation of successful efforts.

AA4-7. Consider an approach for more active communication and delivery of information to stakeholders.

OAP is actively engaging the stakeholder community for input into data and product needs. However, communication of research results and information to stakeholders seems to be generally passive. OAP might consider if there is a need to develop an approach for active delivery of information to stakeholders where appropriate as part of the transdisciplinary science approach (co-production of information for outcome driven science). There is a difference between notifying a stakeholder of availability, and actively delivering information and there may be appropriate instances for both approaches. Stakeholders interviewed felt that a periodic email newsletter could offer a good solution. A monthly or bimonthly roundup of announcements, relevant links, and current events would be appreciated by stakeholders and is used to good effect by other similar programs (e.g., IOOS, OCB). OAP is already doing some of this with the Pier2Peer newsletter, but a regular program-wide "push" of information would be useful as the program grows, and regular personal contact between each member of the community and a NOAA OAP staff member becomes less possible. An email update can be easily forwarded by recipients to other external groups to grow the reach of OAP information.

SUMMARY OF RECOMMENDATIONS FOR NOAA AND OAR

Additional Comments for OAR and Program Management

Reviewer 1 Comments:

OAP could either benefit from adding a communications expert to the program staff or from working more closely with a dedicated member of NOAA's communications staff. The goal would be to aid the program in communicating more strategically and successfully with the wide variety of audiences that OAP serves – internal, external, scientist, citizen, policymaker. Enhancing OAP's strategic communications capacity would help the program make the most of its communications and outreach/education activities in a way that is not currently happening. How this is implemented depends on how NOAA prefers to divide up cross-cutting program support.

Reviewer 2 Comments:

None

Reviewer 3 Comments:

I entered this process with a favorable impression of the NOAA OAP and its staff; I have come away from it with an even stronger impression. Two things really stand out: 1) the tremendous regard with which the OAP and its staff are regarded both within NOAA and by external stakeholders, and 2) the care and integrity and decency embodied by the OAP team and its leadership.

Reviewer 4 Comments:

Program staff, in characteristic form, were thoughtful in their responses during the review, never seeking to dismiss issues without discussing them, and always showing gratitude for feedback in the few cases where unsolved concerns were raised. They exhibited the same "let's solve this together" attitude that they are known for by stakeholders, with genuine interest in improving their program. I attribute much of OAP's success to the trust and admiration of human intellect that it and OAR leadership openly show toward their staff and partners.

Reviewer 5 Comments:

None

Reviewer 6 Comments:

It is understood that OAR provided the definition of stakeholder for this review. The diverse categories of OAP stakeholders should be more distinctly defined in consultation with OAR.

OAR Program should assist with clarifying responsibilities of OAP versus other NOAA programs and laboratories. Institutional guidance from OAR and other NOAA Line Offices on the roles and responsibilities of other NOAA Programs and Laboratories for OA activities may help OAP refine and improve their strategic and implementation planning processes.

Additional Comments and Suggestions on Conduct of the Review for Use in Future Program Reviews

Reviewer 1 Comments:

NOAA staff assigned to support the review process did a fabulous job of anticipating our review panel's needs ahead of time. This was extra difficult for them because 1) this was the first program (not lab) review and 2) it had to be conducted entirely virtually. Our panel kept coming up with questions and requests for more information and NOAA staff responded to our requests promptly and completely. It was a pleasure working with them.

Stakeholder interviews relevant to each activity area were particularly helpful, as the stakeholders often could capture an idea in a really useful phrase. Being able to interview them as a group to reflect on themes emerging in the written interviews was also really useful.

The overall program information provided (short presentations/webinars, and presentations on each activity area following the same outline) was also really helpful for allowing different parts of the program to be compared with each other and with other NOAA programs/activities. We did request (and received) additional information regarding OAR's strategic and implementation plans, which was a particularly helpful addition to show how OAP contributes to the broader context at NOAA.

I would have found more information helpful on the characteristics associated with "Highest performance", "Exceeds expectations", and "needs improvement" ratings. The Charge to Reviewers elaborated only on "satisfactory" and we were left wanting a bit more detail. We wished in particular for some quantitative guidance so we could evaluate this high-performing program fairly, providing suggestions for growth, but also having assurance that suggestions (no matter how small) would not be held against the program in comparison with other high-performing programs that might be reviewed with less scrutiny.

Reviewer 2 Comments:

None

Reviewer 3 Comments:

The documentation and guidance provided by OAP and OAR through this process were excellent. I felt I could have used some additional guidance on the process and how to structure my time, but that may reflect more on me than on the guidance.

I appreciated the tremendous amount of work that everyone put into this, both in terms of the "normal" processes associated with a review and all the "extras" that went in to doing this virtually. Structuring things so that we did not have 8 to 10-hour days as we might have had for an in-person meeting was a huge help.

That said, I found the "watch party" presentations somewhat disconnected from the main event. I re-watched several, and found them more useful, after the review. The overview presentations at the actual review provided essential context for some of the prerecorded videos, such that I did not fully understand their connection to the Activity Area until after the fact. A few minutes of

contextualization prior to the pre-recorded videos would have helped.

Related to this, I found it difficult to translate from the Evaluation Guidelines and Rating Criteria in the Charge to Reviewers to the Evaluation itself, in terms of the mapping to Activity Areas. It was both helpful and yet also somewhat confusing to have some Evaluation Questions called out for Activity Area #1 in particular – it left me wondering which questions to apply (and not) to all the Activity Areas. I have done my best, in part using the presentations during the review as a guide.

Reviewer 4 Comments:

This was a well-managed review. NOAA staff showed appreciation for time commitments by panelists and participating stakeholders and worked hard at every stage to keep those commitments to the minimum necessary for thorough review.

Activities were managed in a way that minimized time lost to meeting transitions and technical snags.

Abundant resources were provided for assessing program quality, relevance and performance and all were easy to revisit throughout the duration.

