FINAL REPORT

NOAA Fleet Societal Benefit Study

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The National Oceanic and Atmospheric Administration's (NOAA) Office of Marine and Aviation Operations (OMAO) manages and operates NOAA's fleet of 16 research and survey ships and nine aircraft. Comprised of civilians and officers of the NOAA Commissioned Officer Corps, OMAO also manages the NOAA Diving Program and the NOAA Small Boat Program.

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Foreward: *Interpreting the Value Estimates from the NOAA Fleet Societal Benefit Study*

NOAA managers and scientists routinely make difficult decisions about how to allocate public investments to study, protect and restore the nation's oceans and coasts. One of the most important considerations in these decisions is the value that will be returned to the public. Thus, NOAA is often asked to demonstrate the economic benefits of its investments, preferably in dollar terms. Despite the uncertainty associated with such estimates, they provide evidence that investments are being managed to produce societal benefits and a basis for comparing benefits and costs. For some decisions, such as those involving public health or safety, economic considerations are secondary. However, even in these situations, managers need to make choices that involve tradeoffs – decisions that call for economic analysis.

The NOAA Fleet Societal Benefit Study provides important new evidence about the value of NOAA's ships to the nation and how the cost of using these assets compares to that of contract vessels. Major results from this study include: "value chains" describing how data from the fleet support products and users; estimated annual dollar values of selected products; and mission-specific cost comparisons between NOAA and contract ships. The study, funded by NOAA and completed by Abt Associates in 2017, was conducted to support NOAA's on-going efforts to modernize the current NOAA fleet.

As the senior NOAA staff managing this project, we concluded, after receiving the final report and fielding questions about the value estimates in particular, that some additional context on interpreting the study results would be useful. We therefore added this Forward to provide additional comments on methods, to introduce some similar recent value estimates for NOAA ships, and to reinforce the challenges of estimating economic value for public goods, even when methods, assumptions, and sources are fully described.

Key considerations when interpreting the Societal Benefit Study findings

The following topics are particularly important considerations regarding the methods and sources used in the Societal Benefit Study and the overall interpretation of the value estimate results.

Data denial: The model used by NOAA to set priorities across its observing systems provided important inputs to this analysis, particularly for estimating the degree to which the quality of final products would be affected by the absence of data from NOAA ships. This model is designed to minimize bias towards any one system and provides estimates of the impact of data denial that are based on extensive input from the subject matter experts who also use the data to generate final products. However, these estimates of the impact of data denial have not been confirmed via "denial of data experiments." Denial of data experiments are commonly used for this purpose but were beyond the scope of this study. Further, the role that could be played by the private sector in responding to any future diminished capacity of the NOAA fleet was not assessed. Any such role would result in private sector costs and benefits whose analysis was also beyond the scope and resources of this study.

Use of existing data: All estimates of value for the Societal Benefit Study were based on existing data and past research. And although the products selected for the Study was based, in part, on the availability of existing analyses, these materials were often dated or incomplete. This affected both the absolute value of dollar estimates and the comparability of dollar estimates between the products analyzed. For example, the value of nautical charting products is based on a 2007 study conducted before the now widespread use of electronic nautical charts. This study estimated the value of a marginal improvement in nautical charts, not their total value, and excluded key beneficiaries such as commercial fishermen and military users. The probable result is that the value of nautical charting products is understated in the Societal Benefit report.

Accrual of value to users versus the economy: Estimating the value of environmental goods and service is challenging not only because the price people would be willing to pay for clean water or healthy marine mammals is not revealed in economic markets, but also because much of the presumed value accrues directly to individual users or consumers whose interests and behaviors are difficult to discern. While economists have methods to estimates of these values such as through the use of surveys to estimate society's willingness to pay for the benefits that they receive, these methods are expensive and time consuming to employ. Therefore, even when existing studies were not sufficient to precisely estimate values for the five products selected, additional investigations or analyses were beyond the scope of our study.

Product quality versus value: The study team assumed a direct correspondence between product quality and value. For example, if the loss of data from the NOAA fleet was expected to reduce the quality of a product by 5 percent, a corresponding 5 percent decline in value to users was assumed. In some use cases, however, the impact of a 5 percent degradation in product quality might be negligible whereas, in other cases, the product might be rendered useless. The simplifying assumption used in this study is reasonable but has not been verified by independent studies.

Comparability of product value estimates: The summary value estimates presented in the Societal Benefit report are all reported in 2016 dollars. However, because different methods were used to derive these estimates, combining the results may present challenges. For example, a value estimate derived from market values (sea level rise viewer) is perhaps not comparable to a value estimate derived via contingent valuation (corals). Readers of the final report are advised to consider these factors before using or referencing the study results.

Comparable recent value estimates

In 2012, NOAA conducted an internal, preliminary assessment of the economic benefits of the NOAA fleet. Although the 2012 study remains unpublished, there are some interesting and useful intersections with the Societal Benefit Study that highlight the challenges of estimating economic value. This is most usefully revealed by contrasting the methods and results for two products or themes where the studies overlapped – Nautical Charting Products and National Marine Sanctuaries Condition Reports.

Nautical Chart Products . NOAA's 2012 study estimated that the NOAA fleet accounts for $12 million annually to the overall value of nautical charts, compared to a lower-bound estimate of $17 million annually in the Societal Benefit Study. Although the results are similar, the methods used to generate these two estimates vary significantly. The 2012 study is based on estimates of the increased loadings of commercial vessels, reduced number of groundings of commercial and recreational vessels, and reduced loss of life associated with the use of nautical charts. The Societal Benefit Study estimate is based on surveys that assessed the willingness of nautical chart users to pay for improved nautical charting. While the Societal Benefit Study estimate is larger, it also likely understates the full value of nautical charts because, as stated above, (a) it assesses the only the marginal value of improved nautical charts and not their full value, and (b) some users were not included in the results, notably commercial fishermen and military users.

National Marine Sanctuaries Conditions Reports. NOAA's 2012 study estimates that the NOAA fleet contributes $10 million annually to the value of products and services developed by the Office of National Marine Sanctuaries that manages the sanctuary sites (though not specifically the Conditions Reports), compared to a lower-bound estimate of $605 million annually in the Societal Benefit Study for the Conditions Reports. There are several probable reasons why these findings are so different. First, the 2012 study reflects an older estimate of the total value of the economic impact of the National Marine Sanctuaries sites ($4 billion annually) while the Societal Benefit Study reflects the more recent and more commonly cited figure of $8 billion annually. However, the most important factors may be that (a) differences in estimates of the degree to which economic values from the National Marine Sanctuaries sites are likely to be eroded without the products and services provided by ONMS, and (b) the degree to which these products and services depend on the NOAA fleet. The value estimates could certainly be improved by a closer investigation of these two factors.

Interestingly, NOAA's 2012 study also recommended that future studies of the economic value of the NOAA Fleet should employ a value or logic chain relationship between products and users - the method used to underpin the Societal Benefit Study - to ensure more accurate value estimates.

In Summary

The table below contrasts the analysis methods and underlying basis of the value estimates for each of the products evaluated in the Societal Benefit Study. We suggest these contrasts are important to note for two reasons in particular. First, adding the dollar value estimates of different products together, even though they are all rendered in 2016 dollars, presents challenges that readers should be aware of. And second, further, more refined analysis of these products would likely lead to different dollar values – some lower and some higher – than the current study results.

Methods and Underlying Basis for Benefit Estimates

Coral Status and Trend Report	contingent valuation (willingness to pay)	reflects values derived from NOAA-funded meta-analysis of recent work
Sea Level Riser Viewer	market-based	based on an EPA study of net benefits from implementation of climate change adaptation measures
Nautical Chart Products	contingent valuation (willingness to pay)	because key sectors/users (e.g. military, commercial fishermen) were not included in source studies, these products are almost certainly undervalued
El Nino Southern Oscillation Outlook	market-based	reflects value of ENSO data for agriculture sector only
National Marine Sanctuaries Condition Reports	economic impact analysis	economic impacts of site use, including commerical and recreational fishing and research

The value chains developed for the Societal Benefit Study will help support NOAA's capacity to write "value stories" that explain how data from the NOAA fleet contribute to the quality of its products, and how specific users benefit in specific ways. These value stories provide a useful context to help decision-makers assess the reasonableness of dollar estimates by explaining the manner, extent, mechanisms, and degrees of impact. They also provide a basis for conducting sensitivity analysis to identify the assumptions under which investments in the NOAA fleet break even which, in turn, allow subject matter experts to make subjective judgements about the reasonableness of those assumptions. Value chains also provides a basis for soliciting input that can improve future estimates. Finally, understanding how users benefit from NOAA products can provide insights into how to modify these products to make them even more beneficial.

In summary, the primary objective for the Societal Benefit Study was to estimate the societal benefits of NOAA fleet. The results strongly indicate that the benefits associated with operation of the NOAA fleet, even when only five of more than 600 fleet-dependent NOAA products are assessed, significantly exceed the cost of operations. Stated another way, the savings realized by not operating NOAA ships would appear to be more than offset by a loss of societal benefits.

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Executive Summary

The purpose of this study is to identify and monetize the benefits associated with a subset of key NOAA products and services that are dependent on the NOAA Fleet, and assess the cost-effectiveness of using charter vessels as a substitute for NOAA's ships for some data collection efforts. The project team developed estimates of the societal benefits for five of the 638 products and services supported by the NOAA Fleet, finding that the value added by the NOAA Fleet to these five products alone significantly exceeds annual operating costs.

Value of Products and Services Dependent on the NOAA Fleet

The NOAA Fleet supports over 600 products and services across the agency's 26 mission service areas. To demonstrate the societal benefits associated with fleet data collection activities, the project team developed qualitative "value chains" for 12 products (Table ES-1) that are highly dependent on the fleet and/or have a relatively large societal benefit, meaning they affect decisions made in important sectors of the economy and/or result in significant savings or increased well-being for U.S. households.

Table ES-1. Product Value Chains developed for this report

(see Table 3 in main report for descriptions of the value chains)

1. **CORAL REEFS:** Coral Reef Status and Trends Report
2. **SEA LEVEL RISE:** Sea Level Rise Viewer
3. **BATHYMETRY/ HYDROGRAPHIC SURVEYS:** Nautical Chart Products
4. **SEASONAL FORECASTS:** El Nino Southern Oscillation (ENSO) Outlook
5. **ECOSYSTEM MANAGEMENT:** National Marine Sanctuary Conditions Report
6. **FISHERIES MANAGEMENT:** Fisheries Stock Assessments
7. **TSUNAMIS:** Tsunamis Inundation Forecast Model
8. **HARMFUL ALGAL BLOOMS (HABS)**: HAB Forecasts and Mitigation Capability (Gulf of Maine)
9. **HYPOXIA:** Hypoxia Watch (Gulf of Mexico)
10. **OCEAN NOISE:** Ocean Noise Mapping
11. **HURRICANES:** Hurricane Outlook
12. **EMERGENCY RESPONSE**

Next, we selected five products for further evaluation based on criteria developed in coordination with the NOAA Office of Marine and Aviation Operations (OMAO) project team and NOAA's Observing Systems Council. For these products, we developed monetary estimates of the anticipated benefits that the product provides, and estimated the portion of this anticipated benefit that is attributable to the NOAA Fleet. This study found that, for these five products, 15 to 37 percent of their value is directly attributable to the NOAA fleet ($0.77 billion to $3.39 billion, Table ES-2). In addition to the five products included in this study, the project team also recommended monetization of a sixth NOAA product – fish stock assessments conducted by the National Marine Fisheries Service (NMFS). However, during this study, we learned that NMFS recently initiated research to estimate the value of this product. To avoid duplication of effort, OMAO will incorporate the results of NMFS' analysis, when it is completed, with the findings of this research.

Cost-effectiveness of NOAA Ships and Contract Vessels

The second component of this study is an assessment the efficiency and cost-effectiveness of the use of contract vessels as a substitute for NOAA's ships for some data collection efforts. We examined several case studies that compared the marginal cost of using NOAA ships for specific individual missions to estimated costs for using contract vessels to provide the same services and support as the NOAA ship and meet the same mission requirements.

Table ES-2. Societal benefits (billions of dollars) of select NOAA products and associated value of NOAA Fleet (see Sections 2-3 of main report and Appendix A for more details)

Value Chain/Product	Annual Anticipated Benefit of Product	Annual Anticipated Benefits Attributed to NOAA Fleet	
		Value	Percent
CORAL REEFS: Coral Status and Trends Report	**$0.590 - $1.190**	**$0.090 - $0.710**	**15.0% - 60.0%**
SEA LEVEL RISE: Sea Level Rise Viewer	**$1.480**	**$0.030 - $0.560**	**2.0% - 37.5%**
BATHYMETRY/HYDRO-GRAPHIC SURVEYS: Nautical Chart Products	**$0.058 - $0.120**	**$0.017 - $0.048**	**30.0% - 40.0%**
SEASONAL FORECASTS: El Nino Southern Oscillation Outlook	**$0.560 - $1.300**	**$0.026 - $0.270**	**4.6% - 20.0%**
ECOSYSTEM MANAGEMENT: National Marine Sanctuary Condition Reports	**$2.420 - $5.180**	**$0.610 - $1.800**	**25.0% - 35.0%**

The single case study involving a single purpose mission of limited scope (TAO maintenance without supplemental scientific research) showed a contract vessel to be the most cost-effective option. The case studies of multi-disciplinary research missions indicated that there are examples where contract vessels are more cost effective and others where NOAA ships are more cost effective.

These case studies were not conclusive regarding the factors that determine cost-effectiveness. Geography could be one factor. NOAA ships appeared more cost effective for the research missions conducted in the remote tropical Pacific, while contract vessels appeared more cost effective for those conducted in U.S. coastal waters. These results, however, could also be related to the specific NOAA ships examined. These case studies where contract vessels were more cost effective involved NOAA ships with higher marginal costs than the average for NOAA's fleet overall.

We also conducted a limited examination of the capacity and availability of contract vessels, along with other factors that could affect NOAA's use of contract vessels. NOAA successfully contracts with a large number of different contract vessel providers and individual vendors report good availability to provide support. Specific projects, however, may have requirements (e.g., vessel capabilities, project scheduling, or location) that are not a good match for a very large number of contract vessels. Of NOAA contracts for vessel services active in fiscal year 2015, just over half received only one offer and almost 70 percent had two or fewer offers. Data are not available on the number of solicitations that received no bids.

In general, contract vessel availability appears to be greater for smaller vessels with more limited capabilities. The individual vessels that are the most obvious substitutes for NOAA ships (UNOLS vessels) are also the least available. There may, however, be opportunities for NOAA to make greater use of contract vessels during periods when those vessels have greater availability (i.e., outside of the summer months).

Lessons Learned

This study provides NOAA with a systematic process for assessing the value of individual observing systems and data streams through the development of value chains for the products and services that depend on them. NOAA can use the general approach to assess the value of Fleet-dependent products and/or additional observing systems (e.g., OMAO aircraft).

While this study represents a significant first step in demonstrating the value of the NOAA Fleet, it is limited in scope. Under this contract the project team was only able to develop value chains for 12 Fleet-dependent products, and quantify the value of 5 products. In addition, we were not able to conduct original valuation analyses; our monetary estimates of value therefore depend on existing studies and estimates from the literature, which are also subject to limitations and caveats. We were also only able to conduct a limited number of interviews, which we conducted with product experts from within NOAA.

In addition, throughout the study we learned that it is difficult to isolate the effect of individual data streams on the performance of a given product, given the interdependency of data that most products rely on. Thus, it is difficult to attribute an exact percentage of product value to the NOAA Fleet. We have attempted to reflect this uncertainty by providing a reasonable range of values using Fleet data-dependency estimates provided by TPIO and the subject matter experts.

The data used as inputs to this analysis represent the best available information. However, the studies upon which the quantifications are based were often few in number and, as with any study, limited in their accuracy, completeness, and broader applicability. Estimates of the contribution of the NOAA fleet to final products and services are based on extensive research and analysis by NOAA's Technology, Planning, and Integration for Observation office (TPIO) but this work has its own limitations and the results have not been independently verified (as with a "denial of data" analysis). In short, the resulting values represent an empirical first step in the direction of developing more accurate and complete estimates of the value of NOAA products and services and the share of that value attributable to the NOAA fleet. A more scientifically rigorous analysis would require additional primary data collection and analysis which, if performed comprehensively, would be cost-prohibitive. This study does establish a scientifically sound process for assessing the societal benefits of the NOAA fleet and identifies critical information requirements that should be used to inform future research agendas.

Despite these challenges, which are inherent in most economic analyses, our use of published studies and extensive interviews with subject matter experts established a highly credible range of value estimates. We are confident that these estimates establish the significant value of the fleet's contributions and provide materially relevant data to support future decisions at NOAA regarding the fleet.

We also learned that a number of factors complicate comparing the cost-effectiveness of contract vessels to NOAA's fleet. When using contract vessels, contract costs alone may not account for the full cost to NOAA of completing a given mission. Furthermore, a day at sea aboard a contract vessel is not necessarily equal to a day at sea aboard a NOAA vessel. NOAA ships often collect multiple data streams and/or conduct multiple missions simultaneously. Although some contract vessels have similar multi-data stream/multi-mission capabilities, many such vessels are better suited for individual projects and a more limited set of data. These "economies of scope" mean that multiple contract vessels can sometimes be required to replace the output of a NOAA vessel.

NOAA ships also have greater endurance than many smaller contract vessels. Therefore, they can remain at sea for the duration of long projects without returning to port. In addition, NOAA ships often can be scheduled and positioned to transition directly from one project to the next without significant travel time. Therefore, the use of contract vessels can entail more transit days (i.e., at the start and finish of the discrete projects for which they are hired and, in some cases, to resupply during longer projects).

Given these factors, it is not appropriate to compare aggregate data on the cost of contract vessels to the cost of using the NOAA fleet. Instead, the comparison must account for mission-specific details. The case study approach we used here attempts to account for these factors and provide a one-to-one comparison of contract vessel costs to NOAA fleet costs.

Recommended Next Steps

There are several ways that NOAA could further refine the value chain and monetary value estimates from this study. First, many of the value chains and quantitative study estimates could benefit from additional interviews with NOAA experts as well as external product users. These interviews would provide a better understanding of the decisions that users make based on the information that the products provide, as well as how the NOAA Fleet contributes to each product. Additional analyses could also be conducted to further refine our monetary estimates. However, this would require primary data collection. Finally, to further inform investment decisions and focus resources, NOAA may also want to expand this analysis to include more fleet-dependent products and/or additional observing systems.

To better examine the factors that determine the cost-effectiveness of contract vessels, NOAA could conduct additional case studies. If carefully selected, additional case studies could help isolate the factors that contribute to cost-effectiveness (e.g., geography, specific NOAA ships used, length of mission, time of year).

A more detailed assessment of existing and future contract vessel capacity and availability would also be useful. The voluntary interviews with vendors that we conducted for this study were limited in number and not geographically representative. A more thorough, perhaps statistically selected, survey incorporating more detailed questions about vessel availability and capabilities could provide a greater understanding of the industry. A detailed examination of NOAA's contract records, beyond the limited descriptive data in USAspending, might also provide more comprehensive data on the industry's size and capabilities.

1. Introduction

The National Oceanic and Atmospheric Administration's (NOAA's) fleet of ocean vessels provides significant value to society through its data collection activities and the products and services that these activities support. To maintain these important societal benefits, and meet growing demands for environmental data collection, NOAA will need to make significant investments in its fleet resources. To inform its investment decisions, NOAA's Office of Marine and Aviation Operations (OMAO) initiated the *NOAA Fleet Societal Benefit Study*. The purpose of this study is to identify and monetize the benefits associated with a subset of key NOAA products and services that are dependent on the NOAA Fleet, and assess the cost-effectiveness of using contract vessels as a substitute for NOAA's ships for some data collection efforts. This report provides an overview and summary of key findings from the *NOAA Fleet Societal Benefit Study*, which Abt Associates and Corona Environmental Consulting (Corona) conducted under Abt Associate's prime contract with NOAA's Office for Coastal Management (BPA EA-133C-14-BA-0039), Task Order C-007.

1.1 Background

NOAA is responsible for collecting, sharing, and utilizing scientific information to help the U.S. understand, manage, and protect the 3.4 million square nautical miles of ocean in our Exclusive Economic Zone, as well as to understand and predict changes in weather, climate, oceans, and coasts. This mission requires extensive data collection capabilities, which OMAO supports. OMAO maintains and operates a fleet of vessels and aircraft that serve as the mobile platforms for NOAA's data collection infrastructure. NOAA also commissions contract vessels and aircraft for some types data collection, when availability coincides with data collection needs.

The NOAA Fleet, managed by OMAO and operated by NOAA Corps, includes 16 research and survey ships, ranging from large oceanographic research vessels capable of exploring the world's deepest oceans to smaller ships responsible for charting the nation's coastal waters (Table 1).[1] NOAA ships are stationed in homeports around the U.S. and operate across the Exclusive Economic Zone and internationally; they are specially equipped and designed to support the agency's programs. Many of the ships fulfill multiple missions, enabling the collection of a wide variety of atmospheric, fisheries, hydrographic, and oceanographic data in support of NOAA's long-term goals and mission service areas (Figure 1). NOAA line offices, other U.S. government agencies, communities, and businesses around the nation rely on this information to keep U.S. ports open to maritime commerce, understand changes to the planet, monitor the health of fish stocks, and make important economic and policy decisions.[2]

Per NOAA's Office of Technology Planning and Integration for Observation (TPIO), data collected from NOAA ships, and/or the operational platforms that the ships maintain, support the development of 638 NOAA products and services across NOAA's 26 mission service areas. As described in the 2016 NOAA Fleet Plan, these products and services are vital to the economy and health of the nation. For example, the National Ocean Service relies on fleet charting and hydrographic survey activities to map and develop nautical charts, which in turn facilitate safe and efficient marine navigation and support the $4.6 trillion in economic activity generated by U.S. seaports each year. Accurate mapping of coastal areas also informs tsunami inundation modeling and storm surge predictions, which are critical for urban planning and emergency management.

Physical, chemical, and biological observations from fleet vessels allow NOAA to effectively manage and protect key species and resources, including National Marine Sanctuaries, which generate nearly $8 billion in local economies each year.[3] These types of observations also serve as the basis for fisheries stock assessments, which allow fishery managers to set accurate catch limits for the $54 billion domestic fish

Table 1. NOAA Fleet Composition

[1] NOAA. 2016. The NOAA Fleet Plan: Building NOAA's 21st Century Fleet. Available: https://www.omao.noaa.gov/sites/default/files/documents/The%20NOAA%20Fleet%20Plan_Final_31OCT.pdf. Accessed 5/3/2017.
[2,] *Ibid*
[3] NOAA Office of National Marine Sanctuaries. 2015. National Marine Sanctuaries and Local Economies. Available: http://sanctuaries.noaa.gov/science/socioeconomic/factsheets/welcome.html. Accessed 5/3/2017

Ship	Length	Class	Primary Mission[1]	Homeport	Ship Age (years)
Rainier	231 ft.	Ocean	2	Newport, OR	49
Fairweather	231 ft.	Ocean	2	Ketchikan, AK	49
Oregon II	170 ft.	Regional	1	Pascagoula, MS	49
Hi'ialakai	224 ft.	Ocean	1, 2, 3	Honolulu, HI	32
Oscar Elton Sette	224 ft.	Ocean	3	Honolulu, HI	29
Okeanos Explorer	224 ft.	Ocean	1, 2	Davisville, RI	28
Gordon Gunter	224 ft.	Ocean	1	Pascagoula, MS	27
Nancy Foster	187 ft.	Ocean	1	Charleston, SC	26
Thomas Jefferson	208 ft.	Ocean	2	Norfolk, VA	25
Ronald H. Brown	274 ft.	Global	3	Charleston, SC	20
Oscar Dyson	209 ft.	Ocean	1	Kodiak, AK	13
Henry B. Bigelow	209 ft.	Ocean	1	Newport, RI	11
Pisces	209 ft.	Ocean	1	Pascagoula, MS	9
Bell M. Shimada	209 ft.	Ocean	1	Newport, OR	8
Ferdinand R. Hassler	124 ft.	Regional	2	New Castle, NH	7
Reuben Lasker[4]	209 ft.	Ocean	1	San Diego, CA	4

1. Mission 1: Assessment and Management of Living Marine Resources
   Mission 2: Charting and Mapping
   Mission 3: Oceanographic Monitoring, Research, and Modeling

Source: NOAA. 2016. The NOAA Fleet Plan: Building NOAA's 21st Century Fleet.

harvest,[5] directly affecting the $153 billion U.S. commercial fishing industry.[6] In addition, NOAA ships and buoy systems collect oceanographic monitoring data that directly feed weather models, forecasts, and oceanographic circulation models. Without this data, weather and climate forecasts would be less accurate, resulting in adverse impacts related to severe storm and emergency planning, coastal management, and planning for the U.S. agricultural industry, which supported $992 billion of economic activity in 2015.[7]

The NOAA Fleet also serve as an important component of the nation's ocean-related emergency and disaster response network. Fleet emergency response services include surveying commercial ports following hurricanes and major storms to ensure their channels are free from debris and other navigational hazards. These surveys must be conducted before affected ports can be re-opened. The ability of NOAA vessels to immediately provide these surveys can significantly reduce the amount of time ports remain closed, allowing

[4] NOAA Ship *Reuben Lasker* did not start operations until 2014
[5] U.S. Department of Commerce. 2014. *Fisheries Economics of the United States.* NOAA Technical Memorandum NMFS-F/SPO-163, p. 6. Washington, D.C.: U.S.
[6] NOAA. 2016. The NOAA Fleet Plan: Building NOAA's 21st Century Fleet.
[7] U.S. Department of Agriculture Economic Research Service. 2016. Ag and Food Sectors and the Economy. Available: Accessed 5/3/2017. Value includes agriculture and related food sectors.

NOAA Fleet data collection activities are critical to the development of a 638 products and services that support the agency's long-term goals and 26 associated mission service areas. The following shows NOAA's long-term goals, per NOAA's Next Generation Strategic Plan, and the number of fleet-dependent products that directly support each goal.

NOAA Next Generation Strategic Plan Goal	***Fleet-Dependent Products***
Climate Adaptation and Mitigation *An informed society anticipating and responding to climate and its impacts*	**137**
Weather-Ready Nation *Society is prepared for and responds to weather-related events*	**195**
Healthy Oceans *Marine fisheries, habitats, and biodiversity are sustained within healthy and productive ecosystems*	**206**
Resilient Coastal Communities and Economies *Coastal and Great Lakes communities are environmentally and economically sustainable*	**63**
Enterprise-wide Capabilities	**37**

Figure 1. NOAA's Next Generation Strategic Plan Long-term Goals

for the delivery of emergency supplies and important economic activity to resume. Additional emergency response activities include locating and mapping debris fields in the ocean for aviation disasters, conducting scientific surveys in response to major oil and chemical spills, and surveying our nation's ports and waterways in response to national security threats. NOAA ships are also often called upon to provide routine search, rescue, and evacuation services.

While the NOAA Fleet and associated data collection activities provide important benefits to society and across economic sectors, OMAO faces several challenges in managing the fleet, including expanding/changing mission requirements, aging ships, evolving technologies, and limited resources available for maintenance and recapitalization.[8] To address these challenges, NOAA desires to understand how to optimize the value of its marine fleet by maximizing the socioeconomic benefits derived from fleet data collection activities and leveraging the use of contract vessels, when appropriate. Accordingly, NOAA retained Abt Associates to 1) estimate the societal benefits of a subset of fleet-dependent NOAA products and services, and 2) assess the cost-effectiveness of using contract vessels to complement the NOAA Fleet's data collection efforts.

1.2 Overview of Research Approach

To demonstrate the societal benefits associated with fleet data collection activities, the project team focused on 12 of the 638 NOAA products and services that the NOAA Fleet supports. For each of the 12 products, we developed a qualitative "value chain" (Figure 2), describing how data from the fleet support/feed into the product, the users of the product, the decisions they make based on the information the product provides, and how this results in value to society.

[8] NOAA. 2016. The NOAA Fleet Plan: Building NOAA's 21st Century Fleet.

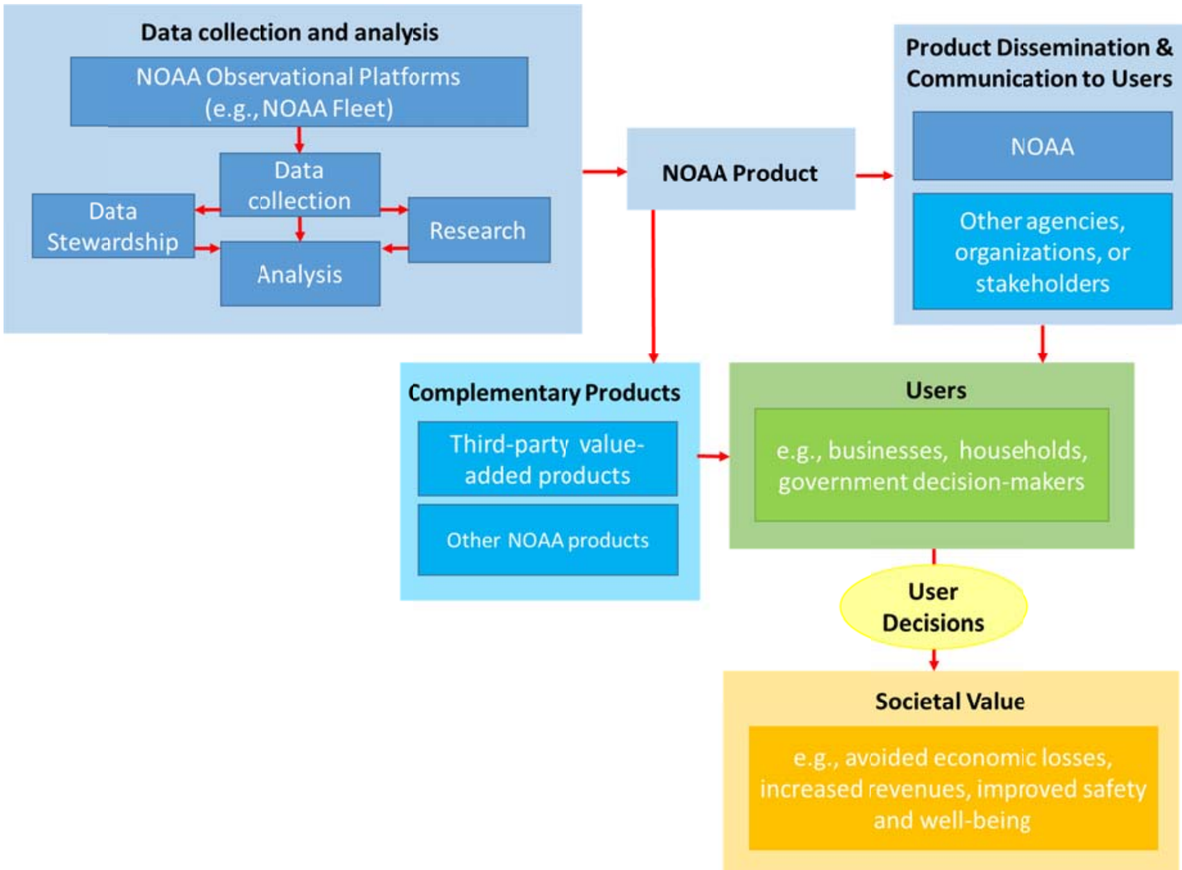

Figure 2. Value Chain Diagram for NOAA Products

To select the initial subset of 12 products for which we developed value chains, we worked with OMAO and TPIO to identify products and services that are highly dependent on the fleet and/or have a relatively large societal benefit, meaning they affect decisions made in important sectors of the economy and/or result in significant savings or increased well-being for U.S. households. In addition, we aimed to select a subset of NOAA products that reflect the many different activities across NOAA line offices and mission service areas. As described in more detail in Section 2, to develop the value chains, we relied on information from the NOAA Observing System Integrated Analysis (NOSIA-II) Value Tree, a hierarchical model developed by TPIO, and conducted in-depth interviews with subject matter experts from the various line offices within NOAA

Next, the research team worked with OMAO and NOAA's Observing Systems Council to select five products for further evaluation. For these products, we developed monetary estimates of the benefits that the product provides, and estimated the portion of this benefit that is attributable to the NOAA Fleet. The products we selected for further evaluation and monetization ranked highest among the following criteria (Table 2):

- The product likely has significant benefits for society
- The product has a significant dependency on data from the NOAA Fleet
- Data are available to robustly quantify/monetize the societal benefits of the product within the scope of this contract
- The product has output data that can be validated as being critical for a specific use and shows improvement with additional measures.

In addition to the five products included in this study, the project team also recommended monetization of a sixth NOAA product -fish stock assessments conducted by the National Marine Fisheries Service (NMFS). However, during this study, we learned that NMFS recently initiated research to estimate the value of this product. To avoid duplication of effort, OMAO will incorporate the results of NMFS' analysis, when it is completed, with the findings of this research.

The second component of this study is an assessment the efficiency and cost-effectiveness of the use of contract vessels. This component of the study includes several quantitative case studies assessing the cost-effectiveness of conducting selected data collection activities using contract vessels as a substitute to NOAA's marine fleet. It also summarizes available information on the capacity and availability of contract vessels. The case studies compare the marginal cost of using the existing capacity of the NOAA Fleet to the cost of using contract vessels. As a basis for analysis, this portion of the study uses cost data for the NOAA Fleet for fiscal year 2015, the most recent year for which complete cost data were available at the outset of this project. It also relies on cost data from NOAA's recent contracts with vessel providers, as well as information, both quantitative and qualitative, from interviews with NOAA subject matter experts and vessel providers, both private and public sector.

1.3 Report Organization

The remainder of this report describes the general methodology and results of our research, as follows:

- Section 2 presents the value chains for each of the 12 products and services that the project team analyzed.
- Section 3 summarizes the results of the economic valuation for the five products and services we selected for further evaluation.
- Section 4 summarizes and presents the findings of the cost-effectiveness analysis, comparing the use of NOAA Fleet and contract vessels for specific data collection activities.
- Section 5 provides a summary of key findings
- Appendix A contains the full value chain write ups for the 12 products we analyzed as part of this research.
- Appendix B contains the full report on the cost-effectiveness of using NOAA ships versus contract vessels, including supporting details.
- Appendix C provides a summary of the project team's interviews with contract vessel providers, which we conducted as part of the cost-effectiveness analysis.
- Appendix D provides the names of the authors of this report, the project team from OMAO, and the names and affiliations of the dozens of NOAA subject matter experts who contributed to the report.

Table 2. NOAA Products and Services Evaluated for NOAA Fleet Societal Benefits Study[9]

Value Chain/NOAA Product Qualitatively Assessed	NOAA Mission Service Area	NOAA Line Office/Owner	Societal Benefits	Dependence on ship-based data collection	Value can be assessed	Output/ value is validated
1. CORAL REEFS: Coral Reef Status and Trends Report	RESILIENT COASTS – Resilience to Coastal Hazards and Climate Change	NOS/Coral Reef Conservation Program	Med/High	Medium	Yes	Yes
2. SEA LEVEL RISE: Sea Level Rise Viewer	RESILIENT COASTS – Resilience to Coastal Hazards and Climate Change	NOS/Office for Coastal Management	High	Med/Low	Yes	Yes
3. BATHYMETRY/ HYDROGRAPHIC SURVEYS: Nautical Chart Products	RESILIENT COASTS – Marine Transportation	NOS/Office of Coast Survey	Med/High	High	Yes	Yes
4. SEASONAL FORECASTS: El Nino Southern Oscillation (ENSO) Outlook	CLIMATE – Climate Predictions and Projections	NWS/National Centers for Environmental Prediction/Climate Prediction Center	High	Medium	Yes	Yes
5. ECOSYSTEM MANAGEMENT: National Marine Sanctuary Conditions Report	RESILIENT COASTS – Planning and Management	NOS/Office of National Marine Sanctuaries	Med/High	Medium	Yes	Yes
6. FISHERIES MANAGEMENT: Fisheries Stock Assessments	HEALTHY OCEANS – Fisheries Monitoring Assessment and Forecast	NMFS/Office of Science and Technology	Medium	High	Yes	Yes
7. TSUNAMIS: Tsunamis Inundation Forecast Model	WEATHER READY NATION - Tsunami	OAR/Pacific Marine Environmental Laboratory	High	Med/Low	Likely	Yes
8. HARMFUL ALGAL BLOOMS (HABS): HAB Forecasts and Mitigation Capability (Gulf of Maine)	RESILIENT COASTS – Coastal Water Quality	NOS/National Centers for Ocean Coastal Science	Medium	Med/Low	Likely	Yes
9. HYPOXIA: Hypoxia Watch (Gulf of Mexico)	RESILIENT COASTS – Coastal Water Quality	NESDIS/National Centers for Environmental Information	Med/Low	High	No	Yes
10. OCEAN NOISE: Ocean Noise Mapping	HEALTHY OCEANS – Protected Species Monitoring	OAR/ Pacific Marine Environmental Laboratory	Medium	Medium	No	Yes

[9] Assessing the value of products with a "No" ranking would require original data collection beyond the scope of this project.

2. Value of Products and Services Dependent on the NOAA Fleet

This section contains a summary of the value chain descriptions that the project team developed for 12 NOAA products and services that depend on data collected from NOAA ships and/or observing networks that the ships maintain. For each value chain, we describe:

- How data from the fleet feed into the product
- Segments of society that use the product
- How users make decisions based on the information the product provides
- The outcomes or values resulting from those decisions. These decision outcomes or values ultimately represent the benefits that these products provide to society.

To develop the value chains, we conducted in-depth interviews with NOAA subject matter experts, who provided information on how data from the NOAA Fleet informs the product, the users of the product, and the product's value to society. We also used information from TPIO's NOSIA-II Value Tree to better understand how data from the fleet supports each product. NOSIA-II is a hierarchical model that documents the relationship between data sources, mission requirements, and respective mission service impacts. Based on a survey of more than 500 NOAA subject matter experts, NOSIA-II allows NOAA to understand the impact of single or multiple observing systems on the key products and services it supports. The model is organized based on NOAA's Strategic Plan Goals and 26 associated mission service areas.

The following sections provide a summary of the value chains for each of the 12 products, including a brief description of the product, key users, and the societal benefits associated with the product (summarized in Table 3). Appendix A contains more detailed value chain descriptions, as well as diagrams that trace the flow of data from the NOAA Fleet through to the product's value.

2.1 Coral Reefs: Coral Reef Status and Trends Report

Product Background: NOAA's National Coral Reef Monitoring Program (NCRMP), as part of the Coral Reef Conservation Program (CRCP), is developing Coral Reef Status and Trends Report Cards for high-level decision-makers, along with many other more detailed reports for local resource managers. The Status and Trends Report Cards are a new product, currently under development, that will provide a summary of standardized indicators for all U.S. coral reef jurisdictions monitored by NOAA's CRCP, while the more detailed reports inform the management of specific coral reef areas. Prior to this effort to standardize sampling methodologies across jurisdictions, CRCP could not roll-up indicators across sites and therefore could not provide a national picture of coral reef health.

Dependency on NOAA Fleet: The Report Cards and underlying indicators require the collection of data by multiple observation systems over a wide geographic region. The stratified random sampling design that NCRMP uses to collect data for the Status and Trends Report Cards is heavily reliant on benthic and other habitat mapping surveys, performed in part by NOAA projects. Ocean profile data collected during NOAA ship marine biological surveys also feed into the report card's climate indicators.

Using NOAA ships and observation systems to perform data collection helps the CRCP adhere to the standardized sampling methodology that underpins the national status and trends report. Other ship-based data collection options, such as contract personal dive boats, are more expensive and scarce, limiting the timeframe for critical sampling. Some efforts associated with coral reef monitoring could not be done without the use of NOAA vessels. For example, NOAA vessels are the only ships that can cover the long distances and access the remote locations associated with the Pacific Reef Assessment and Monitoring Program.

Users: The Status and Trends Report Card will be viewed by U.S. Congressional leaders and NOAA leadership as they make decisions to allocate resources to coral reef protection. Educators and local resource managers will use the Status and Trends Report Card, and the more detailed jurisdictional reports, to monitor reefs and design education programs that further enhance the ecosystem's health. These management actions protect coral reefs and their associated benefits. Outside of the decision-making sphere, the data and indicators also provide useful information for academic and private researchers, as well as the public.

Table 3. Summary of Value Chains for Select NOAA Products

Value Chain/NOAA Product	Description	Users/Uses	Benefits
1. CORAL REEFS: Coral Reef Status and Trends Report Cards	National and jurisdictional-level reports that provide standardized indicators on coral reef health.	Decision-makers will use reports to manage coral reefs under NOAA jurisdiction	Will protect coral reefs and associated ecosystem services, including use and non-use benefits (for example, tourism).
2. SEA LEVEL RISE: Sea Level Rise Viewer	Web-based map viewing tool that provides visuals information on sea level rise inundation, flood frequency, and socioeconomics.	Planners use information to identify potential community vulnerabilities and assess adaptation options.	Avoids impacts/costs of SLR, including: • Property damage • Loss of critical infrastructure • Impacts to vulnerable populations
3. BATHYMETRY/ HYDRO-GRAPHIC SURVEYS: Nautical Chart Products	Electronic and paper navigational charts/maps of coasts of U.S. states and territories, as well as the Great Lakes.	Commercial and recreational vessels use charts for navigation and port entry; also informs scientific efforts and marine infrastructure location decisions.	Provides safe and efficient marine transportation and commerce; avoids losses from accidents and unnecessary slow-downs.
4. SEASONAL FORECASTS: El Nino Southern Oscillation (ENSO) Outlook	Seasonal forecast that describes expected El Nino and La Nina conditions, and temperature and precipitation predictions.	High-level decision-makers, emergency planners, economic sectors (e.g., agriculture, energy, retail) use Outlook to allocate resources and optimize revenues in face of ENSO conditions.	• Avoids costs of ENSO-related events • Provides cost savings from more effective response/preparation • Increases revenues for agriculture, energy, retail, and other sectors
5. ECOSYSTEM MANAGEMENT: National Marine Sanctuary Conditions Report	Reports on ecosystem health, trends, and other indicators for individual National Marine Sanctuaries.	Decision-makers will use reports to manage all Sanctuary resources under NOAA jurisdiction	• Protects special status species, coral reefs, and marine habitat • Helps maintain ecosystem services, including use and non-use benefits (for example, tourism).
6. FISHERIES MANAGEMENT: Fisheries Stock Assessments	Assessment of changes in abundance of fishery stocks and expected future trends.	Fisheries managers use assessments to set catch limits, and manage species, also informs sustainable seafood consumption/fishing.	• More accurate catch limits allow commercial fisherman to catch more than would otherwise be permitted. • Provides sustainable management and harvest of fish species
7. TSUNAMIS: Tsunamis Inundation Forecast Model	Series of models that calculate the height and extent of tsunami flooding in U.S. coastal regions.	NOAA uses in real-time tsunami forecasting. Communities use models to create tsunami inundation maps, evacuation/response plans, and risk assessments and mitigation plans.	• Avoids unnecessary evacuation costs • Decreases tsunami impacts, including lives lost, property damage, and other losses
8. HARMFUL ALGAL BLOOMS (HAB): HAB Forecasts and Mitigation Capability (Gulf of Maine)	Harmful Algal Bloom Operational Forecast System assess and predict extent of HABs.	State/local managers use forecasts to make more informed decisions about beach closures, shell fishing restrictions, and other HAB-affected activities.	Minimizes impacts of HABs, including: • Lost landings • Lost tourism/recreation opportunities • Adverse public health outcomes.

Table 3. Summary of Value Chains for Select NOAA Products (continued)

Value Chain/NOAA Product	Description	Users/Uses	Benefits
9. HYPOXIA: Hypoxia Watch (Gulf of Mexico)	Near real-time, web-based contour maps and data on Gulf region dissolved oxygen for the peak annual hypoxic period. Maps and data provide 15-year baseline of the Gulf hypoxic zone.	Maps and data help form scientific basis upon which policymakers and managers make management decisions to reduce Hypoxic Zone and associated impacts. Commercial and recreational fishermen can use Hypoxia Watch to better plan where to fish to avoid hypoxic areas.	Helps to sustain commercially and recreationally-important fish species in affected by Hypoxic Zone. This supports commercial fishing industry, recreational fishing, and tourism.
10. OCEAN NOISE: Ocean Noise Mapping	Web-based mapping tools that show density, distribution, and migratory patterns, as well as impacts of man-made ocean noise for select species.	Public agencies and industry planners use maps to better understand the effect of man-made noise for proposed ocean-related activities, and to meet environmental regulations.	Protects species by allowing natural defense and mating sound cues to operate normally and by permitting normal migratory patterns.
11. HURRICANES: Hurricane Outlook	Seasonal forecast of expected hurricane activity.	Communities, businesses, and other stakeholders use Outlook to improve hurricane preparedness. High-level decision makers use Outlook to allocate resources to hurricane preparedness.	Reduces property damage, mortality and morbidity, societal costs associated with evacuation, and lost business activity.
12. EMERGENCY RESPONSE	• Deliver emergency supplies, conduct hydrographic surveys to re-open ports, and assess hazardous materials, after hurricanes and major storms • Locate and map debris fields for aviation disasters • Conduct scientific surveys in response to major oil spills • Survey waterways in response to national security threats • Perform search, rescue, and evacuation services	U.S. emergency response network calls on NOAA ships because they have unique technologies and are staffed with scientists and engineers with necessary expertise. They are also available across a wide geographic range, resulting in a timely response.	Saves lives, allows for rapid re-opening of ports after hurricanes, continuation of commercial activities at ports, and informs natural resource damage assessments. Provides cost-effective and timely response capabilities, resulting in cost savings for U.S. taxpayers.

Benefits to Society: Coral reefs provide the U.S. with valuable goods and services including food, coastal protection, and opportunity for recreational activities. These goods and services in turn provide different types of economic benefits: use values (such as snorkeling or recreational fishing) and associated tourism benefits; non-use values, such as willingness-to-pay for the existence of coral reefs; and amenity values, which are increases in property values due to proximity to coral reefs.

Several studies have estimated these benefits for the U.S. using standard economic techniques. In 2013, CRCP commissioned a study with the objective of producing an aggregate total economic value for coral reefs from the seven states and territories with coral reefs.[10] The results of this study, which included a meta-analysis of existing literature, indicated that the total economic value of coral reef services in the U.S. amounts to more than $3.95 billion per year (2016 USD),[11] including direct use values such as swimming, diving, and snorkeling; indirect use values such as coastal protection and habitat functions for commercial and recreational fisheries; and welfare values associated with the existence of diverse natural ecosystems (non-use values).

2.2 Sea Level Rise: Sea Level Rise Viewer

Product Background: Sea Level Rise threatens many coastal areas in the U.S., including some of the most developed, populous, and economically viable areas in the country. Low-lying coastal areas are especially vulnerable to flooding, erosion, habitat loss, and seawater intrusion. The Sea Level Rise and Coastal Flooding Impacts Viewer (SLR Viewer) is a web-based map viewing tool that provides coastal managers, community planners, and other users with visuals, corresponding data, and explanatory information concerning sea level rise inundation, flood frequency, marsh impacts, and socioeconomics. This information allows users to identify potential community vulnerabilities and assess appropriate adaptation options and strategies. As of 2015, the SLR viewer covers all coastal territory in the U.S. except Alaska. NOAA's Office for Coastal Management (OCM) develops and updates/maintains the SLR Viewer.

Dependency on NOAA Fleet: NOAA ships contribute to the SLR Viewer through the collection of hydrographic and geospatial data for US coastal areas (note that the Nautical Charts product described in Section 2.3 and the Tsunami Inundation Forecast Model product described in Section 2.7 also depend on hydrographic survey data provided by the NOAA Fleet). VDatum, a separate software tool developed by multiple NOAA line offices, combines the data that the NOAA Fleet collects into bathymetric-topographic Digital Elevation Models (DEMs) for specific areas. OCM incorporates these DEMs, as well as LIDAR[12] and Conditioned DEMs (DEMs conditioned to a higher specification), tide gauge observations, coastal flooding thresholds, and other jointly developed inputs, into the SLR Viewer. OCM updates the SLR Viewer as new data inputs as become available.

