Summary Report of the Program Review of the NOAA Ocean Exploration Program

October 16-18, 2019

University of Rhode Island

School of Oceanography

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Section 1: Overview

The National Oceanic and Atmospheric Administration (NOAA) Office of Oceanic and Atmospheric Research (OAR) conducts Program reviews every five years, as authorized by OAR Circular 216-3, to evaluate the quality, relevance, and performance of the activities its Programs conduct, including operations, technology development, and research. This review is useful for internal OAR/NOAA planning, programming, budgeting, and in helping the Program progress towards its strategic plan objectives. These reviews also ensure that OAR Program activities support the NOAA Strategic Plan, are relevant to NOAA's research mission and to OAR corporate priorities, and are of high quality and high performance.

This review, conducted October 16-18, 2019, was the first review conducted of the Office of Ocean Exploration Research (OER) Program. It covered the past five years of Program activity and management within the OER Program. Reviewers included members of the existing Ocean Exploration Advisory Board (OEAB) and subject matter experts from not-for-profit organizations, academic institutions, the private sector, and other federal agencies.

OER's primary activities fall into four major areas, which were the themes (listed below) for the review:

1. Ocean Exploration: Mapping and Characterization
2. Technology: Development, Application, and Program Use
3. Data and Information: Availability and Access
4. Engagement: Reaching the Public

Each reviewer independently prepared his or her written evaluations of at least one activity area (see Appendix for individual reviewers' feedback). Reviewers were also asked to provide perspective and advice on how OER and NOAA can most effectively position themselves over the next five years to leverage existing and new exploration challenges, partnerships, technologies, data science and visualization, modes of operation, and other trends relevant to the ocean exploration enterprise. This report is not a consensus, but a summary of the individual reviewers.

Section 2: Summary of Program-wide Findings and Recommendations

The overall reviewer rating generally **exceeds expectations** program-wide (See Table 1). The Panel offers 10 general findings and 22 recommendations.

1. The OER program is congratulated and commended for the work over the past five years, taking the program though challenging circumstances to a well-run, successful program.

2. Given past performance, the OER program should be considered to be very successful, and in many cases it has exceeded expectations.

3. OER should "reimagine" the future for national ocean exploration, as it has an opportunity to make ocean exploration matter in a very human way to the American public as well as the research community.

4. OER should immediately begin to think beyond the *Okeanos Explorer* and beyond direct involvement in marine operations. OER is encouraged to evaluate a system-wide approach to managing a suite of observational assets that may include significant non-NOAA-owned assets.

5. The program should be bold in its vision for the future, taking on risks, and capitalize on the confidence from the community that OER and its director have earned over the past five years.

6. OER should not limit itself to only being a producer of data, but must also be a data consumer, for multiple benefits to data users, science, and ocean exploration.

7. Data governance and usage rights, especially with respect to the cooperative institute (CI), should be firmly established, as the data (including video data) are the program's most important products.

8. Video and telepresence are significant assets that should be advanced further and made even more widely accessible.

9. The program should invest in data science (including artificial intelligence/machine learning, video annotation, and related technology) to fully exploit the value of its collected data assets and make them more usable by a wider community.

10. The new CI is recognized as a significant advantage to the program, and OER should fully engage to realize the full benefit to ocean exploration.

Table 1: Overall Reviewer ratings by activity area. [1]

Reviewer	**Overall Rating**	Ocean Exploration	Technology	Engagement	Data and Information
Reviewer 1	**EE**	EE	EE	EE	S
Reviewer 2	**HP**	HP	**	**	**
Reviewer 3	**HP**	HP	HP	HP	HP
Reviewer 4	**EE**	EE	EE	S	S
Reviewer 5	**EE**	EE	EE	EE	EE
Reviewer 6	**S**	**	**	S	**
Reviewer 7	*	*	*	*	*
Reviewer 8	**HP**	**	**	**	HP

HP = Highest Performance (4), EE - Exceeds Expectations (3), S = Satisfactory (2), NI = Needs Improvement (1)

[1] *Reviewer did not provide an overall rating in accordance with the Evaluation Guidelines
**Reviewer did not provide an overall rating or recommendations in the area of activity.

Section 3: Selected Findings and Recommendations by Research Area

Ocean Exploration: Mapping and Characterization (Overall Rating-Exceeds Expectation)

Finding:
OER should immediately begin to think beyond the Okeanos Explorer and beyond direct involvement in marine operations. OER is encouraged to evaluate a system-wide approach to managing a suite of observational assets that may include significant non-NOAA-owned assets.

A primary goal of OER is to explore the nation's U.S. Exclusive Economic Zone (EEZ) by mapping and characterizing depths greater than 200m, either solely or through partnerships (for example, currently 81% of the U.S. EEZ along the East Coast is mapped at 100m or better). This tasking is unique and critical to our nation's health, prosperity, and security. Promotion of ocean exploration to enable science has been the effective theme running through the program. OER has been focused largely on optimizing the operations of the *Okeanos Explorer* to meet program goals over the review period and has made significant progress in exploring the seafloor and filling large gaps in mapping coverage within the EEZ and in important adjacent areas. This has included collaboration with scientists and explorers aboard the *Okeanos* as well as remotely via telepresence. As a result, OER has acquired significant amounts of high-quality seabed mapping data and has ensured that data (both raw and processed) are made publicly available through the national archives at the NOAA National Centers for Environmental Information (NCEI). Within the scope of traditional ship-based seafloor exploration, this effort has been very successful and is well-regarded throughout the broader community.

From the beginning of the review period, OER has had to make the most of the *Okeanos Explorer*. This vessel created an opportunity in that it was a dedicated vessel for ocean exploration and a national symbol. However, it also was an old vessel. Operations were inefficient compared to other ocean research vessels. The *Okeanos Explorer* requires more than $10 million/year for less than 200 days at sea (DAS). In comparison, the U.S. Navy and offshore industry pay less than $7.5 million/year for over 300 DAS with ships of comparable capability. When performing remotely operated vehicle (ROV) operations, most organizations operate 24/7 in order to maximize bottom time. However, on the *Okeanos Explorer*, ROV launch occurred after breakfast, and the ROV had to be back aboard by evening. This difference in operating approaches is particularly important for several reasons. Transit time to get to/from the seafloor in deep water is measured in hours. In addition, the most dangerous time for an ROV operation is typically at the sea surface during launch and recovery operations.

The charter of exploration affords freedom and also imposes complexity to OER. By its very nature, exploration is ill-defined, has high risk and uncertainty, creates many unknowns, and includes a broad spectrum of potential activities. OER did an outstanding job of navigating challenges and maintaining discipline over the past five years to achieve meaningful results, such

as: successfully producing results in this environment that require exceptional execution in demanding, at-sea operations; successful data collection that requires significant forethought and planning by people of diverse disciplines; and, archiving that requires accommodating a wide variety of formats to make the data and information available and accessible to a variety of stakeholders.

At the beginning of the five-year period, OER viewed exploration as primarily mapping the seafloor. However, they correctly evolved to recognizing the need to also characterize the water column, which has stimulated further research and exploration activities. The partnerships they have formed have enhanced the speed of mapping and new discoveries, and the importance of seafloor mapping and exploration have been amplified. The gradual increase in funding over the past few years has allowed this to happen, and NOAA should ensure that funding is sufficient for this growth and impact to continue.

Recommendations:

1. **Set a Path Forward for Ship Access.**
   The *Okeanos Explorer* is due to retire in 2023. NOAA's Office of Marine and Aviation Operations (OMAO) reports that it requires $150 million and 10 years to procure a new ship. Planning for the future requires a commitment now from NOAA either to provide 200 ship days each year from the OMAO fleet or authorization to lease a ship or another solution. The most cost-effective solution is likely to be a combination of a leased vessel and AUVs. OER should also prioritize a modular, flexible, containerized approach to ocean exploration equipment that can easily be moved from platform to platform for deployment, instead of depending on particular NOAA ships to deploy instrumentation. OER must develop a plan for what comes next. Whatever that plan is, however, should be organized around OER's mission and goals, not around its assets.

2. **Coordinate information and gap-fill across the combined U.S. fleet.**
   While the total area mapped in the U.S. EEZ is based on the combination of the U.S. Academic Research Fleet and the U.S. exploration fleet (*Okeanos Explorer,* R/V *Falkor,* and E/V *Nautilus*), better coordinating information across the combined U.S. fleet would help fill gaps in data coverage. This coordination should be given high priority to ensure that resources and assets are used most effectively and will be important as the nation strives to map all of its EEZ.

3. **Explore New Approaches with a Higher Risk Profile.** By nature, exploration involves risk and discovering unknowns. As a result, an exploration program should be able to react quickly to new information. It must be flexible, adaptable, and resilient. It cannot be risk averse and burdened with overbearing administrative requirements and a lengthy decision chain. OER must be willing to explore and experiment with, and

support and foster, new technologies that are specifically tailored to the kinds of exploration OER wants to achieve.

4. **Identify Goals and a Strategy for a National Program of Ocean Exploration**
   A national program is more important than ever to our nation, and OER has the charter to take leadership of such a program. Embarking on such a program is both important and urgent.

Technology: Development, Application, and Program Use (Overall Rating-Exceeds Expectations)

Findings:
Video and telepresence are significant assets that should be advanced further and made even more widely accessible.

The program should invest in data science (including artificial intelligence/machine learning, video annotation, and related technology) to fully exploit the value of its collected data assets and make them more usable by a wider community.

The effective use of telepresence on the *Okeanos Explorer* has enabled agility during exploration programs and has been an important aspect of engagement both within the science community and with the public. This is critically important technology that will become increasingly important as ocean exploration continues to make use of novel platforms and sensors including unmanned platforms that telemeter data back to shore.

OER has also been proactive in supporting the development of new technology for ocean exploration. With limited resources, the program has not funded technology development directly, but instead has provided critical test bed opportunities and grants to stimulate and explore the use of such technologies for exploration, such as technology demonstrations enabling at-sea experience for others.

A competitive grants program was used to drive innovation to close identified gaps in observations and exploration technologies. Numerous technical innovations have been promoted, from autonomous underwater vehicle (AUV) observing development to Saildrone's observing capabilities and "data as a service" to advances in exploration logistics and operations. New sensor types have been produced and fielded. Opportunities for water column sampling/characterization were also realized that complement other exploration operations and objectives.

Recommendations:

1. **Take advantage of emerging technology** related to at-sea operations and data acquisition. The landscape for maritime (and adjacent) technologies is changing at an

ever-increasing rate. OER's policy and strategy for the next five years needs to be flexible enough to take advantage of new technologies as they emerge.

2. **Identify those techniques and strategies that enable the ocean to be observed remotely** and/or at scale, such as swarms of AUVs, expendable AUVs, instruments launched from VOS or aircraft, etc. Stimulate the market for data as a service provider by outsourcing major observation collection activities to those platforms. Disaggregate OER's existing observational platforms when possible and have strategies to collect different kinds of data in a modular and highly scalable way (e.g., multibeam from Saildrones).

3. **Identify talent and innovation to solve today's Ocean exploration problems.** Technology demonstrations should remain an essential component of OER's exploration mission. However, OER must continually identify how to draw more talent and innovation toward solving ocean exploration problems and should generally play a more active role in ensuring it is a good customer. OER must acknowledge the role it must play to attract innovators to exploring the seas.

4. **Develop a Formal Mechanism for Evaluating Exploration Architectures.** There are a number of opportunities to leverage increasingly mature autonomous systems, artificial intelligence technologies, and high-speed communications infrastructure to transform how OER explores the depths below. These priorities are explicitly identified in the Office of Science and Technology Policies Fiscal Year 2021 Administration Research and Development Budget Priorities and warrant consideration by OER in any of its future plans.

Data and Information: Availability and Access (Overall Rating-Exceeds Expectations)

Finding:
OER should not limit itself to only being a producer of data, but must also be a data consumer, for multiple benefits to data users, science, and ocean exploration

OER data (including observations, information, video, photographs, and documentation) have been successfully made available to researchers and the public. Recognizing that OER did not have the in-house capabilities or resources to fully enact a data management program, NOAA's National Centers for Environmental Information (NCEI) was engaged to manage the data from the vessels, including quality assurance and annotation, archiving, distribution, and accessibility. These data management capabilities are being built upon within NCEI, including a concerted effort to extract historical data (including video footage) and different types of data. The amount

of resources, however, has been minor (approximately 3% of overall budget), which has limited somewhat the effective reach and application of OER's data assets.