The stakeholder concept may need reevaluation. It felt unnatural to think of internal and external investigators as stakeholders while at the same time considering the obligations of NOAA and OAP to a broader array of affected and nontechnical stakeholders.

The watch parties were a good idea that I supported, but in the end, there was not much on-the-spot discussion after each video. Thus, the primary value to me was just being accountable to a schedule so that the work didn't pile up on me as the final meetings approached.

Reviewer 5 Comments:

I very much appreciated the time and effort that OAP staff put into organizing all of the background documents and pre-recorded videos for each activity area.

For me, the virtual format of this review was a benefit, not a disadvantage. Spreading out the delivery of information over time gave me time to process and think about things. This was a LOT of new information for me and had it all been packed into a couple of days, I would have been overwhelmed. I had opportunities to ask many questions throughout the process.

I found the stakeholder responses to be very helpful, but the 30-minute sessions with them went by very quickly – it would have been helpful to schedule an hour and then take a break if we finished early.

I think that it would have been helpful if OAR had provided more quantitative metrics for each rating (Highest performance, exceeds expectations, satisfactory, needs improvement), or at least more descriptions of the ratings other than satisfactory.

Reviewer 6 Comments:

OAP did an outstanding job of organizing and hosting the first OAR Program Review and first ever virtual review! Information was very well organized and distributed well in advance of the formal meetings. Numerous opportunities were provided to request additional information which was provided in a timely manner. OAP staff made themselves available for several unplanned meetings to assist with logistics and questions regarding the review process.

Watch parties for activity area presentations were very helpful and distributing these over the course of a month made it much easier to digest the large amount of information. There were short discussion periods after each presentation for clarifying questions only. However, more detailed follow-up questions were provided to OAP staff in writing for either written responses or further clarification during the review meetings.

Stakeholder responses to questionnaires were invaluable! The number and diversity of stakeholders was appropriate for a program of this breadth and complexity. The formal meetings were well-conducted. More time was needed for stakeholder discussion sessions and for closed panel discussions.

The review panel members considered and discussed development of quantifiable metrics for use in this review to help clarify the qualitative grading criteria (from needs improvement to highest quality) and to standardize the evaluation process for individual reviewers across the Activity Areas and for each evaluation criteria. A final decision was made not to standardize quantifiable metrics for this review due to concerns that similar metrics have not yet been applied to (and standardized for) other NOAA reviews. The review team requested and was provided additional details and statistics regarding publications synthesized with assistance from the NOAA library, project lists with additional information on categories, subcategories, and funding types. This information was extremely helpful in evaluation of all activity areas. I was able to generate summary tables and basic statistics of all mandates, goals, objectives, key questions, tasks from each of the 6 strategic plans to which OAP responds and provided these to the review panel to assist with their (and my own evaluation). These tables are provided to OAR as an attachment to my review. OAP staff generated a similar table in the 2017 Program PI meeting for their specific response to the 2010 NOAA Ocean and Great Lakes Research Plan. I was able to use this information to quantify and develop my own objective evaluation criteria for application to the evaluation areas (quality, relevance, and performance) and for selection of evaluation criteria. OAR should consider incorporating quantifiable metrics in future review processes to help reduce subjectivity in review evaluations.

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LIST OF ACRONYMS

AA1	Activity Area 1
AA2	Activity Area 1
AA3	Activity Area 3
AA4	Activity Area 4
AOAN	Alaska Ocean Acidification Network
AOML	Atlantic Oceanography and Meteorological Laboratory
CAN	Coastal Acidification Network
CCAN	California Current Acidification Network
CDIAC	Carbon Dioxide Information Analysis Center
CO ₂	Carbon Dioxide
COI	Conflict of Interest
CPO	Climate Program Office
CRCP	Coral Reef Conservation Program
CRMP	Coral Reef Monitoring Program
DEI	Diversity Equality Inclusion
DOE	Department of Energy
EPA	Environmental Protection Administration
ERDDAP	Environmental Research Division Data Access Program
FAIR	Findable Accessible Interoperable Reusable
FOARAM	Federal Ocean Acidification Research and Monitoring
GCAN	Gulf of Mexico Coastal Acidification Network
GOAON	Global Ocean Acidification Observing Network
GOM	Gulf of Mexico
GOMO	Global Ocean Monitoring and Observation Program
HAB	Harmful Algal Bloom

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IOOS	Integrated Ocean Observing System
IPCC	Intergovernmental Panel on Climate Change
IWG-OA	Interagency Working Group on Ocean Acidification
MA	Mid-Atlantic
MACAN	Mid-Atlantic Coastal Acidification Network
MAPCO2	Moored Autonomous pCO ₂ buoy
MBON	Marine Biodiversity Observation Network
MHW	Marine Heat Wave
MOCA	Maine Ocean and Coastal Acidification Partnership
NCEI	National Centers for Environmental Information
NECAN	Northeast Coastal Acidification Network
NESDIS	National Environmental, Satellite, and Data Information Service
NMFS	National Marine Fisheries Service
NMS	National Marine Sanctuary
NOAA	National Oceanographic and Atmospheric Administration
NOAWG	NOAA Ocean Acidification Working Group
NOFO	Notice of Funding Opportunity
NOS	National Ocean Service
NWS	National Weather Service
OA	Ocean Acidification
OADS	Ocean Acidification Data Stewardship
OAH	Ocean Acidification and Hypoxia
OAICC	Ocean Acidification International Coordination Centre
OAIE	Ocean Acidification Information Exchange
OAP	Ocean Acidification Program
OAR	Ocean and Atmospheric Research Program
OCA	Ocean and Coastal Acidification
OCADS	Ocean Carbon Data System
OCB	Ocean Carbon and Biogeochemistry
OMAO	Office of Marine and Aviation Operations
pCO ₂	Partial Pressure of Carbon Dioxide
PI	Principal Investigator
PMEL	Pacific Marine Environmental Laboratory
QA	Quality Assurance
QA/QC	Quality Assurance Quality Control
SE	Southeast