Several other federal agencies and educational institutions contribute data to the SLR viewer. For example, the U.S. Geological Survey provides base elevation data for Louisiana, and the NOAA Center for Operational Oceanographic Products and Services conduct analyses that support tool's flood frequency capabilities. The University of Hawaii performed mapping for several outlying coastal territories, and the University of South Carolina Hazards and Vulnerability Research Institute provides Social Vulnerability Index data.

Users: Primary users of the SLR viewer include coastal planners, floodplain managers, municipal representatives, and scientists and engineers interested in assessing community-level vulnerability and planning for sea level rise and coastal flooding. Several U.S. communities have already incorporated the SLR Viewer or underlying data into their adaptation planning. For example, beginning in 2013, the City of Charleston, South Carolina, analyzed sea level rise impacts on the city. As part of this process, OCM demonstrated sea level rise effects on streets, landmarks, and infrastructure to city planners and engineers using the SLR viewer. The City subsequently developed a Sea Level Rise strategy, and has received a coastal resilience grant to implement the strategy. In another case, the City of New York incorporated data from the SLR viewer into a post-Hurricane Sandy comprehensive resilience plan.

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[10] Brander, L. M., Van Beukering, P. 2013. The Total Economic Value of U.S. Coral Reefs: A Review of the Literature. NOAA Coral Reef Conservation Program, Silver Spring, MD.

[11] Unless otherwise indicated, values in this report updated to 2016 USD were updated using the Bureau of Labor Statistics Consumer Price Index.

[12] LIDAR is a remote sensing method that stands for Light Detection and Ranging http://oceanservice.noaa.gov/facts/lidar.html

Other users include universities, scientific and engineering groups, private entities, and NGOs who use the viewer and data for research.

Benefits to Society: The SLR viewer allows users to quickly and easily visualize potential coastal flooding due to future sea level rise. Users can evaluate potential impact on coastal properties and associated resources and help focus contingency plans to protect critical infrastructure and mitigate property damage.

Several studies have estimated the costs of sea level rise and coastal flooding. Zillow, using its property value database and NOAA's SLR maps, estimates that approximately 1.9 million homes worth $882 billion are at risk of being lost due to flooding nationally by 2100.[13] And, the U.S. EPA estimates that national costs of property abandonment and protective adaptation actions (plus some additional costs) associated with sea level rise and storm surge will amount to $5 trillion cumulatively over time through 2100 (discounted at 3%).[14]

2.3 Bathymetry/Hydrographic Surveys: Nautical Chart Products

Product Background: NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS) produces over 1,000 nautical chart products that cover the coasts of U.S. states and territories, as well as the Great Lakes. NOAA is authorized to provide nautical charts and related hydrographic information by the Coast and Geodetic Survey Act of 1947 and the Hydrographic Services Improvement Act of 1998 (and amendments). The charts serve as navigational aids, supporting safe and efficient maritime transportation and commerce. They also provide important information for at-sea engineering, scientific, and commercial activities, coastal zone management and planning, and homeland security efforts along our nations' coasts. Nautical Charts come in two forms, paper and digital. Digital charts are more popular, particularly among commercial mariners. There are two digital formats for electronic charts, Raster Nautical Charts (RNC) and Electronic Navigational Charts (ENC). The RNC is a simple digital image of the paper chart, while the ENC includes much more information that can help warn mariners of dangers ahead and provide other information critical to a safe passage.

Dependency on NOAA Fleet: Four ships in the NOAA Fleet are dedicated to hydrographic surveys that provide bathymetry data NOAA uses to develop nautical charts (see Table 1 for a listing of each NOAA vessel and its primary mission). These ship's officers and crew use special technologies to acquire and process data on board. They send the processed data to NOAA hydrographers and cartographers, who compile it into the nation's nautical charts (note that the Sea Level Rise Viewer product described in Section 2.2 and the Tsunami Inundation Forecast Model product described in Section 2.7 also depend on hydrographic survey data provided by the NOAA Fleet). Crew members immediately report any hazardous features found during these surveys that might endanger vessels to NOAA cartographers, who update the corresponding nautical chart right away. The U.S. Coast Guard Navigation Center also publishes this information in the appropriate Local Notice to Mariners to ensure that the public is made aware of the change.

NOAA also purchases hydrographic survey data and other information for nautical charts from several other sources. In general, it is the intent of NOAA to contract for hydrographic services when qualified commercial sources exist, and when such contracts are the most appropriate and cost effective method of conducting these functions. NOAA procures hydrographic data and services from qualified sources in accordance with its legal authorities, the Federal Acquisition Regulations (FAR) and the Federal Property and Administrative Services Act of 1949 (40 U.S.C. 541 et seq.), including Title IX where appropriate. Commonly known as the "Brooks Act" for Architect/Engineering (A/E) contracts, Title IX is a contract mechanism for use in situations where the professional nature of the services to be procured requires that potential contractors have specialized technical expertise. NOAA obtains approximately half of its hydrographic survey data from hydrographic surveys services contractors and from OCS's Navigation Response Teams. Other significant sources of information include the U.S. Army Corps of Engineers (USACE) surveys of Federal channels and anchorages, and the U.S. Coast Guard and the U.S. Power Squadrons.

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[13] Rao, K. 2016. "Climate Change and Housing: Will a Rising Tide Sink all Homes?" Zillow.com. Available: http://www.zillow.com/research/climate-change-underwater-homes-12890/. Accessed February 5, 2017.

[14] EPA. 2015. Climate Change in the United States: Benefits of Global Action. U.S. Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-15-001. Available: https://www.epa.gov/cira/climate-action-benefits-coastal-property. Accessed 5/3/2017.

Users: Federal and international regulations require many vessels to carry nautical charts and related NOAA products. For example, The U.S. Coast Guard requires commercial and light commercial sector vessels that transit the same U.S. waters on each trip (e.g., cruise lines, ferries, tug boats) to carry large-scale, detailed paper charts of the waters in which they operate. Larger vessels regulated under the Safety of Life at Sea convention are required by federal law to use ENCs. Recreational boaters are not required to use NOAA nautical charts; however, they often use mobile chart plotters or GPS mapping applications from third-party software companies that are based on NOAA's nautical charts. Nautical charts are also mandatory for the international shipping industry. As new cargo ships continue to increase in size, they need additional navigational support. Nautical charts are essential to helping ship crews understand water depths and shoreline infrastructure as they enter ports with which they are unfamiliar.

NOAA's nautical charts are also the authoritative source for maritime regulation (including accident disputes) and political boundaries (e.g., EEZ). The information contained in NOAA's nautical charts also directly informs several NOAA products and services, as well as products/planning efforts developed by other government agencies and the private sector. This includes products and information related to protected species habitat, placement of marine infrastructure, tsunami inundation modeling, and more.

Benefits to Society: By providing the most up to date nautical information, NOAA helps ensure that ships do not navigate blindly and can chart out the safest and most efficient route to their destination. They can also avoid navigational hazards with confidence, which in turn allows them to avoid unnecessary slow-downs. Thus, much of the value of this product can be estimated based on avoided losses from collisions and grounding, injury and possibly death. Because ship time is expensive, nautical charts also provide value in terms of savings in the amount of time spent at sea.

Because of unique use of nautical charts in the national and international shipping industry, one way to understand their value is to examine the value of U.S. ports to the national economy. According the American Association of Port Authorities, U.S. seaports support nearly $4.6 trillion in total economic activity, and provide $1.2 billion in personal income and local consumption (2014 USD).[15] This would be significantly lower without up-to-date nautical chart information.

In addition, by collecting hydrographic data using NOAA ships, NOAA develops and maintains its hydrographic expertise, which ensures that it remains an informed consumer of the hydrographic data that it purchases. This helps maintain overall data quality and provides benefit to all products that depend on hydrographic data for which NOAA is responsible.

2.4 Seasonal Forecasts: El Nino – Southern Oscillation Outlook

Product Background: The El Nino – Southern Oscillation (ENSO) cycle represents annual changes in sea surface temperatures, convective rainfall, surface air pressure and atmospheric circulation over the equatorial Pacific. El Nino describes a year in which sea-surface temperatures are above the long-term average, while La Nina describes a year in which sea-surface temperatures are cooler than average. During El Nino and La Nina years, changes in Pacific Ocean temperatures affect seasonal tropical rainfall patterns from Indonesia to the west coast of South America. These changes in tropical rainfall affect weather patterns throughout the world, including the frequency and severity of storms, floods, droughts, hurricanes, tornadoes, and other weather-related events, as well as temperature and precipitation. To help the public and private sector better prepare for ENSO-related conditions in each season, NOAA National Weather Service's Climate Prediction Center (CPC) creates and disseminates the ENSO Outlook. The ENSO Outlook describes the status of El Nino and La Nina conditions. CPC uses the ENSO Outlook and other tools to inform seasonal temperature and precipitation predictions for the U.S.

Dependency on NOAA Fleet: One of the main inputs to the ENSO Outlook is data from the Tropical Atmosphere/Ocean (TAO) array. The TAO array consists of 70 buoys moored in the Pacific Ocean that collect oceanographic and meteorological data. The NOAA Fleet maintains the TAO array including the solar panels and radios needed for the TAO buoys to transmit the data from these moorings electronically through satellites. Basic measurements on TAO moorings include wind speed, air temperature, relative humidity, salinity profiles, sea surface temperature, and

[15] American Association of Port Authorities. Undated. *Exports, Jobs & Economic Growth*. Available: http://www.aapa-ports.org/advocating/content.aspx?ItemNumber=21150. Accessed 5/3/2017.

subsurface temperatures. Ocean profile information, which is collected directly from NOAA vessels, is assimilated into NWS models that are also used to inform the ENSO Outlook.

The ENSO Outlook also depends on data from the ARGO array, a global array of 3,800 free-drifting profiling floats that provides data on ocean subsurface temperatures, salinity, and velocity. These floats are deployed by the NOAA Fleet (the Hurricane Outlook product is also dependent on the TAO and ARGO arrays – see Section 2.11) In addition to fleet-dependent data, the ENSO Outlook relies on a variety of in-situ and satellite data to develop prediction products.

Users: The information provided in the ENSO Outlook affects the decisions and management actions of many different stakeholders. Public sector users of this information include NOAA, Federal Emergency Management Agency, Department of Defense, U.S. Agency for International Development, U. S. Department of Agriculture, and state and local agencies whose operations or decisions are impacted by short-term climate variations. For example, water resource management agencies, such as the Tampa Bay Water Authority, use predicted precipitation levels form the ENSO Outlook to make decisions about reservoir releases. Emergency management agencies use information from CPC products there are informed by the ENSO Outlook to prepare and allocate resources to areas that will likely experience adverse effects from El Nino or La Nina. Other state and local agencies affected by ENSO-related conditions include those related to agriculture, water resources, transportation and energy.

There are also many private sector users of CPC outlooks that use the ENSO outlook as a prediction tool. These include agriculture, retail, energy, fisheries, and outdoor recreation/tourism. For example, CPC outlooks can inform farmers' decisions on which crops to plant and when to plant them. Private retailers or grocery chains can use the data make decisions about quantities of seasonal items to stock. Individual households also use CPC products to make appropriate preparatory decisions (e.g., undertake maintenance to prepare for anticipated winter storms).

Benefits to Society: Several studies have shown that predicting the life cycle and strength of a Pacific warm or cold episode is critical in helping farmers and other types of businesses plan for, avoid or mitigate potential losses. For example, Adams et al. (1995) found that improving ENSO forecasts by 33% would result in $151 million (2016 USD) per year in economic benefits for the agricultural sector in the southeast U.S., while a 100% accurate forecast would yield $228 million (2016 USD). At the time the study was conducted, these estimates represented about 2 to 3 percent of farm-gate value of total crop production for the southeast region.[16]

ENSO-related forecasts of the potential for extreme climate episodes like floods and droughts can also save the U.S. billions of dollars in damage costs. For example, national and state emergency managers can use CPC forecasts to better prepare for predicted events, which can reduce response costs. Individual households and businesses can also use CPC Outlooks to make appropriate preparatory decisions, resulting in avoided damage costs.

2.5 Ecosystem Management: National Marine Sanctuary Conditions Reports

Product Background: NOAA manages 13 National Marine Sanctuaries and two national marine monuments. Together, these protected marine ecosystems encompass more than 600,000 square miles of marine and Great Lakes waters. The sanctuaries support endangered species and a variety of habitats ranging from coral reefs, to deep-sea canyons, to underwater archeological sites.

National Marine Sanctuary Condition Reports serve as an important tool for managing and protecting the resources within marine sanctuaries from outside pressures. The Condition Reports help managers determine if they are achieving their resource protection and improvement goals, and inform future management plans for the sanctuary. The reports are updated every five years to examine trends, identify how the status of various resources has changed, and establish management responses.

[16] Adams, R., K. Bryant, B. McCarl, D. Legler, J. O'Brien, A. Solow, and R. Weiher. 1995. Value of Improved Long-Range Weather Information. Contemporary Economic Policy. ISSN 1074-3529. Vol XIII: 10 – 19.

Dependency on NOAA Fleet: The NOAA Fleet provides key data that supports many conclusions in the Condition Reports. For example, NOAA vessels collect data through seafloor mapping surveys that characterize sanctuary habitat. They also collect data through observation stations and acoustic surveys on fish and marine mammal species diversity, abundance, and distribution. NOAA weather buoys, many of which are serviced by the NOAA Fleet, also serve as a source of oceanographic data for the Condition Reports of each sanctuary.

While most sanctuaries have access to on-site vessels, they serve different roles than the NOAA Fleet. NOAA vessels can be critical for gathering data in seasons and locations where conditions are too harsh for the operation of smaller vessels (i.e. they can handle weather and sea states during which small craft would be limited under a small craft advisory). NOAA vessels also have sufficient crew to be able to conduct operations 24 hours per day, and can maintain operations for longer periods. This allows sanctuary staff to spend more days at sea, and reach deeper parts of the sanctuary that are not accessible using the sanctuary vessel because of the distance from ports.

Users: The primary purpose of the Condition Reports is to inform sanctuary management decisions. Specifically, NOAA uses data from the Condition Reports to develop Sanctuary Management Plans, which guide future planning and management actions related to resource protection, conservation science, research, and education.

The Condition Reports are also an important tool for the sanctuaries' education and outreach programs. The information in the Condition Reports help sanctuary staff design site-specific education and outreach programs that teach members of the public about resources in the sanctuary, why they are important, and what behavioral changes are needed to protect them. Universities and independent non-profit organizations often use the Condition Reports to identify research needs, and to fill in gaps that further contribute to management and protection of marine resources.

Benefits to Society: The National Marine Sanctuaries Condition Reports directly contribute to regulations, policies, and education programs related to marine sanctuaries, which in turn helps to protect the important benefits the sanctuaries provide. National Marine Sanctuaries provide a range of benefits, including on-site user benefits (e.g., through recreational activities such as fishing and snorkeling) and benefits accruing to individuals who do not use the marine ecosystem directly but who value their existence. Further, many on-site activities generate income directly to participants and indirectly to coastal economies that service the activities. For example, NOAA research indicates that together, national marine sanctuaries generate approximately $8 billion annually (2015 USD) in local coastal and ocean dependent economies from diverse activities like commercial fishing, research and recreation/tourism-related activities.[17]

2.6 Fisheries Management: Fisheries Stock Assessment

Product Background: NOAA conducts stock assessments to help manage commercial and recreational fish species. A stock assessment involves collecting, analyzing, and reporting population information to determine changes in the abundance of fishery stocks and, to the extent possible, predict future trends in stock abundance. NOAA's National Marine Fisheries Service (NMFS) manages roughly 475 fish stocks (the number has varied as new stocks are added), with data and resources to assess approximately 200 stocks each year.

NOAA fisheries managers primarily use NOAA stock assessments to set catch limits and to set and enforce other regulations that prevent overfishing and provide optimal yield for commercial fishermen. This includes eight Regional Fishery Management Councils in the U.S., which are required by mandate of the Magnuson-Stevens Fishery Conservation Act to set annual catch limits for their region based on best available scientific data. Coastal, state and international organizations also rely on NOAA's stock assessments for non-federal and joint jurisdictional management of fish stocks.

Dependency on NOAA Fleet: NOAA uses three primary types of data to develop standard fish stock assessments: abundance, catch, and biological. NMFS uses NOAA Fleet vessels and contract vessels to conduct abundance surveys, and to collect biological data that inform stock the assessments. Catch data typically comes from dockside monitoring, fishermen's logbooks, observations from fishing vessels, and telephone interviews. Collecting abundance and biological fish stock data is a primary purpose for 10 of the 16 ships in NOAA's fleet (see Table 1 for a listing of each NOAA

[17] NOAA Office of National Marine Sanctuaries. 2015. National Marine Sanctuaries and Local Economies. Available: http://sanctuaries.noaa.gov/science/socioeconomic/factsheets/welcome.html. Accessed 5/3/2017.

vessel and its primary mission). These ships are equipped with special technologies and experienced crew to support data collection.

Users: Fish stock assessments support sustainable fisheries by providing fisheries managers with the information necessary to maximize the long-term sustainable yield of the fishery. For example, by providing historical and current data, stock assessments allow scientists and regional fisheries management councils to compare the status of stocks to established targets, and adjust catch limits and stock targets accordingly. The data allows managers to determine how much catch is sustainable in general. In addition to fisheries management councils, states use stock assessments to manage non-Federal fish stocks. International management entities similarly use the assessments to oversee jointly-managed stocks that straddle international boundaries.

Fish stock assessments also enable regional management councils to develop short-, medium-, and long-term projections of fish population and catch trends. This in turn helps the management councils develop appropriate management plans, and scientists and public agencies to develop research priorities. Stock assessments are also used in other NOAA products such as the Living Oceans report, which informs the public of the status of fish stocks, and FishWatch, a national database that helps inform consumers of the sustainability of seafood. This information allows users to see which fish species are under pressure and adjust their consumption or recreational fishing habits accordingly.

Benefits to Society: Effective management of fisheries is essential for the commercial fishing industry as well as the populations that rely on them for food consumption and recreation. U.S. commercial fisheries contribute $153 billion ($54 billion without imports) and 1.4 million jobs to the U.S. economy each year (0.81 million jobs without imports). Recreational saltwater fishing generates $61 billion in sales.[18]

NOAA's fish stock assessments provide Regional Fishery Management Councils and other fisheries managers with stock status information so that they can more accurately set catch limits, thereby allowing commercial fisherman to catch more than would otherwise be permitted. As an example, 3.1 billion pounds of Walleye Pollock were landed in 2014, worth $400 million dollars. NOAA estimates that without the accurate stock assessments, regional fishery managers would have to reduce their catch quotas by approximately 10%, a $40 million annual impact.[19]

In addition, several studies have shown that U.S. residents are willing to pay to protect many different types of fish species, reflecting the value that society places on them. Fish stock assessments contribute to this value by ensuring sustainable catch limits and preventing overfishing of key species.

2.7 Tsunamis: Tsunami Inundation Forecast Models

Product Background: NOAA's Tsunami Inundation Forecast Models are used to predict the potential height and extent of tsunami flooding in U.S. coastal regions. These models, also known as standby inundation models (SIMs), are used in real-time tsunami forecasting and to create tsunami inundation maps (TIMs) for specific regions and communities. SIMs, and the site-specific TIMs, play an important role in community response and evacuation activities during tsunami events. They also support community risk assessments, planning, and preparatory/mitigation actions.

Dependency on NOAA Fleet: The Inundation Forecast Models depend on DEMs created by NOAA's National Centers for Environmental Information (NCEI), part of the National Environmental Satellite Data and Information Service. DEMs map out the elevation of various features in a certain geographic area. This information is important for knowing how tsunamis of various wave heights and amplitudes will translate into inundation zones/levels. To develop the DEMs, NCEI relies on high resolution bathymetry data, some of which is collected from NOAA vessels (note that the Sea Level

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[18] NMFS. 2016. Fisheries Economics of the United States, 2014. NOAA National Marine Fisheries Service. Available: https://www.st.nmfs.noaa.gov/Assets/economics/publications/FEUS/FEUS-2014/Report-and-chapters/FEUS-2014-FINAL-v5.pdf. Accessed 5/3/2017.

[19] NOAA. 2016. The NOAA Fleet Plan: Building NOAA's 21st Century Fleet. Available: https://www.omao.noaa.gov/sites/default/files/documents/The%20NOAA%20Fleet%20Plan_Final_31OCT.pdf Accessed 5/3/2017.

Rise Viewer product in Section 2.2 and the Nautical Charts product described in Section 2.3 also depend on the hydrographic/bathymetry data provided by the NOAA Fleet).

In addition to data from the NOAA Fleet, NCEI also uses coastal and marine LIDAR data, historic soundings, and bathymetry data collected by private vessels to develop DEMs. To develop the inundation forecasts, NOAA incorporates data from the National Water Level Observation Network (NWLON) and the Deep-Ocean Assessment and Reporting of Tsunami (DART) network. NWLON is a network of 210 long-term continuously operating water level stations throughout the U.S. and its territories. DART is an array of 39 buoy systems that detect and measure tsunami waves. While the fleet does not currently maintain the DART network, NOAA ships have been charged with this task as recently as 2014.

Users: Information from the Inundation Forecast Models directly informs community and regional planning efforts related to tsunami response and evacuation. NOAA works with local emergency managers to convert SIMs and site-specific TIMs into evacuation plans for various tsunami scenarios. During an actual tsunami, communities reference the TIMs to understand how the forecasted tsunami wave height will affect their community, and take appropriate response actions.

States and individual communities also use SIMs and TIMS to develop tsunami mitigation plans. For example, planners use information from SIMs and TIMs to assess inundation risks and to make decisions about the location of critical infrastructure, such as nuclear power plants, water and wastewater infrastructure, and hospitals, and implement other preparatory actions. There is also a large demand for the data from SIMs and TIMs from U.S. universities. Academics use this data to conduct further research on tsunamis, including examining ways to better predict tsunami threats.

Benefit to Society: The Inundation Forecast Models help communities better plan for and respond to potential tsunami events, thereby decreasing the impacts of these events, including number of lives lost, property damage, and other economic losses, such as unnecessary response and evacuation costs avoided by more accurate forecasts. The value of tsunami mitigation and response practices is still relatively unknown. While some studies have calculated the amount of damage caused by tsunamis, it is difficult to quantify the damages that would have occurred if effective evacuations and/or mitigation actions had not been implemented. In addition, the extent of damages depends on the magnitude and location of the tsunami, the amount of time available to implement response actions, the accuracy of the forecast, and the effectiveness of the warning system.

However, well-planned response actions and mitigation efforts can significantly reduce the impacts of tsunamis. For example, experts often cite the difference in damages associated with two tsunami events that impacted Crescent City, CA in 1964 and 2011. A tsunami produced by the 1964 Great Alaska Earthquake caused over $50 billion in damage and 11 deaths in Crescent City, while a tsunami produced by the 2011 Great Tohoku, Japan, earthquake resulted in $5 billion in damage and no deaths in the same location. These events produced waves with similar amplitudes and duration. The 1964 event did not benefit from having a response plan in place, but the 2011 event did.[20] While this significant decrease in impacts cannot all be attributed to tsunami response, it does speak to the potential benefits associated with tsunami response and mitigation planning, as well as the value of information in models such as SIMs and TIMs. An additional value of the inundation forecast is the information it provides to academic researchers, who are using this data to improve forecasting abilities. The results of this research will improve the effectiveness of response/mitigation actions, further reducing losses and injuries or deaths associated with tsunami events.

2.8 Harmful Algal Blooms: Forecasts and Mitigation Capability, Gulf of Maine

Product Background: Algae are simple plants that live in both saltwater and freshwater. In some cases, colonies of algae can grow or “bloom” out of control creating Harmful Algal Blooms (HABs), which result in toxic or harmful effects on people, fish, shellfish, marine mammals and birds. There are several species of HABs that can lead to wild and domestic animal deaths, shellfish toxicity, adverse public health effects including shellfish poisoning, and taste and odor problems in drinking water.

[20] Personal communication with Rocky Lopes, National Tsunami Hazard Mitigation Program Administrator Deputy Program Manager, on January 5, 2017.

HABs have occurred in all coastal areas of the U.S., with different species affecting different regions. This study focuses on HABs in the Gulf of Maine because NOAA ships contribute data that support HAB forecasts in this region and several studies have estimated the economic value of these forecasts. Blooms of the species *Alexandrium fundyense* in the Gulf of Maine have resulted in restrictions on commercial and recreational shell fishing. The toxins from *Alexandrium fundyense* can accumulate in shellfish, and if consumed by humans, can cause severe illness or death from paralytic shellfish poisoning (PSP).

In response to HAB and hypoxia threats, Congress passed the Harmful Algal Bloom and Hypoxia Research and Control Act in 1998, which led to the development and funding of integrated regional HAB and hypoxia research programs through NOAA's National Centers for Coastal Ocean Science (which is part of NOAA's National Ocean Service). Today large regional ecosystem programs addressing HAB issues have been implemented in three areas of the U.S., including the Gulf of Maine, Gulf of Mexico (in Florida and Texas), and the Great Lakes. These programs make up the NNCCOS's Harmful Algal Bloom Operational Forecast System (HAB-OFS).

The HAB-OFS forecasts assess and predict the extent of the algal blooms, allowing state and local managers to more effectively sample and monitor these areas. This allows managers to make decisions about beach closures, shell fishing restrictions, and other HAB-affected activities. In the Gulf of Maine, NOAA plans to transform the HAB-OFS from a pilot program started in 2008, to operational seasonal and weekly forecasts starting in 2017.

Dependency on NOAA Fleet: The HAB forecasts for the Gulf of Maine rely on several data sources that depend on the NOAA Fleet, including NOAA's HAB cyst maps [21], Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) moorings, and the National Marine Fisheries Service Northeast Fisheries Science Center hydrographic surveys.

Aside from data collected by the NOAA Fleet, the HAB-OFS also relies on satellite imagery, other remote sensing data, atmospheric data, field observations, models, public health reports and buoy data to provide large spatial scale and a high frequency of observations required for these forecasts. Much of this data comes from NOAA or other federal sources. However, institutions outside of government are also involved in research that supports HAB forecasts. In the Gulf of Maine, three universities help gather and analyze data. Canadian scientists have also been involved in research for HAB Forecasts in the Bay of Fundy, which borders both Maine and the Canadian provinces of New Brunswick and Nova Scotia.

Users: Local authorities use HAB forecasts to guide management decisions and protect public health. In the Gulf of Maine, state shellfish managers are responsible for sampling and testing different areas of the coast to assess the toxicity levels of the water and the shellfish. These managers use the HAB forecasts to determine where they should sample and perform these tests. If toxic levels of shellfish poison are detected, state shellfish managers must determine how much of the beach or the intertidal and submerged lands will be closed to shell fishing until subsequent tests show that the HAB has dissipated. In Maine, weekly forecasts also help managers carve out exception areas where shell harvesters can work even when much of the coast is closed.

The aquaculture industry also uses HAB forecasts to make management decisions. In the event of a HAB, states may monitor the area more frequently and companies may try to harvest their shellfish early.

Benefits to Society: HAB forecasts allow state shellfish managers and public health officials to close fishing areas and beaches more selectively and precisely, minimizing economic impacts associated with lost landings, and lost tourism while effectively protecting against adverse public health outcomes. Several studies have estimated the socioeconomic impact of HABs. For example, Athearn (2008) estimates lost sales of soft-shell clams associated with a strong 2005 HAB event in Maine amounted to approximately $2.21 million (2016 USD).[22] A separate study estimated the direct economic

[21] *Alexandrium fundyense* forms toxic blooms annually, depositing seed-like cysts in the ocean bottom sediments in the fall that remain dormant in the winter and bloom again in the spring. NOAA maps these cysts, and uses these data to initiate HAB forecast models for the upcoming algal bloom season in the spring and summer.

[22] Athearn, K. 2008. Economic Losses from Closure of Shellfish Harvesting Areas in Maine. University of Maine at Machias. Available: http://www.machias.edu/ assets/docs/appliedResearch/eco_losses_shellfish_jan08.pdf.

impacts of the same event in Maine and Massachusetts,[23] at $2.7 million (2016 USD) in economic impacts for Maine, and $20 million (2016 USD) for Massachusetts. These estimates include lost revenue and associated economic effects in the softshell clam and mussel fisheries.

Knowing the extent of past economic impacts due to strong HAB events, it becomes clear how valuable a timely and accurate HAB forecast can be. Before these forecasts were available, public health officials would have to close large portions of beaches to ensure public safety. However, as forecasts improve, decision-makers can narrow the scope of these closures and cut the length of time that they are closed, minimizing economic impacts. One study examined the value of HAB forecasts in the Gulf of Maine, assuming a HAB occurs every 10 years, the forecast is 100% accurate, and the responses are highly effective. The results of this study indicated that the annual value of a 100% accurate HAB forecast is approximately $795,000 (2016 USD). This value falls to $68,000 (2016 USD) per year if a HAB event is less frequent, the forecast is not 100% accurate, and the responses are not effective. However, if a HAB event occurs every other year and the responses are effective, the total value of a 100% accurate forecast increases to over $3 million annually. The study estimated the net present value of the forecasts over 30 years ranges from $57.2 million to $1 million (2016 USD), depending on HAB frequency, accuracy of prediction, and responses.[24]

2.9 Hypoxia: Hypoxia Watch, Gulf of Mexico

Product Background: The hypoxic zone in the Gulf of Mexico is the largest area of oxygen-depleted coastal waters in the US, and the second largest in the world's coastal ocean. In addition to impacting fisheries, hypoxic conditions can cause food web alterations, faunal mortalities, and habitat loss. Since 2001, NOAA's Gulf of Mexico Hypoxia Watch program (Hypoxia Watch) has published near real-time, web-based maps and data on Gulf region dissolved oxygen (DO) for the peak annual hypoxic period. The maps and data form an important part of the scientific basis upon which researchers, policymakers, fishermen, the public, and others base their understanding of the Gulf Hypoxic Zone. In addition, Hypoxia Watch maps and data provide a 15-year baseline of the Gulf hypoxic zone.

Dependency on NOAA Fleet: Each year from early June through mid-July, as part of the combined state/federal Southeast Area Monitoring and Assessment Program (SEAMAP), scientists aboard the NOAA research vessel *Oregon II* take measurements of DO and other water quality variables near the sea floor over the continental shelf from Texas to northwest Florida. Every one to three days, they transmit the data to NCEI scientists at Stennis Space Center, MS, who create dissolved oxygen maps based on these data, publish the maps and underlying data online for public use, and transmit the latest data and maps to Gulf hypoxia science partners.

Users: The information provided in Hypoxia Watch is used to inform managers that control the amount of nutrients entering upstream of the Gulf of Mexico of the progress of their efforts. It also serves as an essential baseline dataset and educational tool for researchers, educators, and decision-makers. For example, the interagency Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, which has a goal to reduce the size of the hypoxic zone through watershed nutrient reductions, relies on Hypoxia Watch maps and data for information on the causes and seasonal dynamics of the hypoxic zone. In every year since 2010, Hypoxia Watch products have also been used to inform proceedings of the Annual NOAA/NGI (Northern Gulf Institute) Gulf Hypoxia Research Coordination Workshops. These workshops and the follow-up activities strengthen communication and coordination between physical, biological, and socioeconomic modelers of Gulf of Mexico hypoxia, and the users and stakeholders, resulting in better planning for adaptive measures. Hypoxia Watch data is also critical to the success be used in of three new projects supported through the NOAA Northern Gulf of Mexico Ecosystems and Hypoxia Assessment Program, that are focused on advancing ecological models used to predict fisheries responses to future scenarios of hypoxia extent and severity.

Benefits to Society: Hypoxia impacts the food supply for commercially and recreationally-important fish species in the Gulf of Mexico. The economy of the Gulf of Mexico includes significant fishery and tourism activity. For example, Louisiana and Texas accounted for approximately $470 million, or two-thirds, of total U.S. revenue for shrimp

[23] Jin, D., E. Thunberg, and P. Hoagland. 2008. "Economic impact of the 2005 red tide event on commercial shellfish fisheries in New England." *Ocean and Coastal Management*, 51, 420-429.
[24] Jin, D. and P. Hoagland. 2008. "The Value of Harmful Algal Bloom Predictions to the Nearshore Commercial Shellfish Fishery in the Gulf of Maine." *Woods Hole Oceanographic Institution Marine Policy Center.*

landings.[25] While knowledge gaps still exist on the impact of the hypoxic zone on individual species, scientists and economists have already demonstrated habitat loss, migration shifts, and reproductive disruption. These impact commercial and recreational fishing patterns, reducing the economic vitality of these industries. While the hypoxic zone has not yet been demonstrated to affect overall population levels of brown shrimp in the northern Gulf of Mexico, during hypoxic conditions, there is an economic loss to fishermen. Hypoxia negatively affects the growth of shrimp resulting in higher numbers of smaller shrimp, which sell for lower prices than larger shrimp. [26]

2.10 Ocean Noise: Ocean Noise Mapping

Product Background: Human induced ocean noise, which is caused by commercial shipping traffic, oil and gas exploration and extraction, military sonar, and other sources, threatens marine life and ecosystems in many ways. Ocean animals use sound signals to communicate with other animals, such as when communicating with potential mates or offspring. They also rely on environmental sound cues that are vital to survival.

To better understand the impacts of rising ocean noise levels on marine life, NMFS, Office of Science and Technology (OST) developed two web-based mapping tools through NOAA's Cetacean & Sound Mapping effort (CetSound) which consists of two working groups that develop mapping tools, and two unique products - CetMap and SoundMap. CetSound's cetacean[27] mapping working group, or CetMap, produced time-, region-, and species-specific maps that use predictive environmental factors to estimate density and distribution of cetacean and fish invertebrates, and their migratory patterns. CetSound's underwater sound mapping working group, SoundMap, generated maps of temporal, spatial, and frequency characteristics of man-made underwater noise. Cetacean and sound maps enable ocean planners to better understand the effect of man-made noise for proposed activities.

Dependency on NOAA Fleet: CetMap incorporates the best available datasets for specific areas and species, including data collected from NOAA vessels, as well as by outside entities such as universities and conservation groups. CetMap is heavily reliant on data from NOAA Fleet habitat and protected species surveys. SoundMap similarly utilizes a variety of data collected from NOAA vessels and other sources to map ocean noise. NOAA ships contribute data to this product by servicing 10 ocean noise reference stations placed throughout U.S. waters to track changes in ocean noise trends over time and collecting empirical evidence man-made noise and its impacts.

Users: Resource managers use both mapping tools and associated data to plan, analyze, and make decisions on how to reduce adverse impacts of ocean noise on marine life. For example, the U.S. Navy, Bureau of Ocean and Energy Management, and other government agencies routinely use these tools to comply with environmental standards. In addition, CetSound's products formed the initial scientific basis for NOAA's 10-year vision for addressing ocean noise impacts, known as the Ocean Noise Strategy, including the implementation of the Ocean Noise Policy and Ocean Noise Procedure. Both CetMap and SoundMap are web-based products available to the public. Additionally, NOAA makes available underlying data (including geographic information system layers) and metadata for both mapping tools, either through the website or by request.

Benefits to Society: Reducing the impacts of man-made ocean noise can protect species by allowing natural defense and mating sound cues to operate normally and by permitting normal migratory patterns. Economists and scientists have conducted numerous studies over the past several decades to estimate economic values for similar species protection and rehabilitation. These studies use established survey methods to determine how much people are willing-to-pay for programs that protect specific species. While these programs are not specifically tied to man-made ocean noise, the overall benefits can be similar. These studies[28] have shown that households are willing to pay up to $82 (2016 USD) per household per year or more to benefit charismatic mammal species in US waters (such as right whales), which can add up

[25] NOAA National Marine Fisheries Service. 2016. Fisheries Economics of the United States, 2014. U.S. Dept. of Commerce. Highlights from the Annual Report. Available: https://www.st.nmfs.noaa.gov/Assets/economics/publications/FEUS/FEUS-2014/Outreach-materials/NOAA%20FEUS2014%20web_ready3.pdf. Accessed 2/3/17.

[26] Seafood prices reveal impacts of a major ecological disturbance. Available: http://www.pnas.org/content/114/7/1512.abstract.

[27] A cetacean is a member of classification of large aquatic mammals that includes whales, dolphins, and porpoises.

[28] Lew, D.K (2015). *Willingness to Pay for Threatened and Endangered Marine Species: A Review of the Literature and Prospects for Policy Use*. Front. Mar. Sci. 2:96. Available: http://journal.frontiersin.org/article/10.3389/fmars.2015.00096/full.

to a significant value for species preservation and habitat improvement. Society's willingness-to-pay to protect these species represent the value that society places on them.

2.11 Hurricanes: Hurricane Outlook

Product Background: NOAA's CPC produces the Atlantic Hurricane Outlook in collaboration with hurricane experts at NOAA's Hurricane Research Division and National Hurricane Center. The Hurricane Outlook serves as a general guide on expected activity for the upcoming hurricane season in the Atlantic Region, including the number of named storms, hurricanes, major hurricanes, and accumulated cyclone energy. The Outlook is probabilistic in nature, which means that it states the "likely" ranges of activity for the upcoming season. CPC releases the Hurricane Outlook in late May (prior to the start of the hurricane season), and updates it in early August (mid-season). The Hurricane Outlook is one of the most widely used/accessed online NOAA products. Communities, businesses, and other stakeholders use the Outlook to initiate and improve hurricane preparedness.

Dependency on NOAA Fleet: The Hurricane Outlook relies on data from various sources, including data collected by the TAO and ARGO arrays (note that the ENSO Forecast product also depends on the TAO and ARGO arrays; see section 2.4 for a discussion of the TAO and ARGO arrays). The Hurricane Outlook also uses sea surface and weather data collected through the Voluntary Observing Ship Program, which the NOAA Fleet is a part of.

Additional sources of global temperature and weather data come from land-based stations, weather balloons, and satellite measurements. CPC synthesizes data from these various sources and feeds it into climate models to make predictions about the upcoming hurricane season.

Users: More than 80 million U.S. citizens are potentially threatened by hurricanes each year. State and local emergency managers, federal agencies, and members of the public use the Hurricane Outlook to focus their resources and prepare for the upcoming hurricane season. Members of the business sector also use the Hurricane Outlook. For example, coastal tourism companies make seasonal operational changes based on the information found in the Outlook. The Small Business Administration promotes the Outlook and recommends preparedness efforts for small businesses. In addition, agencies like FEMA with their ready.gov website, the National Hurricane Center, and the Red Cross, use this Outlook to instruct the public on preparing for these storms.

Benefits to Society: Since 1980, 35 major hurricanes (those causing at least $1 billion in damages) have struck the U.S. with total losses exceeding $500 billion. The average annual losses from these 35 storms is nearly $16 billion.[29] The Hurricane Outlook helps key stakeholders better prepare for the hurricane season, which can lead to reductions in property damage, mortality and morbidity, societal costs associated with evacuation, and lost business activity. For example, Jamieson and Drury (1997) determined that loss of life associated with hurricanes exponentially decreased between 1900 and 1990 because of improved hurricane forecasts.[30] Considine et al. (2004) estimated the value of improved hurricane forecast information to oil and natural gas producers in the Gulf of Mexico. They found that existing hurricane forecast information helped to avoid $10 million (2016 USD) per year in unnecessary evacuation costs, and that this value would increase to more than $19 million (2016 USD) per year with a 50% improvement in forecast accuracy.[31] Emmanuel et al. (2012) also found potentially significant savings for the insurance industry associated with improvements in seasonal hurricane forecasts.[32]

2.12 Fleet Emergency Response Services

Background: NOAA ships are a key part of the U.S. ocean-related emergency and disaster response network, and are often called upon to provide the following emergency response services:

[29] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2017). https://www.ncdc.noaa.gov/billions/
[30] Jamieson, G., and Drury, C. 1997. *Hurricane mitigation efforts at the U.S. Federal Emergency Management Agency*, FEMA, Washington, D.C.
[31] Considine, T., Jablonowski, C., Posner, B., and Bishop, C. 2004. "Value of hurricane forecasts to oil and gas producers in the Gulf of Mexico." *Journal of Applied Meteorology*, 43, 1270–1281.
[32] Emmanuel, K., F. Fondriest, and J. Kossin. 2012. Potential Economic Value of Seasonal Hurricane Forecasts. *Weather, Climate, and Society*, 4(110 – 117).

- Survey our nation's ports and waterway in response to national security threats, helping enable the ability to rapidly re-open ports after they have been secured
- Deliver emergency supplies, conduct hydrographic surveys so that ports can be re-opened, and assess hazardous materials, during and after hurricanes and other major storm events
- Locate and map debris fields in the ocean for aviation and shipping disasters
- Conduct a range of scientific surveys in response to major oil spills
- Perform search, rescue, and evacuation services.

Dependency on NOAA Fleet: NOAA vessels have unique technologies and experienced crew members that, when combined with their availability across an expansive geographic area, can provide superior, timely, and cost-effective response services in many emergency situations.

NOAA Fleet emergency response activities most commonly include hydrographic surveys/data collection and mapping. For example, after hurricanes and large storm eventsat the request of the U.S. Coast Guard, crewmembers on NOAA vessels conduct hydrographic surveys to ensure safe navigation and re-opening of affected ports. NOAA also uses ship hydrographic survey technologies, which include complete seafloor mapping systems, to map debris fields from aviation disasters. This enables the quick recovery of victims and flight recorders. In addition, many of fleet's vessels are equipped with biological, chemical, and acoustic data collection equipment necessary for toxicity and water quality testing. NOAA is frequently called upon to employ these capabilities in response efforts for major oil and chemical spills and hurricanes, where a range of immediate testing is often required.

The vast geographic area across which the fleet operates also contributes to NOAA's response capabilities, because it typically means that at least one NOAA vessel can respond to an emergency location in a timely manner. Fleet vessels can also enter areas that require military or security clearance (e.g., military ports), whereas most contract vessels cannot. Finally, as the administrator of all NOAA Fleet activities, OMAO can easily coordinate across line offices to ensure that NOAA's other critical needs are being met throughout the emergency response period.

Together, these factors often make it much more feasible and cost-effective to utilize NOAA fleet vessels for emergency response activities, rather than having to pay contract vessels, which will likely charge premium prices (e.g., through time and materials contracts) for emergency situations, or other potential responders.

Benefits to Society: NOAA ships' disaster response capabilities are often essential to subsequent efforts in each emergency scenario. For example, pre- and post-event hydrographic surveying allows major ports and harbors to reopen to commercial shipping after hurricanes and other disasters, as well as following national security threats. The ability of NOAA ships to immediately survey ports allows important economic activity to resume. In 2015 alone, 1.39 billion short tons accounting for $1.56 trillion worth of U.S. goods moved through U.S. ports. Imports and exports via water represented 71% of U.S. imports and exports by weight and almost 42 percent of cargo value in 2015.[33]

Debris field location and mapping helps other federal, state, and local groups tailor search and rescue operations for air disasters. Ships already designed for scientific data collection can easily be redeployed to help with critical sampling after major oil spills. These efforts save lives, allow for the continuation of commercial activities and the assessment of natural resource damages. In addition, crew members on NOAA Fleet vessels often perform relatively routine search and rescue activities as required by International Maritime law and provide relief supplies to affected populations during emergencies. These activities have saved many lives over the course of the fleet's history.

The ability of NOAA's fleet to respond to emergencies also can result in cost savings relative to other potential responders. As noted above, NOAA Fleet vessels have unique technologies and are staffed with scientists and engineers

[33] Foxx, A., Perez, T. and Pritzker, P. (2016, March 7). *U.S. Ports: Investing in Engines of Economic Development and American Competitiveness* [U.S. Department of Transportation Blog]. p.1. Retrieved March 14, 2017 from https://www.commerce.gov/news/blog/2016/03/us-ports-investing-engines-economic-development-and-american-competitiveness. Statistics available at North American Transportation Statistics at http://nats.sct.gob.mx/go-to-tables/table-7-international-merchandise-trade/table-7-1-international-merchandise-trade-by-mode/

with expertise in hydrographic and scientific data collection, which accounts for a large majority of response activities, thus gaining significant efficiencies compared to finding vessels and forming crews specifically to respond to emergencies. In addition, NOAA ships are typically relatively easy to reroute with minimal impact to normal program activities. Thus, NOAA vessels can often provide superior, more cost-effective and timely response capabilities compared with other potential responders that may first need formal contractual authorization from the government.

3. Monetized Benefits of Select Products and Services

As detailed in Section 1, we worked with the NOAA/OMAO project team, TPIO, and the National Observing Systems Council, to select five NOAA products for further evaluation and quantification:

- Coral Reefs: Coral Reef Status and Trends Reports
- Sea Level Rise: Sea Level Rise and Coastal Flooding Impacts Viewer
- Bathymetry/Hydrographic Surveys: Nautical Chart Products
- Seasonal Forecast: ENSO Outlook
- Ecosystem Management: National Marine Sanctuaries Conditions Reports

For these five products, we estimated the monetary value or benefits that the product provides to society, and the percentage of this value that can be attributed to the NOAA Fleet. To estimate the benefits associated with each product, we relied on estimates from existing studies and literature, and applied these estimates (or range of estimates) to the relevant product. Collecting primary data to support an original valuation analysis was beyond the scope of this contract.

To estimate the percentage of the products' value that can be attributed to the NOAA Fleet, we relied on data provided by TPIO from the NOSIA-II model, as well as input from NOAA subject matter experts. Our estimates for the contribution of the NOAA Fleet are based on "denial of service," which is intended to capture the percentage decrease in performance that the product would experience if the NOAA Fleet was not available to provide necessary data inputs. Section 3.1 provides additional detail on the methodology we used to assess the contribution of NOAA ships to the value of individual products.

Table 4. Societal Benefits of Select NOAA Products and Associated Value of NOAA Fleet[1]

Value Chain/Product	Annual Anticipated Benefit of Product	Annual Anticipated Benefits Attributed to NOAA Fleet	
		Value	Percent
CORAL REEFS: Coral Status and Trends Report	**$0.590 - $1.190**	**$0.090 - $0.710**	**15.0% - 60.0%**
SEA LEVEL RISE: Sea Level Rise Viewer	**$1.480**	**$0.030 - $0.560**	**2.0% - 37.5%**
BATHYMETRY/HYDRO-GRAPHIC SURVEYS: Nautical Chart Products	**$0.058 - $0.120**	**$0.017 - $0.048**	**30.0% - 40.0%**
SEASONAL FORECASTS: El Nino Southern Oscillation Outlook	**$0.560 - $1.300**	**$0.026 - $0.270**	**4.6% - 20.0%**
ECOSYSTEM MANAGEMENT: National Marine Sanctuary Condition Reports	**$2.420 - $5.180**	**$0.610 - $1.800**	**25.0% - 35.0%**

1. Benefits of El Nino Southern Oscillation (ENSO) Outlook represent benefits associated with U.S. crop agriculture only. However, many other sectors benefit from ENSO information

3.1 Methodology for Estimating Value of NOAA Fleet

As noted above, we relied on two sources of data to estimate the percentage of total product benefits that can be attributed to the fleet: the NOSIA-II model and input from NOAA subject matter experts. The NOSIA-II model contains information on how individual data sources and observing systems contribute to the performance of specific products. To develop this data, TPIO surveyed more than 500 NOAA subject matter experts with knowledge of specific products, asking them to rate how well their products meet users' and stakeholders' needs and expectations. Based on a scale of 1 to 100, the average rating across subject matter experts represents the product's "status quo score." A score of 1 indicates that the product provides no value, while a score of 100 means that the product meets all expectations and exceeds some.

TPIO also asked the subject matter experts to consider the impact of removing individual data sources (such as the NOAA Fleet) from production of the product, and how that would affect the status quo score. For a given data source contributing to a given product, the "product delta" is the difference between the product's status quo score and the reduced product score corresponding to removal of the data source. Characterization of data source impacts to products is known as "swing weighting" in NOSIA-II. The product deltas are also referred to as "swing scores." [34]

TPIO adjusted the swing scores provided by the subject matter experts to better reflect the impact of various data streams on NOAA's mission service areas, rather than individual products.[35] This resulted in "weighted" swing scores. For this study, we were interested in using the unadjusted scores from NOAA subject matter experts because these scores provide a better assessment of the ship's full impact on product performance. Therefore, TPIO provided us with raw "unweighted" swing scores for NOAA ships and the observing systems they support (e.g., buoy systems). We used the unweighted swing scores to help us determine the contribution of the NOAA Fleet to the value of individual products.