OER has established routine data delivery pipelines to ensure that data acquired are made available through NOAA archives. Efforts have focused on ensuring that data are documented, discoverable, and accessible. OER data management has put a strong emphasis on the use of standards and is currently adopting the use of new interfaces for aggregating and presenting information, which is an important step toward improving discoverability. OER has demonstrated community leadership in developing an archiving and discovery system for underwater video acquired during expeditions.

Recommendations:

1. **Dissolve data discovery stovepipes.**
   There remains significant opportunity for better integration of data across different federally funded ocean programs as well as philanthropic organizations engaged in ocean exploration and science (e.g., Schmidt Ocean Institute). This coordination should be pursued both at the program leadership level and at the boots-on-the-ground level of data managers and interface design and deployment.

2. **Improve Searchability and Accessibility of Video Data**
   With respect to video access, OER is a community leader that has developed and deployed a system for a searchable and discoverable archive of video clips leveraging rich metadata curated by the program. This library-like service is hugely important and beneficial for users seeking footage of specific features, species, and/or events. However, this system relies on the assumption that annotations made during the dive (or even post-dive) are accurate and complete. For scientists who may want to explore a dive in its totality, the five minute clips made available are cumbersome and difficult to access. An alternative solution would facilitate this sort of data exploration and use. Also, OER may also want to consider if the video archive/discovery service could be more broadly offered to the community for video acquired on other assets. The NCEI archive serves the entire U.S. ocean science community (OER + U.S. Academic Research Fleet) for many data types but not video. Given the value of video observations for ocean exploration, and the lack of a broader data management solution for it across the federally funded research community, this could have tremendous impact.

3. **Develop a Strategy to Accommodate a Significant Increase in Data Volume.**
   With the use of new systems and sensors, the volume of data collected is expected to increase by orders of magnitude. OER must plan now for storing these data, making them accessible and available, and converting them to useful information. Activity within NOAA to move its data storage to cloud providers will undoubtedly be an

important development with respect to data and information. As the details of new cloud-hosted archives emerge, there may be new opportunities for cloud-based analysis and processing, as well as the opportunity/need to revamp/optimize some of the data management and access pipelines.

4. **Strategically position OER to fully realize the value of its data.**
   Data represent the connective tissue across OER and are the currency of scientific discovery and must be emphasized. To do this, the following steps may be considered: 1) Develop an OER data strategy, in alignment with OAR, NOAA, the Department of Commerce, and Office of Management and Budget data strategies; 2) Define data and intellectual property rights up front in contracts, cooperative agreements, and grants to ensure that data are open and available to all; 3) Use the OER data strategy to focus resources on those elements necessary to achieve the strategy and program goals; 4) Reduce program risk by ensuring that OER data assets are properly collected, curated, and leveraged to maximum program gain; and, 5) Use NOAA data systems at NCEI and other NOAA offices as commodities when appropriate, or even as a vehicle to reach external commodity data services.

5. **Accelerate Telepresence Deployment with Low-Cost Pilots.**
   OER should pilot low-cost telepresence solutions enabled by low-cost cloud computing and commercially available satellite internet capabilities. Piloting these activities now will inform key risks and acquisition pathways as global connectivity matures, saving time and money before large-scale procurement decisions are made.

6. **Invest in Data Leadership and Harmonization.**
   To lead a national ocean exploration program, OER needs to take an active role in developing common data architectures, repositories, and stewardship requirements across the entire ocean exploration enterprise. As a requirement, data from cooperative institutes and other OER-funded partners must be made publicly available and be quality controlled to be virtually indistinguishable from other NOAA data. Looking forward, data collected from the National Science Foundation and U.S. Navy-owned assets should be designed to be interoperable with data collected from the *Okeanos* or other OER platforms. As a larger goal, data from all federal ocean exploration activities should generally be available in the same location or data service.

While many of the Reviewers provided the above recommendations, one reviewer also recommended:

1. **Create a Standardized Template for Data**. Have OER fund, for each cruise, a small team of graduate students (some/most of who might join by telepresence) to create baseline site descriptions/campaign descriptions in real time based on the data coming

out of the various sensors and instruments. These descriptions could later form chapters of their theses or sources for publications (including a citation to the OER dataset DOI). Starting with a standardized template and working with structured data should simplify standardization. More generally, offering small grants to defray the costs of using OER data might help kick-start utilization of the OER datasets.

2. **Support the development of artificial intelligence and machine learning tools** for automatic classification and exploration of the video, still, and acoustic datasets that are loaded into the database.

3. **Produce a master remotely operated vehicle sensor and position reference file** to increase data accuracy and usability with only a moderate amount of development effort.

4. **Build In-house Data Science Capacity.** Future exploration concepts may not lend themselves to OER's current data workflows. Now is the time to explore what type of data infrastructure will be required to fully exploit all of the utility provided by disaggregated exploration architectures. Current mapping and characterization efforts are rate limited by qualified human monitors, which are also prone to introducing their own errors and biases. As data volumes and sources increase, current processes will require substantial automation to help focus the attention of researchers to the key science-relevant data. To get to this point, OER should develop in-house data science capacity to enable future exploration capabilities.

Engagement: Reaching the Public (Overall Rating-Exceeds Expectations)

Finding:
OER should "reimagine" the future for national ocean exploration, as it has an opportunity to make ocean exploration matter in a very human way to the American public as well as the research community.

OER has capitalized on the funding resources available to effectively engage with the public. Through improved telepresence capabilities and a live feed, their audience has grown, and there have been some very notable successes (for example, when new and unusual marine life are discovered). Leveraging strong partnerships (in particular with the Ocean Exploration Trust and Schmidt Ocean Institute) has also strengthened outreach as people become more aware of ocean exploration in general.

Recommendations:

1. **"Make oceans matter" to the public**

Instead of optimizing for the execution of ocean observations themselves, OER should rally around a vision for ocean observations that will "make oceans matter" for the wider nation, beyond the ocean science community, which is the current target of the program. OER must focus primarily on those program elements that will enable it to make oceans matter to the nation, and observations will be collected to support those elements. This includes heavy focus on strategy, guidance, policy, and oversight that will be needed for the national program.

2. **Improving media products to allow greater accessibility to the broader public.** While the videos that have been produced contain a lot of good information, they would be far more impactful if they were edited and produced by video professionals who are experienced with the art of short-focused storytelling and the art of video editing and production. Likewise, the annual Oceanography volumes are beautiful and speak loudly to the science and exploration community, but it would be useful to think more broadly about engagement of the broader public, policy makers, etc. with clear impactful information that is easily understood and describes the benefits, successes, and achievements of this program.

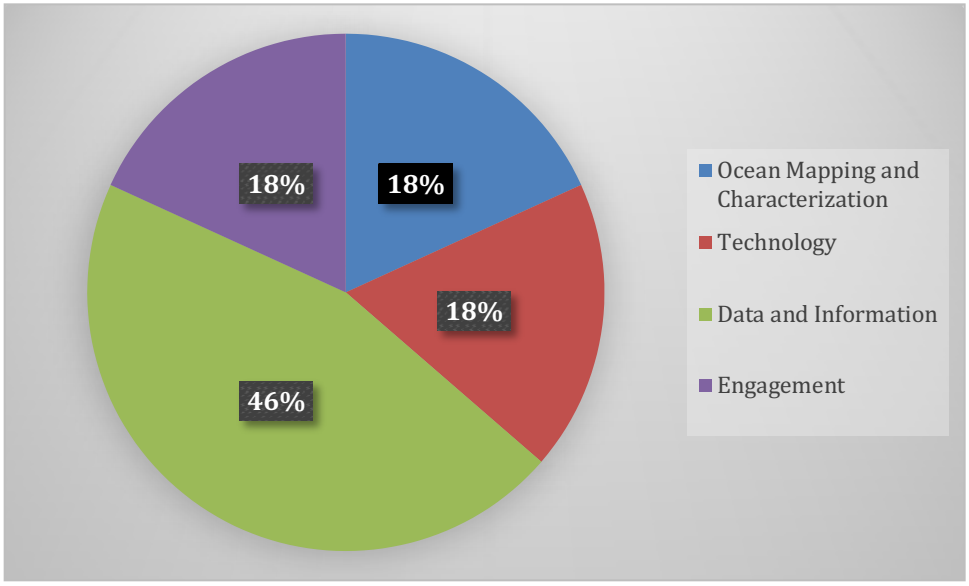
3. **Engage the public in various activities that encourage the use, or "mining", of data.** Examples of such activities could include: having three to five day "Ocean Data Boot Camps," where participants receive a crash course in how to utilize OER data within their own applications; provide scholarships to aspiring high school students who are trying to decide on their careers and college choices (the boot camp could be a bridge to discovering their next educational paths); **w**ork with large universities to establish a set curriculum for potential "yet-to-be-determined" careers within ocean discovery; and, **w**ork with the corporate social responsibility programs of large employers to offer employees the chance to contribute to ocean science.

4. **Build on Partnerships.**
The ability to develop and maintain partnerships will be a key core competency for future success. Partnerships with other NOAA groups, with government agencies (federal, state, and local), with industry (companies large and small), with philanthropic organizations, and with academia will be critical to success. Building long-term relationships with other organizations demands specific skills. OER must improve these skills and increase efforts to ensure successful partnerships going forward.

Section 4: Summary of Recommendations

The results of the 2019 OER Program Review yielded **22** recommendations which are listed below. Of those 22 recommendations: 4 (18%) Ocean mapping and characterization, 4 182%) Technology, 10 (46%) Data and Information, and 4 (18%) Engagement.

Table 2: Breakdown of Reviewer comments by Research Area



List of Recommendations:

1. **Set a Path Forward for Ship Access.**
   The *Okeanos Explorer* is due to retire in 2023. NOAA's Office of Marine and Aviation Operations (OMAO) reports that it requires $150 million and 10 years to procure a new ship. Planning for the future requires a commitment now from NOAA either to provide 200 ship days each year from the OMAO fleet or authorization to lease a ship or another solution. The most cost-effective solution is likely to be a combination of a leased vessel and AUVs. OER should also prioritize a modular, flexible, containerized approach to ocean exploration equipment that can easily be moved from platform to platform for deployment, instead of depending on particular NOAA ships to deploy instrumentation. OER must develop a plan for what comes next. Whatever that plan is, however, should be organized around OER's mission and goals, not around its assets.
2. **Coordinate information and gap-fill across the combined U.S. fleet.**
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priority to ensure that resources and assets are used most effectively and will be important as the nation strives to map all of its EEZ.

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4. **Identify Goals and a Strategy for a National Program of Ocean Exploration** A national program is more important than ever to our nation, and OER has the charter to take leadership of such a program. Embarking on such a program is both important and urgent.
5. **Take advantage of emerging technology** related to at-sea operations and data acquisition. The landscape for maritime (and adjacent) technologies is changing at an ever-increasing rate. OER's policy and strategy for the next five years needs to be flexible enough to take advantage of new technologies as they emerge.
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11. **Develop a Strategy to Accommodate a Significant Increase in Data Volume.**
    With the use of new systems and sensors, the volume of data collected is expected to increase by orders of magnitude. OER must plan now for storing these data, making them accessible and available, and converting them to useful information. Activity within NOAA to move its data storage to cloud providers will undoubtedly be an important development with respect to data and information. As the details of new cloud-hosted archives emerge, there may be new opportunities for cloud-based analysis and processing, as well as the opportunity/need to revamp/optimize some of the data management and access pipelines.
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13. **Accelerate Telepresence Deployment with Low-Cost Pilots.**
    OER should pilot low-cost telepresence solutions enabled by low-cost cloud computing and commercially available satellite internet capabilities. Piloting these activities now will inform key risks and acquisition pathways as global connectivity matures, saving time and money before large-scale procurement decisions are made.
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16. **Support the development of artificial intelligence and machine learning tools** for automatic classification and exploration of the video, still, and acoustic datasets that are loaded into the database.
17. **Produce a master remotely operated vehicle sensor and position reference file** to increase data accuracy and usability with only a moderate amount of development effort.
18. **Build In-house Data Science Capacity.** Future exploration concepts may not lend themselves to OER's current data workflows. Now is the time to explore what type of data infrastructure will be required to fully exploit all of the utility provided by disaggregated exploration architectures. Current mapping and characterization efforts are rate limited by qualified human monitors, which are also prone to introducing their own errors and biases. As data volumes and sources increase, current processes will require substantial automation to help focus the attention of researchers to the key science-relevant data. To get to this point, OER should develop in-house data science capacity to enable future exploration capabilities.
19. **"Make Oceans matter" to the public**

Instead of optimizing for the execution of ocean observations themselves, OER should rally around a vision for ocean observations that will "make oceans matter" for the wider nation, beyond the ocean science community, which is the current target of the program. OER must focus primarily on those program elements that will enable it to make oceans matter to the nation, and observations will be collected to support those elements. This includes heavy focus on strategy, guidance, policy, and oversight that will be needed for the national program.