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SOARCE	Sharing Ocean Acidification Resources for Communicators and Educators
SOCAN	Southeast Ocean and Coastal Acidification Network
SOST	Subcommittee on Ocean Science and Technology
SPCMSC	St. Petersburg Coastal and Marine Science Center
SST	Sea Surface Temperature
STEM	Science Technology Engineering Mathematics
TD	Transdisciplinary
USGCRP	United States Global Change Research Program
USGS	United States Geological Survey
WHOI	Woods Hole Oceanographic Institution

APPENDIX 1: SUMMARY OF RECOMMENDATIONS BY KEY ACTION CATEGORY

All 38 Ocean Acidification Program-Wide and individual Activity Area recommendations mapped to, and were grouped within, eight Key Action Categories including:

1. Creating or updating strategic and other planning documents;
2. Defining Ocean Acidification Program responsibilities;
3. Defining, assessing, and enhancing engagement with stakeholders;
4. Balancing, optimizing, and implementing projects across the OA-Trifecta, regions, and scientific approaches;
5. Tracking and reporting accomplishments;
6. Assessing staffing needs;
7. Addressing data management challenges toward achieving FAIR standards;
8. Enhancing outreach and communication strategies.

Recommendations within each Key Action Category were either related or were consistently repeated across the Activity Areas. Individual recommendation numbers indicate, and are consistent with, the Activity Area within which the recommendation was made including Ocean Acidification Program-wide (OAP), Activity Area 1 (AA1), Activity Area 2 (AA2), Activity Area 3 (AA3), and Activity Area 4 (AA4) recommendations.

1. Creating or Updating Strategic and Other Planning Documents

OAP-1. Develop an Ocean Acidification Program Strategic Plan.

OAP staff identified during review the need and their intent for development of an OAP Strategic Plan. This need was confirmed by reviewers and stakeholders, and many suggestions for content were provided. Information in this plan will help consolidate OAP priorities, responsibilities, activities, definitions and processes into a single document to more efficiently convey Program information to internal and external participants, stakeholders, and broader communities. Content suggestions specific to individual Activity Areas are described in more

detail in recommendations AA1-1, AA1-2, AA4-1 and AA4-7 and are briefly summarized here:

- Consolidate, summarize and map the hierarchy of mandates, goals, objectives, actions, and tasks (and linkages among them) from the numerous strategic plans to which OAP (specifically) responds.
- Synthesize and clarify OAP responsibilities.
- Clarify and include information on program decision making processes such as strategic direction-setting and prioritization, considerations and factors used to set tactical (Prospectus level) priorities and funding allocations across regions and topical areas, processes used to evaluate stakeholder input and resolve conflicts of interest.
- Define the full scope of OAP research evolution and progression (including foundational research and monitoring, multidisciplinary, interdisciplinary, integrated, and full transdisciplinary science), anticipated outcomes, and expectations for participant engagement in each type of research project. Clearly define transdisciplinary science and variations that apply to OAP.
- Define the numerous categories of stakeholders (internal and external) to which OAP responds and serves.

AA1-1. Develop and consider suggestions for information to include in an Ocean Acidification Program Strategic Plan.

The OAP has clearly defined and documented management, scientific, technological, and policy objectives and rationale for funding key activities and projects through leadership of and/or contribution to multiple OA and broader NOAA strategic plans. However, this information is currently distributed among six different strategic plans ranging from Congressional to NOAA Program levels making it difficult to cross-walk and understand the full scope and responsibilities of the OAP. This information became clear to reviewers during an in-depth review of the full program but does not appear to be generally well-understood by many program participants and stakeholders. Additional needs for information related to program processes were identified by stakeholders and reviewers. OAP is encouraged to consolidate information on guiding mandates and NOAA requirements, program responsibilities, activities, definitions and processes into an OAP Strategic Plan to more efficiently convey program information both internally to NOAA and to external participants, agencies, and institutions. Suggestions on specific content to consider include:

- a. **Consolidate, summarize and map the hierarchy of mandates, goals, objectives, actions, and tasks (and linkages among them) from the numerous strategic plans to which OAP (specifically) responds.** Consolidating this information in a ‘digestible’ format will help clarify OAP’s responsibilities, provide context for prioritization particularly for external participants and stakeholders, and will highlight the relevance of OAP. Appendix 1 of the 2017 Principal Investigator’s Meeting (for example) summarizes specific activities OAP addressed from the 2010 NOAA OA Plan, but does not articulate the responsibilities of other NOAA programs. Similar information is difficult to summarize and cross-walk from the other NOAA and OAR strategic plans. This is especially important given the new, more comprehensive NOAA Oceans and Great Lakes Research Plan for OA. *OAR Program should assist with clarifying responsibilities of OAP versus other NOAA programs and laboratories. Institutional guidance from OAR and other NOAA Line Offices on the roles and responsibilities of other NOAA Programs and Laboratories may help OAP refine and improve their strategic and implementation*

planning processes.