In addition to the unweighted swing scores, we also relied on input gathered directly from NOAA subject matter experts. When interviewing experts at the product level, some expressed concerns that the TPIO swing scores did not fully reflect the impact or value of NOAA ships on their individual products We therefore asked the NOAA product experts to estimate the percentage of their product's total data inputs that comes from the NOAA Fleet and/or the buoy systems it supports. We also asked the subject matter experts to estimate the percentage decrease in product performance that would occur if data from the fleet was not available.

The unweighted swing scores and information from subject matter experts allowed us to develop a reasonable range of estimates for assessing the contribution of the NOAA Fleet as a percentage of the product's overall value to society.

The data used as inputs to this analysis represent the best available information. However, the studies upon which the quantifications are based were often few in number and, as with any study, limited in their accuracy, completeness, and broader applicability. Estimates of the contribution of the NOAA fleet to final products and services are based on extensive research and analysis by NOAA's Technology, Planning and Integration for Observation office (TPIO) but this work has its own limitations and the results have not been independently verified (as with a "denial of data" analysis). In short, the resulting values represent an empirical first step in the direction of developing more accurate and complete estimates of the value of NOAA products and services and the share of that value attributable to the NOAA fleet. A more scientifically rigorous analysis would require additional primary data collection and analysis which, if performed comprehensively, would be cost-prohibitive. This study does establish a scientifically sound

[34] NOAA National Environmental Satellite, Data, and Information Service. 2015. NOAA Observing System Integrated Analysis (NOSIA-II) Methodology Report. NOAA Technical Report. doi:10.7289/V52V2D1H. Available: https://nosc.noaa.gov/tpio/docs/NOSIA-II-Methodology-Report-v1.93-NOSC.pdf. Accessed 5/25/2017.

[35] When developing the swing scores for individual data streams, TPIO found that the "total product delta," which represents the sum of a product's swing scores across all data sources, amounted to greater than 100% for most products, which is indicative of the interdependency of data sources. To address excessive total product deltas, TPIO adjusted the swing scores for individual products. This adjustment resulted in "weighted" swing scores, which provided a better assessment of the data streams on NOAA's mission service areas.

process for assessing the societal benefits of the NOAA fleet and identifies critical information requirements that should be used to inform future research agendas.

3.2 Coral Reefs: Coral Reef Status and Trends Report

Monetary Value of the Coral Reefs in the U.S.: Coral reefs provide the U.S. with valuable goods and services including food, coastal protection, and opportunity for recreational activities. These goods and services in turn provide different types of economic benefits, including: recreational use values and associated tourism benefits; non-use values, such as willingness-to-pay for the existence of coral reefs; and amenity values, which can be measured by increases in value of properties located near coral reefs.[36,37]

Brander and van Beukering (2013) summarized studies of the benefits of coral reefs for U.S. states and territories with coral reef areas, including American Samoa, Florida, Guam, Hawaii, Puerto Rico, the Commonwealth of the North Mariana Islands, and the U.S. Virgin Islands.[38] Across all locations and benefit categories, the authors estimated the total economic value of coral reefs in the U.S. to be approximately $3.954 billion per year (2016 USD, Table 5).

Table 5. Annual total economic value of coral reefs in the U.S. (2016 USD)

State/Territory	Area of coral reef value (ha)	Total value (millions)
American Samoa	22,200	$13
Florida	36,000	$201
Guam	7,159	$161
Hawaii	165,990	$2,022
Puerto Rico	12,642	$1,265
North Marina Islands	6,494	$75
U.S. Virgin Islands	34,400	$217
U.S.	**284,885**	**$3,954**

This estimate does not completely cover all coral reefs in each geographic location – for instance the study for the North Mariana Islands only covered Saipan, for Puerto Rico, the study only covered the reef areas in the eastern part of the territory, and for Hawaii, only the Northwestern Hawaiian Islands are covered. Brander and van Beukering (2013) do not expect the underestimation of total value due to lack of geographic coverage to be large. However, the studies also do not cover all of the ecosystem service values in each location. For instance, Florida only covers direct use values but not non-use values, which can be significant.

Value of Report Cards and NOAA Fleet Contribution: The Status and Trends Report Cards will inform decisions by U.S. Congress and NOAA leadership regarding the allocation of resources to protect coral reefs, while the associated jurisdictional-level reports will play a significant role in the direct management of these resources. For

[36] Non-use values reflect the fact that many individuals who do not use a specific resource (e.g, National Marine Sanctuaries, national parks, Great Lakes) for recreation or other purposes still value their existence. Individuals may value these resources for the ecosystem services they provide, because they may want the option to use them in the future, or because they recognize their importance for future generations. Economists often use willingness-to-pay studies to assess the non-use value of specific resources and environmental goods and services.

[37] Brander, Luke and Pieter van Beukering, 2013. "The Total Economic Value of U.S. Coral Reefs: A Review of the Literature". Coral Reef Conservation Program. National Ocean and Atmospheric Administration. Available: https://data.nodc.noaa.gov/coris/library/NOAA/CRCP/other/other_crcp_publications/TEV_US_Coral_Reefs_Literature_Review_2013.pdf. Accessed 1/20/17.

[38] *Ibid.*

purposes of this report, we estimate that between 15% and 30% of the $3.954 billion coral reef value for the U.S. can be attributed to these products. Thus, the value of the Coral Reef Status and Trends Report Cards amounts to approximately $0.593 to $1.185 billion per year.

Based on TPIO's unweighted swing scores from NOSIA-II, 15% of the value of Coral Reefs Status and Trends Report Cards can be attributed to the NOAA Fleet. On the other hand, NOAA subject matter experts in coral reefs estimate that 60% of the data used in the report cards comes from NOAA ships. Therefore, the percent of valuable attributable to the NOAA Fleet is estimated to be 15% at the lower end and 60% at the upper end. Thus, $90 million to $711 million (2016 USD) of the value of the Report Cards can be directly attributed to the NOAA Fleet (Table 6).

Table 6. Annual Benefits of NOAA Fleet, Coral Reefs Status and Trends Report Cards (2016 USD)

	Lower-bound estimate	Upper-bound estimate
Value of coral reefs (billions)	$3.95	$3.95
Percent of coral reef value attributable to Status and Trends Report Card	15%	30%
Value of Status and Trends Report Card	$0.593	$1.185
Percent of Status and Trends Report Card value attributable to NOAA Fleet (billions)	15%	60%
Total Annual Benefits of NOAA Fleet (billions)	**$0.090**	**$0.711**

3.3 Sea Level Rise: Sea Level Rise Viewer

Value of Potential Damages in the U.S. From Sea Level Rise: Global sea levels have risen by 8 inches since 1880, and are projected to rise 2 to 6 or more feet by 2100, depending on the emissions scenario modeled.[39] A 2014 study by the U.S. EPA estimates that sea level rise impacts from inundation of coastal property and from storm surge that is amplified by sea level rise will total $5 trillion for the coterminous U.S. by the year 2100 (2014 USD). Adaptation measures can reduce this impact. For example, the study estimates that protective coastal measures such as armoring shorelines could reduce the impacts associated with sea level rise to $810 billion through 2100. This includes the value of abandoned property, residual storm damages, and costs of protective adaptation measures. Results of the study also indicate that mitigation measures to reduce greenhouse gas emissions could further reduce total costs to approximately $790 billion, if these measures are adopted.[40]

The Value of the Sea Level Rise Viewer and NOAA Fleet Contribution. The EPA study of sea level rise impacts estimates that implementing effective adaptation options will reduce the impacts/costs of sea level rise from $5 trillion to $810 billion by 2100 (2014 USD),[41] a savings of $4.19 trillion, including the cost of adaptation measures. We divide this value over 86 years from 2014 to 2100 to get an annual value of $48.7 billion (2014 USD). Escalating this to 2016 USD, total annual avoided costs associated with adaptation measures amounts to $49.4 billion.

To estimate the value of the SLR Viewer, we need to account for how it contributes to the reduction in avoided costs associated with adaptation planning and implementation. The SLR viewer is a mapping product that decision makers can use as a first step in assessing vulnerability and deciding on actions to mitigate impacts. Based on input from

[39] Melillo, J., T. Richmond, and G. Yohe, Eds. 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. Appendix 5: Scenarios and Models. U.S. Global Change Research Program. DOI:10.7930/J0Z31WJ2.
[40] U.S. EPA. 2014. "Climate Action Benefits: Coastal Property". Coastal Action Benefits Report. Available at: https://www.epa.gov/cira/climate-action-benefits-coastal-property. Accessed February 5, 2017.
[41] This study applied a 3% discount rate to estimate the value of damages in future years in 2014 USD. The discount rate accounts for the time value of money.

subject matter experts and our understanding of the product, we use 3% as a rough value representing the SLR Viewer's contribution to the overall value of adaptation and associated avoided sea level rise impacts.[42]

In addition, data from the NOSIA-II model indicates that approximately 2% of the benefits associated with the SLR Viewer can be attributed to the NOAA Fleet. On the other hand, NOAA subject matter experts estimate that 50% of the data used in the viewer comes from Vertical Datum Transformation (VDATUM), and that approximately 75% of the data in VDATUM comes from NOAA ships. Therefore, 37.5% of the value of the SLR Viewer can be attributed to NOAA ships (50% of total data from VDATUM * 75% ships share of VDATUM). For estimation purposes, we use the 2% TPIO estimate as the low end of the range and 37.5% as the upper end of the range of the percent of value from the SLR Viewer attributable to NOAA ships. This yields an annual benefit estimate for the NOAA Fleet of approximately $30.0 million to $556 million (2016 USD, Table 7).

Table 7. Annual Benefits of NOAA Fleet, Sea Level Rise Viewer (2016 USD)

	Lower-bound estimate	Upper-bound estimate
Annual Value of Sea Level Rise Adaptation (billions)	$49.4	$49.4
Percent of value attributable to SLR Viewer	3%	3%
Value of SLR Viewer (billions)	$1.48	$1.48
Percent of SLR Viewer value attributable to NOAA Fleet	2%	37.5%
Total Annual Benefits of NOAA Fleet (billions)	**$0.0296**	**$0.556**

3.4 Bathymetry/Hydrographic Surveys: Nautical Chart Products

Value Estimates for Nautical Chart Products: NOAA's nautical charts support safe and efficient navigation at our nation's ports and throughout U.S. waterways. Nautical charts also support improved environmental/ecological planning and analysis, including hazardous material spill response, as well as efforts related to homeland security, protection of the marine environment, and coastal zone management. In 2007, Kite-Powell conducted a study for the NOAA Office of the Coast Survey to estimate the benefits of nautical charts for recreational and commercial vessels, based on a survey asking users what they would be willing-to-pay for 'ideal' nautical charts (i.e., nautical charts containing specific characteristics identified by users).[43] Assuming a minimal difference between the nautical charts that were available at the time and ideal charts, the author estimated that the combined benefits of nautical charts amounted to $47.5 million (2007 USD),[44] including $15.3 million/year in consumer surplus for recreational users, $27.5 million/year in consumer surplus for commercial users, and $2 million/year in producer surplus. We estimate that today, this value amounts to approximately $57.9 million/per year (2016 USD), accounting for the increase in foreign flag ships visiting U.S. ports between 2007 and 2016.[45]

While this study provides an order of magnitude estimate of the value of nautical charts, the authors acknowledge that it serves as a lower bound estimate, largely because the study did not include military and other federal users, commercial fishing vessels, or marine resource managers, among others. In addition, since the study was conducted in

[42] The 3% estimate is based on our understanding of how stakeholders use the product to make decisions. The project team believes this represents a conservative estimate of the value of the data and tools incorporated into the SLR Viewer in terms of reducing potential impacts of SLR.
[43] Kite-Powell, H. 2007 Use and Value of Nautical Charts and Nautical Chart Data in the United States. Prepared for NOAA Office of Coast Survey.
[44] Leveson, I., (2012). Socio-Economic Study: Scoping the Value of NOAA's Coastal Mapping Program Final Report. *Leveson Consulting.* p. 47
[45] Values for recreational and commercial consumer surplus and producer surplus increased to 2016 USD using BLS Consumer Price Index.

2007, digital nautical charts have become even more popular, now allowing for weekly updates that provide additional value to users.[46]

In a more recent study, NOAA (2013) evaluated the benefits associated with the Physical Oceanographic Real Time System (PORTS), a decision support tool that combines nautical charts and other data critical for navigation (e.g., information on water levels, currents, waves, water temperature, bridge heights, winds, visibility, atmospheric pressure, and air temperature) to provide mariners with accurate and reliable real-time information about environmental conditions in seaports. This "coastal intelligence" helps mariners make better safety and economic decisions. PORTS was first introduced in Tampa Bay in 1991 and as of 2013, was available at 58 of the nation's 175 major seaports (which account for 75% of the total tonnage that passes through U.S. seaports). NOAA estimates that the value of PORTS amounts to more than $238 million per year at the 58 major seaports where it is available, in terms of reduced marine accidents, increased marine transportation efficiency (including increased cargo capacity and reduced transit delays), and oil spill reduction and containment benefits (Table 8).

Table 8. Value of NOAA PORTS to the U.S. Economy

Benefit	Annual Benefits at 58 Ports w/access to PORTS ($, Millions)[a,b]	Potential Annual Benefits from 117 Ports without access to PORTS ($, Millions)	Total current and potential benefits ($, Millions)
Commercial traffic – increased cargo capacity	$131.6	$44.8	$176.4
Commercial traffic – reduced delays in transit	$ 84.1	$31.7	$ 115.8
Oil spill reduction and containment	$3.9	$1.9	$5.7
Reduction in commercial marine accidents Property damage Morbidity and mortality	$ 18.7	$10.8	$29.5
Reduction in recreational boating accidents Property damage Morbidity and mortality	$0.3	$0.3	$0.7
Total	**$238.6**	**$89.5**	**$328.1**

Source: Wolfe, K. and McFarland, D. 2013. *An Assessment of the Value of the Physical Oceanographic Real-Time System (PORTS) to the U.S. Economy*. NOAA National Ocean Service.

a. Benefits associated with enhanced commercial and recreational fishing experiences were excluded from this table because they mostly relied on data/information that was not derived from nautical charts.

b. All values updated from 2010 USD using Bureau of Labor Statistics Consumer Price Index.

Value of Nautical Chart Products and NOAA Fleet Contribution. While the NOAA PORTS 2013 study included benefits associated with the entire PORTS system and associated data inputs, PORTS is heavily reliant on nautical charts. For this analysis, we assumed that 50%, or $119.4 million (2016 USD), of the $238.6 million value of PORTS can be attributed nautical charts; we used this estimate as an upper bound value for the benefits of nautical charts for marine transportation. As a lower end of the range, we used the willingness-to-pay estimate of $57.9 million per year.

Based on information from TPIO and NOAA subject matter experts, approximately 30% (TPIO estimate) to 40% (subject matter expert estimate) of the value of nautical charts can be attributed to the NOAA Fleet. Thus, the annual value of the NOAA Fleet contribution to nautical charts amounts to between $17.4 million and $47.8 million per year (Table 9). While we provide a range of estimates, we believe they both represent a lower bound for several reasons. First, they reflect benefits associated with marine transportation only; they do not reflect the other benefits and uses of nautical charts, such as those related to coastal zone management, homeland security, and ecological management. In

[46]In addition, because survey respondents knew how much they paid for nautical charts, this could have resulted in an anchoring bias, leading to more conservative estimates of value.

addition, the value of PORTS focuses on 58 of the nation's major seaports – it does not capture benefits associated with nautical charts at the remaining 117 major ports, or elsewhere within the U.S. Exclusive Economic Zone.

Table 9. Annual Benefits of NOAA Fleet, Nautical Charts (2016 USD)

	Lower-bound estimate	Upper-bound estimate
Annual value of Nautical Charts for Marine Transportation (billions)	$0.0579 million	$0.119
Percent of nautical chart value attributable to NOAA Fleet	30%	40%
Total Annual Benefits of NOAA Fleet (billions)	**$0.0174**	**$0.0478**

3.5 Seasonal Forecasts: ENSO Outlook

Value of ENSO Information: Over the last 40 years, NOAA and others have drastically improved the accuracy of ENSO forecasts, and can now predict these events, and their expected impacts on different regions, with 70% to 80% accuracy a year before they occur.[47] Seasonal outlooks of temperature and precipitation make use of ENSO information and other tools. ENSO is the largest driver of climate variability on the seasonal timescale. Decision-makers in sectors affected by seasonal variations in temperature and precipitation to help turn climate events to their advantage (Table 10). For example, farmers can use seasonal forecasts of precipitation and temperature to make decisions about what crops to plant. Similarly, energy distribution companies can increase stockpiles of heating oil and gas if the coming winter is forecast to be colder than usual, thereby avoiding shortfalls that are costly to both distributors and consumers.[48] Private retailers or grocery chains can use seasonal climate forecasts to rearrange merchandise to anticipate shifts in seasonal needs.

In addition to private industry sectors, decision-makers working in the public interest can use seasonal climate forecasts to make decisions that result in significant societal benefits. For example, a 2016 study analyzed the potential benefits of using ENSO forecasts to manage water resources in small to mid-sized communities of the southeastern U.S. Using Auburn, Alabama as a case study, the researchers found that the city could have saved $1.2 million and $490,000 in avoided water purchases during 1999-2000 and 2007-2008, respectively, if they would have developed a drought management plan based on seasonal forecast information. Study results also showed that higher savings were associated with more severe drought conditions.[49]

In addition, ENSO can result in a range of natural disasters, including severe droughts, floods, wildfires, and disease outbreaks. In the absence of any forewarning of near future climate conditions, mitigation options tend to be reactive in nature. Emergency managers and other decision makers can use seasonal climate forecast information to develop proactive mitigation strategies and allocate resources accordingly, which can result in significant cost savings. For example, prior to the 1997-1998 El Niño, NOAA's National Weather Service (2011) reports that California's emergency management agencies and FEMA spent an estimated $245 million (2016 USD) preparing for storms and heavy rain. Actual storm losses in the 1997- 1998 El Niño were close to $1.6 billion (2016 USD), compared to over $3.2 billion (2016 USD) in damages resulting from the intense 1982-1983 El Niño, for which little preparatory actions were taken. Although portions of the $1.6 billion difference are due to different intensities and durations of storminess during each El Niño, NOAA believes that a significant portion of the savings came from heightened preparedness.[50]

Value of ENSO Outlook and NOAA Fleet Contribution: In the U.S., one of the sectors most impacted by ENSO is crop agriculture. Several studies have shown that individual farmers can use forecasts to maximize revenues or increase economic gains, relative to a "no forecast" scenario (e.g., by planting crops that perform best under expected

[47] Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.210.381&rep=rep1&type=pdf
[48] Weiher, R. and H.L. Kite-Powell. 1999. Assessing the Economic Impacts of El Niño and Benefits of Improved Forecasts.
[49] Sharda, V. and P. Srivastava. 2016. Value of ENSO-Forecasted Drought Information for the Management of Water Resources of Small to Mid-Size Communities. Dollar year not reported.
[50] NOAA National Weather Service. 2011. Value of a Weather-Ready Nation. http://www.performance.noaa.gov/wp-content/uploads/PPI-Weather-Econ-Stats-10-13-11.pdf

ENSO conditions). Chen et al. (2002)[51] estimated the value of ENSO forecasts for both U.S. agricultural producers and consumers, accounting for changes in supply and demand, and the associated impact on prices for agricultural goods. Assuming farmers optimize their decisions based on forecast information, the authors estimated that the total economic benefits of ENSO forecasts ranged from $295 and $700 million per year (1996 USD) for crop agriculture,[52] depending on forecast accuracy and ENSO phase definition.

[51] Chen, C., B. McCarl, and H. Hill. 2002. Agricultural Value of ENSO Information Under Alternative Phase Definition. *Climatic Change*. 54:305-325.
[52] Including wheat, sorghum, corn, and soybeans.

Table 10. Value of ENSO Forecasts across Economic Sectors[1]

Economic Activity	Total Amount of Sector Economic Activity[2]	Effect of Long Term Weather Fluctuations	How Forecasts Can Be Used	Example Forecast Value Estimates (updated to 2016 USD)[3]
Crop agriculture	$188 billion (2016 cash receipts, all U.S.)[4]	Temperature and rainfall affect crop yields	Farmers can select crop varieties and planting timelines appropriate to expected temperature and rainfall conditions; distributors can reduce commodity storage if uncertainty about future yields is reduced	$719 - $1,410 million in benefits for agricultural producers and consumers.[5]
Fisheries	$5.3 billion (2015 landings, all U.S.)[6]	Water temperature and streamflow affect fish abundance and reproductive behavior	Fishery managers can adjust harvesting to ensure adequate spawning	Up to $1.43 million/year for one northwestern Coho salmon fishery.[7]
Oil and Gas	$86 billion (2015 natural gas distribution) $92 billion (2015 fossil fuel electric power generation)	Temperature affects demand for heating fuels	Energy suppliers can adjust fuel stores and better time drawdown of stored fuel	~$720,000 savings for one university heating plant where manager used ENSO forecast to guide natural gas purchasing decisions.[8]
Hydropower	$7.8 billion (2015 Hydroelectric and other non-fossil fuel power generation)	Streamflow/water availability affects hydropower production	Energy managers can use long-lead ENSO-based streamflow forecasts to improve reservoir operating system performance for hydropower generation.	Up to $204 million/year increase in average revenues from major Columbia River hydropower dams.[9]
Storm damage mitigation and repair	$246 billion (2015 residential and non-residential maintenance and repair)	Storms (wind and precipitation) cause damage to buildings and other infrastructure	homeowners can take measures to minimize storm damage (preemptive repairs); municipalities can prepare for possible floods (clearing drainage canals, etc.)	Not available

Table 10. Value of ENSO Forecasts across Economic Sectors (continued)

Economic Activity	Total Amount of Economic Activity	Effect of Long Term Weather Fluctuations	How Forecasts Can Be Used	Example Forecast Value Estimates (updated to 2016 USD)
Recreation	$364 billion (2015 hotels and relevant recreational and amusement sectors)	Temperature and snowfall affect winter sports conditions; rainfall affects other outdoor recreation	vacationers can improve their vacation experience by better planning their travel and sports activities; resort managers (e.g., ski resorts) can use forecasts to set prices, hire, market, understand snowmaking costs	Not available
Construction	$1.1 trillion (2015 construction industries)	Temperature and precipitation affect whether construction can proceed	construction managers can better schedule projects, make staffing decisions	Not available
Retail	$714 billion (2015 relevant retail sectors)		Retailers can use ENSO forecast to optimize seasonal inventory decisions, minimize losses due to either unsold inventories or maximize gains when anticipated demand does occur.	Not available

1. Adapted/modified from table originally developed by Weiher and Kite-Powell, 1999
2. Except for agriculture and fisheries, dollar amounts represent economic output by sector as published by U.S. Bureau of Economic Analysis. Economic activity provided to indicate scale of sector relative to other sectors in U.S. economy.
3. Values updated based on Consumer Price Index, as published by Bureau of Labor Statistics unless otherwise indicated. For crop agriculture, benefits escalated based on percent increase in output for relevant crop sectors (see Section 3.5.2)
4. USDA Economic Research Service, Farm Income and Wealth Statistics, https://data.ers.usda.gov/reports.aspx?ID=39625
5. Chen, C., B. McCarl, and H. Hill. 2002. Agricultural Value of ENSO Information Under Alternative Phase Definition. *Climatic Change*. 54:305-325.
6. NOAA Office of Science and Technology Commercial Fisheries Statistics, https://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/
7. Costello, C.J., Adams, R., and S. Polasky. 1998. The Value of El Niño Forecasts in the Management of Salmon: A Stochastic Dynamic Assessment. American Journal of Agricultural Economics, 80(4), 774.
8. Changnon, D.T. Creech, N. Marsili, W. Murrell, and M. Saxinger. 1999. Interactions with a Weather-Sensitive Decision Maker: A Case Study Incorporating ENSO information into a Strategy for Purchasing Natural Gas. Bulletin of the American Meteorological Society.
9. Hamlet, A.F., D. Huppert, D. P. Lettenmaier. 2002. Economic Value of Long-Lead Streamflow Forecasts for Columbia River Hydropower. Journal of Water Resources Planning and Management. 128(2): 91 – 101.

The authors also estimated that ENSO forecasts resulted in an additional $54 - $104 million (1996 USD) in benefits to foreign producers and consumers, due to global nature of the agricultural markets.

Agricultural yields for the crops assessed in Chen et al. have increased by 90 percent since 1996, the year assessed in their study.[53] For this reason, we increased the figures in Chen et al. by 90 percent, reflecting the assumption that the additional crop production would also benefit from the use of ENSO forecasts. This yields an estimated value of ENSO information for U.S. crop agricultural producers and consumers of between $560 to $1,328 million per year (2016 USD). Including foreign surplus, total annual benefits amount to between $719 to $1,410 million (2016 USD), with higher foreign surplus associated with lower U.S. benefits.[54] However, benefits to foreign nations are not a strong argument for U.S. investments in the NOAA Fleet. For this reason, we did not include benefits accruing to foreign nations in our benefit estimates for this product.

The unweighted TPIO swing score representing the NOAA ship impact on the ENSO Outlook is 4.6%. This estimate includes the TAO and ARGO arrays, which the fleet support. NOAA subject matter experts estimated a much higher dependence on the NOAA Fleet, indicating that the ships and observing systems they support account for approximately 50% of the Global Ocean Data Assimilation System (GODAS), which supports ENSO prediction and monitoring reflected in the Outlook. In addition, the subject matter experts indicated that there is no substitute for the data collected by the TAO array, and therefore, by maintaining the TAO buoys, the NOAA Fleet contributes significantly to the value of the Outlook. Recognizing that GODAS accounts for only a part of the total production of the Outlook, we attributed 20% of total benefits of the ENSO Outlook to the NOAA Fleet as the upper end of our range. Given that NOAA data serve as the primary resource for ENSO forecasts/publications in the U.S. (not just the ENSO Outlook), we did not attempt to separately value the Outlook as being distinct from other forecast products.

Based on existing studies we know that seasonal climate forecasts that are dependent on ENSO information can result in $560 to $1,328 million dollars in benefits each year in the U.S. agricultural sector alone. Approximately $26 to $266 million (2016 USD) of this total can be directly attributed to the NOAA Fleet (Table 11).

Table 11. Annual Benefits of NOAA Fleet, ENSO Outlook (2016 USD)

	Lower-bound estimate	Upper-bound estimate
Annual value of ENSO Forecast for U.S. agricultural (crop) producers and consumers, and associated foreign surplus (billions)	$0.560	$1.33
Percent of forecast value attributable to the product	100%	100%
Percent of value attributable to NOAA Fleet	4.6%	20%
Total Annual Benefits of NOAA Fleet (2016 USD)[a]	**$0.0258**	**$0.266**

a. Represents benefits for U.S. crop agriculture sector, including U.S. producer and consumer surplus

3.6 Ecosystem Management: National Marine Sanctuaries Conditions Report

Background: The National Marine Sanctuary Conditions Reports directly contribute to regulations, policies, management actions, and education programs related to marine sanctuaries, which in turn helps to protect the important benefits that the sanctuaries provide, including:

[53] The 90% increase in production value accounts for price changes from 1996 to 2016 for each of the four crops included in the study, which included inflation-related effects, increases in the acreage cultivated, and increased productivity (output per acre).
[54] Foreign surplus updated to 2016 values based on Bureau of Labor Statistics Consumer Price Index.

- *Market benefits*, which reflect the positive local economic impacts associated with sanctuary-related activities, such as tourism, recreation, and commercial fishing

- *Non-market benefits*, including benefits for individuals and recreators who directly use and/or passively enjoy sanctuary resources, as well as benefits for those who do not visit or use the sanctuaries, but who value the important habitat and species protection services they provide.[55]

The market benefits associated with National Marine Sanctuaries represent the direct spending/revenues generated by sanctuary-related activities, and the additional economic activity (i.e., sales, income, employment) that this spending creates as it ripples through the local economies in which the sanctuaries are located.

NOAA and others have conducted several studies to examine the market benefits associated with individual sanctuaries. Most of these studies have focused on tourism and recreation because these activities account for the largest portion of sanctuary-related economic activity. In total, NOAA estimates that spending on coastal tourism and recreation in areas adjacent to all National Marine Sanctuaries amounts to $5.2 billion (2015 USD) per year. After accounting for multiplier effects in the economy, this spending generates more than $7.3 billion in total economic activity (i.e., sales/output).[56]

In addition, NOAA estimates that commercial fishing activity associated with the sanctuaries generates approximately $463 million (2015 USD) in total economic activity per year. This estimate includes revenues associated with commercial fish landings, as well as for businesses that supply the fishing industry, and spending by individuals (e.g., fishermen) that benefit from the increase in commercial fishing revenues. Finally, NOAA estimates that spending by the federal government, educational institutions, and non-profit groups for sanctuary-related research generates approximately $200 million (2015 USD) in economic activity per year.[57]

In total, NOAA reports that tourism, recreation, commercial fishing, and research activities associated with the sanctuaries generate more than $8 billion (2015 USD) per year in economic activity in adjacent local economies.[58]

In addition to positive economic effects for local economies, National Marine Sanctuaries provide benefits to individuals who directly use sanctuary resources for recreational activities such as boating, fishing, snorkeling, or other more passive beach activities. The values associated with these activities result in what economists refer to as "use benefits." There are also many individuals who may not use the sanctuaries directly, but who value their existence for various reasons. The values that these individuals derive from National Marine Sanctuaries are known as "non-use benefits."

Economists refer to use and non-use benefits as non-market benefits because there is no market in which their price, or value, is determined. For example, when users of sanctuaries go on a scuba diving trip, there is no cashier taking their money as they enter the water. Similarly, it is difficult to capture the value that individuals hold for the species protected by the sanctuaries. While there is no established price for these services, economists employ a variety of methods for measuring these benefits indirectly.

While NOAA has not conducted a comprehensive study of the nonmarket benefits associated with all marine sanctuaries, several studies provide insights into the magnitude of different types of use and non-use benefits at individual sites. For example, in 2012 NOAA conducted a national survey to assess how much households within the U.S. would be willing to pay to expand the boundaries of the Flower Garden Banks National Marine Sanctuary (Gulf of Mexico) from its current three banks to nine additional banks. Results of the study indicated that households were willing to pay $36 to $111 (2015 USD) per year to expand the sanctuary – a total of $4.1 to $12.7 billion (2015 USD)

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55 Wiley, P. 2003. Valuing Our National Marine Sanctuaries. National Oceanic and Atmospheric Administration - National Ocean Service Office of Management and Budget - Special Projects

56 Personal communications, Bob Leeworthy, Chief Economist, NOAA/NOS/Office of National Marine Sanctuaries. April 11, 2017. Based on studies of market benefits at individual National Marine Sanctuary sites.

57 *Ibid.*

58 NOAA Office of National Marine Sanctuaries. National Marine Sanctuaries and Local Economies. Available: http://sanctuaries.noaa.gov/science/socioeconomic/factsheets/welcome.html. Accessed 5/3/2017.

across all U.S. households. Since most of the survey respondents did not use/visit the sanctuary, these totals represent non-use values.[59]

Another study estimated the use values associated with recreating on artificial and natural reefs in Monroe County (Florida Keys) for residents and visitors. Employing an on-site survey, the authors estimated that the total use benefits associated with these resources amounted to more than $69 million (2015 USD) per year at this site. This included values for residents and visitors for reef -related activities such as boating, fishing, scuba diving, and snorkeling.[60]

Total Value of National Marine Sanctuaries: The amount that individuals spend to participate in sanctuary-related tourism or recreation (or the amount that businesses benefit from these activities) provides an indication of how much they value these activities, and therefore how much they value the sanctuaries themselves. Similarly, commercial fishing revenues made possible by the sanctuaries provides an indication of sanctuary value for this industry. Thus, the $8 billion in market benefits associated with all sanctuaries serves as order-of-magnitude estimate for the sanctuaries' total use value. However, the market benefits represent a lower-bound estimate of value for several reasons. First, individuals may be willing to pay even more to enjoy National Marine Sanctuaries – in this case, total spending is not equal to total value. In addition, NOAA's market value estimates include only the money spent or revenues generated in the economies adjacent to the sanctuaries; it does not represent for example, the amount that tourists spend to get to the sanctuary location (e.g., on plane tickets, etc.).[61]

The market benefits associated with the sanctuaries do not capture non-use benefits. However, based on the study on the Flower Garden Banks National Marine Sanctuary, we know that U.S. households would be willing to pay $36 to $111 per year to expand just one site. This means that across the 116 million households in the U.S., total non-use values amount to between $4.2 and $12.9 billion per year (2015 USD) for the expansion of that Sanctuary. Thus, it is not hard to imagine that households would be willing to pay at least this much to maintain the non-use benefits associated with all 13 National Marine Sanctuary sites.

Based on the studies described above, the total use and non-use values of the sanctuaries amount to at least between $12.2 and $20.9 billion per year (Table 12).

[59] Stefanski, S. F., and J. Shimshack. 2015. Valuing Marine Biodiversity in the Gulf of Mexico: Evidence form the Proposed Boundary Expansion of the Flower Garden Banks National Marine Sanctuary. Marine Resource Economics. 31(2): 211-232.
[60] Johns, G. M., Leeworthy, V. R., Bell, F. W., & Bonn, M. A. Socioeconomic Study of Reefs in Southeast Florida. NOAA Office of National Marine Sanctuaries.
[61] To estimate use value, economists use well-established methods such as travel cost models or willingness-to-pay surveys. Economic impacts/market benefits are not typically included in benefits analysis. However, due to limited available data, we are applying market benefits to provide an order of magnitude estimate of use value.

Table 12. Annual Economic Value of National Marine Sanctuaries (billions, 2016 USD)

	Lower-bound estimate	Upper-bound estimate
Annual use value of National Marine Sanctuaries[a] (based on market benefits)	$8.0	$8.0
Annual non-use value of National Marine Sanctuaries	$4.2	$12.9
Total annual economic value	**$12.2**	**$20.9**

a. Includes $8 billion in use benefits and $4.1 to $12.9 billion in non-use benefits per year.

Value of National Marine Sanctuaries Condition Reports and NOAA Fleet Contribution: NOAA and other stakeholders rely heavily on the National Marine Sanctuary Conditions Reports to make decisions about sanctuary management. Thus, they contribute significantly to the sanctuaries' value by protecting the important benefits they provide. Based on input from subject matter experts, we estimate that 20% to 25% of the total value of National Marine Sanctuaries can be attributed to use of the Conditions Reports, which improve management actions that maintain the benefits associated with the Sanctuaries and prevent their future degradation. Thus, the total value of the Conditions Reports amounts to between $2.4 and $5.2 billion per year. Based on information from TPIO and NOAA subject matter experts, 25% to 35% of the value of the Conditions Reports can be attributed to the NOAA Fleet. Thus, the benefits associated with fleet inputs amounts to approximately $0.61 to $1.8 billion per year (Table 13).

Table 13. Annual Benefits of NOAA Fleet, National Marine Sanctuary Conditions Reports (2016 USD)

	Lower-bound estimate	Upper-bound estimate
Annual value of National Marine Sanctuaries[a] (billions)	$12.1	$20.9
Percent of National Marine Sanctuary value attributable to Conditions Reports	20%	25%
Value of Marine Sanctuary Conditions Reports (billions)	$2.42	$5.23
Percent of Conditions Reports value attributable to NOAA Fleet	25%	35%
Total Annual Benefits of NOAA Fleet (billions)	**$0.605**	**$1.83**

a. Includes $8 billion in use benefits and $4.1 to $12.9 billion in non-use benefits per year.

4. Cost-Effectiveness of NOAA Ships and Contract Vessels for Select Data Collection Efforts

This project included an assessment of the effectiveness and efficiency of using contract vessels. Specifically, we examined several case studies to compare the cost-effectiveness of using contract vessels as a substitute for NOAA's Fleet for certain data collection activities. We also examined available information on the capacity and availability of contract vessels. This section summarizes and presents conclusions from the cost-effectiveness analysis. Appendix B presents complete details.

4.1 Marginal Cost of Using the NOAA Fleet

As a basis for the cost-effectiveness analysis, we used cost data for the NOAA Fleet for fiscal year 2015, the most recent year for which complete cost data were available at the outset of this project. Specifically, we used these data to compare the marginal cost (as opposed to total cost) of operating the NOAA Fleet to the cost of using contract vessels to accomplish the same goals. This approach assumes that NOAA will not make dramatic changes to the overall mix of contract versus fleet ship time employed or radically alter the composition of its fleet in the immediate future. In other words, we assumed that substitutions would take place at the margins.

Given this assumption, it is not appropriate to account for the entire budget associated with NOAA's marine operations in the comparison. Some elements of the budget (e.g., fixed maintenance costs, certain support and management costs) are not reduced when NOAA Fleet missions are accomplished using contract vessels. Some of these fixed costs would be reduced only by extreme substitution to the extent of eliminating one or more ships from the NOAA Fleet. Other fixed costs would still be required even in a hypothetical scenario where the NOAA fleet were completely replaced by contract vessels. These costs are associated with functions (e.g., safety and compliance) that would be required regardless of which vessels NOAA uses to acquire ocean observations.

With this approach in mind, we used data from OMAO's Office of the Chief Financial Officer for fiscal year 2015 to estimate the variable (or marginal) operating cost for each ship in the NOAA fleet.[62] We used data provided by OMAO on fiscal year 2015 days at sea for each ship to calculate the cost per day at sea (Table 14). These costs include only variable costs that are proportional to the level of effort expended. They exclude fixed costs that would not be reduced by substitution at the margins. Therefore, they are not comparable to costs for the NOAA fleet reported in certain other sources. For example, costs developed for the NOAA Fleet Recapitalization Team[63] cover the total cost of all of OMAO's observing systems, including fixed costs. Appendix B provides more details on the derivation of these costs.

[62] "OMAO Ship Cost Effectiveness Combined Submission_022317.xlsx." Spreadsheet received via e-mail from Linda Mallinoff, OMAO Office of Chief Financial Officer. February 23, 2017.

[63] The NOAA Fleet Recapitalization Team was a team of senior subject matter experts from across NOAA established to summarize the relevant legal, policy and programmatic at-sea mission needs to describe the NOAA Fleet core capabilities to support NOAA's missions. The Team documented the extent to which these needs are currently addressed and describe the capability gap that will exist absent fleet recapitalization. The Team developed a Fleet Plan, sequencing the planned end of service life of current vessels, and acquisition of new vessels (to include all phases of acquisition).

Table 14. Fiscal Year 2015 Marginal Cost of Using the NOAA Fleet

Ship	2015 Days at Sea	Marginal Cost Total ($)	Marginal Cost $/Day at Sea
Bell M. Shimada	190	8,803,356	46,333
Fairweather	136	8,027,114	59,023
Ferdinand R. Hassler	203	5,180,034	25,517
Gordon Gunter	175	6,290,749	35,947
Henry B. Bigelow	172	6,151,592	35,765
Hi'ialakai	202	6,332,617	31,350
Nancy Foster	166	5,345,956	32,205
Okeanos Explorer	168	9,722,189	57,870
Oregon II	191	5,079,373	26,594
Oscar Dyson	192	8,538,806	44,473
Oscar Elton Sette	145	5,366,281	37,009
Pisces	131	6,169,307	47,094
Rainier	141	8,100,746	57,452
Ronald H. Brown	233	8,427,715	36,170
Reuben Lasker	80	4,754,080	59,426
Thomas Jefferson	119	6,278,611	52,761
TOTAL	2,644	108,568,526	41,062

Note: The totals presented here include variable direct cost along with those indirect costs that are proportional to level of effort, but exclude fixed costs. Therefore, they are not comparable to costs derived elsewhere (e.g., for the NOAA Fleet Recapitalization Team), which cover the total cost of all OMAO observing systems, including fixed costs.

4.2 Cost-Effectiveness Case Studies

NOAA currently uses contract vessels to support a variety of operations. Examples include fisheries surveys, deployment and maintenance of buoys, and collection of hydrographic data. Vessels employed by NOAA also include research vessels, both public sector and privately owned, for scientific data collection. NOAA also uses vessels from partner federal agencies, including the U.S. Coast Guard and the National Science Foundation. In some cases, this usage is a no-cost exchange of ship time. In other cases, NOAA reimburses the partner agency.[64,65]

In fiscal year 2015, NOAA used approximately 2,700 days at sea aboard contract vessels, roughly equal to the total days at sea executed by the NOAA fleet (2,644, as shown in Table 14). NOAA's use of contract vessels has remained fairly stable during the last few years: contract vessel days at sea varied by 11 percent or less from fiscal year 2014 to fiscal year 2016.[66] Although data are also available on the total cost of these contracts, it is not appropriate to compare

[64] NOAA. 2016. *The NOAA Fleet Plan: Building NOAA's 21st Century Fleet.* V3.1. NOAA Internal Use Only – Pre-decisional. October 4.
[65] O'Clock, Bill. 2016. "Charters." Presentation at NOAA Fleet Independent Review Team Meeting and Supporting Spreadsheets. Office of Marine and Aviation Operations. May 10.
[66] O'Clock, Bill. 2016. "Charters." Presentation at NOAA Fleet Independent Review Team Meeting and Supporting Spreadsheets. Office of Marine and Aviation Operations. May 10. Data do not include no-cost exchanges of days at sea with partner agencies.

these aggregate data to the cost of using the NOAA fleet. Factors that must be considered in comparing unit costs for NOAA ships and contract vessels include the following:

- Data on contract vessel costs generally reflect the contract price only. Some contracts cover “bare boat” costs only, while others encompass a more complete scope of support for the mission (e.g., fuel, crew to operate deck equipment supporting the mission). Even when the contract covers more than “bare boat” costs, there can be other costs associated with the use of contract vessels that are not reflected in the contract price. Examples of these additional costs can include: costs for provisions for NOAA staff aboard the contract vessel, mobilization and demobilization of NOAA staff and equipment, and calibration of instruments used aboard the contract vessel. On the other hand, some contracts encompass other services in addition to use of vessels. In particular, NOAA contracts for hydrographic surveys are structured as data buys that purchase a quantity of data instead of a number of days at sea. In addition to providing ship time to collect the data, the contractor also provides quality assurance/quality control and data processing and formatting according to detailed specifications.[67]

- A day at sea aboard a contract vessel is not necessarily equal to a day at sea aboard a NOAA vessel. NOAA ships often collect multiple data streams and/or conduct multiple missions simultaneously. Although some contract vessels, such as certain University National Oceanographic Laboratory System (UNOLS) ships,[68] have similar multi-data stream/multi-mission capabilities, many vessels are better suited for individual projects and a more limited set of data. These “economies of scope” mean that multiple contract vessels can sometimes be required to replace the output of a NOAA vessel. In addition, NOAA uses NOAA ships for advancing technology through testing new equipment and procedures, maintaining and building expertise within the science field and marine operations.

- NOAA ships have greater endurance than many smaller contract vessels. Therefore, they can remain at sea for the duration of long projects without returning to port. In addition, NOAA ships often can be scheduled and positioned to transition directly from one project to the next without significant travel time. Both of these factors mean that the use of contract vessels can, in some cases, entail more transit days (i.e., at the start and finish of the discrete projects for which they are hired and, in some cases, to resupply during longer projects).

- Contract vessels used for missions with NOAA personnel aboard must meet certain safety standards.[69] Aggregate data on contract vessel costs include missions without NOAA crew aboard. The vessels used for these missions might not meet these standards and, therefore, not be comparable to NOAA ships. In addition, some contract vessels provide services that the NOAA fleet cannot (e.g., data collection in shallow waters). The aggregate data include such missions.

Given these factors, a comparison of cost-effectiveness must account for mission-specific details. Accordingly, we used a case study approach to account for these factors and provide a one-to-one comparison of contract vessel costs to NOAA fleet costs. Table 15 identifies the example missions we examined, along with key mission parameters and estimated costs.

The case studies reflect missions that support three different NOAA line offices. Each of the cases studies involves a different NOAA vessel. Three of the case studies (TAO array maintenance, sanctuary ecosystem assessment surveys for Greater Farallones and Cordell Banks, and reef assessment and monitoring in American Samoa) are of missions that support NOAA products and services evaluated in detail in preceding sections of this report.

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[67] NOAA. 2016. *NOS Hydrographic Surveys: Specifications and Deliverables*. Office of Coast Survey, National Ocean Service, NOAA, U.S. Department of Commerce. March.
[68] NOAA’s use of UNOLS ships includes both no-cost exchange of ship time and cases where NOAA pays the institution operating the UNOLS ship in a manner similar to a commercial charter.
[69] “Vessel Chartering Info.” Office of Marine and Aviation Operations. Available at: http://www.omao.noaa.gov/learn/headquarters/safety-environmental-compliance/vessel-chartering-info. Accessed January 12, 2017.

For each case study, we estimated the cost of using the NOAA ship based on the marginal costs estimated in Table 14. The contract vessel cost estimates in each case study cover providing the same services and support as the NOAA ship and meeting the same mission requirements. The contract vessel cost estimates include adjustments necessary to make an equivalent comparison. Appendix B provides complete details of the cost estimates. It also includes further discussion of the results for each case study. The following paragraphs provide a summary:

1. The case study of TAO array maintenance covers two scenarios. The first scenario is a mission with scope limited to routine maintenance and servicing of the TAO array, along with deployment of Argo and surface drifting floats. The second scenario is a mission that also incorporates scientific research that is directly related to operating the array. If the scope is limited to the first scenario, a commercial contract vessel can complete the mission more cost-effectively than the NOAA ship *Ronald H. Brown*. The commercial contract vessel would not be equipped, however, to supply all the requirements of the second scenario. Substituting for the *Ronald H. Brown* in the second scenario requires the use of a UNOLS ship equipped to collect the underway ocean observations and support the related supplemental science. In this scenario, the *Ronald H. Brown* is more cost-effective than the alternative of using a UNOLS vessel.

2. The 2014 California Current Cetacean and Ecosystem Assessment Survey (CalCurCEAS) expedition was originally planned for the NOAA ship *Reuben Lasker*. When the *Reuben Lasker* did not come on line as scheduled, the expedition was instead conducted aboard the R/V *Ocean Starr*, a contract vessel that was formerly a NOAA ship. Even after accounting for certain adjustments required to make the comparison equivalent, the cost of using the *Ocean Starr* for CalCurCEAS 2014 was much lower than the estimated cost of using the *Reuben Lasker*. Although fiscal year 2015 marginal costs for the *Reuben Lasker* may not be representative of normal operations,[70] more recent cost data are unlikely to change the conclusion. The cost per day for the *Ocean Starr* for CalCurCEAS 2014 was lower than the marginal operating cost for any NOAA vessel (even the *Ferdinand R. Hassler*, which had the lowest marginal cost in 2015, as shown in Table 14). Although the *Ocean Starr* reportedly is nearing the end of her useful life and not being maintained for longevity,[71] she was still in operation as of July 2016.[72] Information about the *Ocean Starr's* future availability and price is not available.

3. The 2016 Sanctuary Ecosystem Assessment Surveys (SEAS) project in the Greater Farallones and Cordell Banks National Marine Sanctuaries was conducted aboard the NOAA ship *Bell M. Shimada*. Commercial contract vessels available near the project location have endurance and/or berthing limitations such that multiple vessels or trips would be required to substitute for the *Bell M. Shimada*.[73] The transit time involved in bringing in a more capable vessel from farther away could be significant, particularly compared to the relatively short nine-day project duration. Given these limitations, a NOAA subject matter expert suggested a vessel operated by the nearby Monterey Bay Aquarium Research Institute (MBARI) as a potentially efficient substitute if the *Bell M. Shimada* were not available.[74] The MBARI ship *Western Flyer* could supply the mission requirements at a slightly lower cost than the *Bell M. Shimada*. MBARI, however, does not actively seek out research assignments for its vessels from other organizations, so the *Western Flyer* would be available only under specific, case-by-case circumstances.