20. **Improving media products to allow greater accessibility to the broader public.** While the videos that have been produced contain a lot of good information, they would be far more impactful if they were edited and produced by video professionals who are experienced with the art of short-focused storytelling and the art of video editing and production. Likewise, the annual Oceanography volumes are beautiful and speak loudly to the science and exploration community, but it would be useful to think more broadly about engagement of the broader public, policy makers, etc. with clear impactful information that is easily understood and describes the benefits, successes, and achievements of this program.
21. **Engage the public in various activities that encourage the use, or "mining", of data.** Examples of such activities could include: having three to five day "Ocean Data Boot Camps," where participants receive a crash course in how to utilize OER data within their own applications; provide scholarships to aspiring high school students who are trying to decide on their careers and college choices (the boot camp could be a bridge to discovering their next educational paths); **w**ork with large universities to establish a set curriculum for potential "yet-to-be-determined" careers within ocean discovery; and, work with the corporate social responsibility programs of large employers to offer employees the chance to contribute to ocean science.
22. **Build on Partnerships.**
    The ability to develop and maintain partnerships will be a key core competency for future success. Partnerships with other NOAA groups, with government agencies (federal, state, and local), with industry (companies large and small), with philanthropic organizations, and with academia will be critical to success. Building long-term relationships with other organizations demands specific skills. OER must improve these skills and increase efforts to ensure successful partnerships going forward.

Additional Recommendations for NOAA:

1. **Develop a Strategy to Build a Strong Organization and Team.** In the past five years, OER has struggled for survival and managed an annual budget of less than $35 million. As a result of OER's success and current administration priorities, there is an opportunity to significantly increase visibility and budget of the ocean exploration program. The human resources strategy for the future should address the following:

a. Addition of engineers to develop a technology roadmap and interface with other organizations developing and using new technology;
b. Upgrade business operations;
c. Employ a full-time head of data and information (this is a critical competency and should not be outsourced);
d. Quality program to instill a culture of self-evaluation and continuous improvement; and,
e. Experienced program manager to manage the Cooperative Institute (CI).

Appendix: Individual Reviewers' Feedback

Reviewer 1

Summary

The NOAA Office of Ocean Exploration and Research (OER) is a successful program that has **exceeded expectations** over the past five years and has tremendous future potential to transform the nation's approach to ocean exploration. The program overcame many administrative, programmatic, and technical hurdles during the review period (2015-2019) through program staff's creative problem-solving and diligence. Overall, OER has met its strategic goals in its most recent strategic plan.

From 2015-2019, OER has been focused largely on exploration operations to meet its program goals. The dominant theme has been enabling science by the ocean science community by providing observing platforms and data. Program funding prioritization has been placed on supporting science through grants and collection of observations. Data-related program elements have been almost completely outsourced, and OER has positioned itself almost exclusively as a provider, not a consumer, of data.

OER has expressed a vision of leading not just NOAA's but the nation's ocean exploration program in the future. To realize this vision, OER must transition from its current state to a more mature program. This transition will need to include substantial and even foundational changes in how OER — and NOAA — conducts ocean exploration. The program should become focused less on the operations and management of its observation system assets and more on the users of its data and information, the needs of its stakeholders and partners in the ocean exploration and research enterprise, and the ultimate national and societal benefits of ocean exploration. OER's past performance and leadership leads me to believe this future vision is attainable.

OER's 2016-2020 Strategic Goals and Objectives

Overall, the OER program has met its strategic goals and **exceeded expectations**.

Explore the Oceans

OER has been focused largely on optimizing the operations of the *Okeanos Explorer* to meet program goals over the review period. Promotion of ocean exploration to enable science has been the effective theme running through the program. OER funding prioritization has been placed on supporting science through grants to those outside of NOAA, and, in general, the collection of observations. Significant progress has been made in exploring the U.S. Exclusive Economic Zone (EEZ) and other targeted areas, and many logistical obstacles were overcome to achieve this high level of success. **Exceeded Expectations**

Promote Technical Innovation

A competitive grants program was used to drive innovation to close identified gaps in observations and exploration technologies. Numerous technical innovations have been promoted, from autonomous underwater vehicle (AUV) observing development to saildrone's observing capabilities and "data as a service" to advances in exploration logistics and operations. New sensor types have been produced and fielded. Opportunities for water column sampling/characterization were also realized that complement other exploration operations and objectives. **Exceeded Expectations**

Provide Public Access to Data

OER data (including observations, information, video, photographs, and documentation) have successfully been made available to researchers and the public. The responsibility for data access has largely been outsourced to the NOAA Centers for Environmental Information (NCEI), which has been executing their mission of data stewardship and access well for the amount of resources provided. The amount of resources, however, has been minor (3%), which has limited somewhat the effective reach and application of OER's data assets. **Satisfactory**

Encourage the Next Generation

The telepresence capabilities employed by OER are a major asset of the program. Telepresence and related outreach activities have begun to engage the next generation of oceanographers and ocean explorers, and have also been cutting across the current community of explorers and researchers. The demonstrated ability to shift rapidly from biology to geology to archeology during an exploration mission in order to optimize the ongoing exploration operations is excellent. The use of social media and other outreach mechanisms to capture the imagination of the public and draw them to the exploration activities shows great promise. **Exceeded expectations**

Expand the National Ocean Exploration Program Through Partnerships

The OER program has successfully nurtured and leveraged partnerships with academia and private industry for research, the collection of observations, the development of new measurement techniques, and similar exploration needs. However, I feel that the partnerships have been more focused on filling gaps in current exploration activities than truly expanding the OER program, and the program's grants and contracts may have been emphasized over establishing more complex or formal partnerships. Given the program's success with the relatively minor amount of investment in the current partnerships, however, I believe the great potential to expand the national OE program has been successfully demonstrated. **Satisfactory**

Make Organizational Improvements

The organization of the OER program has been sufficient to meet the program's goals. The dedication and professionalism of the program staff has resulted in a fully successful program, and these staff should be commended. Funding for the program itself was at minimal levels (8%), which speaks well to efficiencies, but there are natural limits to what an organization can do to improve or expand without adequate resources to do so. Whether the NOAA Office of Oceanic and Atmospheric Research (OAR) and the wider NOAA organization has adequately helped the OER program through organizational improvements is somewhat difficult to judge, however. Given this and the very limited funding used to support and improve the organization itself, I am unable to accurately judge the program on this topic.

Programmatics

Over 70% of the available program funds have passed through the program as grants to enable observations and science. Program staff have supported execution at a minimalistic rate (labor <10% of the available budget) focused largely on executing observational campaigns and ensuring the continued collection of data. This results in what appears to be a highly efficient program, from a funding perspective. (That limited funding was spent within the program office can be viewed as a programmatic feature, especially in the academic research world.) However, more mature programs will typically spend approximately twice that rate (12-18%) when significant advances, expansions, or modifications are required to achieve their advancing strategic goals. That OER was able to be successful despite limited investment in its program office is laudable, but may not be sustainable as the program's goals continue to expand on the national stage. OAR's portfolio managers do not appear to have the authority to help by redirecting resources or efforts, but are mainly in a coordination role. **Exceeds Expectations**

Data

Data elements, including execution, access, and integration, have been almost completely outsourced to OER partners at NCEI, who have delivered access, visualization, and archive services under a reimbursable service level agreement. This is an effective internal partnership within NOAA that leverages the existing practices, capabilities, and infrastructure within NOAA, meaning that OAR did not need to invest significant resources to build them. However, OER also chose to direct its resources to other program needs instead of expanding and expounding upon the NCEI capabilities. NCEI is primarily an archive, not an access and distribution tool, and while capturing exploration data and video was a priority, there could have been investments to make those data more easily used, quality controlled, and transformed to other types of information. While I understand the program's choices given limited resources, the program did not make the investments necessary to make the most effective use of its data assets. The program

positioned itself as a provider of data, not also as a consumer, and outsourced its responsibilities for quality assurance, access, and governance. While economical and adequate to meet basic requirements, the program's data practices were only satisfactory, when the potential was far greater. **Satisfactory**

Other Aspects

n/a

Recommendations for OER Program 2020+

OER has expressed a vision of not only leading NOAA's ocean exploration activities, but also leading a national ocean exploration program in the future. To reach this goal and lead the national program successfully, OER must transition from its current state to a more mature program focused on those goals that will enable OER to scale effectively to a national scale. This can be accomplished through several considerations, listed below:

- Instead of optimizing for the execution of ocean observations themselves, OER should rally around a vision for ocean observations that will "make oceans matter" for the wider nation, beyond the ocean science community, which is the current target of the program. OER must focus primarily on those program elements that will enable it to make oceans matter to the nation, and observations will be collected to support those elements. This includes heavy focus on strategy, guidance, policy, and oversight that will be needed for the national program.
- Program focus should not be primarily on marine operations. Operational elements such as the *Okeanos Explorer* and any other physical and computing infrastructure should be outsourced to services. Ships, ship time, data storage, telecommunications, and computing time are commodities, and the program should keep them at arm's length to improve programmatic efficiencies and agility. The program can gain these efficiencies by engaging partners, contractors, cooperators, and other service providers in a consumer-producer relationship that challenges the service producers to innovate and find economies to produce the required data and services needed by the program. Seek to lease observing platforms, or otherwise acquire ship time, but not manage it directly. Operations is not OER's focus, exploration is.
- Strategically position OER to fully realize the value of its data. Data represent the connective tissue across OER and are the currency of scientific discovery. Data must be emphasized. Develop an OER data strategy, in alignment with OAR, NOAA, the Department of Commerce, and Office of Management and Budget data strategies. Define data and intellectual property rights up front in contracts, cooperative agreements, and grants to ensure that data are open and available to all. Use the OER data strategy to focus resources on those elements necessary to achieve the strategy and program goals. Reduce program risk by ensuring that OER data assets are properly collected, curated, and leveraged to maximum program gain. Use NOAA data systems at NCEI and other NOAA offices as commodities when appropriate, or even as a vehicle for external commodity data services. But do not use NOAA offices or NCEI by default when innovation, special services, etc. are needed — they can be part of a competitive business solution, but that should include commercial solutions as well.
- Tell the human story of OER's activities well. Encourage the development of data and information products that are easily accessible and consumable by a wider audience. Employ the NASA outreach model that shows that science is not just for scientists. Leverage telepresence and social media to get the story of exploration out there. There is a compelling human story in ocean exploration — machines may be doing the observation, but humans are making the discoveries! Identify those humans and put them at the forefront of OER stories. It is not just about the undersea discoveries.
- The OER program should assert its role as both a data provider and a data consumer. The responsibility for data strategy, requirements, governance, quality, and innovation resides with OER and should not be outsourced, though many aspects of data operations (ingest, storage, access) may be. Use data buys instead of directly supporting the operations of NOAA observation assets. Specify the data needed, but buy from multiple

providers to drive competition and realize efficiencies. Use funding as a strategic tool to build an effective and resilient data collection program.