- b. **Clarify and document factors and considerations used to set tactical priorities, project and funding distributions.** Full review of all program elements and documents indicates the data, considerations, and justifications used by OAP for both long-term (strategic) and short-term (tactical) priority setting. However, this information is distributed across many documents, presentations, statistical analyses, etc. The process for setting priorities and the transparency of that process are excellent; and the outcomes of that process are also very clear in the products and progress. What is less clear to both internal and external participants are the considerations and factors that set the tactical priorities and determine the distribution of funding by region and topical area.
- c. **Clarify and summarize the process used to evaluate and prioritize stakeholder input.** It is also unclear as to how stakeholder input is evaluated and prioritized particularly with the potential for conflicting requests from diverse audiences and geographic locations.
- d. **Clearly define the categories of internal and external stakeholders and stakeholder subgroups to which OAP responds and serves.** Clarify roles of stakeholder categories in the program's priority setting process, and what types of activities and products target these specific categories.
- e. **Clarify roles and procedures for shared and temporary staff. OAP has established creative solutions to staffing needs through positions that are shared with other NOAA programs and laboratories and through internships and fellowships.** These positions serve as excellent employee development and workforce capacity-building opportunities. Indicate how conflicts of interest are avoided for shared staff whose NOAA labs/programs receive funding from OAP. Consider and describe the feasibility and role of temporary staff in maintaining and growing program functions.
- f. **Describe the process and considerations used for ending or transitioning projects.** The process for evaluating and selecting proposed project activities is clear and transparent. OAP indicated evaluations are also used to determine project discontinuations or transitions. However, project participants indicated a need for additional guidance and information on the process used to end or transition projects.
- g. **Provide clear definitions of the full spectrum of OAP science.** Define science approaches undertaken and required to achieve the transdisciplinary (TD) approach and outcomes (from basic research, multi-, interdisciplinary, integrated, to full transdisciplinary). Explain that to achieve the OA-Trifecta, a progression from basic research to increased levels of integrated science toward achieving transdisciplinary research is required. Also, the TD definition is being applied to what may be considered different approaches/categories of TD science and this is related to type of stakeholders/participants involved (scientists as stakeholders, resource managers as stakeholders, public as stakeholders). This is appropriate but also needs to be defined clearly.
- h. **Clearly define the terms adaptation and mitigation.** Stakeholders noted that different entities appear to be using different definitions.

AA1-2. Consider and formalize the timing for updates to short and long-term planning documents.

There is potentially a disconnect between the 3-year prospectus and 5-yr review period. Consider

the advantages (e.g., provides flexibility to shift directions/address emerging issues and allows for time to prepare program review materials) and disadvantages (may need to get through 2 complete 3-yr cycles for more robust reporting on outcomes that guide 5-year strategic planning).

AA4-1. Update the NOAA OA Education Implementation plan.

As the OAP develops their own strategic plan, update the Education and Communication Implementation Plan. The new plan should also lay out communications goals and principles (see below), include a refreshed view of OAP's stakeholders (see below), and re-formulate the Outreach and Education Activity Area as a cross-cutting effort. The existing outreach and education plan provided a robust foundation for the outreach and education work OAP does, heavily emphasizing work with educators, and many future outreach/education activities will naturally continue to serve mainly formal and informal educators. However, outreach and education are inseparably tied to communications, and they also reach beyond educators. For example, even data sharing is a type of outreach and communication work. The refreshed outreach/education plan needs to consider the full breadth of audiences, their needs, and how OAP activities serve their needs, and critically, how OAP is pushing that information out to them. Moreover, the stakeholder subgroups served by OAP have evolved, and as OAP refreshes its understanding of its stakeholders and their needs (see below), the outreach/education plan will necessarily need refreshing too. The plan should include an upfront diversity, equity, and inclusion (DEI) statement, as was suggested in the stakeholder meeting. The updated plan can improve education and communication strategy by reflecting on which aspects of the current plan have been most successful. Additionally, efforts should be made to ensure education and communication products are accessible to those with disabilities.

AA4-6. Include information on program decision-making processes in future strategic plans.

OAP is currently extraordinarily transparent and candid about its decision making and achievements to some stakeholder subgroups, but a more rigorous communications approach will improve transparency and serve a wider array of stakeholders. The panel heard from stakeholders that OAP's annual community meetings and other NOAA-wide and science-community-wide activities are some of the most common times when OAP staff provide information on decision making and direction-setting within the program. However, that can unintentionally exclude individuals who miss gatherings. Several stakeholders also expressed a desire for increased transparency about program decision making, ways in which conflicts of interest are handled, and strategic direction-setting, and OAP is encouraged to include descriptions of these processes in an OAP Strategic plan and updated Education and Outreach plan. Additional guidance should be provided to mini-grant recipients on how best to communicate successes to OAP and how to engage in discussions with OAP regarding continuation of successful efforts.

2. Defining Ocean Acidification Program Responsibilities

OAP-2. Engage in discussion with OAR and other NOAA Programs and Laboratories to define responsibilities.

OAP has taken a leadership role in developing guidance for broader NOAA OA research and monitoring activities and in creating and maintaining very successful partnerships among NOAA

programs and laboratories. OAP's leadership in both areas has been essential to achieving the high degree of integration of activities among OAP and other NOAA programs and laboratories that is required to effectively advance OA science. This successful and necessary integration of activities makes it somewhat difficult to identify OAP versus other NOAA program and laboratory responsibilities. Moving forward, it would be beneficial to more explicitly define the appropriate boundaries and overlap of OAP and other NOAA responsibilities, observational, research, and data management requirements, and portfolios. Clear definition of responsibilities will benefit current and future program planning activities and effective resource allocation. See additional details in recommendations AA2-3 and AA3-7.

AA2-3. Engage in discussion with OAR and other NOAA Programs to clearly define OAP's observation and research responsibilities.

Project distribution and resource investments indicate OAP's primary focus has been environmental observation with other NOAA programs primarily responsible for species and ecosystem studies. OAP effectively leverages numerous NOAA programs and laboratories in partnerships to accomplish this work. It is important for OAP and OAR to clearly define responsibilities and limitations for programs and laboratories participating in OA activities. Additionally, clarification of monitoring responsibilities among OAP NOAA partners would also be beneficial. For example, the OAP and GOMO program need to continue to cooperate to determine the appropriate boundaries and overlap of their observational requirements and portfolios.

AA3-7. Engage in discussion with OAR and other NOAA Programs to clearly define data management responsibilities.

OAP has taken a leadership role in creating and maintaining very successful partnerships among NOAA program and laboratories that have been essential to development of effective OA data management. As with other activity areas, there needs to be good clarity (and discussion with OAR) on what is OAP's responsibility and expectations versus other OAR and NOAA program responsibilities with respect to data management, synthesis and product development, and the degree of separation that should exist between Carbon and OA Programs.

3. Defining, Assessing, and Enhancing Engagement with Stakeholders

OAP-3. Define and assess stakeholders and their needs.