4. The 2015 Pacific Reef Assessment and Monitoring Program (RAMP) in American Samoa was conducted aboard the NOAA ship *Hi'ialakai*. Given the remote location and length of mission, commercial alternatives to using the *Hi'ialakai* are limited. Outside of the commercial sector, however, an alternative would be the R/V *Tangaroa*, operated by the New Zealand National Institute of Water and Atmospheric Research (NIWA). The *Tangaroa* could supply the mission requirements, but the cost would be substantially higher than using the *Hi'ialakai*. Scheduling the *Tangaroa* could also require substantial lead time.

[70] The *Reuben Lasker* was at the start of her service life in 2015 and only executed 80 days at sea.
[71] E-mail communication with Michael Gallagher, National Marine Fisheries Service. February 9, 2017.
[72] "2017 Cruise Schedule." California Cooperative Oceanic Fisheries Investigations. Available at: http://calcofi.org/cruises/561-cruise-schedule.html. Accessed March 8, 2017.
[73] Ship Time Request for Sanctuary Ecosystem Assessment Surveys: GFNMS and CBNMS v3. January 12, 2015.
[74] Personal communication with Jan Roletto, Research Coordinator at the Gulf of the Farallones National Marine Sanctuary. January 10, 2017.

For the case study considering a mission of limited scope (the first TAO maintenance scenario, which excludes supplement scientific research), the commercial contract vessel was more cost effective. This result is not surprising, given that the NOAA ship included in the comparison is better equipped than necessary for the limited scope. The case studies also show, however, that even for the multi-disciplinary research missions to which NOAA ships are best suited, cost-effective contract vessel alternatives can sometimes be available. The case studies are not conclusive regarding the factors that determine cost-effectiveness for these research missions. The two case studies where contract vessels came out ahead (CalCurCEAS and SEAS) were for missions in U.S. coastal waters, while the research missions where NOAA ships were more cost-effective (TAO maintenance including research and RAMP) were in the more remote tropical Pacific, suggesting that region of operation is a key factor. This result, however, could be related to the specific NOAA ships examined instead of geography. CalCurSEAS and SEAS involved NOAA ships with marginal costs higher than the average for NOAA (*Reuben Lasker* and *Bell M. Shimada*). TAO maintenance and RAMP involved NOAA ships with marginal costs below NOAA's average (*Ronald H. Brown* and *Hi'ialakai)*.[75]

[75] See Table 14.

Table 15. Summary of Cost-Effectiveness Case Studies

	Case Studies					
	Tropical Atmosphere Ocean Array Maintenance		California Current Cetacean and Ecosystem Assessment Survey	Sanctuary Ecosystem Assessment Surveys: Greater Farallones and Cordell Bank	Pacific Reef Assessment and Monitoring Program: American Samoa
	a.	b.			
NOAA Line Office	National Weather Service	National Weather Service	National Marine Fisheries Service	National Ocean Service	National Ocean Service
Year	2015	2015	2014	2016	2015
Mission	Mooring maintenance and servicing and float deployment	Mooring maintenance and servicing and float deployment, plus related scientific sampling and research	Study of cetacean species and their ecosystem, plus physical oceanographic and El Nino sampling	Assessment of National Marine Sanctuary conditions, resources, and ecosystem	Ecosystem monitoring and research in coral reef habitat, plus data collection on ocean acidification
Location	Tropical Pacific	Tropical Pacific	U.S. West Coast	U.S. West Coast	Tropical Pacific
Days at Sea	40[a]	40[a]	120[a]	9[b]	103[b]
NOAA Ship Estimated Cost[c]	*Ronald H. Brown*: **$1,446,800**	*Ronald H. Brown*: **$1,446,800**	*Reuben Lasker*: **$7,131,120**	*Bell M. Shimada*: **$416,997**	*Hi'ialakai*: **$3,229,050**
Contract Vessel Estimated Cost[d]	Contract vessel: **$955,560**	University National Oceanographic Laboratory System vessel: **$1,710,000**	Contract vessel: **$2,459,353**	Monterey Bay Aquarium Research Institute vessel: **$403,300**	New Zealand Institute of Water and Atmospheric Research vessel: **$5,404,185**
Most Cost-Effective Option	**Contract vessel** (by 34%)	**NOAA ship** (by 15%)	**Contract vessel** (by 66%)	**Contract vessel** (by 3%)	**NOAA ship** (by 40%)
Vessel Actually Used	Contract vessel	NOAA ship and UNOLS ships	Contract vessel	NOAA ship	NOAA ship
Other Factors	Scope does not include related research	Not the top priority for UNOLS ship	Contract vessel may be near end of useful life	Contract vessel available only on a case-by-case basis	Foreign vessel

a. Same mission length, including transit time, for NOAA ship and contract vessel substitute.
b. Contract vessel cost incorporates additional days at sea for transit.
c. Based on the marginal cost estimated in Table 14.
d. Estimated costs to supply the same mission requirements as NOAA ship, including adjustments to make the comparison equivalent.

4.3 Capacity, Availability, and Other Factors Affecting the Use of Contract Vessels

As part of the cost-effectiveness analysis, we also examined available data about the capacity and availability of contract vessels, along with other factors that could affect NOAA's use of contract vessels. A primary source for this part of the assessment included a set of informal, voluntary interviews with nine contract vessel providers. We also used data downloaded from USAspending.gov, a publicly accessible U.S. government website that provides searchable, transaction-level information on federal contracts and grants.[76] Appendix B provides more details on both of these sources. Observations from this part of the analysis, also discussed in greater detail in Appendix B, include the following:

- Data are not available on the number of vessels with capabilities useful to NOAA that might be available under contract. Statistics, for example on the total number of research and fishing vessels, however, suggest that the overall size of the industry is large. NOAA successfully contracts with a variety of different providers. Data on vessel contracts filtered from USAspending show that NOAA had transactions with more than 130 individual vendors under approximately 200 unique contracts in fiscal year 2015.[77]

- Individual vendors interviewed are generally willing and available to provide support, even to the extent of modifying their vessels to suit project needs. It is important to note, however, that the vessel availability is greater for smaller vessels with more limited capabilities. The individual vessels that are the most obvious substitutes for NOAA ships (UNOLS vessels) are also the least available.

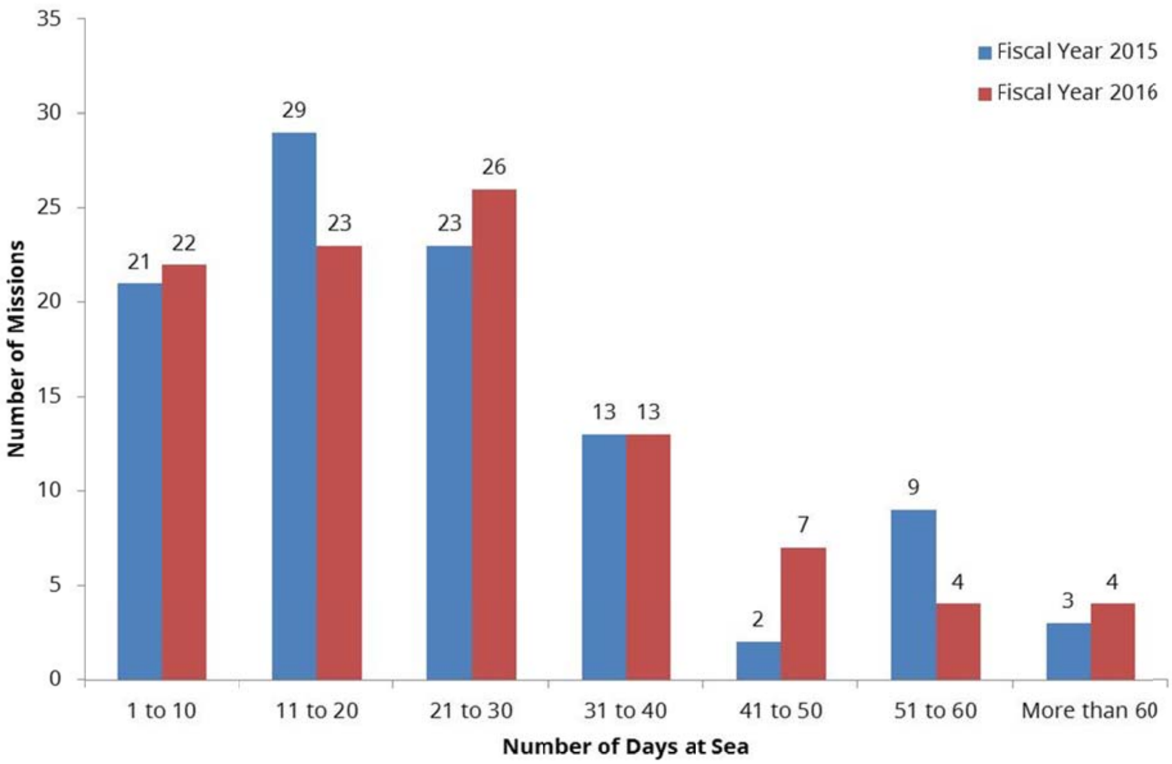
- Most of the vendors interviewed (six of the nine) reported that their availability is greater with more advance planning. The lead time required to access contract vessels varies depending on the length of the project and on the size of the vessel. For longer projects aboard larger vessels, more planning is required, however: often a year or more in advance. For context, the missions conducted by NOAA's fleet in fiscal years 2015 and 2016 spanned a range of lengths (Figure 4), with an average of approximately 25 days at sea.[78]

- A majority of the vendors interviewed (five of the nine) reported that their vessels are busiest during the summer months. In spite of competing priorities during the summer, however, the interviewees reported good availability, particularly with advance planning. NOAA ships execute missions year-round, but, like contract vessels, they are busiest during the summer (particularly June). The NOAA fleet, however, also executes a significant number of days at sea outside of summer (particularly March through April and October).[79] These schedule data suggest there may be opportunities to utilize contract vessels when those vessels have greater availability.

- Despite the overall size of the contract vessel industry and the reports from vendors interviewed of generally good availability, specific projects may have requirements (e.g., vessel capabilities, project scheduling, or location) that are not a good match for a very large number of vessels. The number of such NOAA projects could be significant, based on the available data about the number of vendors bidding on these projects. These data show that, of NOAA contracts for vessel services active in fiscal year 2015, just over half received only one offer and almost 70 percent had two or fewer offers.[80] Data are not available on the number of solicitations that received no bids.

Figure 4. Length of Missions Conducted by NOAA Fleet

[76] Data downloaded for National Oceanic and Atmospheric Administration for fiscal year 2015 from https://www.usaspending.gov/DownloadCenter/Pages/DataDownload.aspx. Accessed November 18, 2016.
[77] See Appendix B for information on how we identified charter contracts in the USAspending data.
[78] Based on data provided by OMAO. Excludes fleet services and program support activities (e.g., inspections, shakedowns, sea trials, and transit not assigned to a specific line office) and scheduled missions where actual days at sea were reported as zero.
[79] Based on total days at sea in each month for the entire fleet, as derived from data provided by OMAO (Ibid).
[80] Data downloaded for National Oceanic and Atmospheric Administration for fiscal year 2015 from https://www.usaspending.gov/DownloadCenter/Pages/DataDownload.aspx. Accessed November 18, 2016.



Source: data provided by OMAO
Note: Excludes fleet services and program support activities (e.g., inspections, shakedowns, sea trials, and transit not assigned to a specific line office) and scheduled missions where actual days at sea were reported as zero.

- All nine of the vendors interviewed identified fuel prices as the major factor that would affect future prices for their services. Outside of major changes in fuel prices, most interviewees predicted only small annual increases (in the range of two to three percent) in the prices for their services. The U.S. Bureau of Labor Statistic's producer price index for the water transportation industry likewise shows that prices in this industry have remained fairly stable during the last five years, changing by less than 3 percent per year (with the exception of a 5 percent decrease in between 2015 and 2016).[81]

- Institutional factors that differ across NOAA programs also affect the use of contract vessels. Some programs have contract vehicles in place that allow easy access to contract vessels. Other programs do not have the mechanisms or budget to access contract vessels. For still other programs, the fleet allocation process may create an incentive to use contract vessels for parts of their mission by limiting the total NOAA fleet time available to the program (i.e., these programs receive a fixed allocation of NOAA fleet time above which they must use contract vessels). See Appendix B for specific examples of each of these institutional factors.

[81] Time series data downloaded for producer price index for NAICS category 483 from https://www.bls.gov/ppi/data.htm. Accessed March 7, 2017.

5. Summary of Lessons Learned and Recommendations for Next Steps

5.1 Conclusions and Lessons Learned

This study demonstrates the value of data collection activities and other services the NOAA Fleet provides through the products it supports. The NOAA Fleet supports a wide range of benefits, including the protection of key resources and species, increased revenues for economic sectors, and increased safety and economic prosperity for U.S. residents. For the five products that we monetized as part of this research, the benefits attributed to the NOAA Fleet amount to between approximately $0.77 and $3.39 billion per year, which is significantly greater than the annual OMAO operating budget for NOAA vessels.

This study provides NOAA with a systematic process for assessing the value of individual observing systems and data streams through the development of value chains for the products and services that depend on them. The project team relied on data from the TPIO NOSIA-II model as well as structured interviews with NOAA subject matter experts to develop the value chains, and to inform our valuation of fleet-dependent products.

While this study represents a significant first step in demonstrating the value of the NOAA Fleet, it is limited in scope. Under this contract the project team was only able to develop value chains for 12 of more than 600 products, and quantify the value of 5 products, that are dependent on data collected from the fleet and/or the observing systems it supports. In addition, we were not able to conduct original valuation analyses; our monetary estimates of value therefore depend on existing data and estimates from the literature. We were also only able to conduct a limited number of interviews, which we conducted with product experts from within NOAA.

In addition, throughout the study we learned that it is difficult to isolate the effect of individual data streams on the performance of a given product, given the interdependency of data that most products rely on. Thus, it is difficult to attribute an exact percentage of product value to the NOAA Fleet. We have attempted to reflect this uncertainty by providing a reasonable range of values using Fleet data dependency estimates provided by TPIO and the subject matter experts.

Another source of uncertainty stems from the studies that the project team relied on to develop monetary estimates for the subset of five NOAA products. While these studies rely on standard economic methods and models, they are also subject to limitations and caveats. To address this uncertainty, we have attempted to provide reasonable ranges and describe key assumptions embedded in the studies.

The data used as inputs to this analysis represent the best available information. However, the studies upon which the quantifications are based were often few in number and, as with any study, limited in their accuracy, completeness, and broader applicability. Estimates of the contribution of the NOAA fleet to final products and services are based on extensive research and analysis by NOAA's Technology, Planning and Integration for Observation office (TPIO) but this work has its own limitations and the results have not been independently verified (as with a "denial of data" analysis). In short, the resulting values represent an empirical first step in the direction of developing more accurate and complete estimates of the value of NOAA products and services and the share of that value attributable to the NOAA fleet. A more scientifically rigorous analysis would require additional primary data collection and analysis which, if performed comprehensively, would be cost-prohibitive. This study does establish a scientifically sound process for assessing the societal benefits of the NOAA fleet and identifies critical information requirements that should be used to inform future research agendas.

Despite these challenges, which are inherent in most economic analyses, our use of published studies and extensive interviews with subject matter experts established a highly credible range of value estimates. We are confident that these estimates establish the significant value of the fleet's contributions and provide materially relevant data to support future decisions at NOAA regarding the fleet.

As part of this research we also examined the cost-effectiveness of using contract vessels as a substitute for NOAA's marine fleet for certain data collection activities. In terms of the number of days at sea executed, NOAA's current use of contract vessels is approximately equal to its use of own fleet. In many cases, however, the missions conducted by these two types of vessels are not directly comparable for a variety of reasons. For example, NOAA ships often collect multiple data streams and/or conduct multiple missions simultaneously. Although some contract vessels, such as certain UNOLS ships, have similar multi-data stream/multi-mission capabilities, many vessels are better suited for individual projects and a more limited set of data. These "economies of scope" mean that multiple contract vessels can sometimes be required to replace the output of a NOAA vessel.

To account for these factors and make equivalent comparisons between contract vessels and NOAA ships, we examined several case studies of specific missions that could be conducted by either type of vessel. The single case study involving a single purpose mission of limited scope (TAO maintenance without supplemental scientific research) showed a contract vessel to be the most cost-effective option. The case studies of multi-disciplinary research missions indicated that there are examples where contract vessels are more cost effective and others where NOAA ships are more cost effective. These case studies were not conclusive regarding the factors that determine cost-effectiveness. Geography could be one factor. NOAA ships appeared more cost effective for the research missions conducted in the remote tropical Pacific, while contract vessels appeared more cost effective for those conducted in U.S. coastal waters. These results, however, could also be related to the specific NOAA ships examined. The case studies where contract vessels were more cost effective involved NOAA ships with higher marginal costs than the average for NOAA's fleet overall.

We also conducted a limited examination of the capacity and availability of contract vessels, along with other factors that could affect NOAA's use of contract vessels. NOAA successfully contracts with a large number of different contract vessel providers and individual vendors report good availability to provide support. Specific projects, however, may have requirements (e.g., vessel capabilities, project scheduling, or location) that are not a good match for a very large number of contract vessels. Of NOAA contracts for vessel services active in fiscal year 2015, just over half received only one offer and almost 70 percent had two or fewer offers.[82] In general, contract vessel availability appears to be greater for smaller vessels with more limited capabilities. The individual vessels that are the most obvious substitutes for NOAA ships (UNOLS vessels) are also the least available. There may, however, be opportunities for NOAA to make greater use of contract vessels during periods when those vessels have greater availability (i.e., outside of the summer months).

5.2 Recommended Next Steps

There are several ways that NOAA could further refine the estimates from this study. First, many of the value chains and quantitative study estimates could benefit from additional interviews with NOAA experts as well as external product users. These interviews would provide a better understanding of the decisions that users make based on the information that the products provide, as well as how the NOAA Fleet contributes to each product. Additional analyses could also be conducted to further refine our monetary estimates, particularly our estimates for Nautical Charts and the ENSO Outlook. However, this would require primary data collection. Finally, to further inform investment decisions and focus resources, NOAA may also want to expand this analysis to include more fleet-dependent products and/or additional observing systems (e.g., OMAO aircraft).

To better examine the factors that determine the cost-effectiveness of contract vessels, NOAA could conduct additional case studies. If carefully selected, additional case studies could help isolate the factors that contribute to cost-effectiveness (e.g., geography, specific NOAA ships used, length of mission, time of year).

A more detailed assessment of existing and future contract vessel capacity and availability would also be useful. The voluntary interviews with vendors that we conducted for this study were limited in number and not geographically representative. A more thorough, perhaps statistically selected, survey incorporating more detailed questions about vessel availability and capabilities could provide a greater understanding of the industry. A detailed examination of NOAA's contract records, beyond the limited descriptive data in USAspending, might also provide more comprehensive data on the industry's size and capabilities.

[82] Data are not available on the number of solicitations that received no bids.

Appendix A: NOAA Fleet Data Value Chains for Select Products and Services

Appendix A contains the full value chain descriptions for the 12 NOAA products and services evaluated as part of the *NOAA Fleet Societal Benefits Study*, including:

- Coral Reef Status and Trends Report
- Sea Level Rise (SLR) and Coastal Flooding Impacts Viewer
- Nautical Chart Products
- El Nino Southern-Oscillation (ENSO) Outlook
- National Marine Sanctuary Conditions Reports
- Fisheries Stock Assessments
- Tsunamis Inundation Forecast Models
- Harmful Algal Blooms (HABs) Forecasts and Mitigation Capability, Gulf of Maine
- Hypoxia Watch, Gulf of Mexico
- Ocean Noise Mapping
- Hurricane Outlook
- Emergency Response Services

1. Coral Reefs: Coral Status and Trends Report

1.1 Product Background

Product: Coral Reef Status and Trends Report

Line Office: National Ocean Service, Coral Reef Conservation Program

Mission Service Area: Protect and Monitor Coral Reefs

The National Coral Reef Monitoring Program (NCRMP), as part of the Coral Reef Conservation Program (CRCP), is developing Status and Trends Report Cards for high-level decision-makers, along with many other more detailed reports for local resource managers. The Status and Trends Report Cards are a new product, currently under development, that will provide a summary of standardized indicators for all U.S. coral reef jurisdictions monitored by NOAA's CRCP. In addition, the CRCP produces more extensive, tailored reports for the jurisdictional level.

The CRCP, a matrix program spanning NOS, NMFS, OAR and NESDIS and headquartered from the National Ocean Service's Office for Coastal Management, has monitored coral reefs to develop status indicators since the program was established in 2000. Between 2010 and 2013 NOAA consolidated and standardized sampling methodologies so that trends in coral reef ecosystems could be compared across jurisdictions and presented at the national level. CRCP uses data from ships, buoys, charter ships, and satellites to develop 15 to 19 biologic (fish and benthic) and climate indicators, and uses surveys to collect socioeconomic indicators that reflect the health of specific coral reef attributes and ecosystem services relative to a historical standard. The indicators within each category (e.g. fish, benthic, climate, socioeconomic) and region are then averaged, compared to thresholds, and presented in a report card to high-level decision-makers such as the U.S Congress and NOAA leadership to set funding priorities needed to ensure the continued health and productivity of these resources and the economic activity that they support. Prior to this effort to standardize sampling methodologies across jurisdictions, the CRCP could not roll-up indicators across sites and therefore could not provide a national picture of coral reef health. The CRCP is in the process of developing the first two pilot Status and Trends Report Cards.

1.2 NOAA Fleet Data that Feed the Product

The report card and underlying indicators require the collection of data by multiple observation systems over a wide geographic region. The stratified random sampling design that NCRMP uses to collect data for the Status and Trends Report is heavily reliant on benthic and other habitat mapping performed in part by NOAA cruises. NOAA ships such as the *Nancy Foster* provide multi-beam sonar, echo sounder sonar, and other capabilities for coral reef and fish habitat mapping.[83] Buoys and satellites also collect data on ocean acidification and thermal stress, which feed into the report card's climate indicators along with ocean profile data collected during marine biological ship surveys.

Using NOAA ships and observation systems to perform data collection helps the CRCP adhere to the standardized sampling methodology that underpins the national status and trends report. Other ship-based data collection options, such as charter personal dive boats, are more expensive and scarce, limiting the timeframe for critical sampling. Some efforts such the Pacific Reef Assessment and Monitoring Program (RAMP) which is NCRMP in the Pacific, conducted by the Pacific Islands Fisheries Science Center and funded by the CRCP, could not be done without the use of NOAA vessels. The long distances and remote locations of the Pacific coral reef jurisdictions make some of these programs only possible with NOAA ships.

1.3 Product Intermediaries and Dissemination

[83] "Two NOAA ships deployed to Caribbean to map coral reefs, explore deep sea". Office of Marine and Aviation Operations. National Oceanic and Atmospheric Administration. Accessed January 25, 2017: http://www.omao.noaa.gov/find/media/articles/2015-11-26/two-noaa-ships-deployed-caribbean-map-coral-reefs-explore-deep-sea

NOAA contracts with The University of Maryland Center for Environmental Science Integration and Application Network (IAN) to generate the final report card. IAN integrates multiple datasets and compares the data to thresholds, then organizes it in a format that is more accessible to the report card's audience.[84]

The CRCP is in the final stages of developing its official roll-out plan, and the program targets the U.S. Congress, NOAA and other federal agency leadership, nonprofit organizations, and the public for its report card. NOAA works on an individual basis with jurisdictional coral reef managers and other management partners to disseminate the more detailed jurisdiction-level reports.

1.4 Users of the Product

U.S. Congressional leaders and NOAA leadership will use the Coral Status and Trends Report to make decisions to allocate resources to coral reef protection. Jurisdiction-level decision-makers, including local resource managers and Marine Protected Area managers, can use the Status and Trends Report Card to effectively monitor reefs and design education programs that further enhance the ecosystem's health.[85] Outside of the decision-making sphere, the data and indicators included in the reports provide a wealth of information for academic and private researchers, as well as the public.

The Status and Trends Report Card provides decision-makers at all levels with a basic understanding of the status and condition of these ecosystems in the context of three general topics of indicators: biological, climate, and socioeconomic. Monitoring biological trends such as coral diversity, fish abundance, and habitat composition allows researchers, scientists, and coral reef managers to evaluate management strategies in response to fishing, climate, and pollution stressors.[86] Climate indicators, including thermal stress, ocean acidification, and various ecological impacts, identify resilient or vulnerable reef areas.[87] While biological and climate indicators influence the value of coral reefs, which we discuss in the next section, socioeconomic indicators in particular link the economic values of coral reefs to management decisions.

1.5 Societal Benefits

Coral reefs provide the United States with valuable goods and services including food, coastal protection, habitat, and opportunity for recreational activities. These goods and services in turn provide different types of economic benefits, including: use values (e.g., snorkeling) and associated tourism benefits; non-use values (e.g., values people hold for the existence of coral reefs); and amenity values (e.g., as measured by increases in property values due to proximity to coral reefs).[88] Several studies have estimated these benefits for the United States using standard economic techniques. Based on a meta-analysis of these studies,[89] Table A.1 presents the sum of coral reef benefits by U.S. state or territory, while Figure A.1 shows per-hectare values for specific ecosystem services.

Various stressors threaten coral reefs and the ecosystem services they provide. Both the status and trends report and the jurisdiction-level report are effective tools for presenting coral reef health to various users. By incorporating data from the NOAA Fleet into several indicators, the CRCP creates a product that stakeholders can use to inform decision-making, thereby helping to protect coral reefs and the important ecosystem services they provide.

[84] "Environmental Report Card Production: How healthy is your ecosystem?" Integration and Application Network. University of Maryland Center for Environmental Science. Accessed January 25, 2017: http://ian.umces.edu/work_with_us/environmental_report_card_production/

[85] "National Coral Reef Monitoring Plan Socioeconomic Monitoring Component". Coral Reef Conservation Program. National Ocean and Atmospheric Administration. Accessed January 20, 2017: https://www.coris.noaa.gov/monitoring/resources/ncrmp_socio_econ_onepager.pdf

[86] "National Coral Reef Monitoring Program: Tracking Biological Trends". Coral Reef Information System. National Ocean and Atmospheric Administration. Accessed January 20, 2017: https://www.coris.noaa.gov/monitoring/biological.html

[87] "National Coral Reef Monitoring Program: Monitoring Climate-Driven Impacts". Coral Reef Information System. National Ocean and Atmospheric Administration. Accessed January 20, 2017: https://www.coris.noaa.gov/monitoring/climate.html

[88] Brander, Luke and Pieter van Beukering, 2013. "The Total Economic Value of U.S. Coral Reefs: A Review of the Literature". Coral Reef Conservation Program. National Ocean and Atmospheric Administration. Available: https://data.nodc.noaa.gov/coris/library/NOAA/CRCP/other/other_crcp_publications/TEV_US_Coral_Reefs_Literature_Review_2013.pdf. Accessed 1/20/2017.

[89] *Ibid.*

Table A.1. Total coral reef values for the United States (2007 USD)

State/Territory	Area of coral reef value (ha)	Total value (millions, US$)
American Samoa	22,200	$11
Florida	36,000	$174
Guam	7,159	$139
Hawaii	165,990	$1,747
Puerto Rico	12,642	$1,093
CNMI	6,494	$65
USVI	34,400	$187
United States	**284,885**	**$3,416**
Source: Edwards, Peter E.T. 2013. "Summary Report: The Economic Values of U.S. Coral Reefs, 2001-2011". NOAA Coral Reef Conservation Program.		

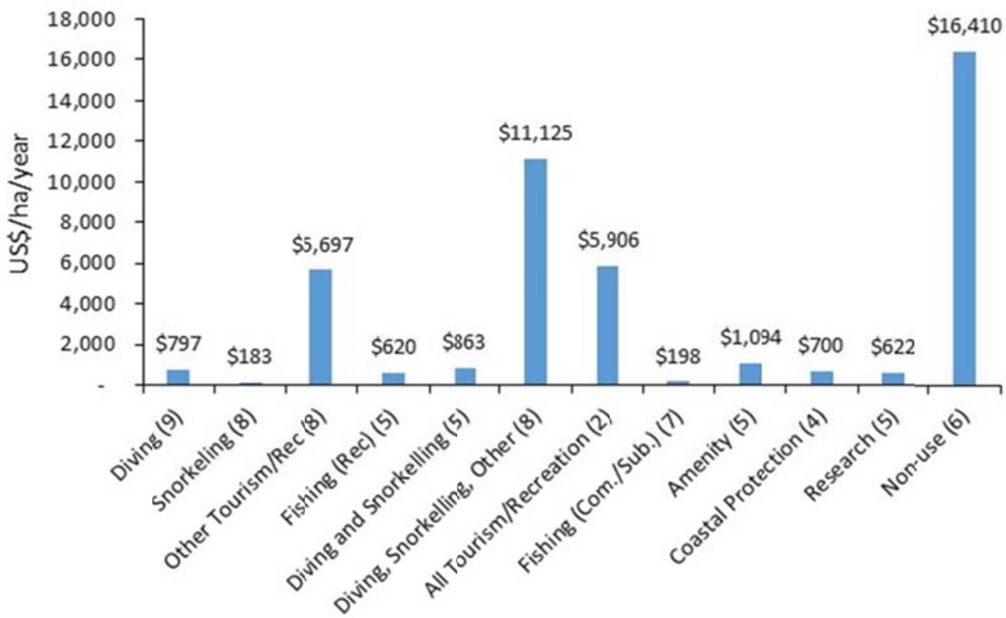


Figure A.1. Mean ecosystem service values (2007 USD).
Number of value estimates from the different studies are provided in parentheses.
Source: Brander, Luke and Pieter van Beukering, 2013

Figure A.2 demonstrates the value chain associated the Status and Trends Report Cards, including the data from the NOAA fleet and other sources that it depends on, and how it ultimately provides value to society.

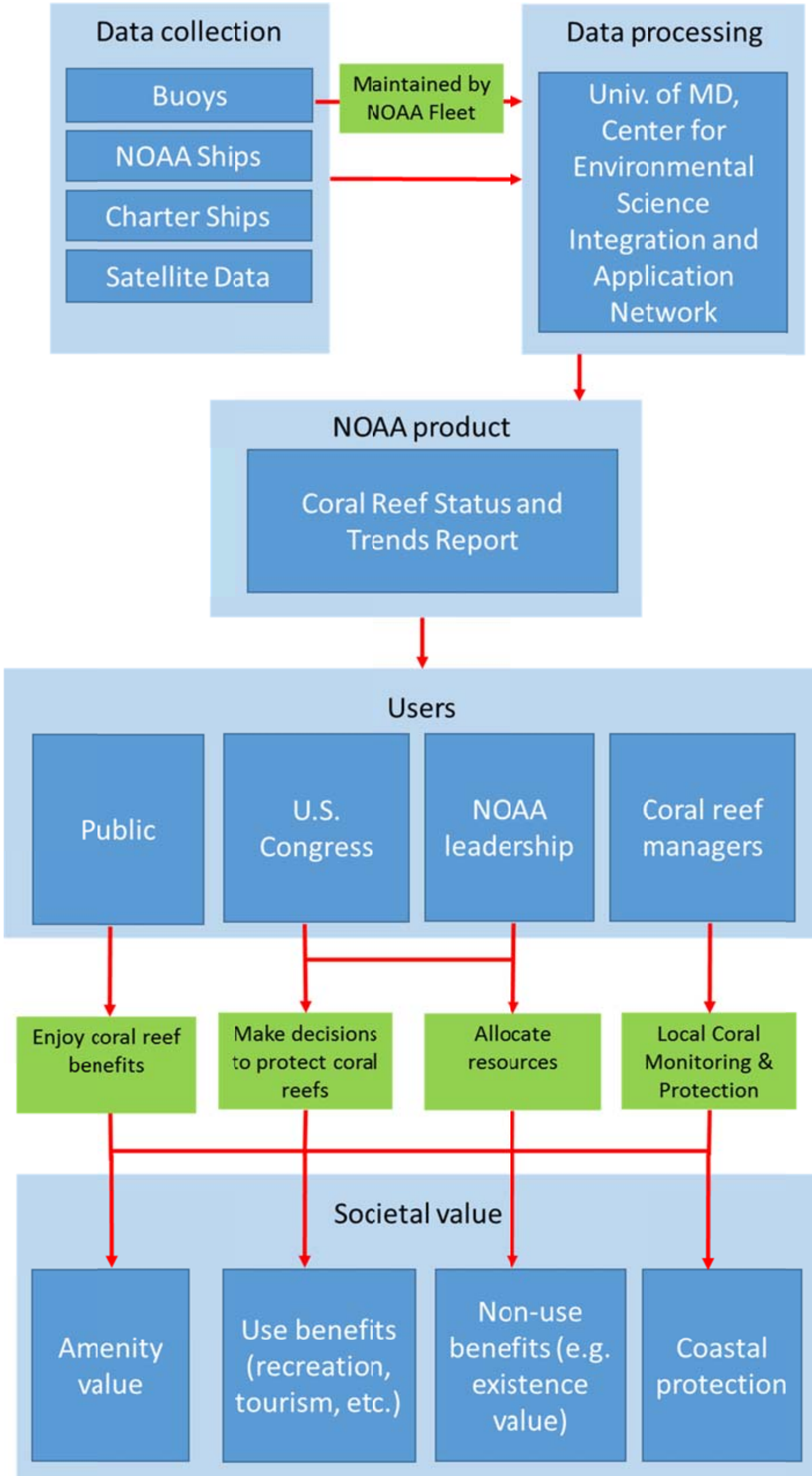


Figure A.2. NOAA Fleet Data Value Chain: Coral Reefs Status and Trends Report

2. Sea Level Rise: Sea Level Rise Viewer

2.1 Product Background

Product: Sea Level Rise and Coastal Flooding Impacts Viewer

Line Office: National Ocean Service, Office for Coastal Management

Mission Service Area: Climate Mitigation and Adaptation Strategies

Sea level rise threatens many U.S coastal areas, which are some of the most developed, populous, and economically viable areas in the country. Low-lying coastal areas are especially vulnerable to flooding, erosion, habitat loss, and seawater intrusion. [90] The Sea Level Rise and Coastal Flooding Impacts Viewer (SLR Viewer), developed by NOAA's Office of Coastal Management (OCM), is a web-based map viewing tool that provides coastal managers, community planners, and other users with visuals, corresponding data, and explanatory information concerning sea level rise inundation, flood frequency, marsh impacts, and socioeconomics[91] This information allows users to identify potential community vulnerabilities and assess appropriate adaptation options and strategies. As of 2015, the SLR viewer covers all coastal territory in the United States except Alaska. NOAA publishes a companion Lake Level Viewer tool for the Great Lakes region, but data collection for that product does not involve NOAA Fleet vessels.[92]

2.2 Data that Feed the Product

NOAA ships contribute to the SLR Viewer through the collection of hydrographic and geospatial data for US coastal areas. VDatum, a software tool developed by multiple NOAA line offices, combines the data collected from NOAA vessels into bathymetric-topographic Digital Elevation Models (DEMs**)** for specific areas. OCM incorporates these DEMs, as well as LIDAR and Conditioned DEMs (DEMs conditioned to a higher specification), tide gauge observations, coastal flooding thresholds, and other jointly developed inputs, into the SLR Viewer. OCM updates the SLR Viewer as new data inputs become available. For example, in 2015, OCM added new land cover, elevation, and levee data updates for San Francisco Bay, coastal Texas, Oregon, and the U.S. Virgin Islands. Most recently, NOAA remapped seven states with new post-Sandy LIDAR elevation data.[93] In 2017, OCM released an enhanced Beta viewer that includes local sea level rise scenarios from the 3rd National Climate Assessment.

Several other federal agencies and educational institutions contribute data to the SLR viewer. For example, the US Geological Survey, in addition to collaborating with the OCM on two SLR mapping tools that led to the development of the SLR Viewer, provides base elevation data for Louisiana. The NOAA Center for Operational Oceanographic Products and Services conducts analyses that support tool's flood frequency capabilities, and the Bureau of Labor Statistics has provided block group analysis in the past, and may do so again for future versions of the viewer. The University of Hawaii School of Ocean and Earth Science and Technology performed mapping for several outlying coastal territories, and the University of South Carolina Hazards and Vulnerability Research Institute provides Social Vulnerability Index data.

2.3 Users of the Product and Related Products

The primary users of the SLR viewer are coastal planners, floodplain managers, scientists and engineers, and municipal representatives who are interested in assessing community-level vulnerability to sea level rise and coastal flooding. Several communities in the United States have incorporated the SLR Viewer or underlying data into their adaptation planning. For example, in 2013, the City of Charleston, South Carolina began to work with OCM to analyze the potential impacts of sea level rise on the city.[94] As part of this process, OCM used the SLR Viewer to demonstrate the effect of sea

[90] "Climate Action Benefits: Coastal Property". Climate Action Benefits Report. US EPA. Available: https://www.epa.gov/cira/climate-action-benefits-coastal-property. Accessed January 26, 2017.
[91] "Sea Level Rise – Map Viewer: Sea Level Rise and Coastal Flooding Impacts". Climate.gov. National Oceanic and Atmospheric Administration. Available: https://www.climate.gov/maps-data/dataset/sea-level-rise-map-viewer. Accessed January 26, 2017.
[92] "Coastal Louisiana added to NOAA Sea Level Rise Viewer". National Oceanic and Atmospheric Administration. Available: http://www.noaanews.noaa.gov/stories2015/121715-coastal-louisiana-added-to-noaa-sea-level-rise-viewer.html. Accessed January 26, 2017.
[93] "Sea Level Rise Viewer: Data Updates". DigitalCoast. NOAA Office for Coastal Management. January 26, 2017. Available: https://coast.noaa.gov/digitalcoast/tools/slr.html. Accessed January 27, 2017.
[94] City of Charleston, 2015. Sea Level Rise Strategy. December, 2015. Available at: http://www.charleston-sc.gov/DocumentCenter/View/10089. Accessed February 5, 2017.

level rise on streets, landmarks, and infrastructure to city planners and engineers. The City subsequently developed a sea level rise strategy, and has received a coastal resilience grant of $766,887 on behalf of the Charleston Resilience Network to implement the strategy.[95] In another case, the City of New York used the SLR Viewer to incorporate coastal flooding and sea level rise risks into a post-Hurricane Sandy comprehensive resilience plan. The city's Office of Long-Term Planning and Sustainability worked with FEMA, the U.S. Army Corps of Engineers, and NOAA to develop the Sandy Recovery Tool, which helped the city consider coastal and emergency planning, coastal protection, critical infrastructure and services, and building code upgrades during the post-Sandy recovery.[96]

Other users include universities, scientific and engineering groups, and NGOs who use the SLR viewer and underlying data for research. The University of Florida, for example, combined flood data from the SLR viewer with critical infrastructure data, land use data and vulnerability indices to develop a new SLR viewer specifically for the Tampa Bay area. The new viewer allows local, non-expert planners in the Tampa Bay area to prioritize adaptation options under different sea level rise scenarios, including adaptation options related to transportation, institutional, and emergency infrastructure.[97]

Various private entities also use the data underlying the SLR Viewer to develop their own sea level rise assessment tools. Zillow and Syndeste LLC, for example, are two private sector companies that use NOAA's SLR data or DEMs to perform assessments. Zillow uses the data to assess the vulnerability of home values to sea level rise, while Syndeste, LLC has developed a unique flood vulnerability application.[98] While there are many additional tools available to assess SLR vulnerability, as part of OCM's DigitalCoast platform, the SLR Viewer, enables users to access a mapping tool and the underlying data, as well as a variety of other coastal vulnerability tools, easily and quickly.

The SLR viewer is available, along with several other coastal analysis tools, on OCM's DigitalCoast website. In addition, NOAA provides technical assistance for the tool via Digital Coast. Users can access underlying data through a data access viewer and data registry, and metadata is available in a separate data catalog. In addition, OCM conducts outreach on the SLR Viewer to different groups through workshops and conferences; these groups include federal, state, county, and local agencies, universities, research agencies, private companies, and non-governmental and international organizations. Several of these entities create apps that further disseminate or use NOAA's data. Additionally, the SLR viewer and underlying data gain recognition through articles, presentations, and through social media outlets.[99]

2.4 Societal Benefits

The SLR Viewer allow planners, emergency managers, and others to visualize the local potential inundation level associated with future sea level rise and understand the potential impact on coastal properties and associated resources. This in turn informs planning decisions, which helps to avoid property damage, maintain critical infrastructure, minimize impacts on vulnerable populations, and preserve or enhance coastal ecosystems.

Several studies have estimated the costs of sea level rise and coastal flooding. The U.S. EPA estimates that the costs of property abandonment and protective adaptation actions (plus some additional costs) associated with sea level rise and storm surge will amount to $5 trillion through the end of the century.[100] Zillow, using NOAA's SLR maps, estimates that approximately 1.9 million homes worth $882 billion are at risk of being underwater by 2100.[101]

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[95] 'Stories from the field: Building the Case for a Comprehensive Sea Level Rise Strategy in Charleston, South Carolina. Available at: https://coast.noaa.gov/digitalcoast/stories/charleston-slr.html. Accessed February 5, 2017.

[96] The City of New York, 2014. Background narrative to support New York City's cooperation with the Federal Administration regarding New York City's Resiliency Plan. The Office of the Mayor.

[97] "Stories from the Field: Creating a Customized Sea Level Rise Viewer to Assist Planners in Florida". NOAA Office for Coastal Management. Available at: https://coast.noaa.gov/digitalcoast/stories/tampa-viewer.html. Accessed February 5, 2017.

[98] "Stories from the Field: Understanding Comprehensive Flood Risk with NOAA Data". NOAA Office for Coastal Management. Available at: https://coast.noaa.gov/digitalcoast/stories/beyond-floods.html. Accessed February 5, 2017.

[99] "SLRViewer – Outreach Capture". Doug Marcy, NOAA. Personal communication. January 10, 2017.

[100] "Climate Action Benefits: Coastal Property". U.S. EPA. Coastal Action Benefits Report. Available at: https://www.epa.gov/cira/climate-action-benefits-coastal-property. Accessed February 5, 2017.

[101] "Climate Change and Housing: Will a Rising Tide Sink all Homes?" Zillow.com. Available at: http://www.zillow.com/research/climate-change-underwater-homes-12890/. Accessed February 5, 2017.

The SLR viewer has enabled communities and areas to assess vulnerability in dollar terms on a local scale. An analysis performed by the Southeast Florida Regional Climate Change Compact Counties (Monroe, Miami-Dade, Broward, and Palm Beach), as well as the South Florida water Management District, local universities, NOAA and other federal agencies, revealed that a one-foot rise in sea level could yield $4 billion-worth of vulnerable homes, and a three-foot scenario could result in $31 billion in vulnerable homes in the Southeast Florida region[102]

Figure A.2 presents the value chain for the SLR Viewer, including the data from the NOAA Fleet and other sources that the tool depends on, and how the tool ultimately results in value to society.

[102] Southeast Florida Regional Climate Change Compact Inundation Mapping and Vulnerability Assessment Work Group. 2012. Analysis of the Vulnerability of Southeast Florida to Sea Level Rise.

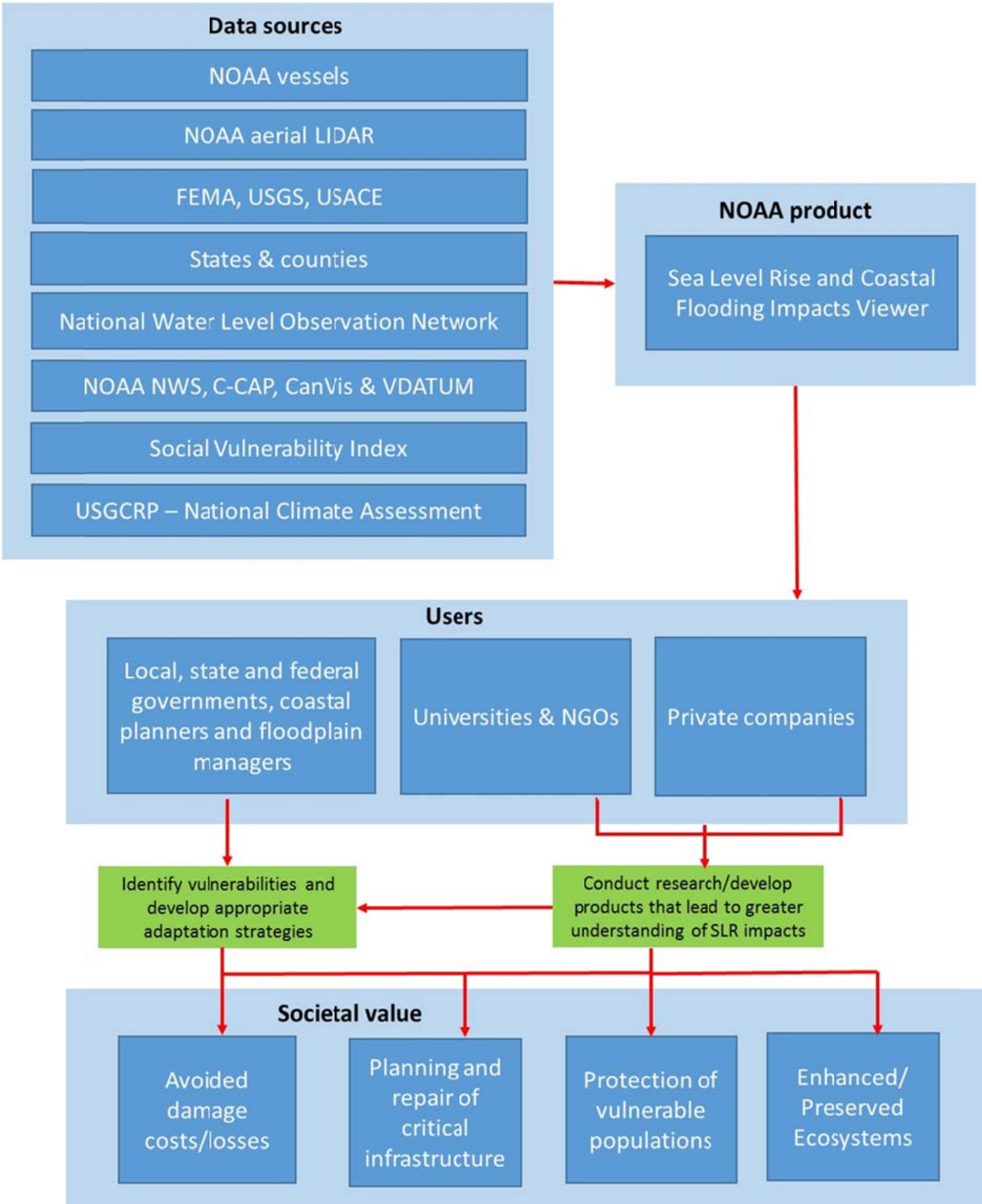

Figure A.2. NOAA Fleet Data Value Chain: SLR Viewer

3. Bathymetry/Hydrographic Surveys: Nautical Chart Products

3.1 Product Background

Product: Nautical Charts

Line Office: National Ocean Service, Office of Coast Survey

Mission Service Area: Resilient Coastal Communities and Economies, Marine Transportation

NOAA provides nautical charts and related hydrographic information for the safe navigation of maritime commerce, engineering, scientific and other commercial and industrial activities.[103] NOAA's nautical charts and associated hydrographic data support safe and efficient navigation, homeland security, protection of the marine environment, coastal zone management, and economic prosperity for the Nation. NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS) is responsible for producing a suite of over 1,000 nautical charts that cover the coasts of U.S. states and territories, as well as the Great Lakes. [104]

NOAA's nautical charts show water depths, shoreline of adjacent land, prominent topographic features, aids to navigation (including locations of dangers to navigation), anchorages, and other features.[105] Nautical charts come in two forms, as paper charts and electronically. Paper charts are more traditional, and are less in use today. NOAA used to print NOAA lithograph nautical charts in large runs and sell them to commercial chart agents who would then distribute them to the public. However, the Federal Aviation Administration took over federal chart production in 1999 and closed the printing operation as a cost-saving measure on April 13, 2014. Instead, NOAA has formed partnerships with print-on-demand (POD) distributors. These distributors take orders from the public and print the most up-to-date version of the chart from the NOAA website. NOS updates each chart online every week. Thus, individuals can be certain that they are purchasing the most up to date version of the chart the moment it is printed.[106] NOAA-certified vendors print and sell paper charts throughout the world. Individuals can also purchase and print charts for free directly from NOAA's OCS website.