- While OAR is providing an adequate environment for OER today, OAR is missing elements that could help it expand to the national scale — data science innovation, telepresence improvements, communications advances, etc. OER is mostly a stand-alone silo within OAR and within NOAA and may need to establish formal partnerships within the federal government to reach centers of excellence at other agencies and bureaus to entrain the federal expertise needed for the challenge. Partners outside of the federal government must also be engaged in order to build the necessary elements for a successful national program.
- OER needs to build and leverage effective partnerships in almost every aspect of ocean exploration. Partner with innovators in order to move fast and with agility. This includes marine operations, data, communications, outreach, education, and more. Seek additional partners in the data space — especially artificial intelligence, machine learning, data analysis, and data access — that are leaders in the data community. Partner in the communications space — especially telepresence, and the looming global WiFi networks (coming in five years, should partner now) — to understand what the capabilities will be not just next year but in 5-10 years so OER can be positioned properly as new technologies come online. Partner in the outreach space — to enable others to make ocean exploration contributions in novel ways and produce science education content using OER data and expertise — to broaden the impact of OER activities to a national scale.
- Do not wait for 2024 to stop using the *Okeanos Explorer*, but instead proactively phase out its use sooner. OER should approach the NOAA Office of Marine and Aviation Operations (OMAO) as a service provider like any other, where the use of OMAO services should be based on the business case — not politics internal to NOAA — that drives solutions in a competitive marketplace. NOAA may not realize (or even need) a NOAA-owned replacement for the *Okeanos* in the foreseeable future, and the marine transportation industry may have effective platforms for rent or lease instead. OER should prioritize a modular, flexible, containerized approach to ocean exploration equipment that can easily be moved from platform to platform for deployment, instead of depending on particular NOAA ships to deploy instrumentation.
- OER should attract industry to the ocean exploration marketplace through requests for information and proposals that describe what OER needs to accomplish over the next five years. Promote the ocean technology community and identify specific gaps. OER should explore the use of other transaction authority agreements as a research and development vehicle in addition to cooperative research and development agreements and small business innovation research awards. Explore partnerships with existing technology incubators to introduce them to OER and ocean exploration challenges, of which they may not be aware.
- Identify those techniques and strategies that enable the ocean to be observed remotely and/or at scale, such as swarms of AUVs, expendable AUVs, instruments launched from VOS or aircraft, etc. Stimulate the market for data as a service providers by outsourcing major observation collection activities to those platforms. Disaggregate OER's existing observational platforms when possible and have strategies to collect different kinds of data in a modular and highly scalable way (e.g., multibeam from saildrones).
- OER must take full advantage of the new NOAA cooperative institute (CI) for ocean exploration. Lean in to the new CI to take full advantage of the expertise of the CI members via the cooperative agreements at the heart of the CI. OER must actively engage in every step along the way and must not be a passive partner. Cooperative agreements are task driven, and OER should actively participate in those tasks, not just provide oversight and guidance. The CI provides a unique opportunity to gain research insights and results in a rapid and agile manner.

Reviewer 2

Overall Assessment

I rank OER's overall performance over the past five years as **highest performance**. Key reasons for this ranking are as follows:

- The purpose of OER is exploration. As a result, OER's mission is not as well-defined as most other government organizations. OER is not accountable to produce day-to-day deliverables. Rather, they must define the meaning of ocean exploration and focus on achieving results in a potentially very broad spectrum of activities. Achieving notable accomplishments under these conditions requires discipline to avoid distractions and long-term focus, since successful outcomes result from multiyear efforts. OER leadership did an outstanding job of identifying strategic goals, socializing within NOAA and external communities, and remaining dedicated to achieving these goals throughout the past five years.
- OER has achieved multiple successes across a very wide front of disciplines:
    - **Exploration** — OER has significantly increased mapping of the U.S. Exclusive Economic Zone (EEZ) in depths greater than 200m. In addition, OER recognized exploration should also include characterization of the water column, and they initiated meaningful efforts to fill this void.
    - **Science** — OER has made significant contributions to science in many fields of biological, chemical, physical, and geological oceanography, as well as marine archeology. Not only have NOAA scientists achieved recognition from this exploratory work, but their data have been referenced in publications by many other scientists.
    - **Technology** — OER has recognized the importance of technology in ocean exploration. Correctly, they also realized their limited budget did not allow development of new technology. As a result, they implemented technology demonstrations on their cruises, which has provided significant opportunities for others to test and verify their new technology in the real world at sea.
    - **Data and Information** — OER has pioneered the use of telepresence in making data and information available in real time in order to maximize at-sea effectiveness, engage experts who were on shore and not at sea, and engage multiple audiences (scientific communities as well as the public) in ocean exploration. They have also made initial steps to improve data storage and make it available and accessible to others.
    - **Outreach** — OER has done a great job of engaging multiple audiences with different requirements. They have identified and included appropriate communities in cruise planning. They have provided real-time access during cruises. They have made initial attempts to engage the public in the importance of oceans to the health of our planet.
- OER successfully achieved these results while hobbled by multiple constraints, including an inadequate budget, an old vessel, and inefficient vessel operations. The OER budget was significantly less than that recommended by previous reviews and advisory boards. In fact, NOAA leadership tried to zero out OER's budget early in the previous five-year period. It is only recently that OER has received support from NOAA leadership. The *Okeanos Explorer* is an old vessel. In addition, as addressed in more detail below, vessel operations were very inefficient. OER's record of achieving many successes is even more impressive given these substantial obstacles.
- OER developed and implemented a meaningful strategy of campaigns and telepresence. These approaches transformed ocean exploration.

- OER initiated partnerships with communities and philanthropic organizations to improve opportunities for success. These efforts should provide a foundation on which to build going forward, which will be particularly important to the future of ocean exploration.

Finally, ocean exploration is currently at a critical turning point. The value of ocean exploration to our nation and to the world is vital — it has never been higher. We desperately need leadership and commitment to a national ocean exploration program. The need for decisiveness is both urgent and important. As is true of many disciplines today, the pace of change is rapid and accelerating. As a result, the needs for future success are different. What created success for OER over the past five years is necessary, but not sufficient, for future success. This topic is addressed in more detail in my last section: "Ocean Exploration Going Forward."

As requested, my review first provides an assessment of exploration. Comments on historical performance in other areas (technology, data and information, engaging the public, and business operations) follow. Finally, recommendations for going forward are provided.

Assessment of Exploration: Mapping and Characterization

A primary goal of OER is to explore the nation's EEZ by mapping and characterizing depths greater than 200m. This tasking is unique and critical to our nation's health, prosperity, and security.

I rank OER as **highest performance** in the research area of exploration. OER goes well beyond satisfactory and is outstanding in almost all areas.

The charter of exploration affords freedom and also imposes complexity to OER. By its very nature, exploration is ill-defined, has high risk and uncertainty, creates many unknowns, and includes a broad spectrum of potential activities. Successfully producing results in this environment is intellectually challenging and requires exceptional execution in demanding, at-sea operations. Successful data collection requires significant forethought and planning by people of diverse disciplines. Archiving requires accommodating a wide variety of formats. These data and information must then be made available and accessible to a variety of stakeholders. OER did an outstanding job of navigating these challenges and maintaining discipline over the past five years to achieve meaningful results.

The past five years have been particularly challenging for OER. Several years ago, NOAA leadership tried to zero out the OER budget. OER's efforts received very little support in publicizing successes and/or lobbying for increased funding. OER's persistence early in the previous five-year period is now paying off with well-deserved recognition by current NOAA leadership.

A key factor for success was OER's campaign strategy. They demonstrated good outreach to engage communities early in the process. They also maintained good communications with other research and development groups to coordinate activities. For example, coordination with Schmidt Ocean Institute and the Ocean Exploration Trust (OET) enabled major successes in the Pacific during the Campaign to Address Pacific monument Science, Technology, and Ocean Needs (CAPSTONE). In addition, OER significantly improved internal communications with other NOAA groups to align goals and strategies and to increase impacts. As a result, these partnerships also recently enabled OER to leverage efficiently an existing NOAA contract for mapping.

One of OER's most visible and important innovations over the past five years has been use of telepresence. This has proven to be an exceptionally valuable tool in transforming the way in which ocean exploration is performed. Historically, oceanographic cruises were planned in advance. Once the ship left the dock, decisions were made entirely by researchers on board the vessel and ship's crew. This small group of personnel had major limits in terms of multiple disciplines. More importantly, they were constantly under tight time constraints while operating in a physically

demanding environment. Scientists on board would work long hours to collect data and then have to make quick decisions about what, if anything, should be changed before grabbing a few hours sleep and starting over again. They were able to consult only briefly with others aboard the ship. In addition, their job was frequently made even harder by bad weather, which impacts safety of operations and impedes thinking clearly (because they are being tossed about).

Telepresence revolutionized ocean exploration. Because of real-time data feedback and communication, scientists on the ship could consult with a broad community of scientists ashore and benefit from both diversity in expertise and deep proficiency in any selected field. The community ashore could consider implications of the data collected as it unfolded. They had access to a wealth of prior research and information and the time to analyze it. As a result, cruises became much more effective and efficient as this broader expertise was input and decisions were much improved.

In addition, telepresence had many other benefits. It was an effective technique to engage the public in ocean exploration. People of all ages and backgrounds could experience the excitement of exploration as it happened. The impact on both interested local communities as well as the public at large was exceptional.

In short, OER, in cooperation with OET, pioneered a very valuable tool, which proved successful over the past five years and will prove incredibly useful going forward.

OER also made a good start in recognizing the need for and in developing partnerships. Stakeholder feedback provided as part of this review consistently acclaims OER as a "good partner" in all regards — soliciting input, listening, enabling real-time input, adapting during cruises, and making data available and accessible.

At the beginning of the five-year period, OER viewed exploration as primarily mapping the seafloor. However, they correctly evolved to recognizing the need to also characterize the water column. Efforts in this regard are still in early stages, but are progressing.

Technology demonstrations have also been a significant contribution. While OER had neither the budget nor expertise to develop new technology on their own, they recognized the importance of new technology and contributed by making ship time available for technology developers. This at-sea experience contributed to successful development of new tools and approaches.

From the beginning of this period, OER had to make the most of the *Okeanos Explorer*. This vessel created an opportunity in that it was a dedicated vessel for ocean exploration and a national symbol. However, it also was an old vessel. Operations were inefficient compared to other ocean research vessels. The *Okeanos Explorer* requires more than $10 million/year for less than 200 days at sea (DAS). In comparison, the U.S. Navy and offshore industry pay less than $7.5 million/year for over 300 DAS with ships of comparable capability. When performing remotely operated vehicle (ROV) operations, most organizations operate 24/7 in order to maximize bottom time. However, on the *Okeanos Explorer*, ROV launch occurred after breakfast, and the ROV had to be back aboard by evening. This difference in operating approaches is particularly important for several reasons. Transit time to get to/from the seafloor in deep water is measured in hours. In addition, the most dangerous time for an ROV operation is typically at the sea surface during launch and recovery operations.

While I believe OER performed at an overall ranking of **highest performance**, there are areas for improvement:

- As discussed above, the efficiency of vessel operations leaves room for improvement.

- OER should continue to look at technology beyond the ship. This includes making use of rapid advances in technology in platforms, sensors, communications, and data management. There is a critical need to employ autonomous systems, artificial intelligence/machine learning, image recognition, and cloud-based data services.
- While OER has performed research in a wide variety of oceanographic disciplines, there seems to be limited integration taking a systemwide perspective. The ocean is an extremely complex system. As such, exploring and understanding the ocean demands an integrated, multidisciplinary approach. True understanding results from observing and modeling the oceans as a complex system. Data collection should be planned and executed with a focus on exploring the complex interactions among biological, chemical, physical, and geological factors, not just researching a single, narrow aspect.
- I encourage OER to develop a culture of self-examination and continuous improvement. A disciplined process to collect and make use of lessons learned would be valuable. These critiques should encompass both failures and successes. Multiple processes have been developed and proven effective in industry and by the U.S. Navy to identify root causes and recommend improved processes and training. Most importantly, the only way to improve quality is through a disciplined focus on continuous improvement. Success requires not only new processes, but a change in culture.
- The risk profile for OER is currently risk averse with little tolerance for failure. The charter of exploration offers the opportunity to try new approaches and increase the risk profile. "Failing fast" can be beneficial, particularly when key lessons are captured and improvements implemented.

Comments on Technology: Development, Application, and Program Use

OER has recognized the need to support development of new technology for ocean exploration. Unfortunately, their limited resources do not permit a meaningful effort to develop new technology. As a result, they have correctly focused on support such as technology demonstrations enabling at-sea experience for others. In addition, they are to be commended for efforts to experiment with autonomous vehicles (Remus), unmanned surface vessels (Saildrone), and advanced gliders.

Comments on Data and Information: Availability and Access

Other reviewers are more qualified and specifically tasked to review this research area. A few general comments:

- OER is to be commended for recognizing the importance of data storage and access and for taking initial steps to archive the wide variety of data collected.
- The current approach of manually annotating video data seems inefficient and prone to error. Tired observers can easily miss key images. There appears to be inadequate quality checking of the manual annotations to verify accuracy. Image recognition has been developed and matured in multiple industries and is now commonly in use. OER should require application of this technology for its own video data.

Comments on Engaging the Public in Ocean Exploration

OER has done a good job of engaging various groups in the public to increase awareness of the importance of ocean exploration. In their presentation, OER identified five groups with whom they try to engage: ocean-interested public, science community, resource managers/decision makers, educators, and internal NOAA. Needs and communication styles for these groups are very different, and it is difficult to satisfy all, particularly with limited resources. I recommend OER reevaluate priorities of these groups and focus on only the highest priority groups. Otherwise, limited resources become too dispersed.