The nature and diversity of OAP's stakeholders has evolved since the program was developed and as science has moved from fundamental research to transdisciplinary applications. Examine and clearly define OAP's diverse stakeholder groups, subgroups, and their needs. *It is understood that OAR provided the definition of stakeholder for this review; therefore, these definitions may need to be developed in consultation with OAR.* OAP could benefit from performing a strategic assessment of stakeholders. Identify which groups will be prioritized, the different needs of these groups, and the research approaches needed to achieve outcomes to continue to improve stakeholder participation, meet stakeholder needs, and clarify expectations from OAP projects and PIs for participation in OAP activities. See additional details in recommendations AA1-4, AA3-5 and AA4-4.

OAP-4. Enhance stakeholder engagement in under-invested and investigated regions.

Stakeholder engagement in some regions has been challenging. Limited engagement from stakeholders in the Southeast and Gulf of Mexico may be due to lack of sensitivity information to determine risk and vulnerability and/or focus on other environmental stressors that are perceived as more pressing such as HABs, hypoxia, and marine heat waves. OAP has begun (and should continue) improving engagement in these areas by addressing OA in the context of these multiple stressors and is encouraged to continue supporting the work needed to fully understand risk and vulnerability in these regions. Stakeholders indicated that the Regional Coastal Acidification Networks (CANs) can be better engaged, both directly and in partnership with Sea Grant, to assist with communication, distribution of information, and stakeholder engagement. OAP can provide guidance to the CANs on how to better engage within the regions to ensure local and regional priorities are being met. Periodic re-evaluation of needs, readiness, and feasibility for engagement in the Great Lakes Region should continue as resources and partnership opportunities allow. See additional details in recommendations AA1-3, AA1-5, and AA2-7.

AA1-3. Continue developing creative and alternative methods for collecting stakeholder input.

It was noted that formal stakeholder input to OAP occurs primarily during in-person stakeholder and OA PI meetings. Several stakeholders also noted the dedication, willingness, and responsiveness of OAP staff to stay engaged with direct (person to person) communications with stakeholders. Some concern was expressed that broader stakeholder input may be limited in formal meetings due to less input from ‘less vocal’ members of the community, limitations on ability of participants to attend, or lack of input from potential stakeholders not directly involved in OAP activities. The OAIE is an excellent example of an alternative method for collecting stakeholder input. OAP should continue to consider and communicate other alternative methods and options to stakeholders for direct communication with the OAP. This could include, for example, having virtual community meetings so those who are not able to travel can attend, which could increase stakeholder participation.

AA1-4. Perform a strategic assessment of stakeholders.

Identify which stakeholder groups will be prioritized, the different needs of these groups, and the research approaches needed to achieve outcomes to continue to improve stakeholder participation, meet stakeholder needs, and clarify expectations from OAP projects and PIs for participation in OAP activities.

AA1-5. Continue to enhance communications and engagement with the Regional Coastal Acidification Networks.

Some of the Coastal Acidification Networks are well engaged and others are not. Continue to engage the Coastal Acidification Networks both directly and in partnership with Sea Grant offices. OAP can provide guidance to CANs (based on lessons learned from those regions with effective CAN engagement) on how to better engage within regions to ensure local and regional priorities are being met.

AA2-7. Enhance stakeholder engagement in Southeast and Gulf of Mexico.

There is an apparent lack of external-to-NOAA stakeholder engagement in this region,

potentially due to other environmental stressors that are more pressing including HABs and hypoxia. OAP has already identified this issue in the 2020 NOAA Ocean and Great Lakes Acidification Plan. Stakeholder engagement in this region may need to be focused on multiple stressors and it was noted that OAP is working toward this approach with their recent HABs workshop and partnership with Sea Grant for student fellowship grants. As stakeholder needs are largely driving research priorities, this lack of engagement has been used as rationale for the lower amount of funding for biological sensitivity projects in this region. Perhaps OAP can directly assist scientists in this region to connect with potential stakeholders.

AA3-5. Clearly define stakeholder subgroups and their data management and product needs.

Refine and resolve the meaning of “stakeholder” so that data products and syntheses can be appropriately developed, targeted, disseminated, discovered, and accessed. Clarify which OAP stakeholder subgroups depend on which data management services and product development activities and ensure that their needs are being fully served (through interviews, panel discussions, open comment periods on planned activities, etc.).

AA4-4. Examine and clearly define OAP’s diverse stakeholder groups, subgroups, and their needs.

It is time for OAP to refresh its understanding of who its stakeholders are. There is no single type of stakeholder, and for a program like OAP that works so closely with local resource managers, the scientific community, high-level elected officials, and even local educators, this is doubly true. As a result, there is a diversity of audiences that OAP serves, and there is insufficient clarity about who these audiences are, what they need, and how they need it. Moreover, in keeping with efforts across STEM to improve diversity of those served, OAP needs to examine how they are serving information to these groups. A diversity, equity, and inclusion improvement plan should be included as part of the overall education/outreach plan refresh.

4. Balancing, Optimizing, and Implementing Projects Across the OA-Trifecta, Regions, and Scientific Approaches

OAP-5. Continue to re-evaluate and rebalance distribution of projects among the OA-Trifecta, regions, and scientific approaches.

Advancement of the state of OA science will require more investment in sensitivity, human dimension projects, and related data management, outreach and communication needs while maintaining environmental monitoring, particularly in under-investigated Regions. OAP should strive for greater regional balance in the distribution of ecosystems studied and co-occurring issues (e.g., HABs, MHWs) that interact with OA. As needs for applied research increase, there will also need to be consideration of the balance that OAP is targeting with respect to fundamental, multidisciplinary, interdisciplinary, integrated, and transdisciplinary research approaches, and clear guidance on expected outcomes for each approach and engagement/roles/responsibilities of project participants. See additional information on specific implementation suggestions in recommendations AA2-1, AA2-2, AA2-4, AA2-5, AA2-6, AA2-8 and AA2-10.

AA2-1. Continue leveraging partnerships and research results to strategically prioritize research activities.