In today's world, electronic charts are more popular and mandated for certain commercial vessels. There are two digital formats for electronic charts, Raster Nautical Charts (RNC) and Electronic Navigational Charts (ENC). The RNC is a simple digital image of the paper chart, while the ENC carries a significantly greater amount of information that can help warn mariners of dangers ahead and provide other information critical to a safe passage. ENCs are basically geographic information systems; they utilize a computerized system called an Electronic Chart Display and Information System (ECDIS) to display the chart data and the ship's position. The ENCs digital format allows quicker updates, which means the mariner has the most up to date information to make a safe passage. This same data can also be used for ocean modeling and other scientific activities. The ENC and their associated ECDIS system rely on satellite positioning systems like the Global Positioning System (GPS) and have different capabilities, and limitations compared to their paper counterparts. Electronic charts are the legal equivalent of a paper chart if the ENC and ECDIS meet International Hydrographic Organization (IHO) and International Maritime Organization (IMO) specifications.[107]

3.2 NOAA Fleet Data that Feed the Product

The NOAA fleet conducts hydrographic surveys that provide some of the bathymetry data NOS uses to maintain Nautical Charts. Four of the ships in NOAA's fleet are primarily dedicated to hydrographic surveying, including *Fairweather*, *Ferdinand R. Hassler*, *Rainier*, and *Thomas Jefferson*. Each of these ships use full bottom coverage echo sounding

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[103] NOAA is responsible for producing nautical charts pursuant to the Coast and Geodetic Survey Act of 1947 and the Hydrographic Services Improvement Act of 1998 (and amendments). NOAA's mapping and surveying activities for safe navigation are a primary contributor to U.S. commitments for nautical charts under the international Safety of Life at Sea Treaty, directly sustaining Coast Guard chart carriage regulations.

[104] "NOAA's Suite of Nautical Charts." NOAA Office of Coast Survey. https://www.nauticalcharts.noaa.gov/mcd/learnnc_chartsuite.html

[105] "What is a Nautical Chart?" (2002). NOAA Office of Coast Survey. https://www.nauticalcharts.noaa.gov/mcd/learnnc_chart.html

[106] Personal Communication with Rachel Medley, Chief of Customer Affairs Branch of the Navigation Services Division on January 11, 2017.

[107] "What is a Nautical Chart?" (2002) NOAA Office of Coast Survey. https://www.nauticalcharts.noaa.gov/mcd/learnnc_chart.html

technology to measure water depth and identify navigational hazards. The *Fairweather*, *Rainer*, and *Thomas Jefferson* also have 2-6 smaller boats or launches to survey shallow areas.[108] The ship's officers and crew acquire and process the data on board the ship. The data is passed to NOAA hydrographers and cartographers at the Office of Coast Survey's shoreside processing centers for quality control and compilation to the nation's Nautical Charts.

In addition, crew members immediately report any hazardous features found during these surveys that might endanger vessels to NOAA cartographers, who update the corresponding nautical chart right away. The U.S. Coast Guard Navigation Center also publishes this information in the appropriate Local Notice to Mariners to ensure that the public is made aware of the change.[109]

3.3 Complementary Data

NOS also receives hydrographic survey data from other federal and state agencies, as well as the private sector. For example, Hydrographic Survey Services Contractors provide a about half of the hydrographic data that NOAA uses to develop nautical charts. In addition, the Office of Coast Survey operates six Navigation Response Teams (NRTs) which consist of 27-foot small boats and the *Bay Hydro II*, a 55' aluminum catamaran. These vessels have many of the same sonar capabilities as the NOAA survey vessels and focus on surveying the depths of the ever-changing seafloor and searching for dangers to navigation.[110] Because of their smaller size, these vessels can be more economically deployed and can be used in shallow, inland waterways where the NOAA fleet vessels cannot go – for example, they are responsible for surveying the near shore areas of the nation's 175 major U.S. ports.[111]

A significant source of pertinent data is from the U.S. Army Corps of Engineers, which provides NOAA with survey data and underwater construction permit information for federal channels, anchorages and inland waterways. NOAA cartographers analyze these surveys and permits to determine necessary updates to nautical charts because of shoaling or dredging in channels or new construction.[112]

Finally, NOAA also receives information from the recreational boating community through a Cooperative Charting Program with the U.S. Power Squadrons (USPS) and the Coast Guard Auxiliary. USPS members and the Coast Guard can report any chart discrepancies to NOAA online. If the update is deemed critical it is applied to the nautical chart.

3.4 Complementary Products

In addition to nautical charts produced by NOAA and certified POD vendors, there are several software companies that use electronic nautical charts to build mapping applications for recreational boaters. The developers of these apps rely on the RNCs and ENCs that NOS produces to provide nautical chart information to their users. Any time changes are made to the NOAA nautical charts, these apps are automatically updated. NOS is currently working to format the data that goes into Nautical Charts in a way that makes it easier for these software developers to use.

[108] "Survey Vessels." (2016). NOAA Office of Coast Survey. https://www.nauticalcharts.noaa.gov/hsd/surveyplatforms.html
[109] "How Publications are Updated." NOAA Office of Coast Survey. https://www.nauticalcharts.noaa.gov/mcd/learn_chartupdate.html
[110] "Navigation Response Teams." NOAA Office of Coast Survey. https://www.nauticalcharts.noaa.gov/nsd/nrt.html
[111] "NOAA R/V Bay Hydro II." NOAA Office of Coast Survey. https://www.nauticalcharts.noaa.gov/nsd/bayhydro.htm
[112] "How Publications are Updated." NOAA Office of Coast Survey. https://www.nauticalcharts.noaa.gov/mcd/learn_chartupdate.html

3.5 Users of the Product and Related Products

Nautical Charts and their related products have many uses. Federal regulations require certain vessels to carry "navigational charts and publications published by the National Ocean Service."[113] These regulations are set by the Coast Guard and the by the international maritime community.

Commercial and light commercial sector vessels that transit the same U.S. waters on each trip, such as cruise lines, ferries, tug and tow vessels, rely heavily on NOAA Nautical Charts. The Coast Guard requires each of these vessels to have a large-scale, detailed paper chart of the waters in which they operate. This chart can be printed through any of the NOAA-certified print-on-demand vendors that sell Nautical Charts.[114] The vendors provide a Certificate of Authenticity with each chart to ensure that it meets regulatory requirements. There are 20 to 25 of these vendors that work directly with NOAA.[115] In 2011, direct users and vendors downloaded 210,843 paper nautical charts from NOAA, and there were 18,695 public sales of the Coast Pilot chart books.[116]

Most users rely on electronic Nautical Charts for navigation purposes, including both ENCs and RNCs. In 2011 downloads of ENCs totaled 141.6 million, while downloads of RNCs amounted to 97.6 million.[117] Larger vessels in the SOLAS class (meaning they are regulated under the Safety of Life at Sea (SOLAS) convention) are required to use ENCs.[118].

Recreational boaters are not required to use NOAA nautical charts by law. However, they often indirectly use NOAA nautical chart products through third-party software applications on electronic chart plotters using Global Positioning Systems (GPS) or mobile devices.

Nautical charts are also important for the international shipping industry. Cargo ships continue to increase in size and draft and need more logistical support to navigate new waters. When a new ship arrives at an American port, they are required to use NOAA nautical charts to understand water depths and the port shoreline infrastructure to determine whether their ship can enter. If mariners cannot rely on nautical charts as an accurate and up-to-date product, ships may avoid U.S. ports and go elsewhere to unload their cargo.[119]

In addition, NOAA's nautical charts are the authoritative source for maritime regulation and political boundaries (e.g. Exclusive Economic Zone, EEZ). Further, when a marine accident occurs, the Nautical Chart in use at the time serves as a record for reconstructing the event and assigning liability in a court of law. These events include grounding, collision, and other accidents. Charts that are used to reconstruct these incidents can also be used for training purposes.[120] Finally, nautical charts directly inform several other NOAA products, as well as products developed other government agencies and the private sector. Figure A.3 presents the official NOAA products and services that directly depend on nautical charts.

3.6 Societal Benefits

[113] Personal Communication with Rachel Medley, Chief of Customer Affairs Branch of the Navigation Services Division on January 11, 2017.
[114] "Print-on-Demand Paper Charts." NOAA Office of Coast Survey. https://www.nauticalcharts.noaa.gov/pod/index.html
[115] Personal Communication with Rachel Medley, Chief of Customer Affairs Branch of the Navigation Services Division on January 11, 2017.
[116] Leveson, I., (2012). Socio-Economic Study: Scoping the Value of NOAA's Coastal Mapping Program Final Report. *Leveson Consulting.* p. 27
[117] Ibid.
[118] Personal Communication with Rachel Medley, Chief of Customer Affairs Branch of the Navigation Services Division on January 11, 2017.
[119] Ibid.
[120] "What is a Nautical Chart?" (2002) NOAA Office of Coast Survey. https://www.nauticalcharts.noaa.gov/mcd/learnnc_chart.html

The greatest value that NOAA's nautical charts provide is safety for navigators. By providing the most up to date information, ships do not navigate blindly and can chart out the safest and most efficient route to their destination. They can also avoid navigational hazards with confidence, which in turn allows them to avoid unnecessary slow-downs. Thus, much of the value of this product can be estimated based on avoided losses from collisions and grounding, injury and possibly death. Because ship time can be expensive, Nautical Charts also provide value in terms of savings in the amount of time spent at sea.

Figure A.3. NOAA Key Products that Rely Directly on NOAA Nautical Charts

- Marine Cadastre: Political Boundaries; Marine Infrastructure, Habitat, Mammals; Renewable Wind/Tide Energy Potential
- National Marine Sanctuary Condition Reports
- National Marine Sanctuary: Monitoring Reports
- Sanctuary Science Reports: Conservation Series, Biological-Geographic Reports
- Sea Level Rise Impacts: Coastal Ecosystems
- Operational Response Services: National Marine Sanctuary

Source: TPIO (2017)

Because of its unique use in the international shipping industry, another way to consider the value of Nautical Charts is to examine the value of U.S. ports to the national economy. According the American Association of Port Authorities, U.S. seaports generate nearly $4.6 trillion in total economic activity, and provide $1.2 billion in personal income and local consumption.[121] This would likely be significantly lower without up-to-date Nautical Chart information.

In 2007, Kite-Powell conducted a study for the NOAA Office of the Coast Survey to estimate the benefits of ideal nautical charts for recreational and commercial vessels, based on a survey asking users what they would be willing-to-pay for 'ideal' nautical charts.[122] Assuming a minimal difference between the nautical charts that were available at the time and ideal charts, the author estimated that the combined benefits of nautical charts amounted to $47.5 million (2007 USD),[123] including $15.3 million/year in consumer surplus for recreational users, $27.5 million/year in consumer surplus for commercial users, and $2 million/year in producer surplus. We estimate that today, this value amounts to approximately $57.9 million/per year (2016 USD), accounting for the increase in foreign flag ships visiting U.S. ports between 2007 and 2016.[124]

While this study provides an order of magnitude estimate of the value of nautical charts, the authors acknowledge that it serves as a lower bound estimate, largely because the study did not include military users, commercial fishing vessels, or marine resource managers, among others. In addition, since the study was conducted in 2007, electronic nautical charts have become even more popular, allowing for more frequent updates that provide additional value to users.[125] The study also does not include the economic activity generated by value-added products that use ENC data as inputs. The development of these products creates jobs, wages, and additional economic output.

Figure A.4 demonstrates the value chain for nautical charts, including the data from the NOAA Fleet and other sources that the charts depend on, and how the charts ultimately result in value to society.

[121] "Exports, Jobs & Economic Growth." American Association of Port Authorities. http://www.aapa-ports.org/advocating/content.aspx?ItemNumber=21150
[122] Kite-Powell, H. 2007 Use and Value of Nautical Charts and Nautical Chart Data in the United States. Prepared for NOAA Office of Coast Survey.
[123] Leveson, I., (2012). Socio-Economic Study: Scoping the Value of NOAA's Coastal Mapping Program Final Report. *Leveson Consulting.* p. 47
[124] Values for recreational and commercial consumer surplus and producer surplus increased to 2016 USD using BLS Consumer Price Index.
[125] In addition, because survey respondents knew how much they paid for nautical charts, this could have resulted in an anchoring bias, leading to more conservative estimates of value.

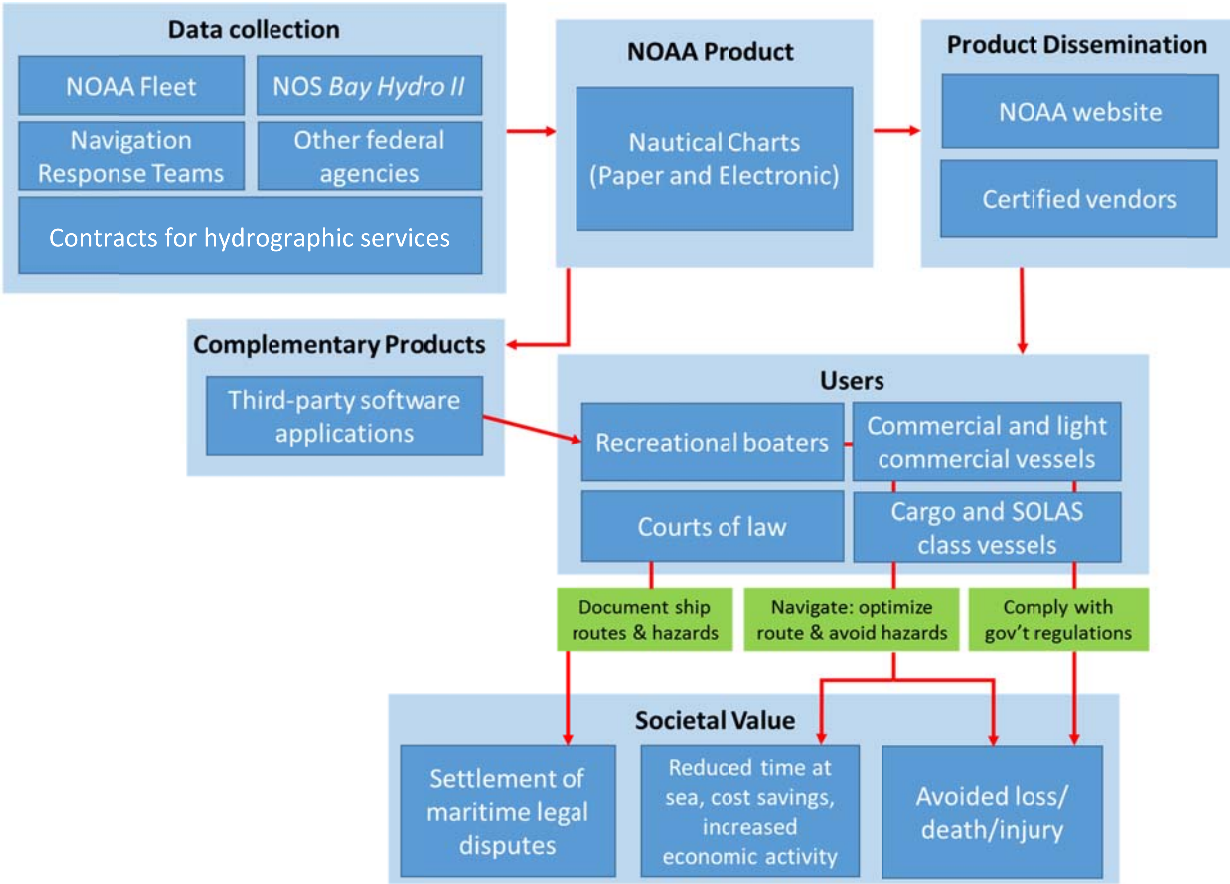

Figure A.4. NOAA Fleet Data Value Chain: Nautical Charts

4. Seasonal Forecast: El Nino – Southern Oscillation Outlook

4.1 Product Background

Product: El Nino Southern Oscillation Outlook

Line Office: National Weather Service, Climate Prediction Center

Mission Service Area: Climate, Climate Predictions and Projections

The El Nino – Southern Oscillation (ENSO) cycle represents year-to-year changes in sea surface temperatures, convective rainfall, surface air pressure and atmospheric circulation over the equatorial Pacific.[126] El Nino describes a year in which sea-surface temperatures are above the long-term average, while La Nina describes a year in which sea-surface temperatures are cooler than average.[127] During El Nino and La Nina years, changes in Pacific Ocean temperatures affect seasonal tropical rainfall patterns from Indonesia to the west coast of South America. These changes in tropical rainfall affect weather patterns throughout the world, including the frequency and severity of storms, floods, droughts, hurricanes, tornadoes, and other weather-related events, as well as temperature and precipitation.

To help the public and private sector better prepare for expected ENSO-related conditions in a given season, NOAA's National Weather Service (NWS) Climate Prediction Center (CPC) creates and disseminates the ENSO Outlook. The ENSO Outlook describes the status of El Nino and La Nina conditions. CPC uses the ENSO Outlook and other tools to inform seasonal temperature and precipitation predictions for the U.S.

4.2 NOAA Fleet Data That Feed the Product

One of the main inputs to the ENSO Outlook is data from the Tropical Atmosphere/Ocean (TAO) array. The TAO array consists of 70 buoys moored ("moorings") in the Pacific Ocean that collect oceanographic and meteorological data.[128] The NOAA fleet maintains the TAO array and transmits the data from these moorings electronically through satellites.[129] Ships go to each buoy once a year to perform necessary maintenance including repairing any damage caused by biological activity, or local fisherman.

Basic measurements on TAO moorings include wind speeds, air temperature, relative humidity, sea surface temperature, and subsurface temperatures at 10 levels.[130] Additional sensors can collect data on rainfall, short wave and long-wave radiation, barometric pressure, salinity and ocean currents.[131] The ENSO Outlook relies on weekly sea surface temperature readings and salinity profiles from the TAO array.

In addition to data from the TAO array, CPC also relies on ocean profile data collected directly from NOAA fleet vessels, including conductivity, temperature, and depth (CTD) and expendable bathythermograph (XBT) data, to develop the ENSO Outlook. The Voluntary Observing Ship Program, which the NOAA fleet is a part of, also provide sea surface temperature and weather data.

4.3 Complementary Data

A second source of data for the ENSO outlook is the ARGO array. This global array of 3,800 floats provides data on subsurface temperature, salinity, and velocity of the upper 2000 meters of the ocean.[132] The ARGO floats go underwater to a depth of about 2 km and then come back to the surface to automatically transmit their data. They require much less

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[126] "What is ENSO (El Nino/Southern Oscillation)?" (2012). NOOA National Weather Service Climate Prediction Center. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensofaq.shtml#ENSO

[127] Ibid.

[128] "Project: Tropical Atmosphere Ocean Buoy Service." (2016). NOAA Office of Marine and Aviation Operations. http://www.omao.noaa.gov/find/projects/3418-tropical-atmosphere-ocean-buoy-service

[129] For example the *Ronald H. Brown* provided maintenance for TAO Buoy in November 2015. http://www.omao.noaa.gov/find/projects/2751-tropical-atmosphere-ocean-tao-buoy-array-maintenance

[130] "TAO Refresh Sampling." (2011). NOAA's National Data Buoy Center. http://tao.ndbc.noaa.gov/proj_overview/sampling_ndbc.shtml

[131] Ibid.

[132] "What is Argo?" Argo – part of the integrated global observation strategy. http://www.argo.ucsd.edu/

maintenance than the TAO array because there are no vandalism issues. ARGO floats are not supported by the NOAA Fleet.

The ENSO Outlook also uses satellite data on Outgoing Longwave Radiation (OLR) to develop precipitation predictions.

Data from the TAO array and other sources is incorporated into numerical models through the Climate Forecast System and the North American Multi-Model Ensemble. CPC uses the results of these models to develop the ENSO Outlook.

4.4 Product Dissemination

The ENSO Outlook is disseminated in four ways: through web dissemination, weekly presentations, monthly discussions, and a blog. The ENSO weekly updates, provided by CPC, describe the recent evolution, status, and predictions for El Nino/La Nina conditions in the world. The update contains a value for the Oceanic Nino Index (ONI), the status of EL Nino/La Nina conditions through the ENSO Alert System Status, and U.S. seasonal precipitation and temperature outlooks.[133] CPC updates this information every Monday.

CPC also issues monthly ENSO Diagnostic Discussions in partnership with the International Research Institute for Climate and Society. These diagnostic discussions provide more technical detail on current El Nino/ La Nina conditions, and include precipitation and temperature predictions for the upcoming months.[134]

Finally, CPC disseminates information from the ENSO Outlook through its ENSO blog. This blog gives information about ENSO and other short-term climate forecasts in a less technical and more readable manner. The blog also provides monthly ENSO updates.[135]

4.5 Users of the Product and Related Products

CPC provides information contained in the ENSO weekly updates and diagnostic discussions primarily to government stakeholders. Internal users of this information within NOAA include NWS weather forecast offices. Other government users include FEMA, DOD, USAID, and state and local agencies whose operations or decisions are impacted by short-term climate variations. CPC provides briefings on the information contained in the ENSO Outlook to these various federal, state and local stakeholders.

The ENSO blog is meant for the public and is mostly used by people with an interest in short-term climate forecasts. The blog uses less technical language than the other products and is more readable. NOAA has received positive feedback on the blog as means of communication from various stakeholders.[136]

The information provided in the ENSO Outlook and associated dissemination venues can affect the decisions and management actions of many different types of stakeholders. For example, a water resource manager, such as the Tampa Bay Water Authority may look at predicted precipitation levels in the ENSO Outlook and make decisions about reservoir releases. Emergency management agencies use ENSO-related information to appropriately prepare and allocate resources to areas that will likely experience adverse effects as a result of El Nino or La Nina. Other state and local agencies affected by ENSO-related conditions include those related to transportation and energy.

There are also many private sector users of the ENSO outlook, including agriculture, retail, energy, fisheries, and outdoor recreation/tourism. For example, CPC has a longstanding collaboration with the U.S. Department of Agriculture (USDA). The ENSO information can inform farmers' decisions on which crops to plant and when to plant based on expected precipitation levels and other factors. In December 2016, the Department of Interior's Climate Hub hosted a

[133] "ENSO: Recent Evolution, Status and Predictions." (2017). NOAA Climate Prediction Center and National Centers for Environmental Prediction. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf
[134] "El Nino/Southern Oscillation (ENSO) Diagnostic Discussion - 8 December 2016" (2016). NOAA Climate Prediction Center/NCEP/NWS/International Research Institute for Climate and Society. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.pdf
[135] "ENSO Blog."(2016). Climate Prediction Center. https://www.climate.gov/news-features/department/enso-blog
[136] Personal communication with

briefing in West Texas with private stakeholders and scientists to discuss ENSO forecasts. The goal was to help stakeholders understand short-term climate forecasts including the ENSO Outlook and use that information to decide when to plant their winter wheat. Through these briefings, stakeholders have the tools necessary to get the maximum benefit from the forecasting information provided by the CPC.

Private retailers or grocery chains may use the data to rearrange merchandise based on seasonal expectations. Mild or warmer winters may affect private retail stock purchasing decisions. The CPC recently held a briefing with over 100 participants from various grocery chains including Walmart on the record El Nino from last year. The briefing included the same information from the Diagnostic Discussions and Weekly Updates. The participants also asked specific questions and used this information to adjust their inventory for seasonal products. For example, they would not want to send many snow shovels or winter coats to areas expected to have mild winters.

The energy sector serves as another example of a private industry that is affected by ENSO conditions, and that therefore benefit from the information provided in the ENSO Outlook. For example, mild and warmer winters due to El Nino can have a large impact on fuel markets due to changes in winter heating demand.[137] If fuel market decision makers learn of expected normal or below normal temperatures, the fuel market can adjust depending on where there will be more heat days or less heat days.

Finally, the information in the ENSO Outlook feeds several different NOAA products, including the Hurricane Outlook, the 1-Month and 3-Month Climate Outlook, Sea Ice Forecast, and climate analysis tools. These products reach an even greater number of users, thereby increasing the value of this product.

4.6 Societal Benefits

For a forecast to have economic value, it must be true that better decisions can be made if a better weather forecast is available. Several studies have shown that predicting the life cycle and strength of a Pacific warm or cold episode is critical in helping farmers plan for, avoid or mitigate potential losses.[138] For example, Solow et al. (1998) found that by incorporating NOAA’s ENSO forecasts into planting decisions, farmers in the United States could increase agricultural output and produce benefits to the U.S. economy of up to $300 million per year (1998 USD), depending on the accuracy of the forecast.[139] McKnew (2000) estimated that the value to society of ENSO forecasts on corn storage decisions can be as high as $240 million (2000 USD)—or one to two percent of the value of production.[140] In addition to these sectors, ENSO-related predictions can result in significant benefits for the water, energy, transportation, retail, and tourism sectors.

ENSO-related forecasts of the potential for extreme climate episodes like floods and droughts could also save the United States billions of dollars in damage costs. For example, national and state emergency managers can use ENSO forecasts to better prepare for predicted events, which can reduce response costs and avoid weather-related damages. Individual households and businesses can also use the ENSO Outlook to make appropriate preparatory decisions, resulting in avoided damage costs. Tiesberg (2000) reports that on the U.S. West Coast, where El Niño frequently brings a great increase in winter precipitation, prior to the winter of 1997-98, there were reports of heavy demand for the services of roofing contractors, as people repaired or replaced roofs in anticipation of predicted El Niño storms. The benefit of this accelerated maintenance is a reduction in the risk or extent of damage to the inside of structures due to leaking roofs during heavy winter storms.

Figure A.5 demonstrates the value chain associated the El Nino Outlook, including the data from the NOAA Fleet that it depends on, and how this ultimately results in value to society.

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[137] “Strong El Nino helps reduce U.S. winter heating demand and fuel prices.” (2016). U.S. Energy Information Administration. http://www.eia.gov/todayinenergy/detail.php?id=25952
[138] Weiher, R. Improving El Niño Forecasting: The Potential Economic Benefits. NOAA.
[139] Solow, A.,et al. 1998. The value of improved ENSO prediction to U.S. agriculture. Climatic Change 39:47-60.
[140] McNew, K. 2000. The Value of El Niño Forecasts in Agricultural Commodity Markets: The Case of U.S. Corn Storage.

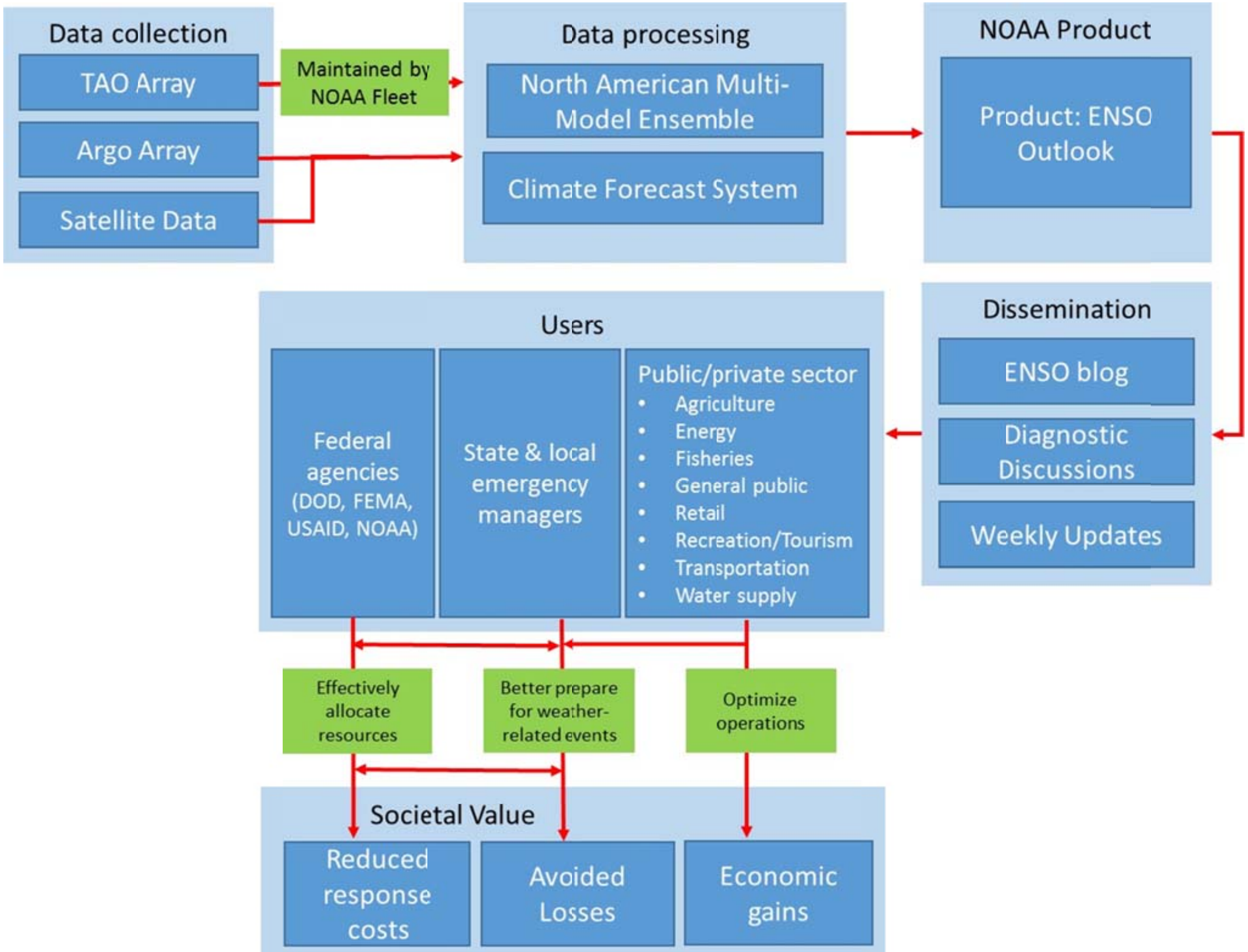

Figure A.5. NOAA Fleet Data Value Chain: ENSO Outlook

5. Ecosystem Management: National Marine Sanctuaries Conditions Reports

5.1 Product Background

Product: National Marine Sanctuary Conditions Reports

Line Office: National Ocean Service, Office of National Marine Sanctuaries

Mission Service Area: Resilient Coastal Communities and Economies, Planning and Management

NOAA's National Ocean Service (NOS) currently maintains 13 National Marine Sanctuaries (NMS) and two national marine monuments. Together, these protected marine ecosystems encompass more than 600,000 square miles of marine and Great Lakes waters. The sanctuaries support thousands of endangered species and a variety of habitats ranging from coral reefs, to deep-sea canyons, to underwater archeological sites.[141] The goal of the sanctuaries is to promote the responsible and sustainable use of the ocean's resources through conservation, research and monitoring, education and outreach, and community engagement.[142]

NMS Condition Reports serve as an important tool for managing and protecting the resources within marine sanctuaries from outside pressures. The Condition Reports help sanctuaries determine if they are achieving their resource protection and improvement goals, and informs future management plans for the sanctuary.[143] Specifically, the reports summarize the current condition of resources in the Sanctuary, the pressures that threaten these resources, and the proposed management responses to these pressures.[144]

Individual sanctuaries within the NOS Office of NMS produce the reports, with support from NMS headquarters. Each sanctuary releases an updated Condition Report every five years. The first condition report serves as a baseline assessment of sanctuary resources and focuses on characterizing the species and habitats in the sanctuary. Subsequent condition reports are meant to examine trends, identify how the status of various resources has changed, and establish appropriate management responses. Towards that end, all of the reports answer the same set of 17 questions that touch on a variety of topics including keystone species, keystone habitats, human influences, and climate change impacts.[145] Each sanctuary answers the questions with the goal of relating the report results back to sanctuary-specific regulation, education and outreach, and management actions.

5.2 NOAA Fleet Data That Feed the Product

The NOAA fleet provides key data that serves as the basis for many conclusions in the NMS Condition Reports. For example, NOAA vessels participate in habitat characterization for NMS through seafloor mapping surveys. They also collect data on species abundance, diversity and distribution of fish and marine mammals within the sanctuary through bird and mammal observation stations and acoustic surveys. Other NOAA ship data that are often incorporated into the Conditions Reports include information from water quality surveys (e.g., harmful algal blooms), ocean profile data that informs hypoxia forecasts, and processed hydrographic data from NOAA ship bathymetry surveys.

While most sanctuaries have access to a sanctuary vessel, these vessels can be smaller and less effective than the NOAA Fleet. The NOAA research vessels are critical for gathering data in seasons where the sanctuary vessel is too harsh for the operation of smaller vessels, such as April, May and June.[146] Some sanctuaries see large seasonal changes in species composition, so it is important to get measurements during each season. NOAA vessels also allow sanctuary staff to spend more days at sea, and reach parts of the sanctuary that are not accessible using the sanctuary vessel because of the distance from ports. They are also able to conduct research in deeper areas of individual sanctuaries.

Ultimately, NOAA vessels streamline the data collection process ensuring that it is comprehensive and timely. For example, for their 2010 Condition Report the Greater Farallones National Marine Sanctuary was able to complete

[141] Gittings, S. R., Broughton, K. (2016). "Guide for Developing National Marine Sanctuary Condition Reports." NOAA National Marine Sanctuaries., pp. 2
[142] "About." (2016). NOAA National Marine Sanctuaries. http://sanctuaries.noaa.gov/about/
[143] "Frequently Asked Questions." (2015). NOAA National Marine Sanctuaries. http://sanctuaries.noaa.gov/science/condition/faq.html
[144] Ibid.
[145] Personal communication with Jan Roletto, Research Coordinator at the Greater Farallones National Marine Sanctuary on January 10, 2017.
[146] Ibid.

sampling for the entire sanctuary in nine days using the *Bell M. Shimada* vessel.[147] The data gathered by NOAA vessels like the *Bell M. Shimada* on habitat characterization and species composition are used to answer the 17 questions within each Condition Report.

NOAA weather buoys, many of which are serviced by the NOAA Fleet, also serve as a data source for the Condition Reports of each sanctuary. These buoys collect data on weather and ocean conditions, including oceanographic variables that contribute to these Condition Reports.[148]

5.3 Complementary Data

Some of the data used for the NMS Condition Reports is collected by other vessels, including sanctuary vessels and chartered vessels. For example, the Monterey Bay, the Greater Farallones, and the Cordell Bank National Marine Sanctuaries all use one sanctuary vessel, the *R/V Fulmar*. The *Fulmar* goes about 40 miles offshore to collect data and its cruises are about 10 hours in length.[149] The vessel collects baseline data on emerging management issues such as invasive species and marine reserves.[150] This data helps inform management decisions and Condition Reports.[151]

The Condition Reports also rely on data collected on chartered vessels. One such vessel is the *E/V Nautilus*, which explored five National Marine Sanctuaries in 2016 along the U.S. West Coast.[152] The *Nautilus* supported a variety of projects within each sanctuary by collecting important data including species surveys and sonar bathymetry and sub-bottom profiling data.[153] These data are also often used in the Condition Reports.

5.4 Users of the Product and Related Products

The primary purpose of the NMS Condition Reports is to inform sanctuary management decisions. Effective management of the sanctuaries, in turn, benefits society by []. The Condition Reports serve as an important input into the Sanctuary Management Plan Review Process. Aside from sanctuary staff, the process also involves Sanctuary Advisory Councils comprised of sanctuary staff, members of the public that represent different interests and industries, and jurisdictional partners from local, state, tribal and federal agencies.[154] In addition to summarizing the current condition of key resources in the sanctuary, each Condition Report also describes pressures that threaten these resources. In most cases, NOS NMS will publish a management plan a few years after they develop a Condition Report that addresses the threats described in the report.[155] The Sanctuary Management Plan summarizes existing programs and regulations, lays out the goals and priorities for sanctuary, and guides the future project planning and management decision-making at the sanctuary.[156] The Management Plan affects all sanctuary activities including resource protection, conservation science, research, and education.

The Condition Reports also serve as an internal reporting tool for NOAA and the Department of Commerce.[157] The Reports notes where the sanctuaries are achieving resource protection and improvement goals, and where more work may need to be done. Together, the reports help NOAA better understand the state of the sanctuary network, and develop appropriate management actions.

In addition, the sanctuaries also work closely with organizations, such as universities and independent non-profit organizations that use the data from the Condition Reports in their independent research projects. This research leads to

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147 Ibid.
148 Personal communication with Jan Roletto, Research Coordinator at the Greater Farallones National Marine Sanctuary on January 10, 2017.
149 Ibid.
150 "R/V Fulmar."(2013). Monterey Bay National Marine Sanctuary. http://montereybay.noaa.gov/marineops/about/fulmar/welcome.html
151 Ibíd.
152 "2016 Nautilus Expedition." (2016). NOAA National Marine Sanctuaries. http://sanctuaries.noaa.gov/science/nautilus16/
153 Ibid.
154 "Advisory Councils." (2016). NOAA National Marine Sanctuaries. http://sanctuaries.noaa.gov/management/ac/welcome.html
155 Personal communication with Jan Roletto, Research Coordinator at the Greater Farallones National Marine Sanctuary on January 10, 2017.
156 "Management 101." (2015). NOAA National Marine Sanctuaries. http://sanctuaries.noaa.gov/management/mgt101.html
157 "Frequently Asked Questions." (2015). NOAA National Marine Sanctuaries. http://sanctuaries.noaa.gov/science/condition/faq.html

further understanding and better management of important marine habitat and protected species. For example, NMS often provides funding to independent academic researchers and organizations to conduct research to help them tackle information gaps identified in the Conditions Reports.[158] Non-profit research groups also sometimes partner with federal and state agencies to use the datasets from the Condition Reports to inform important conservation and regulation work. For example, in the San Francisco Bay area, an organization called Point Blue Conservation Science has used data from the *Bell M. Shimada* (a ship in the NOAA fleet) and the *Fulmar* cruises to study the distribution of whales and krill and identify feeding hot spots.[159] Based on the results of this research, Point Blue worked with the sanctuaries, NOAA National Marine Fisheries Service, and the U.S. Coast Guard to redesign ship trafficking lanes that lead into San Francisco Bay. The new lanes reduced overlap of foraging areas and commercial ship traffic. This research also helped to identify when NOAA should install speed advisories to minimize whale deaths due to ship strikes.[160]

Finally, the Condition Report is an important tool for the sanctuaries' education and outreach programs. The information in the Condition Reports help sanctuary staff design site-specific education and outreach programs that teach members of the public about what key resources are in the sanctuary, why they are important, and what behavioral changes are needed to protect them.[161] Each site designs classroom and website activities, outdoor events, summer camps, symposiums etc. with the ultimate goal of instilling a degree of environmental stewardship within each visitor.[162] Universities also support and fundraise for education and outreach efforts conducted by the sanctuaries.

5.5 Societal Benefits

The NMS Condition Reports directly contribute to regulations and policies related to marine sanctuaries, which provide for the protection of key resources, the continued use and enjoyment of these resources, and the economic activity that they support.

NMSs are designated for their irreplaceable resources, making them ideal travel destinations for ocean lovers, marine wildlife viewers and recreation seekers.[163] The ecosystem services and opportunities that the sanctuaries provide result in a range of benefits, including direct on-site user benefits (e.g., such as associated with educational programs, recreational or commercial fishing) and indirect benefits accruing to individuals who do not use the marine ecosystem directly but who value their existence or enjoy them passively. These use and non-use benefits are often referred to as non-market benefits, because there is no established price for them in the marketplace.

Further, many of the on-site activities associated with marine sanctuaries generate income for businesses and individuals in coastal economies that service the activities – these are known as market benefits. For example, NMS reports that the success of many businesses, millions of dollars in sales, and thousands of jobs, directly depend on thriving national marine sanctuaries. NMS research indicates that together, national marine sanctuaries generate approximately $8 billion annually in local coastal and ocean dependent economies from diverse activities like commercial fishing, research and recreation/tourism-related activities.[164]

In addition, the NMS Condition Reports help to identify research and information gaps, which are in turn filled by NOAA, and academic and other research organizations. This research can serve to further protect and maintain sanctuary resources, including endangered species and key habitat, as well as inform regulations that affect all marine resources. A good example of this is the research conducted by Point Blue that directly informed NOAA's recommendations to the Coast Guard on actions to reduce whale deaths by ship strikes.

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[158] Ibid.

[159] Personal communication with Jan Roletto, Research Coordinator at the Greater Farallones National Marine Sanctuary on January 10, 2017.

[160] "Whale Conservation." (2017). Point Blue: Conservation science for a healthy planet. http://www.pointblue.org/our-science-and-services/conservation-science/oceans-and-coasts/whale-conservation/

[161] Personal communication with Jan Roletto, Research Coordinator at the Greater Farallones National Marine Sanctuary on January 10, 2017.

[162] Ibid.

[163] NOAA. Undated. West Coast National Marine Sanctuaries: Unique travel experiences brought to you by America's underwater treasures! Available: http://sanctuaries.noaa.gov/about/travel-writer-brochure.pdf

[164] NMS Socioeconomic Factsheet: http://sanctuaries.noaa.gov/science/socioeconomic/factsheets/national-system.html

Finally, the educational value of the sanctuaries cannot be understated. As noted above, NMS uses the Condition Reports to inform sanctuary outreach and education programs. These programs serve to educate the general public about the sanctuaries, and marine resources in general. These efforts can further protection through education, and increase the value that society places on these resources.

Figure A.6 demonstrates the value chain associated NMS Condition Reports, including the data from the NOAA fleet that they depend on, and how this ultimately results in value to society.

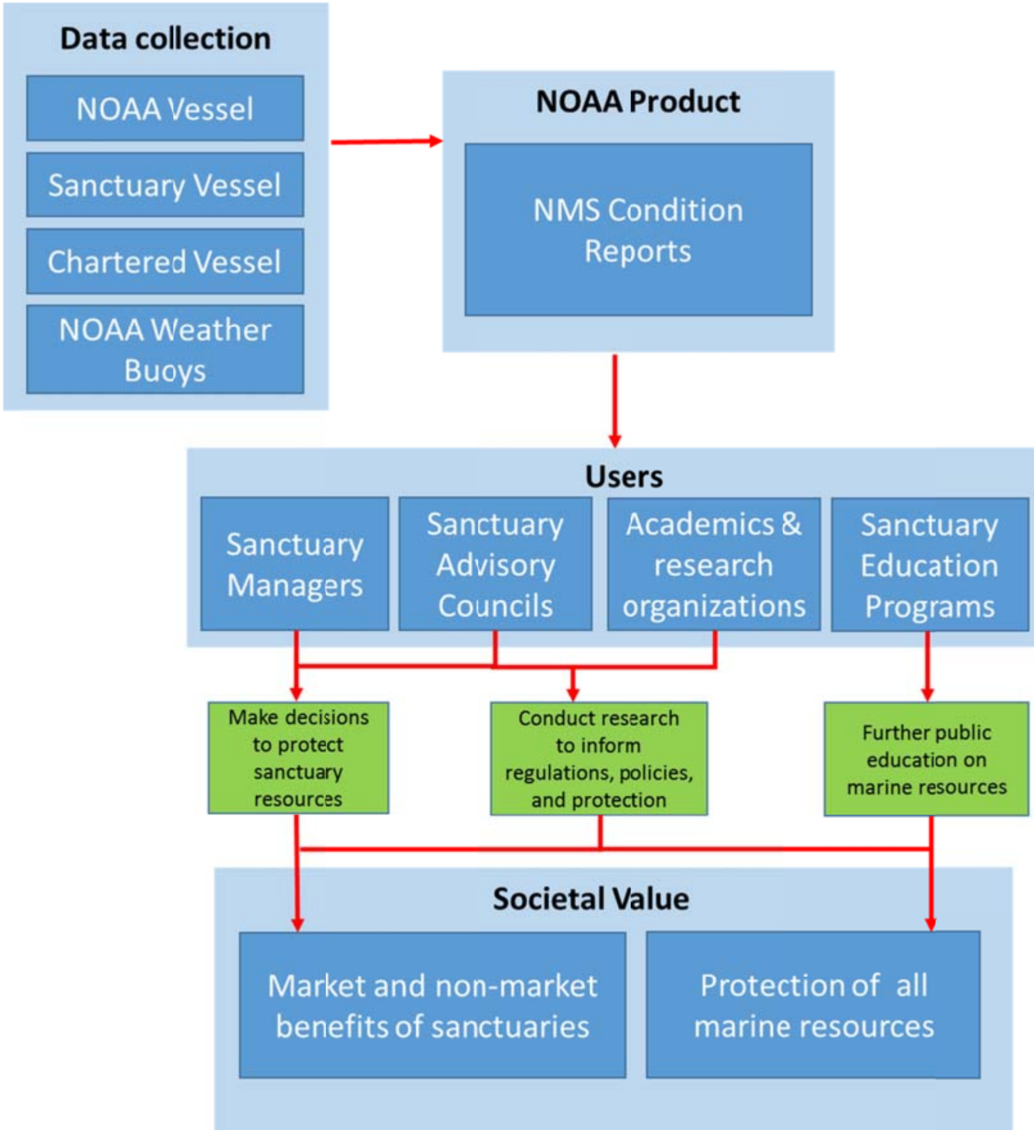

Figure A.6. NOAA Fleet Data Value Chain: National Marine Sanctuary Conditions Report

6. Fisheries Management: Fisheries Stock Assessment

6.1 Product Background

Products: Fish Stock Assessments

Line Office: National Marine Fisheries Service

Mission Service Area: Healthy Oceans Fisheries Monitoring, Assessment, and Forecast

As part of fulfilling NOAA's responsibility for the stewardship of the nation's ocean resources and their habitat, NOAA conducts stock assessments to help manage commercial and recreational fish species. A stock assessment involves collecting, analyzing, and reporting demographic information to determine changes in the abundance of fishery stocks in response to commercial and recreational fishing and, to the extent possible, predict future trends of stock abundance. The NOAA National Marine Fisheries Service (NMFS) manages roughly 500 fish stocks, with data and resources to assess approximately 200 of those stocks each year.[165] The NMFS Office of Science and Technology coordinates NOAA's national stock assessment enterprise. Stock assessments fall under the Healthy Oceans Fisheries Monitoring, Assessment, and Forecast MSA.

Fisheries managers primarily use NOAA stock assessments to set catch limits and other regulations that prevent overfishing and provide optimal yield for commercial fishermen. This includes each of the eight regional fishery management councils in the U.S., which are required by mandate of the Magnuson-Stevens Fishery Conservation Act to set annual catch limits for their region based on best available scientific data. Coastal, state and international organizations also rely on NOAA's stock assessments for non-federal and joint jurisdictional management of fish stocks. Stock assessments are also used in other NOAA products such as the LivingOceans report, which informs the public of the status of fish stocks, and FishWatch, a national database that helps inform consumers of the sustainability of seafood.

6.2 NOAA Fleet Data That Feed the Product

NOAA uses three primary types of data to develop standard fish stock assessments, including abundance data, catch data, and biological data. NMFS uses NOAA ships and charter vessels to conduct abundance surveys, as well as to collect biological data that inform stock the assessments, while catch data typically comes from dockside monitoring, fishermen's logbooks, observations from fishing vessels, and telephone interviews. Collecting abundance and biological fish stock data is a primary purpose for 10 of the 16 ships in NOAA's fleet. These ships are equipped with special technologies and experienced crew members that support various data collection methodologies, including electronic catch monitoring, advanced monitoring equipment attached to traditional sampling gear, visual surveys using imaging systems and robotic and autonomous underwater vehicles, non-extractive hydroacoustic technology for abundance sampling, and electronic fish tags.[166]

Data collection methodologies depend on which category the sampling falls under, and can include electronic catch monitoring, advanced monitoring equipment attached to traditional sampling gear, visual surveys using imaging systems and robotic and autonomous underwater vehicles, non-extractive hydroacoustic technology for abundance sampling, and electronic fish tags.[167] NMFS feeds the abundance, catch, and biological data

into mathematical models that produce time series of historical, current, and forecast fish abundance and fishing mortality rates.[168]

[165] "Stock Assessment Prioritization". National Marine Fisheries Service Office of Science and Technology. National Oceanic and Atmospheric Administration. Available at: http://www.st.nmfs.noaa.gov/stock-assessment/stock-assessment-prioritization. Accessed March 22, 2017.