Comments on Business Operations: Enabling Exploration

As mentioned above in "Assessment of Exploration," I believe OER could improve its culture of self-evaluation and continuous improvement. Business operations should take the lead to address this cultural element and to implement an appropriate quality system and processes.

As ocean exploration gains momentum and more visibility, the OER annual budget is expected to increase. In addition, OER may be tasked to lead a national ocean exploration program. As a result, I recommend OER develop a plan to build a more experienced team that is capable of developing long-term strategies and managing larger programs. Leadership and management of the newly awarded cooperative institute (CI) contract demands an experienced program manager who can lean in to ensure an effective contract. OER can, and should, use the expertise of multiple institutions in the CI for advice. However, the leadership and overall strategy must come from NOAA/OER and should not be entrusted to the CI.

Ocean Exploration Going Forward

The ocean exploration program is at a critical decision point. What has made OER successful over the past five years may not be adequate to ensure future success. I make the following recommendations for OER going forward:

1. OER Should Step Up to Identify Goals and a Strategy for a National Program of Ocean Exploration

A national program is more important than ever to our nation, and NOAA OER has the charter to take leadership of such a program. It is essential to increase public awareness of the importance of our oceans. Embarking on such a program is both important and urgent. The correct approach is not obvious and requires careful evaluation.

2. OER Should Develop and Implement an Architecture and Strategy for Next Generation Ocean Exploration The *Okeanos Explorer* reaches end of life in approximately 2024. Thus, in five years, OER will be without its flagship vessel. NOAA leadership and OER must develop a plan today to accommodate this future event. Multiple options exist, but NOAA must quickly downselect and develop a comprehensive plan of action and milestones (POA&M) to prepare for this event. Without a good POA&M, NOAA ocean exploration will be in a similar situation to NASA when the shuttle reached end of life and the U.S. had no alternative to reach the International Space Station.

With technology changing rapidly, OER should recognize they need a different approach for future ocean exploration compared to what they have used in the past. The new approach should have the following characteristics:

- Be adaptable and resilient, not reliant on a single vessel with embedded assets that cannot be changed easily. Options for a leased vessel(s) should be strongly considered.
- Have the ability to scale rapidly since future budgets are unknown and could potentially increase or decrease rapidly.
- Provide a wider bandwidth of data collection from a vessel at sea. It is critical to consider the vessel as a platform from which unmanned underwater vehicles, gliders, drones, and unmanned surface vehicles can all be used to increase data collection.
- Consider use of vessels of opportunity (VOOs) and fly-away systems. Employing VOOs enables flexibility, but such a program carries additional requirements to ensure fly-away systems arrive in ready-for-sea condition and can be easily mobilized. OER would also need the expertise to survey potential VOOs in advance of mobilization to ensure the ship and crew are adequate.
- Unmanned systems (both undersea and surface) will play a significant role in future at-sea operations. OER must develop the expertise to evaluate and employ these systems. Again, multiple options for ownership and leasing exist.

- OER should promote increased interaction among the various oceanographic disciplines. The ocean is a complex system with many undiscovered interactions. Research to understand these interactions demands an integrated system approach rather than having each oceanographic discipline view the ocean through its own narrow lens.

3. OER Should Have the Ability to Explore New Approaches with a Higher Risk Profile

By nature, exploration involves risk and discovering unknowns. As a result, an exploration program should be able to react quickly to new information. It must be flexible, adaptable, and resilient. It cannot be risk averse and burdened with overbearing administrative requirements and a lengthy decision chain.

4. OER Must Develop Now a Strategy to Accommodate a Significant Increase in Data Volume

With the use of new systems and sensors, the volume of data collected is expected to increase by orders of magnitude. OER must plan now for storing these data, making them accessible and available, and converting them to useful information.

5. OER Should Build on Its Start with Partnerships and Increase These Efforts

The ability to develop and maintain partnerships will be a key core competency for future success. Partnerships with other NOAA groups, with government agencies (federal, state, and local), with industry (companies large and small), with philanthropic organizations, and with academia will be critical to success. Building long-term relationships with other organizations demands specific skills. OER must improve these skills and increase efforts to ensure successful partnerships going forward.

6. OER Should Develop a Strategy to Build a Strong Organization and Team

In the past five years, OER has struggled for survival and managed an annual budget of less than $35 million. As a result of OER's success and current administration priorities, there is an opportunity to significantly increase visibility and budget of the ocean exploration program.

I believe current staffing is inadequate to successfully lead a bigger program. The human resources strategy for the future should address the following:

- Addition of engineers to develop a technology roadmap and interface with other organizations developing and using new technology
- Upgrade business operations
- Employ a full-time head of data and information (this is a critical competency and should not be outsourced)
- Quality program to instill a culture of self-evaluation and continuous improvement
- Experienced program manager to manage the CI

Reviewer 3

Introduction

A national ocean exploration program within NOAA was established through the Ocean Exploration Act of 2009. In collaboration with other relevant federal programs, this program was set up to conduct and lead exploration activities, focusing on the deep ocean within the U.S. Exclusive Economic Zone (EEZ) and Extended Continental Shelf. These activities included advancing exploration technologies, data management, and outreach and education, as well as the establishment of a National Ocean Exploration Forum for partnership development and an Ocean Exploration Advisory Board.

Based on this, the Office of Ocean Exploration and Research Strategic Plan for FY 2016-2020, and other relevant documents, I would give NOAA's Office of Ocean Exploration and Research (OER) a **highest performance** rating for quality, relevance, and performance for the work achieved over the previous five years. This was a program on the verge of extinction but, through its current leadership and staff, it is now a program that is steadily gaining prominence and is poised to lead the U.S.'s ocean exploration work for the next decade. To date, the focus has been on survival and excellent execution to strengthen the program and get it onto a stable footing. Now it is established, the development of a strategy for growth across all program areas is needed. This is particularly important in the light of the recent White House memorandum to accelerate ocean exploration and mapping. OER's new strategy will also be critical not only for the program within NOAA, but to ensure that the country retains a strong position within the framework of the upcoming U.N. Decade of Ocean Sciences and with the global efforts on seafloor mapping (Seabed 2030). Specific activity reviews are below.

Ocean Exploration: Mapping and Characterization

Previous Five Years: 2014-2019

OER has done an excellent job over the past few years in ocean exploration. It is responsible for mapping areas deeper than 200m, either solely or through partnerships (for example, currently 81% of the U.S. EEZ along the East Coast is mapped at 100m or better). In addition to mapping, the *Okeanos Explorer* missions have regularly made new underwater discoveries, both on the seafloor and within the water column, which has stimulated further research and exploration activities. The partnerships they have formed have enhanced the speed of mapping and new discoveries, and the importance of seafloor mapping and exploration have been amplified. The gradual increase in funding over the past few years has allowed this to happen, and NOAA should ensure that funding is sufficient for this growth and impact to continue.

Next Five Years: 2020-2025

The biggest item to address in the next five years is the retirement of the *Okeanos Explorer* in 2023-2024. The sunset of this major asset creates an opportunity for change, but this is something that goes beyond just the OER program and should be a priority for NOAA and other federal agencies, as the ocean exploration act of 2009 called for establishing a national ocean exploration program in consultation with other agencies. Various modes of operation beyond a straightforward vessel replacement are all being considered and are all viable options. These include renting a dedicated vessel, renting multiple vessels of opportunity (which may include both federal and nonfederal vessels), transitioning toward multiple smaller and autonomous platforms, and using the new cooperative institute (CI). There are two reasons for having a dedicated vessel for ocean exploration: as a national point of pride and to have greater oversight and control in campaigns. However, it is possible to have a future where a U.S. ocean exploration program is platform agnostic, and OER is, commendably, already planning to test operations from multiple platforms prior to the retirement of the *Okeanos Explorer*.

Another important component that will have to be considered for a strategic plan for the next 5-10 years is, nationally, the goal of mapping the entire U.S. EEZ and Extended Continental Shelf (including Pacific Islands) at 100m or higher resolution, and, internationally, the Seabed 2030 goals. A detailed year-by-year plan, developed by OER, including both the assets (or combination of assets) and areas to be mapped to achieve the 2030 goals would be useful. A further recommendation for NOAA would be to develop, with other federal agencies, a similar plan for the U.S. EEZ in waters shallower than 200m. Currently, it is not clear who is responsible for mapping those areas by 2030. This second plan may include the need for a central coordinating entity, and it would be natural for OER to assume that role.

Ocean exploration includes the water column, therefore more water column activities should be included in the campaigns. However, until the U.S. EEZ and Extended Continental Shelf seafloor has been fully mapped at 100m or higher resolution, exploration should not be driven by water column questions. To maximize resources and achieve the national and international mapping goals by 2030, water column exploration should be built into all seafloor mapping campaigns.

Technology: Development, Application, and Program Use

Previous Five Years: 2014-2019

The capabilities of the *Okeanos Explorer* as it currently exists have been used to full capacity. This is a vessel with limited berthing space and science/wet lab space. But, its excellent remotely operated vehicle can also collect hydrographic measurements, and the improvements in telepresence capabilities and a focus on engaging with the science community has allowed for excellent remote participation for research and exploration. This is in addition to spectacularly engaging the general public through telepresence.

OER has also been proactive in supporting emerging technologies. With limited resources, the program has done the correct thing of not funding technology development directly, but instead has provided critical test bed opportunities and grants to stimulate and explore the use of such technologies for exploration. Further, the National Ocean Exploration Forums, in addition to building partnerships, have had thematic foci on areas of relevance, including new and novel data visualization and representation techniques.

Next Five Years: 2020-2025

The landscape for maritime (and adjacent) technologies is changing at an ever-increasing rate. OER's policy and strategy for the next five years needs to be flexible enough to take advantage of new technologies as they emerge.

A very important role that OER plays is by utilizing the *Okeanos Explorer* missions for testing technology. OER should continue to be a test bed for new unmanned and autonomous platforms and sensors for exploration that, once proven, can be incorporated into routine application.

OER already recognizes that by 2025 they must be heavily invested in autonomous technologies, and they already have a comprehensive list of technology capability gaps. Continuing to strengthen partnerships with the technology industry (multisector) will be beneficial in order to identify new and upcoming technologies and trends, such as changes in communication coverage and bandwidth brought about by satellites. Technology is getting cheaper, therefore a plan over the next few years should include looking at how funding will transition from hardware to focusing on data and engagement. As part of this, a recommendation to OER is a bolder approach in the uptake of technology that includes increasing the speed at which new exploration technologies get into the pipeline. OER (and NOAA) will also need to consider what to do with old technologies that have been replaced by more efficient, cheaper, faster, and smaller technologies.

In addition to sensors and platforms, another component of the technology strategy must include data management and visualization. Virtual and augmented reality will become more ubiquitous in the next 5-10 years and will enhance engagement and education activities. Machine learning can be used in data management and will free resources to focus on advancing research. Incorporating these exponentially changing technologies are necessary in a strategic plan.

Engagement: Reaching the Public

Previous Five Years: 2014-2019

OER has capitalized on the funding resources available to effectively engage with the public. Through improved telepresence capabilities and a live feed, their audience has grown, and there have been some very notable successes (for example, when new and unusual marine life are discovered). Leveraging strong partnerships (in particular with the Ocean Exploration Trust and Schmidt Ocean Institute) has also strengthened outreach as people become more aware of ocean exploration in general.

Next Five Years: 2020-2025

It should be noted that exploration is one of the few areas within NOAA where the outreach can be consistently positive and inspirational. Tapping into this sentiment will continue to raise the profile of OER, but also of NOAA in its entirety. OER has the capability to provide an exciting facet for NOAA's overall public engagement. It will be important to allocate sufficient resources (financial and personnel) to support public engagement activities as new discoveries are made, which includes new visualization techniques and developing a capability that allows users to build their own experiences through new data platforms (which may include engaging the public through crowdsourcing for interesting app development using exploration data).

Although not "public," a key component of engagement with the ocean exploration community are the National Ocean Exploration Forums. Following on from the thematic flavor of previous forums, each forum should showcase new and emerging exploration technologies. Future forums could be held in partnership with various industries of relevance to ocean exploration, such as biopharmaceutical/biotechnology, energy, management, and marine archeology/tourism.

OER is one of the few entities that provides a telepresence link between exploration and the scientific community. The Ocean Exploration Trust, part of the new CI, is better known for links with the education community. As plans to replace the *Okeanos Explorer* are developed, ensuring that this research-exploration capacity is not lost going forward will be important.