There will be increasing demands for targeted environmental monitoring as the OAP moves forward, and the costs of environmental monitoring will not likely decrease sufficiently to cover these demands with current resources. The OAP needs to be strategic in its investments, continuing to leverage existing partnerships and building new partnerships as possible. The OAP has initiated studies on how to best optimize sampling strategies, and the results of these studies will help guide future investment decisions. The results from standard observational sampling strategy experiments designed in terms of best capturing chemical variability will complement more expert-opinion driven observing priorities developed and built on information on the biological sensitivity of organisms and habitats.

AA2-2. Continue to optimize OAP monitoring to characterize impacts to ecosystems and humans.

As knowledge and understanding grow, the geography of the OAP monitoring element should be optimized adaptively to best characterize ecosystem dynamics and impacts on human dimension as well as providing information in a timely fashion to a diverse range of stakeholders. Near-term challenges include addressing the growing obsolescence of Moored Autonomous pCO₂ (MAPCO₂) sensor systems and exploiting observing platforms that will fill in time/space gaps in the current observing system. Current gaps in the OAP observing network, such as in the Great Lakes region, will need to be reevaluated with time depending on the needs of potential new stakeholders.

AA2-4. Develop and implement an approach to improving utility of species response data in ecological scaling studies.

The OAP should work toward decisions about how to handle large unknowns in the meaning of laboratory response data. The major alternatives are 1) accept, acknowledge, and communicate the effect of the ecological unknowns on higher scale uncertainty envelopes; 2) allocate some of the increased vulnerability funding to quantify these unknowns; or 3) rebalance the OA Trifecta funding to increase investment in the sensitivity area. If the unknowns are to be addressed rather than merely quantified and communicated, emphasis should be on ecological scaling studies (more observations and experiments, fewer models) and other issues that complicate the assumed relationships (e.g., adaptation and acclimation). Grear et al. (2020) is one example of item number 1, and involved OAP-funded investigators, but there are other examples as well, especially from other fields. Studies of in situ response and acclimation in shellfish include Thomsen et al. (2017), Leung et al. (2017), and Grear et al (2020). As already noted, the OAP-funded work by Bednarsek and others is another excellent example, but there needs to be much more like that work if forecasting is to include ecological responses at any scale above that used in laboratory studies (i.e., individuals of a specific life stage). Any divestment whatsoever from environmental observing is not suggested. Rather, the beauty of the Bednarsek work is that it has moved toward inclusion of pteropod biology indicators within the environmental observing program, but with solid underpinning in the basic biology and ecology.

AA2-5. Consider creative approaches for implementing future larger scale ecosystem studies.

Engage the broader OA community and other agencies in discussions and consideration of

creative approaches to pursuing larger scale ecosystem experiments that are needed to better inform models. This is not OAP's or NOAA's responsibility alone, and the answer is not clear as to how it can be accomplished with limited funding across agencies, other entities and, perhaps, limited bandwidth. Integrated chemical/biological studies have depended heavily on academic colleagues. Continued discussions and collaboration with MBON to pursue work in this area is encouraged.

AA2-6. Invest in under-sampled regions to better inform risk and vulnerability.

The OAP should also continue to seek opportunities for investment in regions that are under sampled in terms of environmental measurements or biological sensitivity. The threshold for defining “relevant” environmental change 1) should be determined by biological/ecological sensitivities; 2) should inform environmental observing; 3); and may be lower (i.e., higher sensitivity) in regions with lower background variability during recent evolutionary history. There are numerous academic and other external institutions that have the capacity and expertise to perform the sensitivity research needed to improve understanding of risk and vulnerability in the SE and GOM regions. OAP may consider more external support/collaboration with external labs and academia where NMF response is slow to help move science forward in these areas. There is also existing NOAA infrastructure and labs at AOML that are equipped and capable of these studies that could be more fully engaged. Consider re-engaging/check-in with stakeholders from Great Lakes to determine readiness, potential, and need for moving activities forward in that region. The answer may be no, but this will provide updated information and justification for not addressing that region.

AA2-8. Provide clarity and guidance on targeted research approaches for project participants.

There may need to be some clarity moving forward as to the balance that OAP is targeting with respect to fundamental, multidisciplinary, interdisciplinary, integrated versus transdisciplinary research approaches – including clear language as to what OAP will not fund and expects other agencies to fund. Additional guidance regarding the expected type of research approach and, thus, relationship among participants from different disciplines could be included in future NOFOs. Natural and social scientists are often not used to working together and may benefit greatly from such guidance from OAP so that human dimensions projects can be productive and effective immediately upon receiving funding instead of requiring a ‘ramp up’ period while the team gets used to working together. Further guidance may be required from OAP on how to target budget reductions for [especially multidisciplinary to transdisciplinary] projects requested to reduce budgets. OAP may consider developing a training presentation or webinar that funded teams can use to facilitate their interactions.

AA2-10. Continue efforts to better engage social scientists.

OAP has actively tried to engage social scientists and economists from the Office of Economists and NMS and continued conversations are encouraged moving forward. OAP has also reached out to WHOI social scientists due to limited response from other NOAA contacts. OAR may be able to help with these communications. OAP is continuing to seek better ways to link natural and social scientists through workshops and NOFOs and are encouraged to continue with these efforts.

5. Tracking and Reporting Accomplishments

OAP-6. Consider ways to track or document accomplishments that are not recorded in peer-reviewed publications.

OAP has an outstanding portfolio of peer-reviewed journal articles that illustrates its many accomplishments. However, OAP has many other accomplishments that are not documented in journal publications that should be recognized and similarly documented. For example, results and data are getting directly applied in decision making and resource management tools; many education, outreach, and communication tools have been developed and are highly utilized in formal and informal educational activities; numerous capacity building activities have advanced national and international OA science interest and participation. OAP is encouraged to continue periodic reporting of accomplishments including those that are not published in journals. See additional details in recommendations AA1-6 and AA2-9.