[166] "Fish Stock Assessment 101 Series: Part 1—Data Required for Assessing U.S. Fish Stocks". NOAA Fisheries. National Oceanic and Atmospheric Administration. Available at: http://www.nmfs.noaa.gov/stories/2012/05/05_23_12stock_assessment_101_part1.html. Accessed March 22, 2017.

[167] "Fish Stock Assessment 101 Series: Part 1—Data Required for Assessing U.S. Fish Stocks". NOAA Fisheries. National Oceanic and Atmospheric Administration. Available at: http://www.nmfs.noaa.gov/stories/2012/05/05_23_12stock_assessment_101_part1.html. Accessed March 22, 2017.

[168] "Stock Assessment Basics – Data Types". National Marine Fisheries Service Office of Science and Technology. National Oceanic and Atmospheric Administration. Available at: http://www.st.nmfs.noaa.gov/stock-assessment/stock-assessment-101. Accessed March 22, 2017.

6.3 Product Intermediaries and Disseminators

NOAA disseminates the results of the fish stock assessments to scientists, fishery managers, and the public in several ways. The Species Information System (SIS) houses both regional and national stock assessment data for public consumption. Scientists, managers, and members of the public can access this web-based portal and download summaries and results from the most recent stock assessments.[169] NOAA also releases the Fish Stock Sustainability Index (FSSI), an index that measures the performance of Federally-managed fish stocks and ranks them based on importance to commercial and recreational fishing.[170] Eighty-five of the roughly 185 annual assessments performed by NOAA and its affiliates are included in the FSSI.[171] Both the FSSI and SIS provide the public and fishery managers with up-to-date and vital information on the status of U.S. fish stocks.

Additionally, NOAA fisheries disseminates fish stock assessment data through discussions and workshops it conducts with scientists and related partners who advise or participate in regional management councils. NOAA also provides scientists and fishery managers up-to date fishery-independent data through digital mapping and tabular reporting.[172] The Fishery-Independent Survey System (FINSS) allows users to view and query data collected by NOAA and chartered vessels.[173] Every year, NMFS provides an annual report to Congress on the status of U.S. fish stocks.

Fish stock assessment data feed into two additional NOAA products. NOAA produces a more comprehensive report card of the status of living marine resources in the United States called the Our Living Oceans Report. This includes resource analyses as well as featured articles on important and relevant issues.[174] NOAA also produces FishWatch, a web-based national database on sustainable seafood that includes data on specific species as well as information on various aspects of consumer issues related to seafood, such as fraud, inspection, and health.[175]

6.4 Users of the Product

Fish stock assessments support sustainable fisheries by providing fisheries managers with the information necessary to make sound decisions. For example, by providing historical and current data, stock assessments allow scientists and Regional Fisheries Management Councils to compare the status of stocks to established targets, and adjust catch limits and stock metric targets accordingly. Stock assessment data also allows managers to determine how much catch is sustainable in general, and decide the best way to replenish depleted stocks.[176] In addition, states can use stock assessments to manage non-Federal stocks. International management entities similarly use the assessments to oversee jointly-managed stocks that straddle international boundaries.[177]

Outside of influencing catch limits, fish stock assessments permit regional management councils to develop short-, medium-, and long-term projections of fish population and catch trends.[178] This in turn helps fishery management councils decide between various management options, and allows scientists to develop research priorities.[179]

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[169] "Species Information System Public Portal". NOAA Fisheries Service. National Oceanic and Atmospheric Administration. Available at: https://www.st.nmfs.noaa.gov/sisPortal/. Accessed March 22, 2017.
[170] "Status of U.S. Fisheries". NOAA Fisheries. National Oceanic and Atmospheric Administration. Available at: http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries. Accessed March 22, 2017.
[171] "Assessment Summaries and Trends". National Marine Fisheries Service Office of Science and Technology. National Oceanic and Atmospheric Administration. Available at: http://www.st.nmfs.noaa.gov/stock-assessment/reports. Accessed March 22, 2017.
[172] "Fishery-Independent Survey System (FINSS)". National Marine Fisheries Service Office of Science and Technology. National Oceanic and Atmospheric Administration. Available at: http://www.st.nmfs.noaa.gov/finss/index. Accessed March 22, 2017.
[173] National Oceanic and Atmospheric Administration. 2013. Fisheries Independent Surveys System (FINSS). National Marine Fisheries Service Office of Science and Technology. January 10, 2013. Available at: http://www.st.nmfs.noaa.gov/Assets/FINSS/documents/FINSS-SI%20Public%20User%20Manual%20V5.0_01182013.pdf
[174] "Our Living Oceans (OLO)". NOAA Fisheries: Office of Science & Technology. Available at: http://www.st.nmfs.noaa.gov/LivingOceans.html. Accessed March 27, 2017.
[175] "FishWatch U.S. Seafood Facts". NOAA Fisheries. Available at: https://www.fishwatch.gov/. Accessed March 27, 2017.
[176] "Science and Technology Stock Assessment Program". National Marine Fisheries Service Office of Science and Technology. National Oceanic and Atmospheric Administration. Available at: http://www.st.nmfs.noaa.gov/stock-assessment/about
[177] "Fish Stock Assessment 101 Series: Part 1—Data Required for Assessing U.S. Fish Stocks". NOAA Fisheries. National Oceanic and Atmospheric Administration. Available at: http://www.nmfs.noaa.gov/stories/2012/05/05_23_12stock_assessment_101_part1.html. Accessed March 22, 2017.
[178] National Oceanic and Atmospheric Administration. 2001. Marine Fisheries Stock Assessment Improvement Plan: Report of the National Marine Fisheries Service National Task Force for Improving Fish Stock Assessments. NOAA Technical Memorandum

While the public probably does not use the stock assessment data and results as much as fishery managers and scientists, the publicly-available information through web portals and the national FishWatch database allow any user to see which fish species are overfished and adjust their consumption or recreational fishing habits accordingly.

6.5 Societal Benefits

Effective management of fisheries is essential for the commercial fishing industry, as well as the populations that rely on them for food consumption and recreation. U.S. commercial fisheries contribute $153 billion ($54 billion without imports) and 1.4 million jobs to the U.S. economy each year (0.81 million jobs without imports). Recreational saltwater fishing generates $61 billion in sales.[180] Commercial fishermen harvested $5.5 billion worth (9.4 billion pounds) of fish in 2014.[181]

Even though only 20 of the 179 fish stocks for which NOAA determined a stock status in 2016 were overfished, fisheries are under a constant threat of overfishing.[182] Given the history of overfishing for many fish stocks in U.S. and international fisheries, regional management councils may set overly strict limits on catch to avoid stock depletion. NOAA's fish stock assessments provide management councils with stock status information so that they can more accurately set catch limits, thereby allowing commercial fisherman to catch more than would otherwise be permitted. While some information on stocks would be available through more limited stock assessments, it is likely that limited assessments would not provide enough data for regional management councils and their scientific advisory councils to feel comfortable setting anything other than conservative catch limits. Accurate stock assessments allow fishery managers and scientists to more confidently estimate stock status and therefore set more appropriate catch limits. As an example, 3.1 billion pounds of Walleye Pollock were landed in 2014, worth $400 million dollars. NOAA estimates that without the fishery-independent surveys, regional fishery managers would have to reduce their catch quotas by approximately 10%, resulting in a loss of approximately $40 million dollars due to overly conservative catch limits.[183]

Figure A.7 presents the value chain for fish stock assessments, showing the different data sources that the assessments depend on, and how the assessments ultimately result in benefits to society.

NMFS-F/SPO-56. October, 2001; National Oceanic and Atmospheric Administration. 2014. Fisheries Economics of the United States, 2014: Economics and sociocultural Status and Trends Series. National Marine Fisheries Service. NOAA Technical Memorandum NMFS-F/SPO-163. May, 2016.

[179] "Regional Fishery Management Councils". NOAA Fisheries. National Oceanic and Atmospheric Administration. Available at: http://www.nmfs.noaa.gov/sfa/management/councils/

[180] NMFS. 2016. Fisheries Economics of the United States, 2014. NOAA National Marine Fisheries Service. Available: https://www.st.nmfs.noaa.gov/Assets/economics/publications/FEUS/FEUS-2014/Report-and-chapters/FEUS-2014-FINAL-v5.pdf. Accessed 5/3/2017.

[181] Ibid.

[182] National Oceanic and Atmospheric Administration. 2016. 2016 Quarter 4 Update through December 31, 2016. NOAA Fisheries Sustainable Fisheries; National Oceanic and Atmospheric Administration. 2001. Marine Fisheries Stock Assessment Improvement Plan: Report of the National Marine Fisheries Service National Task Force for Improving Fish Stock Assessments. NOAA Technical Memorandum NMFS-F/SPO-56. October, 2001.

[183] National Oceanic and Atmospheric Administration. 2016. The NOAA Fleet Plan Building NOAA's 21st Century Fleet. U.S. Department of Commerce. October 31, 2016.

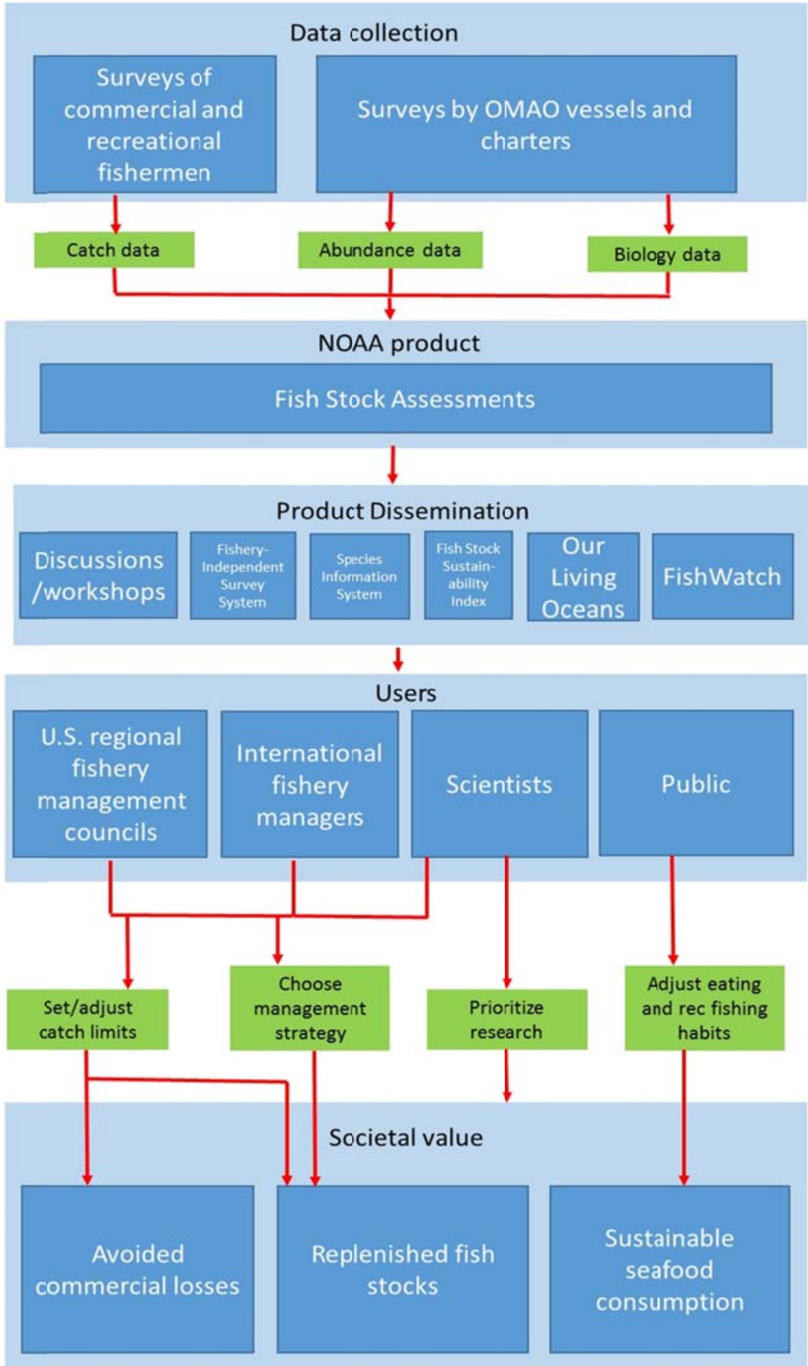

Figure A.7. NOAA Fleet Data Value Chain: Fisheries Stock Assessments

7. Tsunamis: Tsunami Inundation Forecast Modeling

7.1 Product Background

Product: Tsunami Inundation Forecast Model

Line Office: Office of Oceanic and Atmospheric Research

Mission Service Area: Weather Ready Nation - Tsunami

NOAA's Tsunami Inundation Forecast Models represent a series of models that calculate the height and extent of tsunami flooding in U.S. coastal regions.[184] These models, also known as standby inundation models (SIMs), are used in real-time tsunami forecasting and to create tsunami inundation maps (TIMs) for specific regions and communities.

SIMs, and the site-specific TIMs, play an important role in long-term community planning for tsunami events. NOAA' s National Tsunami Research Center (NTRC) creates SIMs and supports the development of TIMs in partnership with the National Tsunami Hazard Mitigation Program (NTHMP).[185] NTHMP is a consortium of federal and state agencies formed by NOAA at the direction of Congress in 1995 with the objective of reducing the potential impacts of tsunamis in the U.S.

NTHMP works with local and state officials and communities to build evacuation maps based on TIMs.[186] A series of TIMs are typically developed for potentially affected areas, showing inundation levels associated with alternative tsunami forecast scenarios and wave heights. In the event of a tsunami, state and local officials use short-term forecast information from the National Tsunami Warning Centers (NTWC) and the pre-run TIMs to guide their immediate response and keep their communities safe. The mapping data from TIMs also support community risk assessments, planning, and mitigation actions related to tsunamis.

NOAA's NTWCs also rely on SIMs to develop short-term tsunami forecast information. However, the information from the SIMs that support these forecasts does not rely on data collected by NOAA vessels.

7.2 NOAA Fleet Data that Feed the Product

Tsunami Inundation Forecast Model depends on Digital Elevation Models (DEMs) created by NOAA's National Centers for Environmental Information (NCEI). DEMs map out the elevation of various features in a certain geographic area. This information is important for knowing how tsunamis of various wave heights and amplitudes will translate into inundation zones and levels in various communities. The NCEI produces approximately 200 DEMs that cover small and large geographic areas in select U.S. coastal regions to support tsunami forecasting and modeling efforts. NCEI has also begun to develop DEMS for select international locations at the request of the NTWC.[187]

NCEI relies on high resolution bathymetry data and hydrographic surveys, some of which is collected/conducted by NOAA vessels, to develop DEMs.[188] The DEMs rely on this data to accurately map out the areas of interest.

To develop the Tsunami Forecast Inundation Model, NTRC also uses ocean profile data directly collected from NOAA vessels, as well as data from the Voluntary Observing Ship Program, which the NOAA fleet is a part of.

7.3 Complementary Data

There are many other data sources that feed into the DEMs and the Tsunami Inundation Forecast Model overall. Aside from bathymetry data from the NOAA fleet, DEMs rely on coastal and marine Light Detection and Ranging (LIDAR), and historic soundings, as well as bathymetry data collected by private vessels.[189]

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[184] Personal communication with Michael Angove, NOAA Tsunami Program Manager, on January 5, 2017.
[185] Wiley, P. C., Honeycutt, M., Rolleri, J., and Huffer, H. (2013). "Towards a Better Understanding of the Value of NOAA Inundation Products and Services." *National Oceanic and Atmospheric Administration.*
[186] Ibid.
[187] Personal communication with Kelly Stroker, Associate Scientist at Cooperative Institute for Research in Environmental Sciences, on January 27, 2017.
[188] Ibid.

To develop the Tsunami Forecast Inundation Model overall, NOAA also relies on data from the Deep-Ocean Assessment and Reporting of Tsunami (DART) network and the National Water Level Observation Network (NWLON). The DART network is an array of 39 buoy systems. Each buoy consists of a bottom pressure center at the bottom of the ocean that is tethered to a surface buoy. This detects and measures tsunami waves as they pass over and plays a key part in the forecast process.[190] Currently, a chartered ship named the *Bluefin* conducts all necessary maintenance on DART buoys;[191] however, the NOAA fleet maintained DART as recently as 2014, and may do so in the future. Tidal gauge observations from the National Water Level Observation Network (NWLON) also factor into the models. This data is important in developing SIMs because it is used to validate the model and can be used in real-time forecasting.[192]

In addition to the DEMs, the Tsunami Inundation Model also relies on the results of two other models, the Propagation Database and the Method of Splitting Tsunami (MOST) model. NCTR creates and maintain the Propagation Database. The database is made up of a collection of tsunami propagation model runs that are pre-computed for tsunami source functions at certain locations along known and potential earthquake zones. The MOST numerical simulation model helps researchers study tsunami behavior and make long-term predictions about tsunamis.[193] NCTR uses the results from these models, the DEMs, and information from the DART and NWLON, to ultimately create SIMs and subsequent TIMs.

7.4 Users of the Product and Related Products

Information from the Tsunami Inundation Forecast Model directly informs community and regional planning efforts related to tsunami response and evacuation. First, NTHMP works with local emergency managers to convert SIMs and site-specific TIMs into mitigation and evacuation plans for various tsunami scenarios. NOAA funds these processes and sets guidelines for how mitigation plans and evacuation maps should be created.[194]

During an actual tsunami, communities reference the TIMs to understand how NWTC's forecasted tsunami wave height would affect their community and related response actions. For example, after an earthquake of a certain magnitude, NOAA's Tsunami Emergency Centers work as quickly as possible to assess the likely wave height/amplitude of a subsequent tsunami, and pinpoint the locations most at risk. This process takes approximately five minutes from the time an earthquake occurs off the coast to the time that the first amplitude numbers and locations are published. The alert along with the first bulletin goes to Weather Forecast Offices, NOAA Weather Radio, Emergency Alert System Network (banner along the bottom of the TV), and the National Weather Service standard dissemination procedures.[195] State and local emergency officials receive this information from these sources.

After the first alert, emergency managers begin to execute their full response protocol and issue evacuation orders based on the predicted wave amplitude and the results of their pre-run site-specific TIMs. Meanwhile,

NTWC works to get out more refined information in a second and third alert, which allows managers to re-examine their TIMs, scale back their response and take a more measured approach, if warranted. These alerts are usually out within 20 minutes.[196]

It is important to note that the time and distance from the earthquake source and the coast varies by event. In some areas, including parts of Washington and Oregon, the time to the coast can be as short as 20 minutes. In these cases, emergency managers will not have time to adjust their response based on up-to-date forecast information and will have to rely solely

[189] Personal communication with Michael Angove, NOAA Tsunami Program Manager, on January 5, 2017.
[190] "DART 4G Deep-ocean Assessment and Reporting of Tsunami 4th Generation Tsunami Measurement System." *NOAA Pacific Marine Environmental Laboratory*.
[191] Personal communication with Michael Angove, NOAA Tsunami Program Manager, on January 5, 2017.
[192] Wiley, P. C., Honeycutt, M., Rolleri, J., and Huffer, H. (2013). "Towards a Better Understanding of the Value of NOAA Inundation Products and Services." *National Oceanic and Atmospheric Administration.*
[193] Ibid.
[194] Ibid.
[195] Personal communication with Michael Angove, NOAA Tsunami Program Manager, on January 5, 2017.
[196] Ibid.

on the first warning. In other cases, such as Hawaii, the time to the coast is much longer so local officials can use the second and third alerts provided by the emergency center to modify their response.[197]

States and individual communities also use SIMs and TIMS to develop appropriate tsunami mitigation actions before an event occurs. For example, planners use information from SIMs and TIMs to assess inundation risks and to make decisions about the location of critical infrastructure, such as nuclear power plants, water and wastewater infrastructure, hospitals, and implement other preparatory actions. In the event that critical infrastructure is located within an expected inundation zone, communities can develop alternative response actions, such as the use of alternative power sources or shelters for people directly affected by inundation.[198]

There is also a large demand for the data from SIMs and TIMs from U.S. universities. Academics use this data to conduct further research on tsunamis. In particular, these users examine ways to better predict the tsunami threats that many people face. They also consider the potential for tsunami threats in areas that are not typically considered threat areas.[199]

7.5 Societal Benefits

The National Tsunami Inundation Model helps communities to better plan for and respond to potential tsunami events, thereby decreasing the impacts of these events, including property damage and other economic losses, and the number of potential lives lost. In terms of mitigation planning, having accurate TIMs allows communities to make more informed decisions related to the location of critical infrastructure, as well as the planning of efficient evacuation routes and other response preparatory actions. In the event of a tsunami, having the pre-run SIMs and TIMs and associated response plans provide for more effective evacuation processes, reducing damage to people and property.[200]

The value of tsunami mitigation practices is still relatively unknown. While some studies have calculated the amount of damage caused by tsunamis, it is difficult to quantify the damages that would have occurred if effective evacuations and/or mitigation actions had not been implemented (or alternatively the extent to which damages were reduced by mitigation actions). In addition, the extent of damages associated with tsunami events not only depend on effective response, preparation, and evacuation, but also on the magnitude and location of the tsunami, the amount of time a community has to implement response/evacuation actions, the accuracy of the forecast, and the effectiveness of the warning system/communication.

However, it is clear that well-planned mitigation efforts and response actions, combined with an effective warning system, can significantly reduce the impacts of tsunamis. For example, experts often cite the difference in damages associated with two tsunami events that impacted Crescent City, CA. A tsunami produced by the 1964 Great Alaska Earthquake caused over $50 billion in damage and 11 deaths in Crescent City. A tsunami produced by the 2011 Great Tohoku, Japan, earthquake resulted in $5 billion in damage and no deaths in the same location. These events produced waves with similar amplitudes and duration, even though they originated in different locations. The 1964 event did not benefit from having a response/evacuation plan in place while the 2011 event did.[201] While this significant decrease in impacts cannot all be attributed to tsunami mitigation, outreach & education, and disaster planning, it does speak to the potential benefits associated with having a comprehensive Disaster Response Plan in place, as well as the value that the information in models such as SIMs and TIMs provide.

[197] Personal communication with Rocky Lopes, National Tsunami Hazard Mitigation Program Administrator Deputy Program Manager, on January 5, 2017.
[198] Ibid.
[199] Ibid.
[200] Ibid; Wiley, P. C., Honeycutt, M., Rolleri, J., and Huffer, H. (2013). “Towards a Better Understanding of the Value of NOAA Inundation Products and Services.” *National Oceanic and Atmospheric Administration.*
[201] Personal communication with Rocky Lopes, National Tsunami Hazard Mitigation Program Administrator Deputy Program Manager, on January 5, 2017.

An additional value of the Tsunami Inundation Forecast Model is the educational value it provides to universities looking to learn more about tsunami threats.[202] Using these data scientists can improve their forecasting abilities allowing emergency managers to improve their responses during these events. This in turn will lead to further future benefits in the form of avoided losses and injuries or deaths due to future tsunamis.

Figure A.8 demonstrates the value chain associated Tsunami Inundation Forecast Models, including the data from the NOAA fleet that they depend on, and how this ultimately results in value to society.

[202] Wiley, P. C., Honeycutt, M., Rolleri, J., and Huffer, H. (2013). "Towards a Better Understanding of the Value of NOAA Inundation Products and Services." *National Oceanic and Atmospheric Administration.*

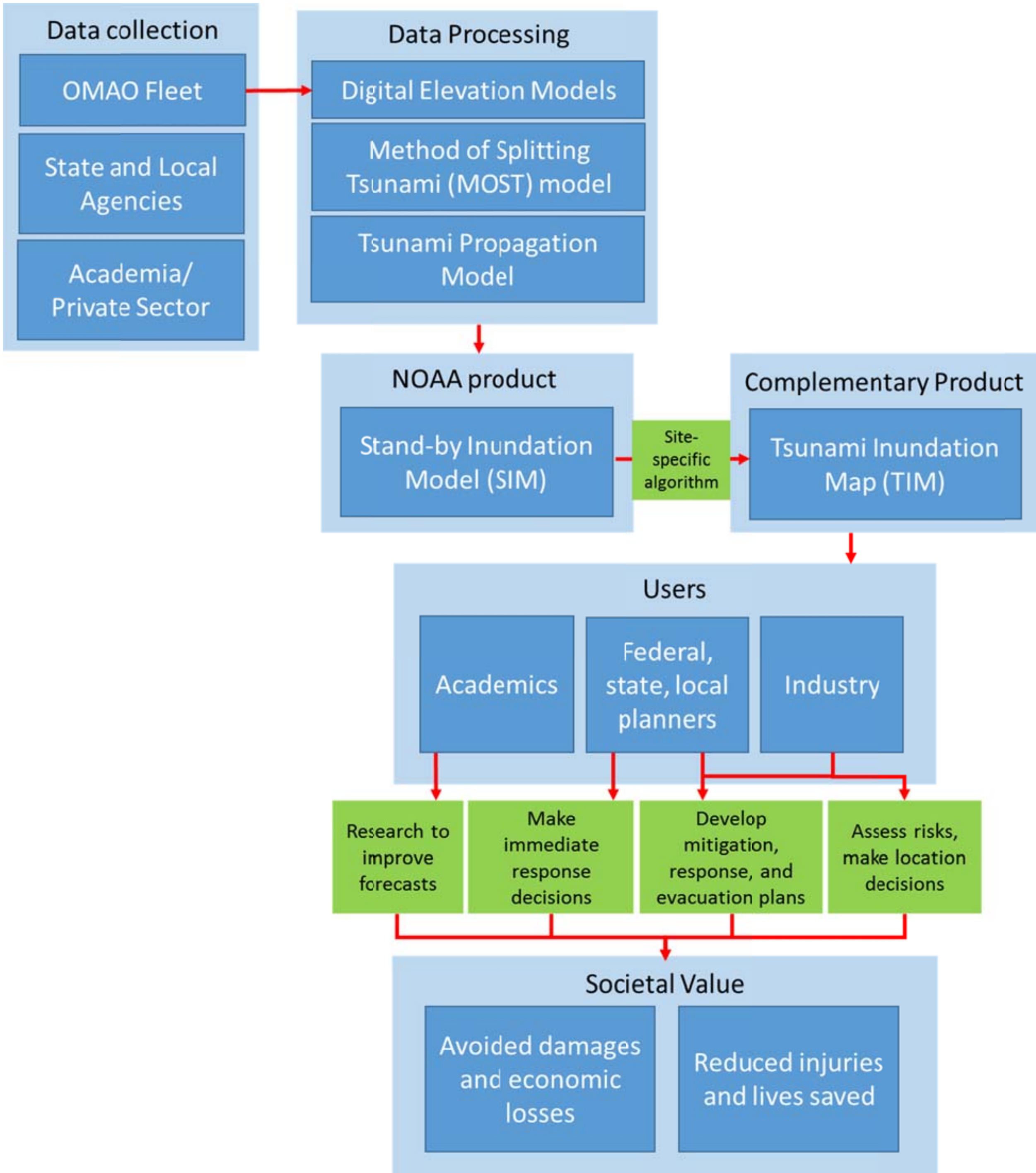

Figure A.8. NOAA Fleet Data Value Chain: Tsunami Inundation Forecast Modeling

8. Harmful Algal Blooms: Forecasts and Mitigation Capability, Gulf of Maine

8.1 Product Background

Product: Harmful Algal Blooms Forecasts

Line Office: Office of Oceanic and Atmospheric Research - Great Lakes Environmental Research Laboratory, National Ocean Service - National Centers for Coastal Ocean Science

Mission Service Area: Resilient Coasts-Coastal Water Quality

Algae are simple plants that live in both saltwater and freshwater. In some cases, colonies of algae can grow out of control creating Harmful Algal Blooms (HABs) or "red tides," which produce toxic or harmful effects on people, fish, shellfish, marine mammals and birds.[203] There are several species of HABs that can lead to wild and domestic animal deaths, shellfish toxicity, adverse public health effects, and taste and odor problems in drinking water.[204] HABs have been spotted in all coastal areas of the United States, with different species affecting different regions of the country. NOAA has identified seven regions where HABs and can have large impacts on local and regional economies:

- Florida and eastern Gulf of Mexico (*Karenia brevis*),
- Western Gulf of Mexico (*Karenia brevis*),
- Lake Erie (cyanobacteria),
- Gulf of Maine (*Alexandrium fundyense*),
- Washington Coast (*Pseudo-nitzschia*),
- California Coast (multiple species), and
- Chesapeake Bay (multiple species).[205]

In response to this threat Congress passed the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA) in 1998.[206] The HABHRCA led to the development and funding of integrated regional programs, coordinated by NOAA's National Centers for Coastal Ocean Science (NCCOS), that focus on developing tools for detecting and predicting HABs, monitoring their toxicity and determining their effects on local wildlife, humans and local economies.[207] Today large regional ecosystem programs have been implemented in the Gulf of Mexico (in Florida and Texas), the Gulf of Maine and the Great Lakes. These programs make up the NNCCOS's Harmful Algal Bloom Operational Forecast System (HAB-OFS).

The HAB-OFS relies on data from a variety of sources, including data collected from the NOAA fleet, to develop operational HAB forecasts. The forecasts predict and assess the extent of algal blooms, allowing state and local managers to more effectively sample and monitor HAB areas.[208] This in turn informs decisions about beach closures, shellfishing restrictions, and other HAB response actions. NOAA's goal is to ultimately develop a national forecast capacity through the HAB-OFS. NOAA anticipates that several new regions will be operational over the next decade.[209]

This discussion focuses on HAB forecasts for the Gulf of Maine because NOAA ships contribute data that support HAB forecasts in this region and several studies have estimated the economic value of these forecasts. HAB forecasts for the Gulf of Maine will transform from a pilot program started in 2008, to operational seasonal and weekly forecasts starting

[203] "Harmful Algal Blooms," *NOAA National Ocean Service.* Available at: http://oceanservice.noaa.gov/hazards/hab/
[204] "Harmful Algal Bloom (HAB) Forecasting" (2016). *NCCOS Projects Explorer*. Available at: https://coastalscience.noaa.gov/projects/detail?key=144
[205] Ibid.
[206] "Mitigating Harmful Algal Blooms." (2012). *NOAA Celebrates 200 years of Science, Service, and Stewardship*. Available at: http://celebrating200years.noaa.gov/transformations/habs/welcome.html#then
[207] "Harmful Algal Bloom (HAB) Forecasting,"(2016). *NCCOS Projects Explorer*. Available at: https://coastalscience.noaa.gov/projects/detail?key=144
[208] "Harmful Algal Bloom (HAB) Forecasting,"(2016). *NCCOS Projects Explorer*. Available at: https://coastalscience.noaa.gov/projects/detail?key=144
[209] Ibid.

in 2017. In the Gulf of Maine, the primary concern associated with HABs is paralytic shellfish poisoning, which can result in adverse public health effects. Thus, HABs result in restrictions on shellfish harvesting.

8.2 NOAA Fleet Data That Feed the Product

The HAB forecasts for the Gulf of Maine rely on data from several NOAA ships. The NOAA ship *Pisces* helped build a map of cysts of harmful algae along the New England coast for use in HAB forecasts. The ship went on a seven-day voyage during which scientists collected more than 55 sediment core samples throughout the Gulf of Maine. Researchers will use these sediment samples to determine the presence and abundance of cysts of the harmful alga *A. fundyense* to incorporate into the forecasting of HAB events along the New England coast in 2017.[210] The *Pisces* also provides maintenance for the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) moorings.[211] These moorings collect real-time weather and ocean data along with other platforms in the area which is incorporated into HABs forecast models.[212]

Ships from the NOAA fleet also support HAB Forecasts by conducting NMFS NFSC Hydrographic Surveys. In 2015 and 2016, the *Gordon Gunter* helped conduct Ecosystem Monitoring Surveys for the NMFS NFSC.[213] In November 2015, the *Henry B. Bigelow* conducted a Harmful Algal Bloom Forecast Support Survey of the Gulf of Maine over the course of five days.[214]

8.3 Complementary Data

In addition to the cyst map, the NERACOOS moorings, and the NMFS NFSC Hydrographic Surveys provided by NOAA ships, the HAB Forecasts also rely on data from several other sources. For example, the HAB-OFS uses satellite imagery, field observations, models, public health reports, and buoy data to provide large spatial scale and a high frequency of observations required for these forecasts.[215] NOAA, National Science Foundation, and the National Institute of Environmental Health Sciences have funded research since the early 1990s, including both field and laboratory data, that has been used for developing and validating the HABs forecast model.[216]

Specific data sources for the HAB Forecasts include the NOAA National Weather Service, the GNOME Oceanographic Data Server, the NOAA National Data Buoy Center (wind data), and NOAA CoastWatch (remote sensing data). The NOAA Center for Operational Oceanographic Products and Services conducts bloom analysis, and supports forecast production and outreach. NOAA Coastal Services Center and NOAA National Centers for Coastal Ocean Science both supported the scientific development.[217]

Many institutions outside of government are also involved in this research. In the Gulf of Maine, three universities help gather and analyze data, the University of Massachusetts – Dartmouth, University of New Hampshire, and the University of Maine. In addition, the Woods Hole Oceanographic Institution participates in the research for the Bulletin. Canadian scientists have also been involved in the development of HAB Forecasts in the Gulf of Maine, as there are large

[210] "Harmful Algal Cyst Sampling Lays Groundwork for 2017 Gulf of Maine Forecast."(2016). *NCCOS News and Features* Available at: https://coastalscience.noaa.gov/news/habs/harmful-algal-cyst-sampling-lays-groundwork-2017-gulf-maine-forecast/
[211] "Project: NERACOOS Mooring Maintenance." (2016). *NOAA Office of Marine and Aviation Operations.* Available at: http://www.omao.noaa.gov/find/projects/3726-neracoos-mooring-maintenance
[212] "Modeling and Satellites." (2011). *NERACOOS Integrated Ocean Observing System*. Available at: http://p5.neracoos.org/projects/modeling.html
[213] "Project: Spring Ecosystem Monitoring Survey." (2016). *NOAA Office of Marine and Aviation Operations.* Available at: http://www.omao.noaa.gov/find/projects/3567-spring-ecosystem-monitoring-survey ; "Ecosystem Monitoring Integrated Pelagic Survey of the Northeast U.S. Shelf." (2015). *NOAA Office of Marine and Aviation Operations.* Available at: http://www.omao.noaa.gov/find/projects/3423-ecosystem-monitoring-integrated-pelagic-survey-northeast-us-shelf
[214] "Project: Gulf of Maine Harmful Algal Bloom Forecast Support Survey." (2016). *NOAA Office of Marine and Aviation Operations.* Available at: http://www.omao.noaa.gov/find/projects/3486-gulf-maine-harmful-algal-bloom-forecast-support-survey
[215] "NOAA Harmful Algal Bloom Operational Forecast System (HAB-OFS): Assisting HAB Mitigation through Early Detection and Forecasting." (2013). *NOAA Tides and Currents*. Available at: https://tidesandcurrents.noaa.gov/hab/overview.html#overview
[216] Ibid.
[217] Ibid.

Alexandrium blooms and high shellfish toxicity in the Bay of Fundy, which borders both Maine and the Canadian provinces of New Brunswick and Nova Scotia.[218]

8.4 Product Dissemination

HAB forecasts for the Gulf of Maine have been distributed in two forms during the pilot phase: 1) a seasonal forecast issued prior to the bloom season, usually in March, and 2) weekly updates that provide both a hindcast of the bloom up to that date, and a forecast of bloom conditions for the coming week (HAB Bulletin). It is expected that future forecasts will follow this same format.[219]

Both forecasts depend on high-resolution modeling of the region, in which regional models are nested in a global model. The global model used for forecasts is being transitioned from the HYCOM (HYbrid Coordinate Ocean Model) to the NOAA Real Time Operational Forecast System (RTOFS). The nested set of models for the Gulf of Maine will be referred to as the Gulf of Maine Operational Forecast System (GoMOFS).

The weekly updates are emailed to a subscriber list of various stakeholders including state and local coast resource managers, public health officials and research scientists twice a week during a HAB event and once a week during the HAB season. The format of each Bulletin varies by region but generally provides bloom analysis including information about the location, size and movement trajectory of algal blooms, predicting its location within the next 3-4 days.[220] In some cases, the Bulletin includes graphs of the winds and currents affecting the bloom.[221] This information is used by stakeholders to make important management decisions that minimize risks to the local population.

8.5 Users of the Product and Related Products

There are many users of the HABs forecasts, many of whom subscribe to receive HAB forecasts from NOAA. Subscribers receive seasonal and weekly forecasts and are kept informed via the NE PSP Listserv. Subscribers include a variety of types of users, including federal and state government agencies, research/academic institutions, industry representatives, regional observing system representatives, and Canadian scientists.[222] Industry subscribers include members of the fishing/aquaculture industry, makers of HAB sensors and toxin tests, and consulting firms. Federal users are primarily within NOAA and the FDA (with indirect interest due to their responsibility to regulate food sources), but also include users in the EPA and the Mid-Atlantic Fishery Council.[223]

HABs forecasts are used by local authorities and other public decision-makers to guide their efforts to protect public health. State shellfish managers are responsible for sampling and testing different areas of the coast to assess the toxicity levels of the water and the shellfish. These resource managers use the HAB forecasts to determine where they should sample and perform these tests. If toxic levels of shellfish poison are found in the sampled shellfish, state shellfish managers must determine how much of the beach or the intertidal and submerged lands will be closed to shellfishing until subsequent tests show that the HAB has dissipated.[224] These closures are motivated by public health concerns and these officials do not consider the commercial costs associated with these closures when making these decisions.[225]

The HAB forecasts allow state shellfish managers and public health officials to close fishing areas and beaches more selectively and precisely, thereby minimizing economic impacts due to lost landings or lost tourism.[226] In Maine, weekly

[218] Ibid.
[219] Personal communication with Dr. Quay Dortch, Acting Program Manager, Prevention, Control, and Mitigation of Harmful Algal Blooms (PCM HAB) Program, on February 24, 2017.
[220] "Harmful Algal Bloom (HAB) Forecasting,"(2016). *NCCOS Projects Explorer*. Available at: https://coastalscience.noaa.gov/projects/detail?key=144; "Great Lakes HABs and Hypoxia." *NOAA Great Lakes Environmental Research Laboratory (GLERL)*. Available at: https://www.glerl.noaa.gov/res/HABs_and_Hypoxia/
[221] "Great Lakes HABs and Hypoxia." *NOAA Great Lakes Environmental Research Laboratory (GLERL)*. Available at: https://www.glerl.noaa.gov/res/HABs_and_Hypoxia/
[222] Personal communication with Dr. Quay Dortch, Acting Program Manager, Prevention, Control, and Mitigation of Harmful Algal Blooms (PCM HAB) Program, on December 12, 2016.
[223] Ibid.
[224] Jin, D., E. Thunberg, and P. Hoagland. (2008). "Economic impact of the 2005 red tide event on commercial shellfish fisheries in New England." *Ocean and Coastal Management*, 51, 420-429.
[225] Ibid.
[226] Ibid.

forecasts also help managers carve out exception areas where shell fish harvesters can work even when much of the coast is closed.[227] In some cases, these forecasts can help state officials secure resources to mitigate the effects of HABs. One former manager in the Maine Department of Marine Resources used the seasonal HAB forecast to convince the State Legislature to budget enough funds for monitoring for the season.[228]

Members of the aquaculture industry can also use the HAB forecasts to make management decisions. For example, when a HAB is predicted, harvesters can use HAB forecast information to harvest their shellfish early.[229] As climate change leads to an increase in frequency, intensity, duration and geographic distribution of HABs, fish are more likely to be recurrently exposed to HABs. More efforts are being made to understand the longer-term effects of the resulting toxins on fish at individual, population, and community levels.[230] The results of this research may indicate to fisheries managers the extent to which HAB forecasts should influence fishery management actions.

8.6 Societal Benefits

HAB forecasts allow state shellfish managers and public health officials to close fishing areas and beaches more selectively and precisely, thereby minimizing economic impacts associated with lost landings, lost tourism, and/or adverse public health outcomes. Several studies have estimated the socioeconomic impact of HABs. For example, one study estimated the impact of lost harvester sales of shellfish due to a strong HAB event in 2005. The study estimated losses in Maine to be $1.98 million for soft-shell clams.[231] A separate study estimated the direct economic impacts of the same event in Maine and Massachusetts using data from the NMFS, the Division of Marine Fisheries in Massachusetts and other sources. This study estimated these impacts ranged from $2.4 million in Maine to $18 million in Massachusetts. This estimate includes lost revenue in the softshell clam and mussel fisheries.[232] The study also found that the 2005 HAB event led to an increase in shellfish imports to make up for the drop in local supply. This increase in imports may mitigate the indirect impacts of a HAB event on the seafood industries. Finally, the study found that soft-shell clam price increases were spatially linked, meaning that shellfish closures in Maine may result in price increases in New York.[233]

A more recent study examined the impact of temporary pollution closures (either due to HAB events or sewer overflows) on commercial soft-shell clam harvests in Machias Bay, Maine. Over their nine-year study period from 2001-2009, temporary pollution closures contributed to a loss of $3.6 million in forgone revenue, 27.4% of total revenue.[234]

Knowing the extent of past economic impacts due to strong HAB events, it becomes clear how valuable a timely and accurate HAB forecast can be. Before these forecasts were available, public health officials would have to close large portions of beaches to ensure public safety. However, as forecasts improve, decision-makers can narrow the scope of these closures and cut the length of time that they are closed, minimizing economic impacts to many industries including shellfishing and tourism.[235]

One study examined the value of HAB forecasts in the Gulf of Maine, considering both the frequency of the HAB event, the accuracy of the forecast, and the effectiveness of the response. Assuming a HAB occurs every 10 years, the forecast is perfect, and the responses are highly effective, the study found that the annual value of HAB forecasts amounts to $713,000. This value falls to $61,000 per year if HAB events are less frequent, the forecast is not perfect, and the

[227] Personal communication with Dr. Quay Dortch, Acting Program Manager, Prevention, Control, and Mitigation of Harmful Algal Blooms (PCM HAB) Program, on February 24, 2017.
[228] Ibid.
[229] Personal communication with Dr. Quay Dortch, Acting Program Manager, Prevention, Control, and Mitigation of Harmful Algal Blooms (PCM HAB) Program, on February 24, 2017.
[230] Costa, P.R. (2016). "Impact and effects of paralytic shellfish poisoning toxins derived from harmful algal blooms to marine fish." *Fish and Fisheries*, 17, 226-248.
[231] Athearn, K., (2008). Economic Losses from Closure of Shellfish Harvesting Areas in Maine. University of Maine at Machias. Available at: http://www.machias.edu/ assets/docs/appliedResearch/eco_losses_shellfish_jan08.pdf.
[232] Jin, D., E. Thunberg, and P. Hoagland. (2008). "Economic impact of the 2005 red tide event on commercial shellfish fisheries in New England." *Ocean and Coastal Management*, 51, 420-429.
[233] Ibid.
[234] Evans, K. S., Athearn, K., Chen, X., Bell, K. P., & Johnson, T. (2016). Measuring the impact of pollution closures on commercial shellfish harvest: The case of soft-shell clams in Machias Bay, Maine. *Ocean & Coastal Management*, *130*, 196-204.
[235] "Satellites See Red, Blue and Green: Monitoring Harmful Algal Blooms from Space."(2015). *NOAA Satellite and Information Service*. Available at: https://www.nesdis.noaa.gov/content/satellites-see-red-blue-and-green-monitoring-harmful-algal-blooms-space

responses are not effective. However, if a HAB event occurs every other year, and the responses are effective, the total value of a perfect forecast increases to over $3 million per year. Results indicate that the net present value over 30 years of HAB forecasts ranges from $51.3 million to $0.9 million, depending on HAB frequency, accuracy of prediction, and responses.[236]

Figure A.9 provides a diagram of the value chain associated with HABs in the Gulf of Maine.

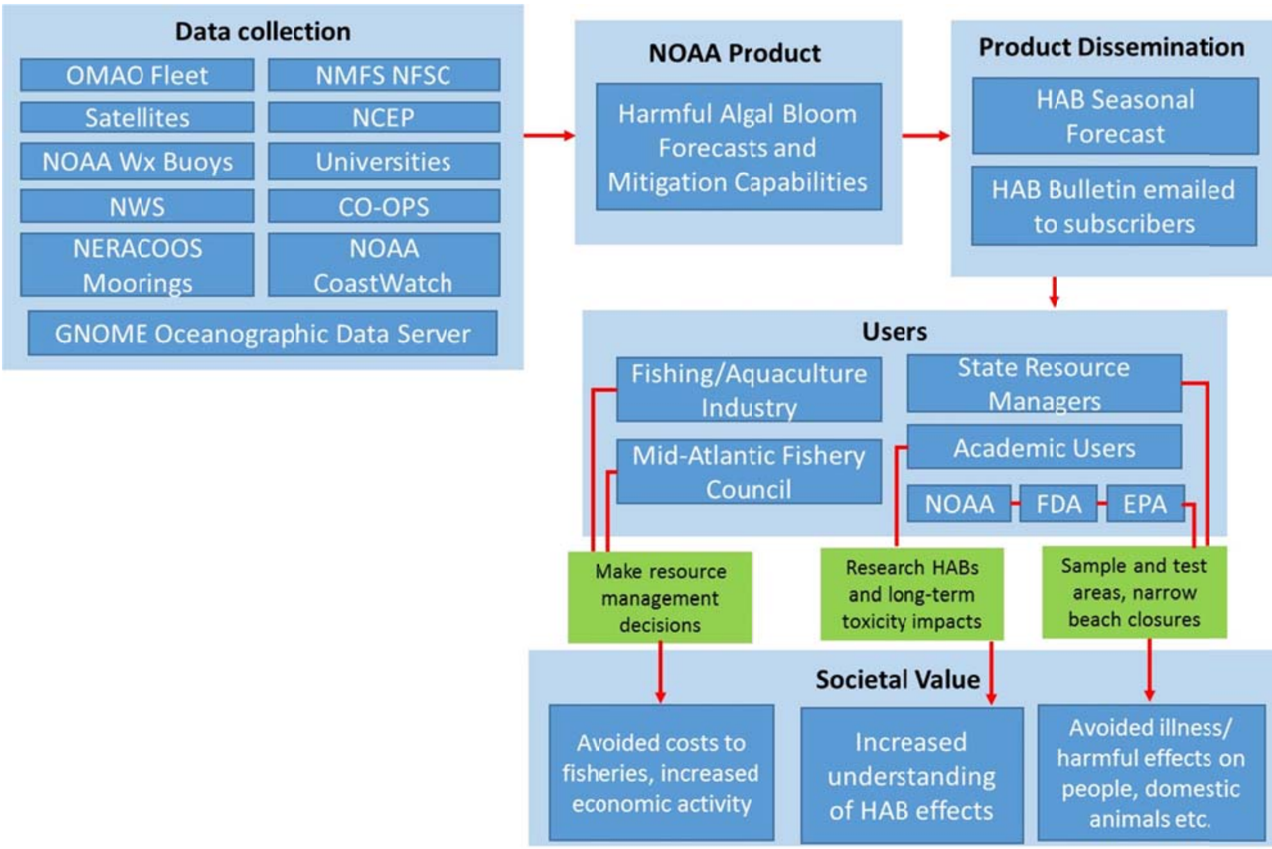

Figure A.9. NOAA Fleet Data Value Chain: Harmful Algal Bloom Forecasts in the Gulf of Maine

[236] Jin, D. and P. Hoagland. (2008). "The Value of Harmful Algal Bloom Predictions to the Nearshore Commercial Shellfish Fishery in the Gulf of Maine." *Woods Hole Oceanographic Institution Marine Policy Center.*

9. Hypoxia Watch, Gulf of Mexico

9.1 Product Background

Product: Hypoxia Watch: Gulf of Mexico

Line Office: National Environmental Satellite, Data, and Information Service, National Centers for Environmental Information

Mission Service Area: Resilient Coastal Communities & Economies, Coastal Water Quality

The hypoxic zone in the Gulf of Mexico is the largest area of oxygen-depleted coastal waters in the US, and the second largest in the world's coastal oceans.[237] In addition to impacting fisheries, hypoxic conditions can cause food web alterations, faunal mortalities, and habitat loss.[238]

Since 2001, NOAA's Gulf of Mexico Hypoxia Watch program (Hypoxia Watch) has published near real-time, web-based contour maps and data on Gulf region dissolved oxygen (DO) for the peak annual hypoxic period. The maps and data form an important part of the scientific basis upon which policymakers, fishermen, the public, and others base their understanding of the Gulf Hypoxic Zone. In addition, Hypoxia Watch maps and data provide a 15-year baseline of the Gulf hypoxic zone.