Data and Information: Availability and Access

Previous Five Years: 2014-2019

Recognizing that OER did not have the in-house capabilities or resources to fully enact a data managementprogram, NOAA's National Centers for Environmental Information (NCEI) was engaged to manage the data from the vessels, including quality assurance and annotation, archiving, distribution, and accessibility. These data management capabilities are being built upon within NCEI, including a concerted effort to extract historical data (including video footage) and different types of data.

Next Five Years: 2020-2025

The proliferation of unmanned and autonomous technology, multiple platforms, and new and improved sensors will result in more complex and diverse data and a radically increased volume of data. Marine data gaps have been identified through various reports, but a concerted effort will be needed to develop the tools and capabilities rapidly to maintain pace with new data streams and provide a central repository (with backup) that can be easily accessible by

end users. A recommendation is to strengthen partnership with entities outside government (e.g., Google, YouTube etc.) who handle large and diverse data streams and disseminate information to the public.

One roadblock is the pace of annotation of data. There are potential intersections with public engagement here through crowdsourcing of annotations. One suggestion is a small competition to speed up machine learning tools or to develop a game or app that will allow members of the public to participate. However, as machine learning techniques improve, annotating underwater imagery should no longer be a problem.

Regarding data availability and access, all grants and contracts should be reviewed to ensure that data collected through funding from NOAA has correct ownership and licensing so that it can be made available to the public in a relatively short time. This is especially important for OER as it transitions to other modes of operation for exploration activities.

General Recommendation

A final general recommendation to NOAA is that OER is given sufficient resources to grow and strengthen to its full potential, which includes funding for personnel, including a CI program manager who sits within the OER program office. Either directly or through the new CI, additional staff are needed in science, technology, and engagement.

Reviewer 4

Over the last five years, the NOAA Office of Ocean Exploration and Research (OER) has made great strides in its important mission to explore the world's oceans. Under the leadership of a new director, OER has greatly expanded its capabilities, its ambitions, and its budgets. It has done so by maximizing the utility of its assets while working largely within an inherited vision of OER's mission and approach.

Having achieved so much, it is time for OER to reconsider these constraints and reimagine its mission. What is the role of traditional ship-based seafloor exploration in OER's future? What is the role of autonomy, of dense and persistent sensing, of new technology? How should OER's mission of human exploration and storytelling trade against its mission to provide reliable and dense data to a data-hungry public and national economy? Does it make sense to strive to be a producer, but not a consumer, of its own data? What is the role of OER in the national ocean exploration effort, and how should it provide leadership to the community? What, fundamentally, is OER dedicated to exploring?

Performance on Strategic Goals, 2014-2019

The last five years have seen OER transform from an office very much at risk to a thriving program with expanding budgets and growing ambition. The entire leadership team deserves special praise for OER's impressive success in regard to its key strategic goals, including:

Exploration

OER has done an impressive job of making the most of its largest single asset, the *Okeanos Explorer*, which has sailed on a series of campaigns around the world and made significant progress in exploring the seafloor of the U.S. Exclusive Economic Zone. This has included collaboration with scientists and explorers aboard the *Okeanos* as well as remotely via telepresence. Within the scope of traditional ship-based seafloor exploration, this effort has been very successful and is well-regarded throughout the broader community.

Technological Innovation

The introduction of technology demonstration cruises provided a valuable opportunity to experiment with incorporating novel technology into the *Okeanos* operations, a successful effort that deserves to be expanded however possible, perhaps with the addition of small grants to reduce the barriers to participation by precisely the kind of creators who might most benefit from the opportunity.

Data Products and Access

OER has done a good job of collecting the sprawling multitude of data assets produced on *Okeanos* cruises (bathymetry, video, sensor data, annotations, etc.) and making them publicly accessible. Much of the back end has been outsourced to NOAA's National Centers for Environmental Information, which has freed the OER team to focus on other priorities.

Public Engagement

OER has done a good job of getting images from the *Okeanos* into the public arena through social media. Telepresence has meanwhile transformed the way the public engages with ocean exploration in general and the *Okeanos* in particular. Both efforts have proven high "bang for the buck," and probably deserve considerably more resources.

Partnerships with the National Exploration Community

The annual National Ocean Exploration Forums have had a huge impact, both by forging ties between OER and various academic and business partners and by catalyzing collaborations directly between the various partners themselves.

Recommendations for the Future

Many important issues have been raised in other reviewer's comments, so I will focus on just a few that I think deserve particular emphasis:

OER Must Make a Plan for Exploration After the *Okeanos*

Much of the success of the past years at OER has boiled down to maximizing the utilization of OER's core asset, the *Okeanos Explorer*. In the words of Director Alan Leonardi, "we have optimized the priorities we can hit given our assets."

By 2024, if not sooner, the *Okeanos* will be gone. OER must develop a plan for what comes next. Whatever that plan is, however, should be organized around OER's mission and goals, not around its assets.

To that end, it is crucial for OER to formulate a clear set of priorities — to determine precisely what it is that OER is committed to exploring. For example, if collecting bathymetric data from the seafloor is a priority, an "*Okeanos* II" is likely much less cost-effective than simply purchasing data from a fleet of saildrones or building a set of towed barges, a la Larry Mayer, equipped with massive multibeam arrays. If exploring the dynamic features of the midocean — mesoscale eddies, for example, or the deep scattering layers of the twilight zone — is a priority, then investing in a large fleet of autonomous underwater vehicles and new generations of distributed sensors and floats will give a much higher bang for the buck. If the human story of people on a ship at sea exploring the deep is, after all, a top priority, a ship is likely necessary — but does OER/NOAA need to own and operate it, or is it better to containerize the vehicles and sensor arsenal and purchase access on ships of opportunity? (Or might that human story be better served by engaging a large-scale citizen-science effort focused on mass-deployable technology?) If the identity of a NOAA ship of exploration is itself a key priority, for soft-power reasons or for more human motivations, perhaps a replacement is the best course of action after all — but can the new ship's operations be outsourced?

I personally have strong opinions about what the right priorities should be[1] — but whatever NOAA and OER end up deciding to prioritize, OER must design its post-*Okeanos* asset suite to suit its chosen priorities, not the other way around. And here, OER must be willing to explore and experiment with — and support and foster — new technologies that are specifically tailored to the kinds of exploration OER wants to achieve. This has been a low priority for OER in the past. As we enter a post-*Okeanos* era, this probably has to change.

With that in mind, a comment for NOAA leadership directly. It is abundantly clear to everyone in the field that Director Leonardi understands these tradeoffs very well, and that he has given deep and considered thought to the issues involved, technical and practical. It is also clear that he has been very cautious over the past few years as he led OER from the proverbial chopping block to a thriving, successful, and well-funded program with great potential. I hope that

[1] The Atlantic is not the Serengeti: its river valleys and fertile plains move and change as eddies break off global currents. We need to explore the ocean floor, yes, but the ocean is a dynamic volume that needs to be explored in space and time. We have spent millennia exploring the surface, a century exploring the bottom; it is time to focus on the vast invisible bulk of the ocean, a space of the utmost importance for scientific, economic, and conservation reasons. We need to know what is there. There is much, very much, to explore.

NOAA's leadership will encourage Director Leonardi to capitalize on the moment to aim for the fences with a bold and inspiring vision — and that NOAA's leadership will support him as he makes the major changes that will be necessary as OER transitions to a post-*Okeanos* future realizing that bold vision.

An aside: In the context of all of the above, I would encourage OER to make a conscious effort to shift their risk profile further toward risk. The past five years have been quite risk averse, and understandably so. But OER is now sitting on a reservoir of goodwill, confidence, funding, and opportunities. This is the time to start trying things a little further out over the horizon, whether on the technology demonstration cruises, on stand-alone technology development projects, or with new business models ("data as a service," persistent monitoring, and time series in dynamic environments, etc.).

Data: OER Should be a Consumer of Its Own Data and Should Support Use by Others

OER styles itself as "a use-agnostic purveyor of high-quality data." At the review, we were repeatedly told that OER does not — should not — use its own data. I think these attitudes should be reconsidered, for the following reasons:

- If no one does any scientific analysis on a data stream in real time, it is painfully easy to end up with bad data in your repository — for example, data that are within limits but make no sense, data where the calibration is systematically off, data where the time zones are off, etc. Notably, this is not theoretical, each of these examples was taken from a real case in the OER dataset that my colleagues have run across.
- There are cases where OER cares very much about using its own data — for example, for creating processed maps or for creating media assets for outreach and education, etc. In those cases, OER's interest in the derived data products should be germane to decisions about which data to collect, when, and how.
- Using the data makes it clear that "free" data are not free — processing the raw data into a meaningful scientific result or product takes some combination of time, effort, and computation — all of which are expensive. That is a barrier to the use of OER's lovingly and effortfully constructed datasets.
- In practice, OER data appears to be far less utilized than other comparable datasets. For example, OER reports that there have been a total of 867 OER-supported articles published using OER data. By comparison, there have been roughly 4,000 papers citing the Argo float database DOI. Lowering the barriers to using the OER data should be an OER priority.

Recommendation: Have OER fund, for each cruise, a small team of graduate students (some/most of who might join by telepresence) to create baseline site descriptions/campaign descriptions in real time based on the data coming out of the various sensors and instruments. These descriptions could later form chapters of their theses or sources for publications (including a citation to the OER dataset DOI). Starting with a standardized template and working with structured data should simplify standardization. More generally, offering small grants to defray the costs of using OER data might help kick-start utilization of the OER datasets.

Recommendation: OER should support the development of artificial intelligence and machine learning tools for automatic classification and exploration of the video, still, and acoustic datasets that are loaded into the database.

Recommendation: Produce a master remotely operated vehicle sensor and position reference file to increase data accuracy and usability with only a moderate amount of development effort.

Recommendation: OER needs to hammer out a precise and explicit agreement ensuring that the new cooperative institute commits to releasing all of its data openly, and that spells out in detail what "open" precisely means.

New Cooperative Institute

Conflict of Interest

The new cooperative institute (CI) is a fantastic project that gives both OER and the Ocean Exploration Trust (OET) a whole raft of new opportunities and assets. With that said, the CI includes partners beyond OET who have interests, assets, and responsibilities that are independent of OET. It is thus slightly worrying that the board of OET and the board of the CI are so strongly overlapping. How will the board handle conflicts of interest? When there are competing interests between the various CI members, how will OET board members on the CI board avoid conflicts of interest? I do not have any great ideas here (recusal is a blunt instrument), but this point of governance troubles me and deserves, I believe, more consideration than it seems to have received thus far.

OER Must Plan for a Potential Change of Leadership at OET

OER has long been deeply intertwined with OET, and with the leadership of OET — the new CI only makes the ties more tight and complex. As such, OER needs to have a clear strategy for how to manage that relationship, including shared goals, priorities, responsibilities, and liabilities for if and when there is a transition in leadership at OET. Failure to make such plans is a classic failure mode of otherwise strong and vibrant nonprofits. In discussions at the review, I got the sense that this is a topic that could benefit from more direct discussion, so want to bring it up.

Reviewer 5

The five years 2014-2019 were a period of consolidation for NOAA's ocean exploration program. Its new director gave strong leadership, and the renewed staff provided enthusiasm to expand activities. Together they gained critical funding and credibility for what had been an endangered program. Performance in all areas exceeded expectations. A program that had risked being left for dead gained new life.

Now this program is approaching another crossroads. It can proceed with established goals and methods to perform a modest service to the scientific community and the public. Or, NOAA leadership can go boldly, invest in new technologies, build a more adaptable bureaucratic structure, open up channels of collaboration with industry and academia, and provide leadership for ocean exploration at a national level. Which road will the Office of Ocean Exploration and Research (OER) and NOAA take?

Assessment

During 2014-2019, the program benefitted from good leadership, replenished staffing, doubled funding, and growing support from NOAA leadership. Overall performance exceeded expectations, and in some areas it reached the highest levels.

Exploration

OER adopted a "campaign strategy," dictated in part by its reliance on the *Okeanos Explorer* as its main operating platform. A major success was the integration of telepresence, a pioneering technology, into its explorations, making possible online collaboration with the scientific community on shore and live broadcasts to an expanding public audience. The office made consistent efforts to coordinate with interested communities. Telepresence is now a valued tool for science and public outreach.

Technology

The centrality of the *Okeanos Explorer* to overall operations meant that development of technology and methodology was primarily related to the ship's operations. Performance exceeded expectations. However, this focus may have resulted in foregone opportunities to work with researchers and industry to develop new sensors and operating vehicles.