AA1-6. Continue periodic synthesis and reporting of OAP progress and accomplishments.

It is clear OAP has many accomplishments that are not documented in journal publications including information platforms, outreach and educational materials, citations in state, regional, and other stakeholder plans, among others. NOAA Technical Memorandum OAR-OAP-1 (the 2017 NOAA PI Meeting Summary Report) is an excellent summary of OAP progress and accomplishments and an example for future reporting documents. Reports of accomplishments will help document the full scope of OAP progress and impact and can greatly facilitate future program reviews. The periodicity of these reports could be timed with either renewal of an OAP strategic plan or with the 3-year Prospectus.

AA2-9. Consider ways to document non-published and externally published accomplishments.

OAP results and data are getting directly applied in decision making tools, and OAP should get credit for the high impact, immediate application aspects of their Program data and work that is not evident in publications. It is clear data and information are being included in resource management and adaptation strategies (as indicated during review presentations), but unless reported directly by the stakeholder agency, this information is not widely available, tracked, or known by others. This information should be tracked, documented, and better show-cased (perhaps as a website section of links to non-peer reviewed accomplishments).

6. Assessing Staffing Needs

OAP-7. Assess current and future staffing needs.

The OAP has a small (seven permanent staff members and three temporary positions) but highly effective staff. This small team has done an outstanding job effectively and efficiently leading and managing an incredibly successful program. OAP has implemented creative approaches to ensure adequate human resources through developing and successfully leveraging shared staff positions with other OAR programs and labs, internships, and fellowship positions. Human resources are currently adequate to meet program management needs. However, additional staff resources are likely needed in the near-term to support rapidly growing data management needs, expedite delivery of OAP data and products, and to increase focus on communications. Given the

rate of program growth and potential for continued growth, it is likely that OAP will need additional staff in the future to maintain their current level of productivity. *The review team understands that this discussion is a regular part of OAP to OAR communications.* Assessment of staffing should consider current and future needs and roles for additional permanent, shared, and temporary staff members required to maintain the balance and workload of core program activities and shared program activities. See additional details in recommendations AA1-7, AA3-1, AA3-3, and AA4-5.

AA1-7. Continue creative solutions to future staffing needs. Given the growth trajectory of OAP over the past 5 years and anticipated growth in future years, consider and plan for future staffing needs to maintain level of performance (the balance between being “lean and mean”, and not overtaxed). Shared program positions have worked very well, and this is a good, creative solution to supporting program growth. Additional resources and permanent positions may be required to maintain long-term functions of temporary staff and program productivity in the future. Continue engaging in workforce development activities (educational, intern fellowship opportunities) and identifying other opportunities that will improve diversity and inclusion in the NOAA and OAP workforce.

AA3-1. Evaluate staff and resource needs for data management and product development. The OAP data management effort has ramped up relatively quickly and must deal with a large range of different data types and sources. Investment in this area should be continued as it is setting a precedent within NOAA for program support of big-picture (regional, national, and global research, modeling, and resource management) activities. For the size of the data management and product development effort, the program may potentially be under resourced, depending on only the work of a few key individuals. Stakeholders recognized that data management is different from modeling and synthesis. There are currently capacity and resources to address OA data management. However, including modeling and synthesis in data management will require staff and resources that are currently unavailable. Moving forward, the data needs of the program will only grow both in terms of data volume and the data needs (discoverability and accessibility) of a growing stakeholder base, many of whom in industry and the public may not be sophisticated data users. **OAP could benefit from developing a process to routinely evaluate potential weaknesses, staffing, and resource needs in the data management effort.** OAP is encouraged to continue their strong partnerships and resource leveraging across and outside of NOAA to assist with addressing resource needs. OAP is also encouraged to continue supporting regional-scale data synthesis products through better engagement with the CANs that can help tailor products for regional information needs.

7. Addressing Data Management Challenges Toward Achieving FAIR Standards

AA3-2. Seek to shorten the time between data collection and data publication.

Funding opportunities already require timely data delivery by funded external investigators, but publication/availability still lags considerably. It is unclear whether similar requirements exist for internal investigators. But in both cases, the QA/QC process seems to be a bottleneck. Consider greater investment of resources or other creative solutions to expedite the QA/QC process.

AA3-3. Explore solutions for making real-time data publicly available.

Real-time data is currently being used by a limited number of partners who have individually negotiated access to that data from NOAA labs. However, real-time data is not generally available to all users. As real-time forecast models and resource management tools are increasing in demand, it is likely that development and maintenance of these products will need to be outsourced to external entities for long term maintenance and updates. A future challenge for OAP will be to find ways to make OAP monitoring data (from buoys, etc.) available to better fulfill FAIR requirements. There is potential for collaboration and discussion with IOOS and NWS for development of approaches and solutions to operational activities and data/product requirements as OAP moves in this direction in future years. IOOS may also be able to provide more assistance with development of region-specific products. Other recommendations from stakeholders and reviewers included:

- Serve near-real-time data to technical users (e.g., model developers, synthesis product creators) with appropriate QA/QC flags and metadata; this may require adding staff.
- Lean more on automated QA/QC or changing the data-providing culture to allow temporary use of provisional data.
- Clarify among the PI and stakeholder communities that there is a distinct difference between real-time data that is required by modelers and data products derived from real-time data that are updated in real-time data.
- Continue to work to make monitoring data available to scientific users in the form they need on the time frame they want. Preliminary or “raw” data that are not fully QA/QC’d can be flagged as such. Continue to work to match provision of data & products to stakeholder needs: some want raw data, some want plots.

AA3-4. Engage stakeholders for solutions to data discoverability and consider development of a user guide to data access.