Hypoxia Watch is a cooperative project among the National Marine Fisheries Service (NMFS), National Centers for Environmental Information (NCEI), and Coast Watch-Caribbean/Gulf of Mexico Regional Node.[239]

9.2 NOAA Fleet Data That Feed the Product

Each year from early June through mid-July, as part of the combined state/federal Southeast Area Monitoring and Assessment Program (SEAMAP), scientists aboard the NOAA research vessel *Oregon II* take measurements of DO and other water quality variables near the sea floor over the continental shelf from Texas to northwest Florida. Every one to three days, they transmit the data to NCEI scientists at Stennis Space Center, MS, who create contour maps based on these data, publish the maps and underlying data online for public use, and transmit the latest data and maps to Gulf hypoxia science partners.[240]

9.3 Users of the Product and Related Products

Hypoxia Watch offers the first look at the season's hypoxia conditions and provides critical information for management of the hypoxic zone in the Gulf. This information is accessed by users in two main ways – either directly from the Hypoxia Watch website through contour maps and the underlying DO data, or through forecast and management models of Gulf hypoxia, for which the DO data from Hypoxia Watch data are critical inputs. The Hypoxia Watch product itself is not a forecast of hypoxic conditions, but rather a mapping of current and historical DO data. However, the Hypoxia Watch DO data are critical inputs to 3D time-variable, hydrodynamic, and biogeochemistry models that characterize the hypoxic zone and its ecological impacts.

The information provided in the Hypoxia Watch can directly affect both up- and downstream management practices, and is an essential baseline dataset for researchers, educators, and decision-makers. The interagency Mississippi River/Gulf

[237] Scientific Assessment of Hypoxia in U.S. Coastal Waters (CENR 2010): https://www.coastalscience.noaa.gov/publications/detail?resource=d596/N/PZ790pPMbl3+Me3eaMWtPPGzVXDW7CdGobGM=

[238] NCEI, 2016. Gulf of Mexico Hypoxia Watch. National Centers for Environmental Information. National Oceanic and Atmospheric Administration. https://www.ncddc.noaa.gov/hypoxia/

[239] NCEI, 2016. Gulf of Mexico Hypoxia Watch. National Centers for Environmental Information. National Oceanic and Atmospheric Administration. https://www.ncddc.noaa.gov/hypoxia/

[240] NCEI, 2016 Maps and Data from 2015 to Present. National Centers for Environmental Information. National Oceanic and Atmospheric Administration. https://www.ncddc.noaa.gov/hypoxia/products/

of Mexico Watershed Nutrient Task Force (Hypoxia Task Force, HTF), which has a Coastal Goal to reduce the size of the hypoxic zone by watershed nutrient reductions, relies on Hypoxia Watch maps and data for information on seasonal dynamics of the hypoxic zone. This information is important to delineate natural from manmade (e.g. nutrient loading) causes of the hypoxic zone, and to differentiate between hypoxic regions driven by Mississippi River runoff and those resulting from runoff from Texas rivers. Hypoxia Watch products are routinely presented by NOAA NCCOS to the HTF through reports and presentations.

In every year since 2010, Hypoxia Watch products have been used to inform proceedings of the Annual NOAA/NGI Gulf Hypoxia Research Coordination Workshop, which has an overarching goal to strengthen communication and coordination between invested researchers and stakeholders to advance management of the hypoxic zone and its impacts. Hypoxia Watch outputs are particularly important to meeting workshop objectives on advancing Gulf hypoxia monitoring and mitigation of ecosystem impacts. For example, the 5th Annual Workshop focused on prioritizing fishery management needs, and identifying ways to "best predict and assess the effects of diversions and hypoxia on fisheries through ecological modeling tools".[241] Hypoxia Watch data will be critical to the success of three new projects supported through the NOAA Northern Gulf of Mexico Ecosystems and Hypoxia Assessment Program (NGOMEX), which are focused on advancing ecological models used to inform water quality and resource managers of the predicted responses of fisheries to future scenarios of hypoxia extent and severity.[242]

NOAA-supported scientists use the DO data and maps to help plan ship and glider surveys of the hypoxic zone. Maintaining these data is important to the HTF and other management efforts that aim to mitigate Gulf hypoxia (e.g. Louisiana Master Plan, Landscape Conservation Cooperative Mississippi River Basin/Gulf Hypoxia Initiative) or that target ecosystem restoration goals that include the hypoxic zone region".[243] Other systems such as fixed observation systems, chartered research vessels, and gliders compliment the NOAA-supported and state cruises to complete the picture of the Gulf hypoxic zone.[244]

Hypoxia Watch and forecast/management model results that rely on Hypoxia Watch data are also a source of information for educating stakeholders, politicians, managers and citizens about Gulf of Mexico hypoxic zone. These models allow managers to characterize the multiple factors affecting the hypoxic zone, including nutrient loading from the Mississippi River watershed. Twelve state agencies within the Mississippi Watershed have nutrient loading reduction goals, and data provided by the HTF, including the Hypoxia Watch data, helps these agencies better understand the status and progress of hypoxia mitigation allowing them to use the most effective management strategies. Data on the hypoxic zone also influence the U.S.D.A.'s Mississippi River Basin Healthy Watersheds Initiative, which supports nutrient, tillage, and residue management projects to reduce hypoxic effects in the Gulf.[245] While state actions to reduce watershed nutrient loading are voluntary, a strong scientific foundation with increased monitoring efforts helps ensure effective management.[246]

9.4 Societal Benefits

Hypoxia impacts the food supply for commercially and recreationally-important fish species in the Gulf of Mexico. As their food sources leave due to lack of oxygen, fish and shrimp crowd into areas with better oxygen levels, which can

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[241] 5th Annual NOAA/NGI Hypoxia research Coordination Workshop: Advancing Ecosystem Modeling of Hypoxia and Diversion Effects on Fisheries in the Northern Gulf of Mexico: http://sero.nmfs.noaa.gov/habitat_conservation/hcd_headlines/homenews_hypoxiamodeling.html

[242] 2016 NOAA Press Release on Gulf hypoxic zone seasonal forecast: http://www.noaa.gov/media-release/average-dead-zone-for-gulf-of-mexico-predicted

[243] NOAA Northern Gulf of Mexico Ecosystems and Hypoxia Assessment Program: https://coastalscience.noaa.gov/research/pollution/hypoxia/ngomex

[244] Meckley, T. et al., 2016. Gulf of Mexico Hypoxia Monitoring Strategy. Sixth Annual NOAA/NGI Hypoxia Research Coordination Workshop. September 12-13, 2016. Accessed: https://service.ncddc.noaa.gov/rdn/www/media/documents/activities/2016-workshop/HypoxMonStrat.pdf

[245] Mississippi River Basin Healthy Watersheds Initiative. United States Department of Agriculture. Accessed January 4, 2017: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/la/programs/farmbill/rcpp/?cid=stelprdb1097321

[246] Gulf Hypoxia Monitoring Stakeholder Committee, 2007. Terms of Reference. September 3, 2007. Accessed: https://service.ncddc.noaa.gov/rdn/www/media/documents/activities/stakeholders/Hypoxia-Stakeholder-Committee-Terms-of-Reference.pdf

lead to competing for food in smaller habitats where it is easier for fishes and shrimp to be consumed by predators or harvested by fishermen. Hypoxia can also affect shrimp spawning and migration, negatively as well as the amount of catch available for harvest. Tourism can also be affected as fish available for recreational fishing can be reduced. Hypoxia Watch can help commercial and recreation fishermen better plan where to fish to avoid hypoxic areas.

The economy of the Gulf of Mexico includes significant fishery and tourism activity. Louisiana and Texas accounted for approximately $470 million, or two-thirds, of total U.S. revenue for shrimp landings. While knowledge gaps still exist on the impact of the hypoxic zone on individual species, scientists and economists have already demonstrated habitat loss, migration shifts, and reproductive disruption.[247] These impacts not only alter commercial and recreational fishing patterns, but can also reduce the economic vitality of these fishing industries. While the hypoxic zone has not yet been demonstrated to affect overall population levels of brown shrimp in the northern Gulf of Mexico, during hypoxic conditions, larger shrimp are priced significantly higher in relation to smaller shrimp than when hypoxic conditions are not present.[248]

Figure A.10 shows the value chain for the Hypoxia Watch and related products.

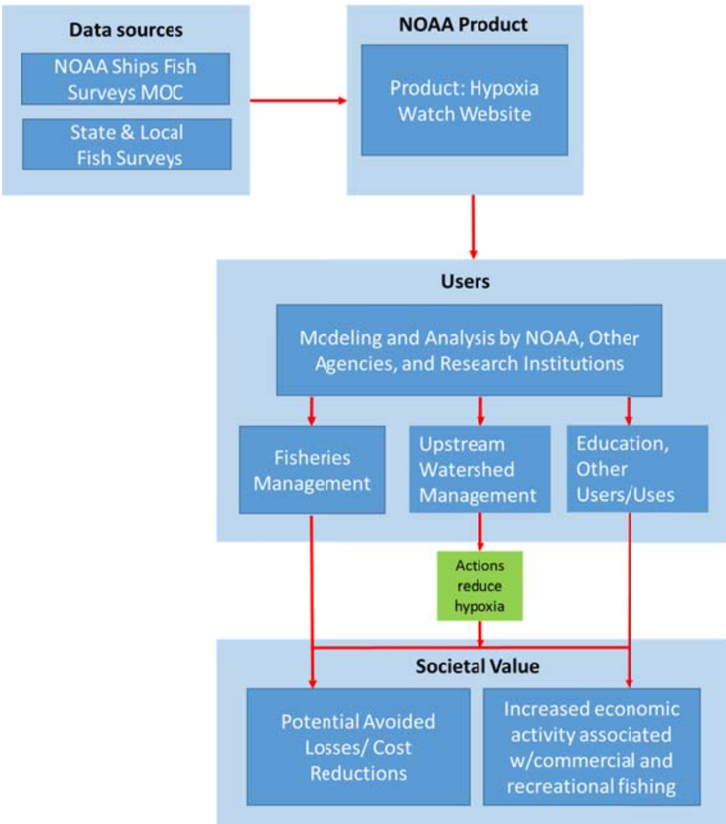

Figure A.10. NOAA Fleet Data Value Chain: Hypoxia Watch, Gulf of Mexico

[247] Committee on Environment and Natural Resources. 2010. Scientific Assessment of Hypoxia in U.S. Coastal Waters. Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology. Washington, DC. Available at: https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/hypoxia-report.pdf.. Accessed February 3, 2017.

[248] Smith, Martin D. et al. 2017. Seafood prices reveal impacts of major ecological disturbance. PNAS 2017. Available at: http://www.pnas.org/content/early/2017/01/24/1617948114.full?tab=author-info.. Accessed February 3, 2017.

10. Ocean Noise: Ocean Noise Mapping

10.1 Product Background

Products: CetMap and SoundMap Mapping Tools

Line Office: National Marine Fisheries Service, Office of Science and Technology

Mission Service Area: Healthy Oceans Protected Species Monitoring and Assessments

Ocean noise, which is caused by commercial shipping traffic, oil and gas exploration and extraction, military sonar, and other sources, threatens marine life and ecosystems in many ways. Ocean animals use sound signals to communicate with other animals, such as when communicating with potential mates or offspring. They also rely on environmental sound cues that are vital to survival.[249] NOAA's National Marine Fisheries Service (NMFS), Office of Science and Technology (OST) developed two web-based mapping tools through NOAA's Cetacean & Sound Mapping effort (CetSound), to better understand the impacts of rising man-made ocean noise levels on marine life. CetSound consists of two working groups that develop the mapping tools, CetMap and SoundMap.

CetSound's cetacean mapping working group, or CetMap, produced time-, region-, and species-specific maps that use predictive environmental factors to estimate density and distribution of cetacean and fish invertebrates.[250] CetMap complements these maps with information on biologically important areas (BIAs) for which sufficient data do not exist. BIAs include areas within the U.S. Exclusive Economic Zone (EEZ) that are critical for animal reproduction, feeding, migration, or habitat for small and resident populations.[251]

CetSound's underwater sound mapping working group, SoundMap, generated maps of temporal, spatial, and frequency characteristics of man-made underwater noise. SoundMap's website offers larger (regional or ocean basin) scale annual average sound field maps as well as more localized and comprehensive examples of short-term noise events.[252] These maps incorporate two aspects of mapping developed by separate working subgroups: extensive predictive modeling of areas in U.S. EEZ waters of the continental U.S., Hawaii, and Alaska where sound is likely to be produced; and mapping of four localized events of known noise-producing human activity such as military sonar training and oil and gas exploration and activity.[253]

Having both cetacean and sound maps at their disposal allows ocean planners to better understand the effect of man-made noise for proposed activities. CetSound's products formed the initial scientific effort towards NOAA's 10-year vision for addressing ocean noise impacts, known as the Ocean Noise Strategy, including the implementation of the Ocean Noise Policy and Ocean Noise Procedure.

10.2 NOAA Fleet Data that Feed the Product

OST worked with more than 30 other NOAA agencies, fisheries science centers, and outside private and academic groups to develop CetSound mapping tools.[254] CetMap incorporates the best available datasets for particular areas and species, including from outside entities such as universities and conservation groups, and is heavily reliant on NOAA Fleet habitat and protected species surveys. A recently published cetacean density

model for the U.S Atlantic and Gulf of Mexico, for example, utilized data from Northeast and Southeast NOAA Fisheries Science Centers, the New Jersey Department of Environmental Projection, the University of St. Andrews, the University

[249] "Underwater Noise and Marine Life". Cetacean & Sound Mapping. National Oceanic and Atmospheric Administration. Available at: http://cetsound.noaa.gov/index. Accessed January 30, 2017.
[250] "Phase 1 – CetSound". Cetacean & Sound Mapping. National Oceanic and Atmospheric Administration. Available at: http://cetsound.noaa.gov/cetsound. Accessed January 30, 2017.
[251] "Biologically Important Areas". Cetacean & Sound Mapping. National Oceanic and Atmospheric Administration. Available at: http://cetsound.noaa.gov/important. Accessed January 30, 2017.
[252] "Phase 1 – CetSound". Cetacean & Sound Mapping. National Oceanic and Atmospheric Administration. Available at: http://cetsound.noaa.gov/cetsound. Accessed January 30, 2017.
[253] "What is SoundMap?" Cetacean & Sound Mapping. National Oceanic and Atmospheric Administration. Available at: http://cetsound.noaa.gov/sound-index. Accessed January 30, 2017.
[254] "Participants." Cetacean & Sound Mapping. National Oceanic and Atmospheric Administration. Available at: http://cetsound.noaa.gov/participants. Accessed January 30, 2017.

of North Carolina, and the Virginia Aquarium and Marine Science Center.[255] NOAA selects surveys from these sources based on an established hierarchy of information and modeling types: habitat-based density models, stratified density models, probability of occurrence models, records of presence, and expert knowledge. After an initial data assessment of cetacean data availability, NOAA models or re-models density primarily using habitat-based density models.[256]

SoundMap similarly utilized a variety of NOAA and non-NOAA data sources to map ocean noise. For known man-made noise sources due to oil and gas exploration, BP Exploration (Alaska) Inc. and JASCO research LTD provide sound modeling results from the Beaufort Sea, and the Resource Evaluation Office of Bureau of Ocean Energy Management (BOEM) provides 2D and 3D seismic survey results from the Gulf of Mexico.[257] The U.S Navy provides data on specific sound-producing naval activities such as active sonar training in Hawaii. NOAA ships also contribute in a couple ways. Ten ocean noise reference stations are placed throughout U.S. waters to track changes in ocean noise trends over time. NOAA ships service these buoys and may drop new ones or replacements. The Fleet also provide an opportunity to collect empirical evidence of man-made noise and its impacts, as opposed to relying on predictive modeling.

10.3 Product Intermediaries and Dissemination

Members of CetMap's working group from Duke University's Marine Geospatial Ecology Lab create the standardized GIS files for CetMap, both for new modeling results as well as previous model results that lacked GIS layers. NOAA OST subsequently takes the data and maps and develops website portals that the public can easily access. Similarly, Heat, Light, and Sound Research Inc. helps SoundMap generate the predictive models of anthropogenic underwater noise.

Both CetMap and SoundMap are web-based products available to the public. Additionally, NOAA makes available underlying data (including GIS layers) and metadata for both mapping tools, either through the website or by request.

NOAA performs outreach to educate the general public and specific members of the oceanic community who have an interest in sound-producing activities. In 2012, NOAA demonstrated near-final CetMap and SoundMap products to approximately 170 representatives from government agencies, scientists, consultancies, regulated industries, media, and conservation advocacy groups.[258] NOAA also participated in an international workshop on underwater sound mapping and impacts in 2014 that included the International Whaling Commission, the Office of Naval research Global, the Netherlands Organisation for Applied Scientific Research, and the Netherlands Ministry of Infrastructure and the Environment.[259]

NOAA has a close relationship with the U.S. Navy, who not only provides data for sound field mapping but is also a high-profile emitter of ocean noise, the Bureau of Ocean Energy Management (BOEM) and various non-governmental organizations. Through professional relationships and working groups NOAA further disseminates CetSound products to these users.

Additionally, the Ocean Noise Strategy garners press coverage that helps NOAA educate the public on ocean noise impacts.

10.4 Users of the Product

[255] "Habitat-Based Cetacean Density Models for the U.S. Atlantic and Gulf of Mexico (2015 version)". Marine Geospatial Ecology Lab. Duke University. Available at: http://seamap.env.duke.edu/models/Duke-EC-GOM-2015/. Accessed January 30, 2017.

[256] "What is CetMap?" Cetacean & Sound Mapping. National Oceanic and Atmospheric Administration. Available at: http://cetsound.noaa.gov/cda-index. Accessed January 30, 2017.

[257] "Phase 1 – CetSound". Cetacean & Sound Mapping. National Oceanic and Atmospheric Administration. Available at: http://cetsound.noaa.gov/cetsound. Accessed January 30, 2017. And
"Sound Field Data Availability: Overview". Cetacean & Sound Mapping. National Oceanic and Atmospheric Administration. Available at: http://cetsound.noaa.gov/sound_data. Accessed January 30, 2017.

[258] National Oceanic and Atmospheric Administration. 2012. Mapping Cetaceans and Sound: Modern Tools or Ocean Management. Final Symposium Report of a Technical Workshop held May 23-24 in Washington, D.C. 83 pp. Available at: http://cetsound.noaa.gov/Assets/cetsound/documents/symp-docs/CetSound_Symposium_Report_Final.pdf

[259] National Oceanic and Atmospheric Administration. 2014. "Joint Workshop Report: Predicting Sound Fields-Global Soundscape Modelling to Inform Management of Cetaceans and Anthropogenic Noise". April 15-16, 2014. Available at: "http://cetsound.noaa.gov/Assets/cetsound/documents/Predicting%20Sound%20Fields%20Report_Final.pdf". Accessed January 31, 2017.

CetMap and SoundMap's mapping tools help NOAA achieve its' four primary goals for the Ocean Noise Strategy: filling knowledge gaps and building understanding of noise impacts; integrating management actions to minimize effects of noise on marine species; developing tools for assessment, planning, and mitigation of noise-making activities; and educating the public and stakeholders on noise impacts.[260] Both mapping tools and data can help resource managers plan, analyze, and make decisions on how to reduce adverse impacts. The breadth of knowledge gained from these two tools allows for improved characterization and management of noise impacts on marine life and habitat, in particular on seasonally resident marine species that are not captured by empirical sound data collection.

NOAA's Ocean Noise Strategy Roadmap includes two case studies that highlight the ability of ocean managers to understand noise impacts on critical marine life and habitat through cetacean and sound modeling. In the first, scientists combined CetMap's mapping tool methodology with higher resolution shipping data to identify and characterize noise impacts of shipping vessels to Baleen Whales off Southern California. The scientists recognized the need for uncertainty and risk metrics in the model, but their framework could be used to evaluate the consequences of potential shipping traffic management actions.[261] In the second study, a separate team studied the impacts of noise on spawning grounds using SoundMap model predictions and produced recommendations to protect these critical spawning grounds. These recommendations, which NOAA usually communicates to relevant action agencies through consultations, included spatial and temporal measures such as avoiding certain areas or time periods to reduce impact, water noise monitoring, and assessment of transiting vessel noise. The team suggested that NOAA work with the U.S. Coast Guard and U.S. Maritime Administration to evaluate chronic impacts in acoustically sensitive federally designated areas, evaluate impacts in key spawning locations associated with federal actions and predicted growth in East Coast shipping traffic, and encourage the implementation of new, voluntary guidelines to quiet commercial ships. These scientists also proposed that NOAA work with the U.S. Navy to assess overlap of training activity with acoustically sensitive federally designated areas. [262]

NOAA's ONS identifies thirteen domestic policy acts such as the Endangered Species Act and the Mitchell Act under which ocean managers may be able to address noise issues.[263] However, organizations and entities outside of the federal government are responsible for many of the decisions that can reduce noise impacts on critical marine species and habitat, and CetSound's products can still influence these decisions. In 2014, for example, the Marine Environment Protection Committee approved guidelines for voluntary underwater noise reduction for member governments in the International Maritime Organization, the UN agency that creates regulation and standards for the shipping industry.[264]

10.5 Societal Benefits

CetMap and SoundMap tools provide a variety of benefits to different users. CetMap products provide current and consolidated density data for compliance, identify data gaps and necessary specifications for data integration, provide a useful tool for ocean planning for proposed activities and for alternative NEPA analysis, and improve current understanding of migratory patterns. SoundMap similarly provides a useful tool for ocean planners to predict noise

[260] "Phase 2 - NOAA's Ocean Noise Strategy". Cetacean & Sound Mapping. National Oceanic and Atmospheric Administration. Available at: http://cetsound.noaa.gov/ons. Accessed January 31, 2017.
[261] Gedamke, J. et al. Ocean Noise Strategy Roadmap. National Oceanic and Atmospheric Administration. September, 2016. Available at: http://cetsound.noaa.gov/Assets/cetsound/documents/Roadmap/ONS_Roadmap_Final_Complete.pdf. Accessed January 31, 2017.
[262] Ibid.
[263] National Oceanic and Atmospheric Administration. "Spreadsheet of Potential Authorities (e.g. Statutes, Executive Orders) to Address Ocean Noise Issues". Ocean Noise Strategy Roadmap Appendix C. September, 2016. Available at: http://cetsound.noaa.gov/Assets/cetsound/documents/Roadmap/ONS_Roadmap_Final_AppendixC.pdf. Accessed January 31, 2017.
[264] International Maritime Organization. "Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life". April 7, 2014. Available at: http://cetsound.noaa.gov/Assets/cetsound/documents/MEPC.1-Circ%20883%20Noise%20Guidelines%20April%202014.pdf. Accessed January 31, 2017.

impacts of proposed activities. In addition, it offers a more robust picture of the cumulative effects of noise on marine species and habitat and an improved tool for forecasting and scenario building.[265]

Private firms have created sound mapping tools in the past, but not on the geospatial scale achieved by SoundMap. SoundMap's products provide a cost-efficient single web portal for ocean planners, decision-makers, and regulators to assess current and potential impacts on marine life and habitat.

Reductions in man-made noise can provide protection for and increase the population of species by allowing natural defense and mating sound cues to operate normally and by permitting normal migratory patterns. Economists and scientists have conducted numerous studies over the past couple decades to estimate economic values for similar species protection and rehabilitation. These studies use established survey methods to determine what people are willing to pay for particular ecosystem services related to specific species. This can include recovery or protection programs, improved status, and population increases. While these programs are not specifically tied to man-made noise, the overall benefits can be similar. This review of the studies have shown that households are willing to pay up to $80 per household or more [266] (in 2013 dollars) to benefit charismatic mammal species in US waters (such as right whales), which can add up to a significant value for species preservation and habitat improvement.

Figure A.11 shows the value chain diagram for ocean noise mapping.

[265] National Oceanic and Atmospheric Administration. 2012. Mapping Cetaceans and Sound: Modern Tools or Ocean Management. Final Symposium Report of a Technical Workshop held May 23-24 in Washington, D.C. 83 pp. Available at: http://cetsound.noaa.gov/Assets/cetsound/documents/symp-docs/CetSound_Symposium_Report_Final.pdf

[266] Lew, D.K (2015). *Willingness to Pay for Threatened and Endangered Marine Species: A Review of the Literature and Prospects for Policy Use*. Front. Mar. Sci. 2:96. Available at: http://journal.frontiersin.org/article/10.3389/fmars.2015.00096/full

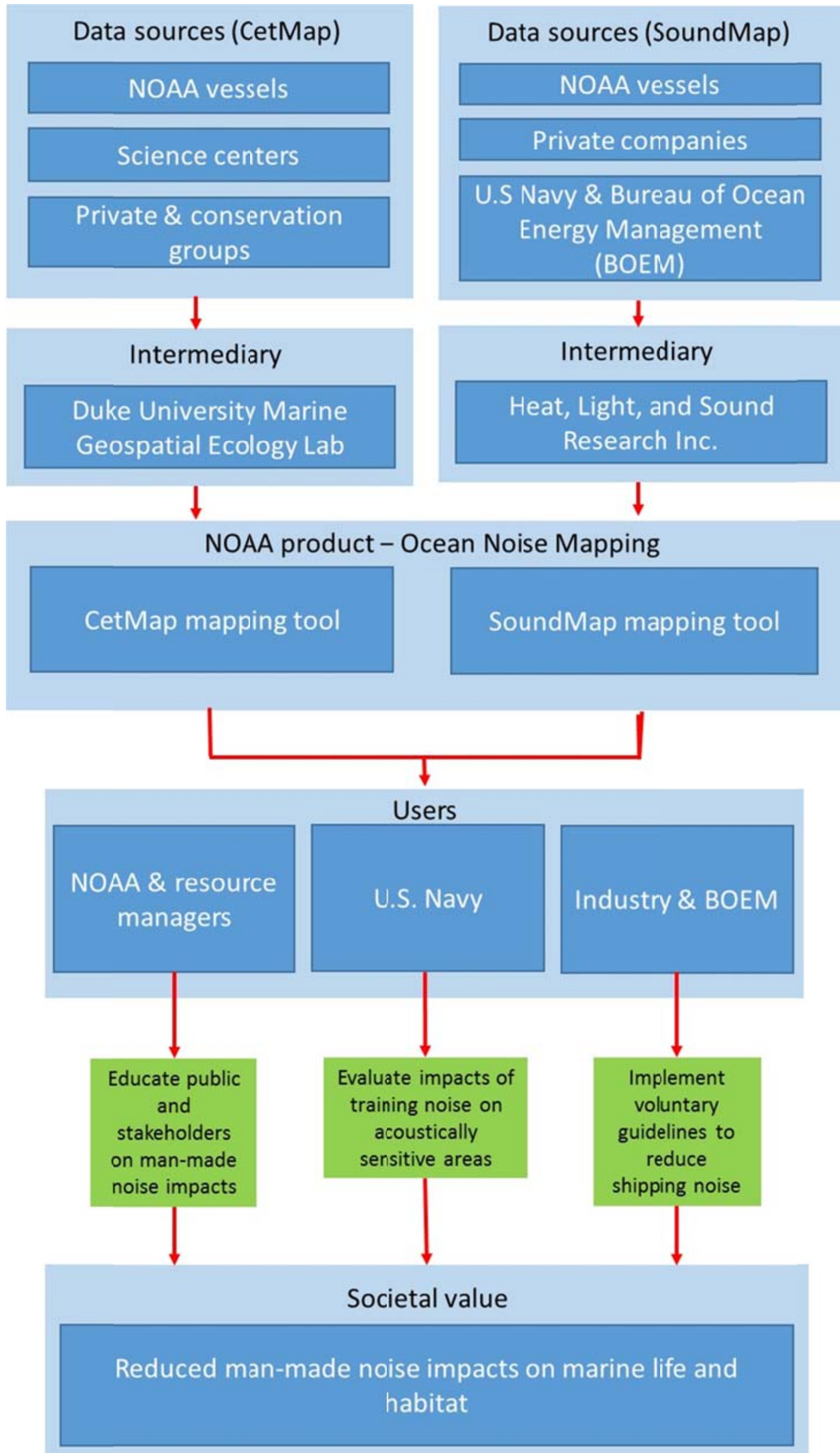

Figure A.11. NOAA Fleet Data Value Chain: Ocean Noise Mapping

11. Hurricanes: Hurricane Outlook

11.1 Product Background

Product: Hurricane Outlook

Line Office: National Weather Service

Mission Service Area: Climate, Climate Predictions and Projections

NOAA's National Weather Service (NWS) Climate Prediction Center (CPC) produces the Atlantic Hurricane Outlook in collaboration with hurricane experts at NOAA's Hurricane Research Division and National Hurricane Center.[267]

The Hurricane Outlook serves as a general guide on expected activity for the upcoming hurricane season in the Atlantic Region, including the number of named storms, hurricanes, major hurricanes, and accumulated cyclone energy. It does not predict which of these storms will make landfall or levels of activity for any particular geographic area. The Outlook is probabilistic in nature, which means that it states the "likely" ranges of activity. It is based on predictions of large-scale climate factors that influence hurricane activity, as well as climate models that directly predict hurricane activity.[268]

Various stakeholders use the Hurricane Outlook to improve hurricane preparedness. With the hurricane season spanning June to November, CPC releases the Outlook in late May, prior to start of season, and updates it in early August, mid-way through the season. NOAA publishes the Hurricane Outlook online and issues a press release about it, sending it to more than 3,000 reporters. CPC also publishes a technical write-up of the Outlook, which explains the science and data behind the analysis and summarizes key findings.

11.2 NOAA Fleet Data that Feed the Product

The Hurricane Outlook uses data from various sources including data collected by the Tropical Atmosphere Ocean (TAO) array, which is maintained by the NOAA Fleet. The TAO array consists of 70 buoys moored ("moorings") in the Pacific Ocean that collect oceanographic and meteorological data.[269] The NOAA fleet maintains the TAO array and transmits the data from these moorings electronically through satellites.[270] Monitoring data from the TAO array tell researchers about the state of the ocean and the atmosphere. Basic measurements on TAO moorings include wind speeds, air temperature, relative humidity, sea surface temperature, and subsurface temperatures. Additional sensors can collect data on rainfall, short wave and long-wave radiation, barometric pressure, salinity and ocean currents.[271]

Ships go to each buoy once a year to perform necessary maintenance, including repairing any damage caused by biological activity or local fisherman. The data from the TAO array is particularly important because of the information it provides on the El Niño and La Nina phenomenon. El Niño and La Nina strongly influence the hurricane pattern in the Atlantic Ocean and the Central and Eastern Pacific Ocean.

The Outlook does rely on some data collected directly by the NOAA fleet,[272] including ocean profile data and sea surface temperature and weather data collected through the Voluntary Observing Ship Program, which the NOAA fleet is a part of.

11.3 Complementary Data and Intermediate Products

[267] "NOAA 2016 Atlantic Hurricane Season Outlook Issued: 11 August 2016." (2016). National Weather Service Climate Prediction Center. http://www.cpc.ncep.noaa.gov/products/outlooks/hurricane.shtml
[268] Ibid.
[269] "Project: Tropical Atmosphere Ocean Buoy Service." (2016). NOAA Office of Marine and Aviation Operations. http://www.omao.noaa.gov/find/projects/3418-tropical-atmosphere-ocean-buoy-service
[270] For example the *Ronald H. Brown* provided maintenance for TAO Buoy in November 2015. http://www.omao.noaa.gov/find/projects/2751-tropical-atmosphere-ocean-tao-buoy-array-maintenance
[271] "TAO Refresh Sampling." (2011). NOAA's National Data Buoy Center. http://tao.ndbc.noaa.gov/proj_overview/sampling_ndbc.shtml
[272] Personal communication with Dr. Gerry Bell, Lead Forecaster and Meteorologist at the NOAA Climate Prediction Center on January 5, 2017.

A second source of data for the Hurricane Outlook is the ARGO array. This global array of 3,800 floats provides data on subsurface temperature, salinity, and velocity of the upper 2000 meters of the ocean.[273] The ARGO floats go underwater to a depth of about 2 km and come back to the surface to automatically transmit their data. They require much less maintenance than the TAO array because there are no vandalism issues. The NOAA Fleet does not support these floats but the floats provide important data used in the Hurricane Outlook. Other sources of global ocean temperature data come from land-based stations, weather balloons, and satellite measurements.[274]

Data from the TAO array, the ARGO array, and other sources feed into climate models that synthesize this data. These models create a long archive of gridded model climate data that is used to make predictions about the upcoming hurricane season. The Hurricane Outlook includes dynamical model predictions from the NOAA Climate Forecast System (CFS), NOAA Geophysical Fluid Dynamics Lab (GFDL), the European Centre for Medium Range Weather Forecasting (ECMWF), and the United Kingdom Meteorology (UKMET) office.[275] Data from the TAO array also feeds into the El Niño Southern Oscillation (ENSO) outlook. Forecasters rely on the ENSO outlook to predict hurricane activity because of the impact of La Nina and El Niño on seasonal hurricane patterns.

Figure A.12. Hurricane Outlook Online Viewership Statistics

May 2016 Outlook. Headline: Near-normal Atlantic hurricane season is most likely this year

Unique visitors (users) - 131,517

Page views - 158,271

Unique page views - 145,274

(82% of readers were new visitors)

August 2016 Outlook. Headline: Atlantic hurricane season still expected to be strongest since 2012 (August)

Unique visitors (users) - 124,581

Page views - 146,710

Unique page views - 133,956

(76% of readers were new visitors)

Source: Personal Communications, Susan Buchanan, Acting Director of Public Affairs, National Weather Service, May 1, 2017.

11.4 Users of the Product and Related Products

The Hurricane Outlook is used by a variety of interests to prepare for the hurricane season and is widely distributed and publicized. As shown in Figure A.12, the May 2016 Outlook garnered approximately 131,500 views online (unique visitors), while the August 2016 Outlook had 134,000 (unique visitors). When it is published, the authors of the Outlook hold briefings with key stakeholders, including state, local and emergency managers, federal departments such as the Hurricane Center and the NOAA Atlantic Oceanographic and Meteorological Laboratory, Congress, the President, and members of the public. The authors also participate in interviews with magazines and interact with the public on social media through Reddit Ask Me Anything question sessions, the most popular of which had 27,000 participants. These interviews and other interactions with the public and other stakeholders focus on preparedness. In general, more than 80 million U.S. citizens are potentially threatened by hurricanes. Agencies like FEMA with their ready.gov website, the National Hurricane Center, and the Red Cross, use this Outlook to instruct the public on preparing for these storms.[276] The Hurricane Outlook helps agencies and decision-makers to better focus their resources when preparing for the upcoming hurricane season.

Members of the business sector also use the Hurricane Outlook. The Small Business Administration promotes the Outlook and recommends preparedness efforts for small businesses.[277] CPC does not collect data on how the information provided in the Outlook directly impacts business decisions. Nonetheless, it is not hard to imagine how the information

[273] "What is Argo?" Argo – part of the integrated global observation strategy. http://www.argo.ucsd.edu/
[274] Personal communication with Dr. Gerry Bell, Lead Forecaster and Meteorologist at the NOAA Climate Prediction Center on January 5, 2017.
[275] "NOAA 2016 Atlantic Hurricane Season Outlook Issued: 11 August 2016." (2016). National Weather Service Climate Prediction Center. http://www.cpc.ncep.noaa.gov/products/outlooks/hurricane.shtml
[276] Personal communication with Dr. Gerry Bell, Lead Forecaster and Meteorologist at the NOAA Climate Prediction Center on January 5, 2017.
[277] Ibid.

could significantly impact certain business sectors. For example, coastal tourism companies make seasonal operational changes based on the information found in the Outlook.

11.5 Societal Benefits

Since 1980, 35 major hurricanes (those causing at least $1 billion in damages) have struck the United States with total losses exceeding $500 billion. The average annual losses from these 35 storms is nearly $16 billion.[278]The Hurricane Outlook helps key stakeholders to better prepare for the hurricane season, which can lead to reductions in property damage, mortality and morbidity, societal costs associated with evacuation, and lost business activity.

Several studies have attempted to value hurricane forecasts based on the costs and damages that they can help to avoid, for both society and individual industry sectors. For example, using data from 1900 to 1990, Jamieson and Drury (1997) determined that loss of life associated with hurricanes exponentially decreased over this time period because of improved hurricane forecasts.[279] Considine et al. (2004) used the cost-of-evacuation to estimate the value of improved hurricane forecast information to crude oil and natural gas producers in the Gulf of Mexico. They found that the current value of existing hurricane forecast information is $8 million per year, and that the value rises by more than $15 million per year when this forecast is 50% more accurate.[280] Emmanuel et al. (2012) also found potentially significant savings for the insurance industry associated with improvements in seasonal hurricane forecasts.[281]

Figure A.13 demonstrates the value chain associated the Hurricane Outlook, including the data from the NOAA Fleet that they depend on, and how this ultimately results in value to society.

[278] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2017). https://www.ncdc.noaa.gov/billions/
[279] Jamieson, G., and Drury, C. 1997. *Hurricane mitigation efforts at the U.S. Federal Emergency Management Agency*, FEMA, Washington, D.C.
[280] Considine, T., Jablonowski, C., Posner, B., and Bishop, C. 2004. "Value of hurricane forecasts to oil and gas producers in the Gulf of Mexico." *Journal of Applied Meteorology.*, 43, 1270–1281.
[281]Emmanuel, K., F. Fondriest, and J. Kossin. 2012. Potential Economic Value of Seasonal Hurricane Forecasts. *Weather, Climate, and Society*, 4(110 – 117).

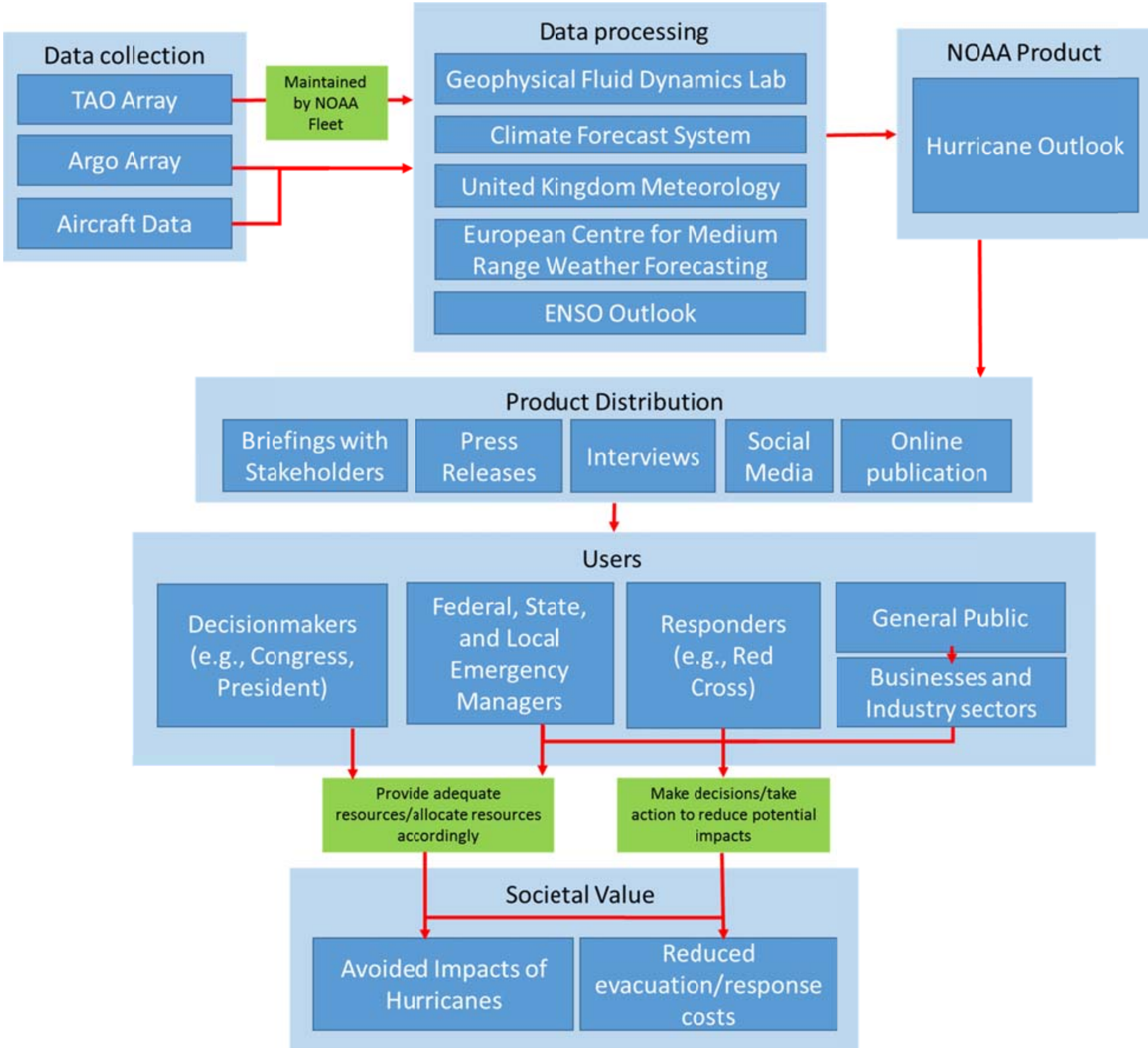

Figure A.13. NOAA Fleet Data Value Chain: Hurricane Outlook

12. Fleet Emergency Response Services

12.1 Background

Many maritime-related natural disasters and emergency situations require a coordinated response by U.S. government and non-government organizations. These events include hurricanes, oil spills, terrorist attacks, and other disasters. During, and immediately following these events, highly skilled crew members and vessels equipped with specific technologies are often needed to perform search and rescue activities, provide relief services, re-open affected ports, assess damages, and/or collect scientific data.

Depending on the nature and extent of the disaster or emergency, the U.S. has a variety of potential maritime-based responders, including the U.S. Coast Guard (USCG), U.S. Army Corps of Engineers (USACE), U.S. Navy, and multiple NOAA Line Offices and divisions. These agencies work with other federal, state, local, and non-profit organizations, including port authorities, maritime ship pilots, Air National Guard, Federal Emergency Management Agency (FEMA), Red Cross, and others, to launch coordinated land-, air-, and ocean-based response efforts.

The NOAA Fleet is a key part of the ocean-related emergency and disaster response network, and are often called upon to provide the following emergency response services:

- Survey our nation's ports and waterway in response to national security threats
- Deliver emergency supplies, conduct hydrographic surveys so that ports can be re-opened, and assess hazardous materials, during and after hurricanes and other major storm events
- Locate and map debris fields in the ocean for aviation and maritime disasters
- Conduct a range of scientific surveys in response to major oil spills
- Perform search, rescue, and evacuation services

NOAA vessels have unique technologies that, when combined with their availability across an expansive geographic area, can provide superior, timely, and cost-effective response services in many emergency situations. In addition, in the event of an emergency, OMAO can easily coordinate fleet response activities across NOAA's line offices, resulting in a more seamless response effort.[282]

12.2 NOAA Fleet Capabilities that Support Emergency Response Efforts

As described below, NOAA Fleet emergency response activities most commonly include hydrographic surveys/data collection and mapping. For example, after hurricanes and large storm events, crewmembers on NOAA vessels conduct hydrographic surveys to ensure safe navigation and re-opening of affected ports as directed by the U.S. Coast Guard. NOAA also uses ship hydrographic survey technologies, which include complete seafloor mapping systems, to map debris fields from aviation and maritime disasters. This enables the quick recovery of victims and flight recorders.

Four NOAA ships, including *Fairweather*, *Ferdinand R. Hassler*, *Rainier*, and *Thomas Jefferson*, conduct hydrographic surveys, which NOS primarily uses to update the nation's suite of 1,000 nautical charts. These ships each have 2-6 smaller boats (called launches) that can be lowered into the water for surveying in shallow areas. NOAA's hydrographic survey ships are equipped with side-scan sonar (SSS) and single- or multi-beam sonar technology, which provides detailed and precise data on subsurface obstructions.[283][284] In addition, the hydrographic surveys that NOS conducted prior to an event provide an immediate baseline comparison to conditions after a hurricane or disaster.

Besides hydrographic survey capabilities, many NOAA vessels are equipped with biological, chemical, and acoustic data collection equipment necessary for toxicity and water quality testing, which can be beneficial to response efforts for major oil spills and hurricanes, where a range of immediate testing is often required.

[282] Pers. comm. Megan Greenaway, Technical Advisor, Office of Coast Survey, NOAA, February 2, 2017.
[283] SSS is a specialized system contained in a small, towed instrument that can provide accurate acoustical imaging up to a range of 200 meters. SSS is normally used with single beam or multi-beam sonar to gather all necessary bottom coverage specifications. "Side Scan Sonar". NOAA Office of Coast Survey. Available at: https://www.nauticalcharts.noaa.gov/hsd/SSS.html. Accessed February 6, 2017.
[284] "NOAA's Hydrographic Survey Ships Aid the Nation During Disaster Recovery Efforts". NOAA.gov. Available at: http://www.publicaffairs.noaa.gov/grounders/disasterresponse.html. Accessed February 6, 2017.

The vast geographic area across which the NOAA Fleet operates also contributes to NOAA's response capabilities, because it typically means that at least one fleet vessel can respond to an emergency location in a timely manner. NOAA vessels can also enter areas that require military or security clearance (e.g., military ports), whereas most charter vessels cannot. Finally, as the administrator of all NOAA fleet activities, OMAO can easily coordinate across line offices to ensure that NOAA's other critical needs are being met throughout the emergency response period.

Together, these factors often make it much more feasible and cost-effective to utilize NOAA Fleet vessels for emergency response activities, rather than having to pay charter vessels, which will likely charge premium prices (e.g., through time and materials contracts) for emergency situations, or even using other government-owned vessels. For example, NOAA/OMAO has a standard agreement in place with the Federal Emergency Management Agency (FEMA) so that they can respond quickly in the event of an emergency; USACE requires that an arrangement be in place for each incident before they respond.

12.3 Emergency response services

The following sections provide an overview of the emergency and disaster response services, and associated value, that the NOAA Fleet provides, including services related to hurricanes, aviation disasters, oil spills, national security, and routine search and rescue activities.

12.3.1 Hurricanes

Aside from routine search and rescue activities, the emergency response activities that NOAA ships most commonly provide relate to hurricanes and large coastal storms. During and after hurricanes and other major storm events, NOAA ships conduct hydrographic surveys of ports and important waterways, assess hazardous materials, and provide emergency relief.

USCG typically closes potentially-affected ports and shipping lanes 24 to 48 hours before a hurricane strikes. During the storm, a hurricane can cause hazardous situations for water-based traffic in and around ports by sinking harbored ships, knocking over/damaging oil platforms, washing land-based objects such as cars and shipping containers out to sea, moving the location of main shipping channel navigation buoys, and by changing the natural topography of the sea floor. These changes create a potentially hazardous situation for commercial, recreational, or government-owned vessels trying to enter the port. Accurate post-hurricane mapping of waterways allows partner agencies, such as USCG and USACE, to immediately clear sub-surface hazards so that vessels can re-enter economically significant waterways and ports.

Reopening ports and harbors, such as New York, Baltimore and Norfolk after Hurricane Sandy, allowed commercial and naval vessels to continue normal operations. USCG reports that 95% of all goods in the U.S. economy come through U.S. ports.[285] Several estimates have been placed on the value of cargo that moves through U.S. ports. The Port of New York and New Jersey, for example, estimated that the value of all cargo that passed through that port alone was greater than $200 billion ($550 million per day, on average).[286] A 2012 study by NOAA's National Ocean Service (NOS) reports that that ocean commerce for the entire nation is worth more than $1 trillion.[287] By speeding up the process of clearing waterways, NOAA's emergency response capabilities can reduce the number of days a port is closed, allowing hundreds of millions of dollars of daily commercial activity to resume.