Cooperative Institute

The 10-year relationship with the Cooperative Institute for Ocean Exploration, Research, and Technology (CIORT) provided good value and significant exploration results. Going forward, the contract for any such relationship should require both compliance with NOAA's standards regarding free public access to data acquired in publicly funded operations and branding recognition for NOAA's support.

Data and Information

NOAA collects, archives, and manages a vast trove of data. OER contracted out the data management function, an option that met program needs and enabled ongoing improvements. This program must participate fully in NOAA efforts to consolidate its collection and management of data. Today, researchers and specialists have adequate access to these data, but going forward this data asset would have more value if it were more accessible and interesting to the public.

Engaging the Public

Funding for these activities is modest. Education efforts, directed at schools, have evolved and were reviewed previously. The annual National Ocean Exploration Forums have been well-prepared with industry and academic co-hosts, and widely attended, generating public interest in ocean exploration. Telepresence during campaigns has served a growing public audience. But during the years of this review, the world of media has shifted toward social media, presenting challenges for a small staff. Performance was outstanding but limited by the resource level.

Business Operations

To use an analogy, OER is out of the recovery room but still convalescing. Due to systemwide practices, it takes 350 days to bring on board a new federal hire. Management has performed at a high level given these constraints, but business operations need further improvement.

Going Forward

Today's circumstances provide the possibility of a different future for OER, a chance to provide national leadership for ocean exploration. These circumstances include:

- A growing level of appropriations;
- Increased public awareness of the importance of oceans for our economy and environment;
- Leaps forward in the technologies used to collect, store, and process vast amounts of data; and
- Evolutions in how the public benefits from digital information and in enterprises moving from hierarchies to networks.

Here are seven steps to put this program on the road to national leadership for ocean exploration.

1. Reimagine the Future

The public has caught on to the fact that the oceans are of growing importance to our economy and future. OER (and NOAA) needs to reimagine its future as the national leader in ocean exploration, within a NOAA that acts as an advocate for our oceans.

2. Promote Advances in Technology

OER should build closer ties to industry to invest in technological advances, such as sensors and autonomous underwater vehicles (AUVs), that can revolutionize how data are collected, reducing dependence on the *Okeanos Explorer*.

3. Set a Path Forward for Ship Access

The *Okeanos Explorer* is due to retire in 2023. NOAA's Office of Marine and Aviation Operations (OMAO) reports that it requires $150 million and 10 years to procure a new ship. Planning for the future requires a commitment now from NOAA either to provide 200 ship days each year from the OMAO fleet or authorization to lease a ship or another solution. The most cost-effective solution is likely to be a combination of a leased vessel and AUVs.

4. Improve Data Management

Five years is a generation in data management. Data are OER's main products. It must keep up in how it acquires, manages, and makes data available.

5. Manage Cooperative Institute Relations Actively

A large part of OER's current and future resources are pledged to its cooperative institute relationship. OER should insist on prominent branding for NOAA support and active engagement in planning and review.

6. Expand Public Outreach and Access

If NOAA is to advocate effectively for our oceans, OER must develop a broader strategy for public engagement. Perhaps there should be a periodic report on the state of our oceans and the blue economy, expanded ties to the nation's many aquaria, and better connections via mobile devices. No doubt there are other good ideas for public engagement.

7. Build a Team for the Tasks Ahead

If OER is set on the path to provide national leadership for ocean exploration, it needs now a five-year plan to build its team. An early emphasis on strategic planning and relationship management might be the best places to start.

Reviewer 6

The NOAA Office of Ocean Exploration and Research (OER) made significant strides from 2014-2019 by investing in leadership, partners, staff, and technology. OER's procurement and use of funding, coupled with an increased focus on driving efficiency and accuracy, helped to build trust with partners, confidence within the government, and appreciation from the public.

Past Insights (2014-2019)

Any private sector startup can tell you how difficult it is to survive the first five years of its existence. The challenges seem insurmountable at best, and impossible at worst. Survival is predicated on courage, taking bold risks, and a clear vision. And that's for a startup that is funded, has full private autonomy, and is working with a clean slate from the beginning. As an established government entity, and without the ability to move at speed like the private sector, OER had all of the challenges a private startup would have in spades, yet the outcomes they produced in this five-year period were astounding. They continually invested in technology and collaborations and leveraged any and all assets they could to their maximum potential. The *Okeanos Explorer* was a globally recognized emblem of exploration, their partnership with the Cooperative Institute for Ocean Exploration, Technology, and Research provided much needed outside stimulus and research, and the standardization of data that OER provided to the educational community was invaluable.

Future Imagining (2020 and Beyond)

OER is at a critical inflection point where they can choose to either fully capitalize on the improvements, good will, and equity that they have both with partners and the public, or stay the course that they have now settled into. The same satisfaction the OER team can take in their strides over the past five years can easily be their greatest risk, essentially settling into a comfortable status quo while enjoying their success and "new" performance standard.

Below are three areas where OER might continue to iterate and innovate.

1. Excite

Young talent and startups should be the new life blood of OER. A dedicated focus to recruitment and partnerships will not only infuse fresh perspectives and solutions into the office, but also ensure the future of the office is viewed through a relevant and current lens for both storytelling and the use of technology.

A few considerations:

- Partner to create an "Ocean Exploration Accelerator" modeled after other technology accelerators. Startups receive from OER data, resources, and a small amount of funding, with the expressed goal of advancing overall understanding of oceans.
- Raise awareness with unexpected commercial collaborations, such as a shoe collaboration with Adidas around their sneakers made from plastic pulled from our oceans.
- Reimagine the oceans. Go bigger than "exploration" alone. It's just as much about what our oceans support as it is to what they hold.

- Create a "Think Tank" within OER which is comprised of three or four of the most promising employees, shareholders, and thinkers. Use this team as an internal "R&D-like" model, with a continual focus on the future of OER and our oceans. Publish their "experiments" frequently.
- Launch a campaign to "make oceans matter" — identify a new enemy other than environmental destruction and bring attention in unpredictable ways. For instance, the "Got Milk" campaign wasn't against an enemy of calcium deficiency, but rather about the pain of milk deficiency, making it about the absence of milk over the benefits of milk.

2. Expand

OER has done a wonderful job of seeking input from leading experts and partners in the space industry, as well as bringing in outside perspectives in instances. Their partnership with XPRIZE is tremendous, and there is no question as to their authority and understanding about oceans. However, there seems to be some latent energy and untapped potential in going deeper with consumer research. How do we amplify the voice of our choir (after all, they are our biggest fans), while expanding our audience beyond the predictable sectors (education, science, etc.)?

A few considerations:

- Spend three to six months to deep dive on customer segmentation, their mental models, brand equities they relate to, and insights which can be fast forward buttons for all initiatives.
- Conduct an "Insight Activation Workshop" based on the research, with a desired outcome of results at the "how might we" and "for instance" levels.

3. Educate

OER's greatest asset to the broader community is their data. Data are more valuable than gold in today's age. But like gold, data needs to be mined.

A few considerations:

- Create and run three to five day "Ocean Data Boot Camps," where participants receive a crash course in how to utilize OER data within their own applications.
- Provide scholarships to aspiring high school students who are trying to decide on their careers and college choices. The boot camp could be a bridge to discovering their next educational paths.
- Work with large universities to establish a set curriculum for potential "yet-to-be-determined" careers within ocean discovery.
- Work with the corporate social responsibility programs of large employers to offer employees the chance to contribute to ocean science.

Final Thoughts

Are you ready to deal with challenges that you can't identify now?
Tactics
Strategies
Organizational Changes

Will you be producing a product that our citizens and country are demanding at this time?

Push out anything that is not "inherently governmental" and let private industry handle it.

Stimulate partnerships with private industries.

Make oceans cool, not NOAA cool.

Exploration by its nature requires a willingness to take risk.

Make oceans important.

Explore. Educate. Engage.
Discover. Document. Dream.

Your moonshot should be how you explore the ocean, not where. Galvanize all audiences through the difficult mission of finding new ways to explore our oceans. We do these things not because they are easy, but because they are hard.

Deconstruct what NASA did.

Create a Blue Ocean Lab with a team of three outside experts that helps build the strategy and roadmap for the next five years. Hire an internal Chief Experience Officer as in internal "sherpa" of design and strategic thinking.

AirBNB for ships. Utilize other ships for missions, and set the *Okeanos Explorer* aside as a "museum" to aqua- nautical history.

Reviewer 7

Over the past five years, the NOAA Office of Ocean Exploration and Research (OER) has done an outstanding job pursuing its mission. Its successes are evident in its exploratory achievements, scientific impact, and public engagement. One of its greatest achievements is its transformation from a struggling program at risk of termination to a vibrant program with significant opportunity and an impressively increased annual budget. This is all a testament to strong leadership and vision, and the team should be congratulated on their collective efforts. The program now sits on a very solid foundation and has the potential to scale into an even more impactful national ocean exploration program.

Mapping

Successes

OER has done a great job in the past five years of acquiring significant amounts of high-quality seabed mapping data and has ensured that data (both raw and processed) are made publicly available through the national archives at the NOAA National Centers for Environmental Information (NCEI). In addition to successfully employing a campaign model for exploration, the *Okeanos Explorer* has filled significant gaps in mapping coverage within the U.S. Exclusive Economic Zone (EEZ) and in important adjacent areas.

Opportunities

While the total area mapped in the U.S. EEZ is based on the combination of the U.S. Academic Research Fleet and the U.S. exploration fleet (*Okeanos Explorer,* R/V *Falkor,* E/V *Nautilus*), better coordinating information and gap-filling across the combined U.S. fleet would help fill gaps in data coverage. This coordination should be given high priority to ensure that resources and assets are used most effectively and will be important as the nation strives to map all of its EEZ.

Technology

Successes

The effective use of telepresence on the *Okeanos Explorer* has enabled agility during exploration programs and has been an important aspect of engagement both within the science community and with the public. This is critically important technology that will become increasingly important as ocean exploration continues to make use of novel platforms and sensors including unmanned platforms that telemeter data back to shore. OER has positioned itself well to adopt this emerging technology and to take advantage of emerging autonomous platforms. The program that OER offers to enable testing of technology during *Okeanos Explorer* expeditions is also a very positive activity that serves both the community and the program.

Opportunities

With the anticipated end of life of the *Okeanos Explorer* and the newly awarded cooperative institute, OER has an opportunity to take increasing advantage of telepresence, autonomous vehicles, and ships of opportunity. Engaging the scientific community and the public through telepresence technology and by transferring data back to shore will likely become an increasingly common and useful aspect of ocean exploration. Technologically the program is well positioned to take advantage of emerging technology related to at-sea operations and data acquisition. That said, there have been clear benefits in having a dedicated exploration vessel, and continuing to have a dedicated vessel after the retirement of the *Okeanos Explorer* would be advantageous for the program.

Data and Information

Successes

OER has established routine data delivery pipelines to ensure that data acquired are made available through NOAA archives. Efforts have focused on ensuring that data are documented, discoverable, and accessible. OER data management has put a strong emphasis on the use of standards and is currently adopting the use of new interfaces for aggregating and presenting information, which is an important step toward improving discoverability. OER has demonstrated community leadership in developing an archiving and discovery system for underwater video acquired during expeditions.

Opportunities

While OER has established robust data-delivery pipeline, and some data are archived with similar data acquired on other ships (e.g., multibeam data at the NCEI archive), data discovery can be a bit challenging due to the "stovepipes" that have been established for different vessels and different programs. If we really want to capitalize fully on the investment made in data acquisition, and pursue ocean exploration within the data itself, data discovery stovepipes need to be dissolved. Efforts are being made toward this, but there remains significant opportunity for better integration of data across different federally funded ocean programs as well as philanthropic organizations engaged in ocean exploration and science (e.g., Schmidt Ocean Institute). This coordination should be pursued both at the program leadership level and at the boots-on-the-ground level of data managers and interface design and deployment. Scientists do not care where the data are stored and/or managed, they are interested in easily finding data of interest and making use of it.

With respect to video access, OER is a community leader that has developed and deployed a system for a searchable and discoverable archive of video clips leveraging rich metadata curated by the program. This library-like service is hugely important and beneficial for users seeking footage of specific features, species, and/or events. However, this system relies on the assumption that annotations made during the dive (or even post-dive) are accurate and complete. For scientists who may way want to explore a dive in its totality, the five minute clips made available are cumbersome and difficult to access. An alternative solution would facilitate this sort of data exploration and use.