OAP is encouraged to continue “live fire” exercises to identify data discoverability and accessibility issues. Continue to keep up the good work toward the goal of FAIR data. Stakeholders offered good suggestions for ways forward to improve data discoverability and potential ways forward for broader real-time data access. OAP is encouraged to reach out to the data management stakeholder panel group from this review perhaps through a workshop as they move forward with these aspects of data management. OAP may consider development of a user guide to data access targeted at various groups of stakeholders. A closer examination of which stakeholders are using which data and information may be needed to inform development of a user guide. Other reviewer and stakeholder recommendations included:

- As a growth opportunity (recommended by a stakeholder) consider a federated data discovery solution based on platforms already available (ERDDAP) that can greatly enhance the data access and data discovery of OAP supported data over and above what NCEI provides.
- Improve announcements to data-using stakeholders about what products are available and advances in data availability and storage to improve active distribution of information.
- Make effort to steer clear of the constantly shifting landscape of web pages hypertext links (used for other NOAA resources such as basic tides and currents, historical SST info, and El Nino calculations) that may confuse repeat users. Avoiding this for OA data will require a delicate trade-off between improving discoverability and maintaining a

stable landscape.

AA3-6. Continue efforts in collaboration with NOAA programs and IWGOA to improve interoperability of data.

Interoperability of data is recognized as an enormous challenge moving forward, as is defining interactions and responsibilities among participants in data management. OAP is clearly taking a leadership role in working with internal programs and external agencies to improve interoperability and is encouraged to continue this effort.

8. Enhancing Outreach and Communication Strategies

AA4-2. Consider public accessibility to some OAIE content to increase interest in membership.

The OAIE is a central forum for outreach/education across the OA community, and it should continue to be cultivated over the next 5 years. The OAIE receives consistent praise as a forum for supporting connections across the community and offering quick responses to obscure questions. OAP’s approach to developing it has been thoughtful, evidence-driven, and inclusive. The OAIE has also been embraced by the international community and has provided a good deal of knowledge transfer from well-established OA scientific efforts to newly established activities, especially in developing countries. A reviewer suggested opening some OAIE posts to the public to “lure” in people more peripheral to the OA community; perhaps this strategy could work well for discussions of how OA intersects with other ocean issues, such as heat waves, harmful algal blooms, hypoxia, or discussions that relate to a specific industry. Other suggestions included having discussions open for anyone to view (but not contribute to without membership) to increase the usefulness of the OAIE to those who may not wish to create an account but could benefit from quickly reading a discussion. A compromise could be to make key discussions open and ‘Google-searchable’ so that stakeholders may be lured in by Google results.

AA4-3. Update the OAP website to make content and information more ‘discoverable’.

Some stakeholders noted that the OAP website isn’t serving their needs, because they can’t easily find and share key products. Since the OAP’s offerings have broadened so much over the life of the program, the products can no longer be offered in a simple way, but the website should provide a straightforward portal to finding everything under the OAP umbrella. Products need to be indexed and searchable in a number of ways (e.g., by date, technical level, subject, region, etc.; perhaps OAIE themes and interest areas could be informative about useful indexing terms) to allow users to more easily find and share what they need. Although feedback on this activity area from stakeholders focused mainly on accessibility of webinars and reports, data users could also use a better road map on where to find various OAP-related data products. Suggestions for organization included having sub-navigation leading to categories of products and information. Website redesign must take into account accessibility for users of all abilities and search engine optimization. Website redesign must also incorporate insights gained from metrics about website traffic to current OAP sites; different types of users will have different information needs and different levels of determination in digging them out. As the welcome mat for OAP, the OAP website needs to serve all the stakeholder subgroups OAP is charged with serving, more so than any other product OAP creates. OAP staff indicated they are performing an analysis for

determining how website visitors are finding info and who is using what pages. OAP is encouraged to use results from that analysis to tune content on pages to focus on who (audience) is looking at the pages in a similar manner to how they are already doing this on Facebook, Instagram, and Twitter. Additionally, consider creation of web navigation tuned to audiences that are targeted for different categories of information (students, teachers, etc.).

AA4-5. Evaluate all education and outreach activities including communication.

There is a robust evaluation cycle in place for mini-grant-funded education and outreach activities, and a very good protocol in place for improving the OAIE through a steering committee and evidence-based decision-making about site improvements. It's important to recognize that communications to internal and external stakeholders about OAP activities is a type of outreach, as are OAP activities such as developing partnerships and data dissemination. Data discoverability by users is tightly connected to communication by OAP, either by announcements of what's available or a well-designed website. There should be a similarly robust evaluation cycle in place for other education, outreach, and communication activities beyond mini-grants and the OAIE. As noted above, this could be captured in a revised outreach/education/communication plan and supported by regular monitoring of metrics. These could include things like website and media metrics, monitored in conjunction with NOAA's Communications office and metrics showing who is being served by different activities (e.g., affiliation, role, experience level of SOARCE webinar attendees or specialized events like OA week). Education/outreach goals should be set and measured that are associated with other areas of OAP besides the activities that serve mainly educators. Attention to the education/outreach/communications "metadata" associated with OAP activities (visitor types, topics of interest, etc.) that fall outside the education/outreach plan may also help identify where a broader audience could be served. Adding a partial or full-time staff member focused on communications may be necessary in the near-future to support a more intentional focus on disseminating information.

AA4-7. Consider an approach for more active communication and delivery of information to stakeholders.

OAP is actively engaging the stakeholder community for input into data and product needs. However, communication of research results and information to stakeholders seems to be generally passive. OAP might consider if there is a need to develop an approach for active delivery of information to stakeholders where appropriate as part of the transdisciplinary science approach (co-production of information for outcome driven science). There is a difference between notifying a stakeholder of availability, and actively delivering information and there may be appropriate instances for both approaches. Stakeholders interviewed felt that a periodic email newsletter could offer a good solution. A monthly or bimonthly roundup of announcements, relevant links, and current events would be appreciated by stakeholders and is used to good effect by other similar programs (e.g., IOOS, OCB). OAP is already doing some of this with the Pier2Peer newsletter, but a regular program-wide "push" of information would be useful as the program grows, and regular personal contact between each member of the community and a NOAA OAP staff member becomes less possible. An email update can be easily forwarded by recipients to other external groups to grow the reach of OAP information.