The OER program, and the NOAA archive that supports it, may also want to consider if the video archive/discovery service could be more broadly offered to the community for video acquired on other assets. The NCEI archive serves the entire U.S. ocean science community (OER + U.S. Academic Research Fleet) for data types like multibeam, acoustic Doppler current profiler (ADCP), conductivity, temperature, and pressure (CTD), etc., but not video. Given the value of video observations for ocean exploration writ large, and the lack of a broader data management solution for it across the federally funded research community, this could have tremendous impact.

Activity within NOAA to move its data storage to cloud providers will undoubtedly be an important development with respect to data and information. Hopefully this will be a cost-effective solution that will help ensure long-term preservation while freeing up data management specialists to focus on data and metadata curation. As the details of new cloud-hosted archives emerge, there may be new opportunities for cloud-based analysis and processing, as well as the opportunity/need to revamp/optimize some of the data management and access pipelines.

Outreach and Engagement

Successes

OER has done a great job of raising public awareness about ocean exploration and the activities aboard the *Okeanos Explorer*. Its social media presence and uptake of compelling content by the public has been excellent. Outreach videos that have been produced are well-conceived and include clear messaging and spectacular footage. Collaboration with

the Octonauts is also a very positive development that helps to make ocean exploration more accessible to the public through the eyes of children.

The National Ocean Exploration Forums that have been held over the past several years have focused on critically important topics: ocean exploration beyond ships, exploration within data, and outreach and engagement. They have brought not only the traditional ocean exploration community together, but also other perspectives and disciplines that can enrich the program.

Opportunities

The content and information routinely acquired through this program are so compelling and visually stunning that they provide tremendous potential for even more engagement and support for its activities. The program should continue doing what it is doing, but the team should also think big about how it can further raise the profile of the important work that is being done.

While the videos that have been produced contain a lot of good information, they would be far more impactful if they were edited and produced by video professionals who are experienced with the art of short-focused storytelling and the art of video editing and production. Likewise, the annual Oceanography volumes are beautiful and speak loudly to the science and exploration community, but it would be useful to think more broadly about engagement of the broader public, policy makers, etc. with clear impactful information that is easily understood and describes the benefits, successes, and achievements of this program.

Cooperative Institute

The new cooperative institute (CI) that has been awarded to the University of Rhode Island, University of New Hampshire, Woods Hole Oceanographic Institute, and the University of Southern Mississippi is a positive development that is consistent with the technological trajectory of the program toward increased use of autonomy and telepresence as well as an ongoing emphasis on mapping. Notably, during the presentation of governance of this new CI, there was a lack of data management oversight. This should be addressed as the details of the CI are worked out.

Reviewer 8

Executive Summary

The Office of Ocean Exploration and Research (OER) stewards a unique and critical national endeavor in its charge to explore the depths of the ocean. Exploration is a self-evident goal that enhances the nation's economy and security by fostering innovative technologies, inspiring the public to take on great challenges, and contextualizing the importance of our oceans to life as we know it. OER's success in this mission depends on a sustained national commitment, despite the risks inherent and obstacles encountered.

In addition to OER's exploration mission, the office performs targeted research in a diverse array of domains, including physical, chemical, and biological oceanography; ocean engineering; and marine archaeology. These research activities are intertwined with OER's exploration mission: research goals can help drive focus and decisions about exploration, and exploration activities are designed to be agile enough to allow for unexpected research opportunities to arise.

OER performed at the **highest performance** overall across the defined assessment areas: quality, performance, and efficiency. This rating was determined after presentations from OER leadership and staff, consultations with internal NOAA and outside stakeholders, and supporting documents and research findings.

However, OER is at a crossroads. Despite remarkable performance over the past several years, the program will be unsuccessful if it does not plan for radical changes in how it achieves its mission. This rationale is threefold:

- The operational and technological environment enabling ocean exploration has changed rapidly and is likely to accelerate in the coming years;
- The mission itself may evolve as our oceans reflect rapid changes in our climate system; and
- The data and samples collected will become more voluminous and diverse, and structural investments will be required to recover value from these data.

The timing of this review is also prescient. OER has benefited substantially from the highly subsidized operations of NOAA's flagship exploration vessel, the *Okeanos Explorer*. As the vessel nears its expected retirement in 2024, the organization needs to rapidly ramp-up operational planning for a post-*Okeanos* environment. This challenge presents enormous opportunities for OER to reimagine how it explores not just our oceans, but also the wealth of data we collect about it.

Retrospective

OER has managed to create a thriving exploration enterprise in the previous five years, recovering from a nadir at which the program was nearly eliminated. These years have been characterized by optimizing and refining operations of the *Okeanos Explorer*, as well as expanding the utilization of partner assets E/V *Nautilus* and R/V *Falkor*. These activities have resulted in exemplary outcomes, including highly visible research findings. According to bibliographic analyses presented to the independent panel, the OER program has supported science that has resulted in 867 peer-reviewed publications receiving 23,619 citations and an h-index of 72. The program itself has produced 303 peer-reviewed publications with 2,810 citations and an h-index of 25. These metrics, while imperfect at capturing the full extent of OER's research findings, demonstrate the depth and breadth of the program's impact.

In fact, if there is any baseline to judge OER's past performance, one might look to the report of the President's Panel for Ocean Exploration, which helped catalyze initial support for the program: Discovering Earth's Final Frontier: A U.S.

Strategy for Ocean Exploration (2000). Despite accomplishing nearly all of the objectives laid out in the report, OER has never been funded close to the envisioned level of $75 million/year. OER should be commended for its performance with limited financial and institutional support over the years.

Looking Forward: Ocean Exploration

Recommendation 1: Develop a Formal Mechanism for Evaluating Exploration Architectures in the Post-2024 Epoch and Communicate Findings with Stakeholders

With the *Okeanos Explorer* expected to retire within the next five years, OER has a unique opportunity to revitalize and reimagine new operational concepts, research techniques, and exploration missions. However, it is not abundantly clear that OER or NOAA leadership are fully aligned or aware of the available tradespace for future exploration architectures. There are a number of opportunities to leverage increasingly mature autonomous systems, artificial intelligence technologies, and high-speed communications infrastructure to transform how OER explores the depths below. These priorities are explicitly identified in the Office of Science and Technology Policy's Fiscal Year 2021 Administration Research and Development Budget Priorities and warrant consideration by OER in any of its future plans.

Further, informal conversations with stakeholders have asserted that continuing OER's exploration mission "business-as-usual" with a NOAA-owned/operated replacement vessel would require tremendous capital investment while having limited benefit over lower-cost alternative platforms that could be leased or commercially operated. A reasonable inference may be drawn suggesting that OER will be incapable of replicating its present success at current funding levels unless it changes the way it conducts its mission. However, data justifying this claim were not readily available. Whatever path OER ultimately takes, it should be made with the best available information and socialized to the relevant stakeholders, else OER risks having this decision made for them.

Recommendation 2: Develop a System for Evaluating and Justifying Exploration Decisions

Along a similar rationale, OER makes a number of routine but significant decisions for how it deploys its resources, such as where it conducts its research cruises, what instruments to manifest, and what science objectives present the best opportunities. However, there does not seem to be available data for how OER makes these decisions. Not all exploration activities will be as successful as others, but OER needs a structure in order to survive individual failures and continue to justify high-risk, high-reward exploration opportunities.

Since OER's success also rests in its programmatic agility, the program should take great caution to avoid having this recommendation result in additional bureaucratic processes that otherwise slow down or trade off with its core activities. However, as the program matures, it requires the development and communication of a certain logic for how it operates. If OER does not actively have systems in place to collect orthogonal and creative ideas, it will not succeed in pushing the cutting edge. Some examples of "logical" systems might include: recurring and predictable windows for soliciting input on the next season of cruises, having regular processes to consult the community midexpedition to revector resources quickly, and recurring announcements of opportunity for technology development and demonstration.

Looking Forward: Technology

Recommendation 3: Develop an Exploration Architecture That Is Capable of Rapidly Testing, Assimilating, and Scaling Innovative Technologies

Technology demonstrations should remain an essential component of OER's exploration mission, and thankfully, OER has shown an appropriately forward-leaning appetite for exploration technology maturation. However, OER must continually identify how to draw more talent and innovation toward solving ocean exploration problems and should generally play a more active role in ensuring it is a good customer. For many small businesses or research groups,

doing business with the government is a slow and often frustrating process. One way to counteract this endemic issue is to design regular evolutionary and revolutionary technology demonstration cycles as a standard part of OER's exploration portfolio. Having knowledge that future opportunities will be available helps draw in innovators to the problem set. Further, success stories of rapidly scaling from testbed to major client will telegraph to partners that if they invest in creating solutions for OER's challenges, there is a fighting chance OER may be able to act on it. There is competition for attracting talent and resources, and the same minds that may transform ocean exploration will otherwise be drawn to other challenges and industries. OER must acknowledge the role it must play to attract innovators to exploring the seas.

Recommendation 4: Readily Confront Obsolescence

This is a natural corollary to the previous recommendation. To be able to embrace new ways of doing business, OER must first be willing to cast aside the obsolete. As an exploration program, OER must be brutal and vigilant about what aspects of their activities may be outdated, including everything from observational technologies and operational platforms to science targets and outreach metrics. A useful logical test: if the program is unable to document what it might constitute as obsolete, it is probably not effectively embracing innovative ideas. Sunsetting activities is particularly difficult in the federal government, but OER should be given wide latitude to discontinue pursuits, platforms, and processes without pushback to free up resources for more effective or promising ventures.

Looking Forward: Engagement

Recommendation 5: Seek Out Communities Critical to OER Success

OER's commitment to community building is admirable, and the activities of the National Ocean Exploration Forums are a model that should be replicated across other NOAA mission areas. However, OER's success in solving pressing challenges in ocean exploration requires capturing innovators that may not otherwise be drawn to the field. To this end, it is unreasonable to expect those with skillsets in artificial intelligence, data analysis, and sensing to seek out OER. Rather, OER must seek out these communities where they congregate and try to draw them into its mission.

In particular, OER must actively seek partnerships with commercial, academic, and international talent pools and invest in these partnerships with appropriate resources. OER may benefit from unique acquisition authorities, not only to rapidly procure new capabilities, but also to help reduce the burden for nontraditional communities to demonstrate capabilities in ocean exploration.

Looking Forward: Data and Information

Recommendation 6: Accelerate Telepresence Deployment with Low-Cost Pilots

It is clear that telepresence can transform the way science and outreach exploration operations are conducted, democratizing the ocean and enabling the public to participate in the exploration process. OER must invest now in underlying infrastructure to be ready for when all campaigns are designed around telepresence capabilities. To this end, OER should pilot low-cost telepresence solutions enabled by low-cost cloud computing and commercially available satellite internet capabilities. Piloting these activities now will inform key risks and acquisition pathways as global connectivity matures, saving time and money before large-scale procurement decisions are made.

Recommendation 7: Invest in Data Leadership and Harmonization

To lead a national ocean exploration program, OER needs to take an active role in developing common data architectures, repositories, and stewardship requirements across the entire ocean exploration enterprise. As a requirement, data from cooperative institutes and other OER-funded partners must be made publicly available and be quality controlled to be virtually indistinguishable from other NOAA data. Looking forward, data collected from the National Science Foundation and U.S. Navy-owned assets should be designed to be interoperable with data collected

from the *Okeanos* or other OER platforms. As a larger goal, data from all federal ocean exploration activities should generally be available in the same location.

OER should work with the National Science Foundation and other grant-making partners to design and enforce data management plans that ensure data collected by individual federal grantees are made accessible in a timely manner. OER must leverage the capabilities of partners to accomplish its mission, but the data will be siloed until OER invests actively in harmonization and colocation.

OER should also lead efforts within the National Oceanographic Partnership Program to develop a common framework for agencies, industry, and academia to contribute ocean exploration data. If low-cost sensors can be rapidly deployed across a large number of vessels, OER may be able to leverage partnerships with other vessel operators to force multiply exploration efforts.

Recommendation 8: Build In-house Data Science Capacity

Future exploration concepts may not lend themselves to OER's current data workflows. Now is the time to explore what type of data infrastructure will be required to fully exploit all of the utility provided by disaggregated exploration architectures. Current mapping and characterization efforts are rate limited by qualified human monitors, which are also prone to introducing their own errors and biases. As data volumes and sources increase, current processes will require substantial automation to help focus the attention of researchers to the key science-relevant data. To get to this point, OER should develop in-house data science capacity to enable future exploration capabilities.