In some cases, the re-opening of ports can allow for the delivery of essential relief supplies, such as fuel and food supplies. For example, during Hurricane Sandy, NOAA vessels' rapid surveying and charting response allowed the U.S Navy to make a relatively quick determination on possible subsurface obstructions. This led to the USCG Captain of the Port re-opening of many affected ports, which directly alleviated a regional fuel shortage that occurred in the days following the hurricane. In addition, naval vessels from Norfolk Naval Base that were scrambled to sea to avoid damage

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285 Young, Stephanie. 2012. "Opening U.S. ports after disaster: An all-hands on deck evolution." Coast Guard Compass, Official Blog of the U.S. Coast Guard. November 1, 2012. Available at: http://coastguard.dodlive.mil/2012/11/opening-u-s-ports-after-disaster-an-all-hands-on-deck-evolution/. Accessed February 7, 2017.
286 "About the Port". The Port Authority of New York and New Jersey. Available at: http://www.panynj.gov/port/about-port.html. Accessed February 7, 2017.
287 National Ocean Service, 2012. "Hurricane Response". National Oceanic and Atmospheric Administration. May, 2012.Available at: http://oceanservice.noaa.gov/hazards/hurricanes/nosresponse12.pdf. Accessed February 7, 2017.

were able to return to port. Unnecessarily operating naval vessels at sea can be extremely expensive, not only monetarily but also operationally in terms of disrupting normal naval activities.

As part of the hydrographic data collection efforts associated with hurricane response, scientists and engineers on NOAA vessels work closely with mapping partners from sister agencies, such as USACE and U.S. Geological Survey (USGS), to coordinate mapping efforts using an Integrated Ocean and Coastal Mapping approach. The objective of this approach is to reduce redundancies and meet multiple missions with the same datasets. These datasets help state and federal partners with recovery from an event and to begin preparing for the next one.[288]

In addition to hydrographic surveys, the NOAA Fleet also provides scientific support to hazardous materials response efforts in the wake of hurricanes. For example, NOAA ships have conducted post-hurricane surveys to identify vessels or containers that may be leaking fuel, oil, or other hazardous materials. During Hurricane Katrina, NOAA ships collected data to assess potential seafood contamination from these sources. In many cases, NOAA Fleet crew members also conduct search and rescue activities and deliver emergency supplies during or directly following a hurricane event.

Figure A.14 provides several examples of emergency response activities that NOAA ships have provided for major hurricane events.

12.3.2 Aviation disaster search

NOAA Fleet vessels have assisted in aviation disaster searches by conducting hydrographic surveys and field scans, and developing detailed maps of the search areas. For example, after the 1996 TWA Flight 800 crash off the coast of New York State, NOAA Ship Rude, in conjunction with a shore-side NOAA team, created accurate maps of the debris field, allowing U.S. Navy divers to quickly recover the crash victims and the flight data recorder. After the Egypt Air Flight 990 crash in 1999 (31 October 1999), the NOAA ship *Whiting* scanned the seafloor south of Nantucket to find the primary debris field. NOAA's efforts allowed a remotely operated U.S. Navy vehicle to complete the search. Finally, the NOAA ship *Rude* also played key roles in the 1999 plane crash involving John F. Kennedy, Jr, ultimately finding the wreckage using side-scan and multi-beam sonar.

[288] Written Statement by Jeffrey L. Payne Ph.D., Acting Director, Office for Coastal Management, NOAA, U.S. Department of Commerce, U.S. House of Representatives Committee on Homeland Security, Subcommittee on Oversight and Management Efficiency. November 21, 2014.

Hurricane Katrina (2005)

- NOAA Ship *Nancy Foster* quickly outfitted with multi-beam and SSS technology to conduct seafloor surveys on approaches to Mobile, Alabama, helping to reopen the port. The ship then conducted environmental damage and toxic contamination surveys.
- NOAA Ship *Thomas Jefferson* diverted from its working grounds to conduct surveys around entrances to Pascagoula and Gulfport, Mississippi, helping to quickly reopen those ports. The ship's crew also replaced lost and damaged tide gauges, which measure oceanographic and meteorological parameters.

Hurricane Irene (2011)

- NOAA Ship *Ferdinand Hassler* conducted 300 lineal miles of hydrographic surveys in Hampton Roads, Virginia in less than 48 hours to assess seafloor changes and search for underwater hazards, helping U.S. Coast Guard to restore port operations. **The value of commerce through Hampton Roads amounts to $5 million per hour.**

Hurricane Sandy (2012)

- NOAA Ship *Thomas Jefferson* surveyed for possible hazards to navigation throughout the Ports of New York and New Jersey before those ports were reopened, and later conducted surveys in Long Island Sound. **In 2012, the value of cargo through the Ports of New York & New Jersey was $24 million per hour.**
- NOAA Ship *Ferdinand Hassler* supported U.S. Coast Guard efforts to reopen Port of Virginia by surveying Chesapeake Channel.

Pacific Island Hurricanes (2015)

- July 2015 – NOAA Ship *Oscar Elton Sette* delivered water and provided emergency transportation support to inhabitants of Agrihan and Pagan Islands, Northern Mariana Islands
- August 2015 – NOAA Ship *Okeanos Explorer* diverted track and evacuated four researchers from a monk seal camp on Tern Island, French Frigate Shoal ahead of Hurricanes Kilo and Loke.
- August 2015 – NOAA Ship *Hi'ialakai* evacuated three researchers from Laysan Island, and 3 more from Pearl and Hermes Atoll, and 2 more from Lisianski Island ahead of Tropical Storms Kilo and Loke.

Hurricane Matthew (2016)

- NOAA Ship *Ferdinand Hassler* rode out the storm in North Charleston, South Carolina. The day after the storm the ship conducted channel clearance operations in Charleston Harbor per request of the USCG Captain of the Port (COTP). As soon as the sea state permitted, the ship transited to Savannah, Georgia to conduct channel clearance operation also per request of the COTP.

Source: OMAO. Undated. Presentation: NOAA Fleet Disaster Response.

Figure A.14. Examples of Major Hurricane Response Activities by OMAO Fleet, 2005 – 2016

Responses to crash sites are typically joint efforts with USCG, U.S. Navy, and the NTSB. Once a NOAA vessel locates (and maps) a debris field, the U.S. Navy can send out remotely operated vehicles or divers to perform a more detailed search of the area. Trajectory analysis from the National Ocean Service's Hazardous Materials Response Division aids NOAA ships in the search for floating debris, and NOAA has used this analysis for both plane crash response planning as well as oil spill responses. Tailored weather forecasts from the National Weather Service allow for safer and more efficient search and recovery operations. [289]

NOAA's detailed surveys provide agencies such as the US. Navy, U.S Coast Guard (USCG), National Transportation Safety Board (NTSB) and Federal Bureau of Investigation (FBI) the required information to support focused and localized searches. These processes significantly increase likelihood of discovery and reduce the time and effort to conduct and complete the search and salvage mission.

12.3.3 Oil spill response

NOAA vessels have provided sophisticated scientific data collection capabilities for major oil spill responses. Most notably, after the Deepwater Horizon oil spill in 2010, seven NOAA ships collected fish habitat, oceanographic water quality, seafood safety, and other critical scientific data, and conducted subsurface oil monitoring activities. An eighth ship, the *Nancy Foster*, investigated the interaction of oil, dispersants, and tar balls within the Gulf of Mexico Loop Current. Many of these ships were involved in this effort for six months or more. The DWH data collection activities directly supported spill containment and clean-up efforts, as well as NOAA's efforts to assess and restore resources injured by the oil spill and to compensate the public for its' lost use of resources.

NOAA ships also performed hydrographic, biological, and sediment toxicity surveys in response to the 1989 Exxon Valdez oil spill, and oceanographic research to study the effects of the 1990-91 Persian Gulf War oil spills. [290]

12.3.4 National Security

The fleet's disaster response capabilities also yield cost reductions and benefits related to national security, as witnessed in the responses to the terrorist attacks on September 11, 2001. Immediately following this event, in collaboration with the Oceanographer of the Navy and the USCG, NOAA vessels conducted hydrographic surveys to supply critical baseline conditions as an input to a secure USN seafloor change comparison database. The intent was to allow for quick detection of any changes in seafloor conditions that might indicate potential threats in the navigation approach channels to major ports across the country, such as the Port of New York and New Jersey. The NOAA vessel *Whiting* performed this strategic commercial route survey in Boston one month after the 9/11 attack, using similar technologies to those employed by the U.S. Navy to sweep for mines. These efforts allowed the U.S. Navy to ensure that there were no additional national security threats in these areas. NOAA reports that without NOAA ships, more extensive surveying would have been required to provide an accurate assessment of potential threats near the port.

Based on the success of the commercial route survey in Boston following September 11, 2001, NOAA's Office of Coast Survey began coordinating its commercially valuable harbor approach surveys to meet the Maritime Domain Awareness priorities of the USCG and US Naval Oceanographic Office, with the objective of identifying potential national security risks and threats at major ports.

12.3.5 Routine search and rescue response

The dispersal of NOAA vessels throughout U.S. coastal waters makes them well-suited to perform search and rescue operations for stranded sailors, fishermen, and recreational boaters. According to NOAA representatives, these types of activities are a relatively routine occurrence.

12.4 Societal Benefits

[289] "NOAA's Hydrographic Survey Ships Aid the Nation During Disaster Recovery Efforts". NOAA.gov. Available at: http://www.publicaffairs.noaa.gov/grounders/disasterresponse.html. Accessed February 6, 2017.
[290] OMAO. Undated. NOAA Fleet Disaster Response, PowerPoint Presentation.

NOAA ships' disaster response capabilities are often essential to subsequent efforts in each emergency scenario. For example, pre- and post-event hydrographic surveying allows major ports and harbors to reopen to commercial shipping after hurricanes and other disasters. The ability of NOAA ships to immediately survey these areas allows important economic activity to resume. In 2015 alone, 1.39 billion short tons accounting for $1.56 trillion worth of U.S. goods moved through U.S. ports. Imports and exports via water represented 71% of U.S. imports and exports by weight and almost 42% of cargo value.[291]

Debris field location and mapping helps other federal, state, and local groups tailor search and rescue operations for air disasters. Ships already designed for scientific data collection can easily be redeployed to help with critical sampling after major oil spills. These efforts save lives, allow for the continuation of commercial activities and the assessment of natural resource damages. In addition, crew members on NOAA vessels often perform relatively routine search and rescue activities as required by International Maritime law (International Convention on Maritime Search and Rescue, 1979**)** and provide relief supplies to affected populations during emergencies. These activities have saved many lives over the course of the fleet's history.

The ability of the fleet to respond to emergencies also can result in cost savings for U.S. taxpayers. NOAA vessels have unique technologies and are staffed with scientists and engineers with expertise in hydrographic and scientific data collection, which accounts for a large majority of response activities. In addition, NOAA ships are typically relatively easy to reroute with minimal impact to normal program activities. As a result of these factors, and combined with their availability across a wide geographic area, NOAA fleet vessels can often provide superior, more cost-effective and timely response capabilities compared with other potential responders.

The benefits associated with emergency response by NOAA vessels can vary significantly depending on the nature and extent of the emergency or disaster. However, the fleet's unique capabilities (particularly related to hydrographic surveying), geographic distribution, and skilled crewmembers contribute to its' key role as part of the U.S. emergency response network.

Figure A.15 depicts the value chain associated with the NOAA fleet emergency response activities.

[291] Foxx, A., Perez, T. and Pritzker, P. (2016, March 7). *U.S. Ports: Investing in Engines of Economic Development and American Competitiveness* [U.S. Department of Transportation Blog]. p.1. Retrieved March 14, 2017 from https://www.commerce.gov/news/blog/2016/03/us-ports-investing-engines-economic-development-and-american-competitiveness. Statistics available at North American Transportation Statistics at http://nats.sct.gob.mx/go-to-tables/table-7-international-merchandise-trade/table-7-1-international-merchandise-trade-by-mode/

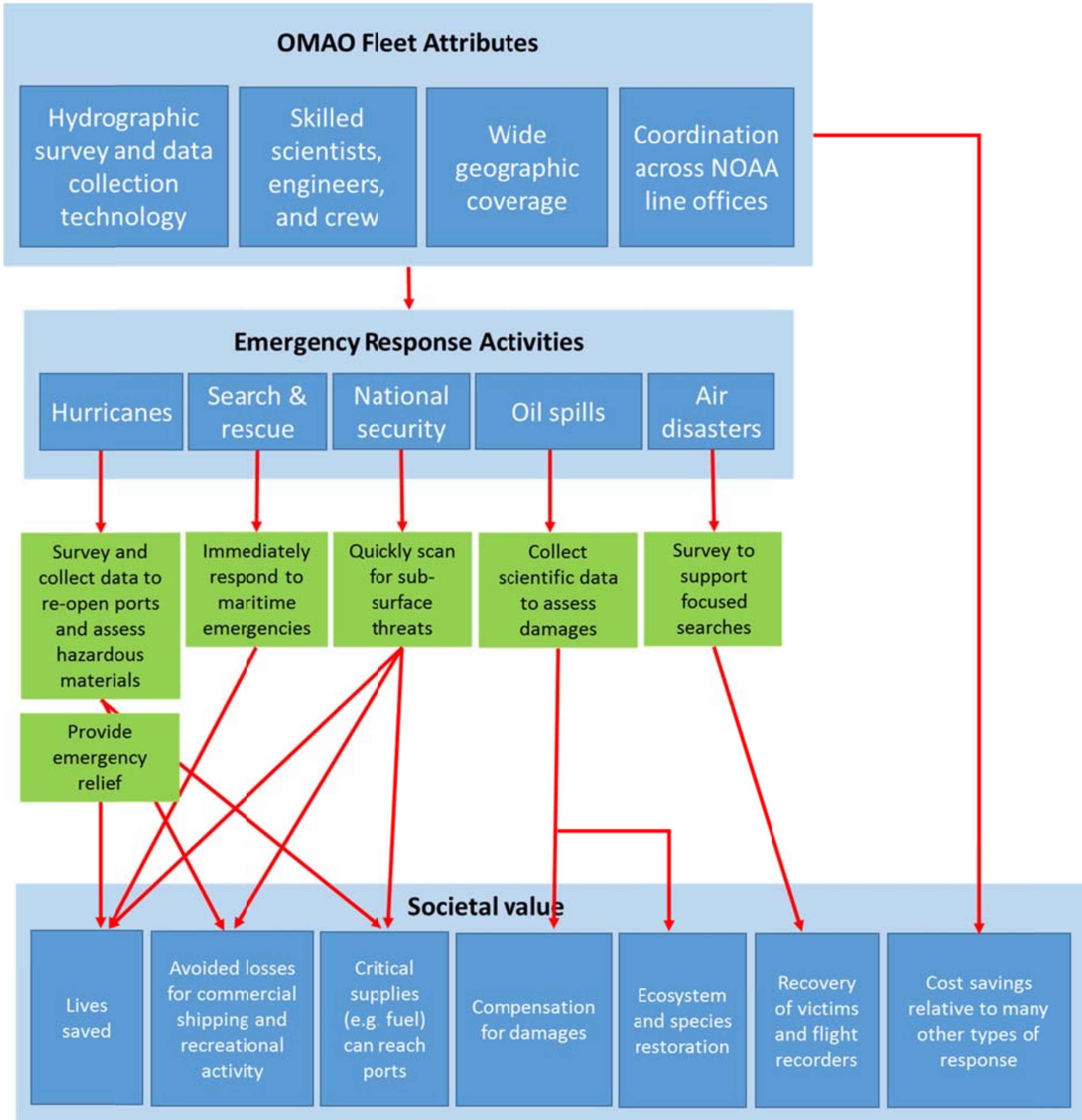

Figure A.15. NOAA Fleet Value Chain: Emergency Response Activities

Appendix B: Efficiency and Effectiveness of Using Contract Vessels

1. Introduction

This appendix provides the detailed analysis supporting the discussion in Section 4 of the main body of this report, which addresses the cost-effectiveness of using contract vessels as a substitute for NOAA's marine fleet for certain data collection activities. This analysis includes several case studies that compare the marginal cost of using the existing capacity of NOAA's fleet to the cost of using contract vessels. As a basis for analysis, it uses cost data for the NOAA fleet for fiscal year 2015, the most recent year for which complete cost data were available at the outset of this project. It also relies on cost data from NOAA's recent contracts with contract vessel providers, as well as information, both quantitative and qualitative, from interviews with NOAA subject matter experts and contract vessel providers, both private and public sector.

This appendix is organized as follows:

- Section 2 presents data on the marginal cost of using the NOAA fleet
- Section 3 discusses NOAA's current use of contract vessels, including the aggregate cost of this usage
- Section 4 presents several case studies that compare the cost of using NOAA ships to contract vessel substitutes for specific example missions
- Section 5 discusses factors other than cost-effectiveness that can affect the decision between using NOAA's fleet and contract vessels, including the capacity and availability of such vessels.
- Section 4 in the main body of this report summarizes the results of the analysis.

Note that this Appendix repeats certain narrative and exhibits from the summary in Section 4 of the main body of the report. This repetition is so that readers can see the information presented in context with the complete supporting details without needing to refer back to Section 4.

2. Marginal Cost of Using the NOAA Fleet

The purpose of this analysis is to compare the marginal cost of operating the NOAA fleet to the cost of using contract vessels to accomplish the same goals. Underlying this comparison is the assumption that NOAA will not make dramatic changes to the overall mix of contract versus fleet ship time employed or radically alter the composition of its fleet in the immediate future. In other words, the assumption is that substitutions take place at the margins.

Given this assumption, it is not appropriate to account for the entire budget associated with NOAA's marine operations in the comparison. Some elements of the budget (e.g., fixed maintenance costs, certain support and management costs) are not reduced when NOAA fleet missions are accomplished using contract vessels. Some of these fixed costs would be reduced only by extreme substitution to the extent of eliminating one or more ships from the NOAA fleet. Other fixed costs would still be required even in a hypothetical scenario where the NOAA fleet were completely replaced by contract vessels. These costs are associated with functions (e.g., safety and compliance) that would be required regardless of which vessels NOAA uses to acquire ocean observations.

Because the costs derived here reflect variable costs only, they are not comparable to costs for the NOAA fleet reported in certain other sources. For example, costs developed for the NOAA Fleet Recapitalization Team[292] cover the total cost of all of the Office of Marine and Aviation Operations' (OMAO's) observing systems, including fixed costs.

To identify the appropriate variable costs, this analysis relies on a document provided by OMAO entitled "Proposal to Document 100% of OMAO Ship Lifecycle Costs".[293] This document identifies and categorizes the costs involved in operating the fleet. For those costs that are not directly attributable to a specific ship, it recommends a method of allocation. This analysis uses the recommended method of allocation to further categorize costs as variable or fixed. The variable costs appropriate for use in this analysis include:

- ***Variable direct costs***: direct operating and maintenance costs are those specifically attributable to a given ship. Variable direct costs are those that are proportional to level of effort and include, for example, fuel, supplies, and wages for personnel operating the ship.

- ***Variable indirect costs***: although not specifically attributable to a given ship, these costs can be allocated across the fleet in a manner that is proportional to direct operating costs. Therefore, they can be considered proportional to the level of effort expended and part of the marginal operating cost. They include, for example, engineering support costs, which are not directly attributed to a particular ship, but are proportional to the level of maintenance required to keep a ship operational.

The costs used in this analysis do not include:

- ***Fixed indirect costs:*** like variable indirect costs, these costs are not specifically attributable to a given ship. Although fixed indirect costs can be allocated across the fleet, the recommended method of allocation (e.g., dividing evenly by the number of ships) is not proportional to operating costs. Therefore, unlike variable indirect costs, fixed indirect costs are not proportional to the level of effort.

- ***Maintenance costs from the procurement, acquisition, and construction (PAC) account:*** although these costs are directly attributable by ship, they are fixed costs (i.e., not proportional to level of effort) based on information provided by OMAO's Office of the Chief Financial Officer.[294]

- ***Sunk capital costs or depreciation costs:*** these costs reflect the initial acquisition cost of the existing fleet. Because these costs have already been expended, they cannot be reduced by substituting contract vessels.

[292] The NOAA Fleet Recapitalization Team was a team of senior subject matter experts from across NOAA established to summarize the relevant legal, policy and programmatic at-sea mission needs to describe the NOAA Fleet core capabilities to support NOAA's missions. The Team documented the extent to which these needs are currently addressed and describe the capability gap that will exist absent fleet recapitalization. The Team developed a Fleet Plan, sequencing the planned end of service life of current vessels, and acquisition of new vessels (to include all phases of acquisition).
[293] Draft, July 29, 2013.
[294] E-mail communication with Linda Malinoff, OMAO Office of Chief Financial Officer. January 19, 2017.

- ***New ship acquisition costs:*** these costs are for acquisition of new ships and, therefore, not allocable to the existing fleet.

Exhibit B - 1 provides a more detailed listing of the specific costs included and excluded from this analysis. Given this categorization, OMAO's Office of the Chief Financial Officer provided data for fiscal year 2015 for each of the costs to be included.[295] This analysis focused on fiscal year 2015 because it is the most recent year for which complete cost data were available at the outset of the project. After allocating the variable indirect costs according to the methods recommended in **Exhibit B - 1**, **Exhibit B - 2** shows the variable (or marginal) operating cost for the each ship in the NOAA fleet for fiscal year 2015.

[295] "OMAO Ship Cost Effectiveness Combined Submission_022317.xlsx." Spreadsheet received via e-mail from Linda Mallinoff, OMAO Office of Chief Financial Officer. February 23, 2017.

Exhibit B - 1: Categorization and Allocation of Operating and Maintenance Costs

	Cost	Method of Allocation[a]
Proportional to Level of Effort / Included in this Analysis	***Variable Direct Costs:***	
	Ship Variable Operations (overtime, fuel, ready/provisioning costs)	Directly attributable by ship
	Wage Marine Salaries and Benefits	
	Maintenance (ORF)	
	Salaries and benefits for NOAA Corps officers assigned directly to ships	
	Construction Work-In-Progress (CWIP)	
	Variable Indirect Costs:	
	MOC: Resource Management Branch	Proportional to variable operations cost
	MOC: Engineering	Proportional to maintenance cost
	MOC: Marine Personnel Branch	Proportional to ship authorized complement (i.e., permanent crew)
	MOC: Relief Pool/Augmentation Indirect	
	CPC: general operating budget	Proportional to NOAA Corps salaries and benefits by ship
Not Proportional to Level of Effort / Not Included in this Analysis	MOC: Director's Staff	Divide evenly by the number of ships
	MOC: Safety, Training, and Environmental Compliance	
	CPC: Salaries and benefits for NOAA Corps officers assigned to MOC Shoreside billets	
	CPC: Salaries and benefits for NOAA Corps officers assigned to OMAO HQ[b]	
	OMAO HQ Divisions other than Platform Acquisition	
	MOC: Atlantic Commanding Officer, Operations, and Health Services	Divide evenly by the number of ships assigned to given ports
	MOC: Pacific Commanding Officer, Operations, and Health Services	
	MOC: Port Offices	
	CPC: Salaries and benefits for NOAA Corps officers assigned to other line offices	Not allocable to fleet
	Maintenance (PAC)	Not proportional to level of effort
	Sunk capital or depreciation costs	Already expended and not reduced by substitution
	New ship acquisition costs	Not allocable to existing fleet
	OMAO HQ: Platform Acquisition Division	

a. Per "Proposal to Document 100% of OMAO Ship Lifecycle Costs," Draft, July 29, 2013.
b. Some officers are assigned directly to CPC. In theory, the salaries and benefits for these officers could be allocated in the same manner as the CPC general operating budget. Data are not available, however, to differentiate salaries and benefits for these officers from the total for those assigned to OMAO HQ.

Acronyms and Abbreviations: CPC = Commissioned Personnel Center; MOC = Marine Operations Center; OMAO HQ = Office of Marine and Aviation Operations Headquarters; ORF = Operations, Research, and Facilities; PAC = Procurement, Acquisition, and Construction

Exhibit B - 2: Fiscal Year 2015 Marginal Cost of Using the NOAA Fleet

Ship	2015 Days at Sea	Variable Direct Cost		Variable Direct Plus Variable Indirect Cost	
		Total ($)	$/Day at Sea	Total ($)	$/Day at Sea
Bell M. Shimada	190	7,251,994	38,168	8,803,356	46,333
Fairweather	136	6,640,315	48,826	8,027,114	59,023
Ferdinand R. Hassler	203	4,225,987	20,818	5,180,034	25,517
Gordon Gunter	175	5,192,584	29,672	6,290,749	35,947
Henry B. Bigelow	172	5,229,886	30,406	6,151,592	35,765
Hi'ialakai	202	5,350,602	26,488	6,332,617	31,350
Nancy Foster	166	4,434,007	26,711	5,345,956	32,205
Okeanos Explorer	168	7,956,552	47,360	9,722,189	57,870
Oregon II	191	4,195,047	21,964	5,079,373	26,594
Oscar Dyson	192	7,122,348	37,096	8,538,806	44,473
Oscar Elton Sette	145	4,449,664	30,687	5,366,281	37,009
Pisces	131	5,110,911	39,015	6,169,307	47,094
Rainier	141	6,639,398	47,088	8,100,746	57,452
Ronald H. Brown	233	7,074,440	30,362	8,427,715	36,170
Reuben Lasker	80	4,053,373	50,667	4,754,080	59,426
Thomas Jefferson	119	5,143,833	43,225	6,278,611	52,761
TOTAL	2,644	90,070,940	34,066	108,568,526	41,062

Note: Because the totals presented here only include those costs that are proportional to level of effort, they are not comparable to costs derived elsewhere (e.g., for the NOAA Fleet Recapitalization Team), which cover the total cost of all OMAO observing systems, including fixed costs

3. Aggregate Cost of Using Contract Vessels

NOAA currently uses contract vessels to support a variety of operations. Examples include fisheries surveys and deployment and maintenance of buoys. Vessels employed by NOAA also include research vessels, both public sector and privately owned, for scientific data collection. NOAA also uses vessels from partner federal agencies, including the U.S. Coast Guard and the National Science Foundation. In some cases, this usage is a no-cost exchange of ship time. In other cases, NOAA reimburses the partner agency.[296,297]

As an overview of the extent of NOAA's use of contract vessels, this section presents data collected to inform the NOAA Fleet Independent Review Team.[298] These data represent the best information available from OMAO's databases associated with NOAA's use of contract vessels. These data do not include no-cost exchanges of ship time with partner agencies. **Exhibit B - 3** shows data on the use of contract vessels for fiscal year 2015.[299] Note that the total days at sea for contract vessels (2,736.5) is approximately equal to the total fiscal year 2015 days at sea for the NOAA fleet (2,644, as shown in **Exhibit B - 2**).

Exhibit B - 3: Fiscal Year 2015 NOAA Use of Contract Vessels

Program	2015 Days at Sea[a]		Cost	
	Days	% of Total	Dollars	% of Total
NMFS	1,598	58%	13,231,360	30%
NOS Hydrographic Services[b]	610	22%	19,804,427	45%
Other NOS Programs	35.5	1%	278,000	<1%
NWS	286	10%	6,854,000	15%
OAR	198	7%	3,841,852	9%
NESDIS	9	<1%	257,300	<1%
TOTAL	2,736.5	100%	44,266,939	100%

a. Does not include no-cost exchanges of days at sea with partner agencies.
b. Days at sea for hydrographic services estimated assuming 2 nautical square miles surveyed per day at sea.
c. Acronyms and Abbreviations: NESDIS = National Environmental Satellite, Data, and Information Service; NMFS = National Marine Fisheries Service; NOS = National Ocean Service; NWS = National Weather Service; OAR = Oceanic and Atmospheric Research

Exhibit B - 4 shows the same fiscal year 2015 data as **Exhibit B - 3** in comparison to equivalent data for fiscal year 2014 and planned data for fiscal year 2016. As shown in Exhibit B- 4, NOAA's use of contract vessels has remained fairly stable during the last few years. Days at sea have varied by 11 percent or less from year to year and spending has changed by 16 percent or less.

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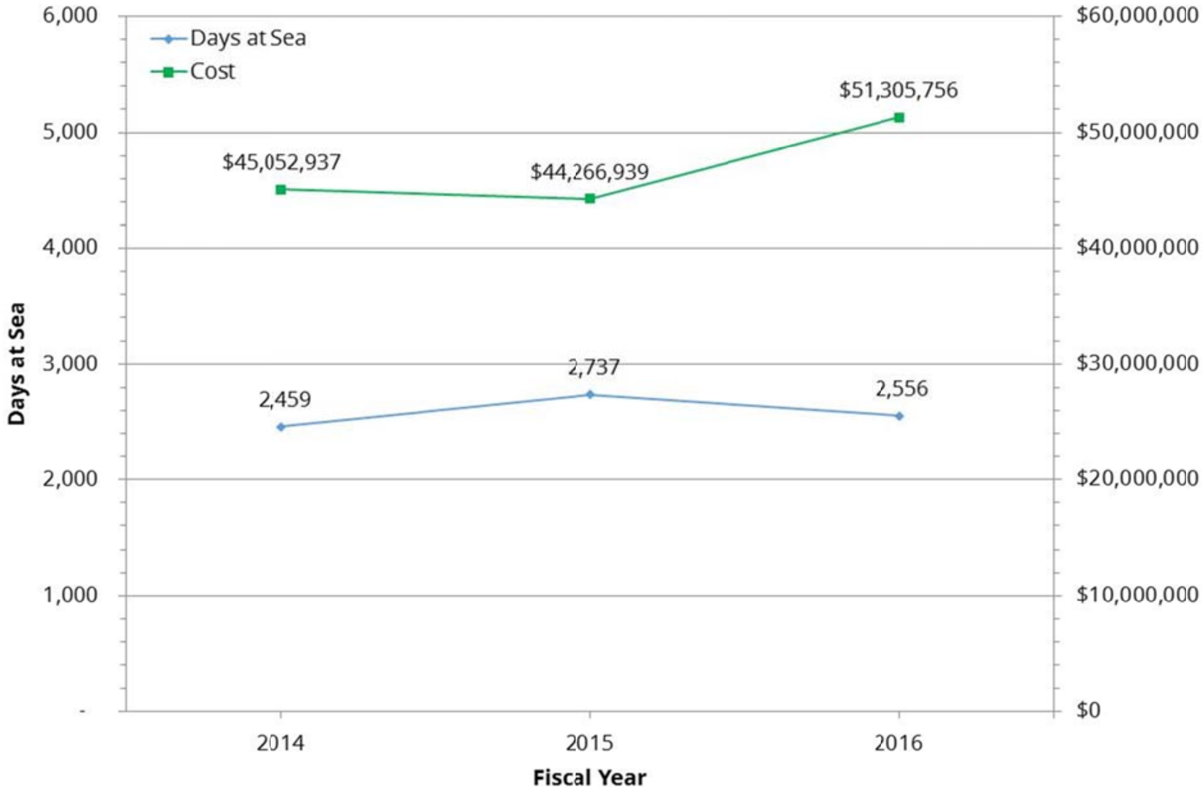
[296] NOAA. 2016. *The NOAA Fleet Plan: Building NOAA's 21st Century Fleet.* V3.1. NOAA Internal Use Only – Pre-decisional. October 4.
[297] O'Clock, Bill. 2016. "Charters." Presentation at NOAA Fleet Independent Review Team Meeting and Supporting Spreadsheets. Office of Marine and Aviation Operations. May 10.
[298] The NOAA Fleet Independent Review Team (IRT) was a senior-level team of outside experts established to assess the health of the NOAA Fleet of research vessels, requirements for recapitalization, and analysis of operational, maintenance practices and technology infusion. The IRT considered the compelling data-collection requirements that need access to the oceans; the applicable technologies and how they change the requirements; the appropriate fleet size and composition to meet needs; and best approaches to meet this need.
[299] O'Clock, Bill. 2016. "Charters." Presentation at NOAA Fleet Independent Review Team Meeting and Supporting Spreadsheets. Office of Marine and Aviation Operations. May 10.

Exhibit B - 4: Use of Contract Vessels over Time



Source: O'Clock (2016)
Notes: Does not include no-cost exchanges of days at sea with partner agencies
2014 and 2015 data are actual; 2016 data are planned.

It might be tempting to use the aggregate data on NOAA's use of contract vessels in **Exhibit B - 3** to calculate an average cost per day at sea for comparison to the cost of the NOAA fleet presented in Section 2. Such a comparison, however, would not be complete or accurate. Specifically, the contract vessel costs presented here are contract costs only. Some contracts cover "bare boat" costs only, while others encompass a more complete scope of support for the mission (e.g., fuel, crew to operate deck equipment supporting the mission). Even when the contract covers more than "bare boat" costs, there can be other costs associated with the use of contract vessels that are not reflected in the contract price. Examples of these additional costs can include: costs for provisions for NOAA staff aboard the contract vessel, mobilization and demobilization of NOAA staff and equipment, and calibration of instruments used aboard the contract vessel. On the other hand, some contracts encompass other services in addition to use of vessels. In particular, NOAA contracts for hydrographic surveys are structured as data buys that purchase a quantity of data instead of a number of days at sea. In addition to providing ship time to collect the data, the contractor also provides quality assurance/quality control and data processing and formatting according to detailed specifications.[300]

Furthermore, the aggregate data presented here reflect a wide range of contract vessels of differing types and with differing capabilities. Due to these differences, data collected from USAspending.gov and interviews with contract vessel providers[301] show that unit costs (i.e., dollars per day at sea) can vary by an order of magnitude. Therefore, an average calculated from the aggregate data is not necessarily representative, particularly for contract vessels that might be the most effective substitutes for NOAA ships. Factors that must be considered in comparing unit costs for NOAA ships and contract vessels include the following:

[300] NOAA. 2016. *NOS Hydrographic Surveys: Specifications and Deliverables*. Office of Coast Survey, National Ocean Service, NOAA, U.S. Department of Commerce. March.
[301] See Section 5 for discussion of these data sources.

- A day at sea aboard a contract vessel is not necessarily equal to a day at sea aboard a NOAA vessel. NOAA ships often collect multiple data streams and/or conduct multiple missions simultaneously. Although some contract vessels, such as certain University National Oceanographic Laboratory System (UNOLS) ships,[302] have similar multi-data stream/multi-mission capabilities, many vessels are better suited for individual projects and a more limited set of data. These "economies of scope" mean that multiple contract vessels can sometimes be required to replace the output of a NOAA vessel. In addition, NOAA uses NOAA ships for advancing technology through testing new equipment and procedures, maintaining and building expertise within the science field and marine operations.

- NOAA ships have greater endurance than many smaller contract vessels. Therefore, they can remain at sea for the duration of long projects without returning to port. In addition, NOAA ships often can be scheduled and positioned to transition directly from one project to the next without significant travel time. Both of these factors mean that the use of contract vessels can, in some cases, entail more transit days (i.e., at the start and finish of the discrete projects for which they are hired and, in some cases, to resupply during longer projects).

- Contract vessels used for missions with NOAA personnel aboard must meet certain safety standards. The aggregate data in **Exhibit B - 3** include missions without NOAA crew aboard. The vessels used for these missions might not meet these standards and, therefore, not be comparable to NOAA ships. Section 5 includes a more detailed discussion of safety standards.

- Conversely, some contract vessels provide services that the NOAA fleet cannot (e.g., data collection in shallow waters). The aggregate data in **Exhibit B - 3** include such missions.

Given these factors, unit costs calculated from aggregate data are not an appropriate basis for comparing cost-effectiveness. Instead, the comparison must account for mission-specific details. Section 4 uses a case study approach to compare cost-effectiveness while accounting for such details.

[302] NOAA's use of UNOLS ships includes both no-cost exchange of ship time and cases where NOAA pays the institution operating the UNOLS ship in a manner similar to a commercial charter.

4. Cost-Effectiveness Case Studies

This section examines cost-effectiveness on a mission-specific basis using selected case studies. These case studies attempt to account for the factors discussed in Section 3 and provide a one-to-one comparison of contract vessel costs to NOAA fleet costs. These four case studies were identified during discussions with NOAA subject matter experts. Additional data used in the case studies includes interviews with contract vessel providers (see Section 5), data for individual contracts downloaded from USAspending.gov, price index data from the U.S. Bureau of Labor Statistics (BLS), and the marginal cost of using specific NOAA ships estimated in Section 2.

The four case studies reflect missions that support three different NOAA line offices. The first two case studies are of missions supporting the National Weather Service (NWS) and National Marine Fisheries Service (NMFS), respectively, which are the two line offices that account for the greatest amount of spending on contract vessels other than contract data buys for hydrographic surveys (see **Exhibit B - 3**). The other two case studies are of missions supporting the National Ocean Service (NOS). Each of the cases studies involves a different NOAA vessel. Three of the four case studies (Sections 4.1, 4.3, and 4.4) are of missions that support NOAA products and services for which the main body of this report describes societal benefits.

4.1 Tropical Atmosphere Ocean (TAO) Array Maintenance

Mission Description: The Tropical Atmosphere Ocean (TAO) array consists of 70 buoys moored ("moorings") in the tropical Pacific Ocean that collect oceanographic and meteorological data. Each of the moorings collects data from just above, at, and below the ocean surface and transmits these data in real-time via satellite.[303,304] The data collected support a number of NOAA products and services, including the El Nino Southern Oscillation Outlook, a product for which the main body of this report describes societal benefits. Many other U.S. and international organizations also use TAO observations.[305]

The NWS National Data Buoy Center (NDBC) uses vessels to service the TAO array by performing necessary maintenance including repairing any damage caused by biological activity or local fishermen.[306] Prior to 2012, NDBC relied on the NOAA ship *Ka'imimoana* to maintain the array. After the *Ka'imimoana* was removed from service in 2012, data availability from the TAO array suffered, dropping to as low as 28 percent in March 2014.[307] Since then, NDBC has used a combination of the NOAA ship *Ronald H. Brown*, UNOLS ships, and commercial contract vessels to service the array and maintain data availability above the 80 percent target performance level.[308,309] Cruises to maintain the TAO array also routinely support the deployment of Argo profiling floats for the Pacific Marine Environmental Laboratory and surface drifting floats for the Atlantic Oceanographic and Meteorological Laboratory (both part of NOAA's Office of Oceanic and Atmospheric Research).[310]

In conjunction with the maintenance, TAO cruises also sometimes incorporate scientific research that is directly related to operating the array. Such research includes meteorological and ocean observations during the maintenance operations, as well as while the vessel is underway to/from and within the cruise track, to validate the sensors on the moorings. Research also includes testing and evaluation of new sensors, systems and, technologies that could ultimately refresh,

[303] "Project: Tropical Atmosphere Ocean Buoy Service." NOAA Office of Marine and Aviation Operations. Available at: http://www.omao.noaa.gov/find/projects/3418-tropical-atmosphere-ocean-buoy-service. Accessed March 8, 2017.
[304] E-mail and personal communication with Kathleen O'Neil, National Weather Service, National Data Buoy Center. January 10 and 12, 2017.
[305] Ibid.
[306] Ibid.
[307] "*NDBC – TAO Performance Continues to Improve*." NOAA National Data Buoy Center. Available at: http://www.ndbc.noaa.gov/tao-performance-continues-to-improve.shtml. Page last modified August 5, 2014.
[308] "NOAA TAO Equatorial Pacific Ocean Data Availability Exceeds Targets." Global Ocean Observing System. Available at: http://goosocean.org/index.php?option=com_content&view=article&id=27:noaa-tao&catid=13&Itemid=247. Published March 23, 2015.
[309] E-mail and personal communication with Kathleen O'Neil, National Weather Service, National Data Buoy Center. January 10 and 12, 2017.
[310] "TAO Cruise Information: reports of activities." National Data Buoy Center. Available at: http://tao.ndbc.noaa.gov/refreshed/taoCruiseInfo.php?hist=true. Accessed April 26, 2017.

upgrade, and/or replace the legacy moorings. In a typical year, NDBC requires that at least some of the TAO maintenance cruises incorporate this type of research.[311]

Mission Requirements: NDBC usually requires about 160 days at sea each year to support TAO servicing, typically using four discrete cruises of 40 days each, including transit.[312] In a typical year, these cruises include some that accomplish maintenance only and some that also incorporate related scientific research. Therefore, this case study examines a typical 40-day cruise, given two different scenarios:

1. The cruise includes routine maintenance and servicing of the TAO array, along with deployment of Argo and surface drifting floats.
2. The cruise incorporates related supplemental science in addition to TAO maintenance and float deployment.

Under either scenario, the vessel used to support the mission must provide the following:

- Global class endurance, capable of operating for 40 days at sea, including 10 days of transit time into the project area and 10 days of transit out of the project area.[313]
- Accommodations and provisions for a NOAA scientific team of three to five people.
- Heavy lift capability and large (400 square feet) adjacent deck space for handling the buoys, moorings, and anchors.
- Stowage for the deep-sea mooring components, buoys, and bridles (2,000 square feet and 100,000 pounds).
- Access to, and support in launching and recovering, one small work boat capable of carrying four passengers.
- Fuel for the voyage.
- Personnel to run the ship, navigate, and operate deck equipment.

Under the second scenario including related supplemental science, the vessel must also provide the following:[314]

- On-board equipment including: real-time data acquisition and processing system, fathometer or multi-beam sonar with a maximum depth of 6,000 meters, salinometer, thermosalinograph, hull-mounted acoustic doppler current profiler with altitude control, dry lab, and dedicated chamber for conducting salinity measurements.
- Additional stowage for additional equipment supplied by NOAA including: conductivity, temperature, and depth (CTD) rosette, associated recording and processing system, and additional electronics (total 350 square feet and 3,200 pounds).
- Equipment and personnel support for deployment and handling of the CTD rosette, salinometer, and thermosalinograph.

NOAA Ship Cost: The NOAA ship *Ronald H. Brown* can supply the requirements described above under either scenario (although she is better equipped than necessary for the first scenario involving TAO maintenance and float deployment only). For example, in fiscal year 2015, NDBC used approximately 80 days at sea on the *Ronald H. Brown* for TAO array maintenance.[315] At the marginal cost of $36,170 per day estimated in Section 2, the cost of using the *Ronald H. Brown* for a typical 40-day TAO cruise under either scenario is $1,446,800.

Cost of Contract Vessel Substitute: NDBC has access to several commercial vessels that perform mooring maintenance (including TAO and other buoy systems) through its marine services basic ordering agreements. In fiscal year 2015, NDBC used one of these commercial vessels for TAO maintenance for 9 days at sea at a cost of $215,000, or $23,889 per day.[316] Using this same cost per day, the cost of using a commercial contract vessel to substitute for the *Ronald H. Brown* on a typical 40-day TAO cruise would be $955,560. This cost, however, only covers supplying the requirements for the

[311] E-mail and personal communication with Kathleen O'Neil, National Weather Service, National Data Buoy Center. January 10 and 12, 2017.
[312] Ibid.
[313] These operational and transit days are as recommended by the NDBC subject matter expert for a typical TAO cruise, regardless of the provider used (NOAA ship or charter vessel).
[314] For example, see Ship Time Request for Tropical Atmosphere Ocean (TAO) Array RHB1 (subset of TAO 2015 O&M Primary request). May 9, 2014.
[315] E-mail communication with Kathleen O'Neil, National Weather Service, National Data Buoy Center. January 18, 2017.
[316] E-mail communication with Kathleen O'Neil, National Weather Service, National Data Buoy Center. January 18, 2017.

first scenario involving TAO maintenance and float deployment. It does not cover a vessel equipped to supply the requirements of the second scenario that includes related supplemental science.

To substitute for the *Ronald H. Brown* in the second scenario would require the use of a UNOLS ship, such as the R/V *Thomas G. Thompson* or R/V *Roger Revelle*, which are equipped to collect the underway ocean observations and support the related supplemental science.[317,318] In fiscal year 2015, NDBC used a UNOLS vessel for TAO maintenance for 40 days at sea at a cost of $1.71 million, or $42,750 per day.[319,320] This cost would cover supplying the requirements discussed above for the second scenario.[321]

Discussion: Exhibit B – 5 compares the costs for a typical 40-day TAO cruise (including transit time) under the two scenarios discussed above. Under the first scenario, where the cruise only includes TAO maintenance and deployment of Argo and surface drifting floats, a commercial contract vessel is the less costly than the *Ronald H. Brown*. In the second scenario where additional equipment and support are required to complete scientific research that is directly related to operating the array, the marginal cost of using the *Ronald H. Brown* is 15 percent less than an appropriately equipped substitute in the form of a UNOLS vessel.

Exhibit B - 5: Cost-Effectiveness Comparison for Typical 40-Day Cruise Servicing the TAO Array

Scenario	Vessel Used	Cost ($)
Routine maintenance and float deployment only	Commercial contract vessel	955,560
	NOAA ship	1,446,800
Maintenance, float deployment, and related supplemental science	NOAA ship	1,446,800
	UNOLS ship	1,710,000

Notes:
- Commercial contract vessel and UNOLS ship cost based on 40 days at sea using the fiscal year 2015 data from NDBC described in the text.
- NOAA ship cost based on 40 days at sea using the *Ronald H. Brown* at the marginal cost estimated in Section 2.

[317] E-mail and personal communication with Kathleen O'Neil, National Weather Service, National Data Buoy Center. January 10 and 12, 2017.
[318] Personal communication with Doug Russell, University of Washington and UNOLS Vessel R/V *Thomas G. Thompson*. February 23, 2017. See Appendix C for interview notes.
[319] This rate is slightly higher than approximate rate identified in the interview conducted with the captain of the *Thomas G. Thompson* (see Appendix C). The cost-effectiveness analysis here uses the data from NDBC because it is in fiscal year 2015 dollars and reflects the rate paid by NOAA, instead of the rate received by the University of Washington. The difference may be due to costs involved in transferring the funds through the National Science Foundation.
[320] E-mail communication with Kathleen O'Neil, National Weather Service, National Data Buoy Center. January 18, 2017.
[321] An UNOLS vessel would also be capable of supplying the requirements of the first scenario (maintenance and float deployment only), but it is unclear whether or not there would be a reduced cost if NOAA did not employ the vessel's observational and scientific capabilities.

In addition to the differences in cost, there are differences in availability for the vessels suitable to provide services under each scenario. The approximately 80 days at sea on the *Ronald H. Brown* that NDBC was able to schedule in fiscal year 2015 is no longer typical since the *Ronald H. Brown* has returned to its Atlantic coast home port. She is scheduled for only 42 days at sea to support TAO servicing in fiscal year 2017, and this level of availability (or less) may be more typical in the future.[322]

As discussed above, NDBC accesses commercial vessels through marine services basic ordering agreements with several different vendors. Although the commercial vessels are not outfitted for research, NDBC prefers this mechanism in some cases due to ease of access and scheduling.[323] These agreements provide NDBC with access to at least six different global class vessels (and several smaller vessels). In addition to supporting NOAA mooring maintenance, the NDBC subject matter expert indicated that these commercial vessels also likely support other uses including the offshore oil and gas industry, offshore construction, and marine salvage. In spite of these competing uses, NDBC has not experienced any lack of availability with these vessels. In fact, NDBC has received multiple responses to support several mooring maintenance cruises for which it has issued requests for proposals (see Section 5 for further information in the typical number of bids received for NOAA's vessel contracts in general).[324]

As discussed in more detail in Section 5, scheduling UNOLS ships requires a long lead time (a year or more) and the Navy and National Science Foundation sometimes have higher priority in the scheduling process. The TAO cruises, however, also receive high priority in the UNOLS scheduling process because they are consistently funded from year-to-year. The R/V *Roger Revelle*, one of the two UNOLS ships NDBC has used for TAO servicing, is scheduled for mid-life maintenance during 2018, which will reduce her availability.[325]

4.2 California Current Cetacean and Ecosystem Assessment Survey (CalCurCEAS)

Mission Description: The California Current Cetacean and Ecosystem Assessment Survey (CalCurCEAS) was a multi-disciplinary expedition, conducted by the NMFS in 2014, with the primary purpose of estimating the abundance of cetacean species (whales, dolphins, and porpoises) in the California Current and studying factors that affect their distribution. Additional objectives included characterizing the ecosystem within the study area, research on mid-trophic level organisms (prey) and non-protected apex predators (sea birds), and identification of cetacean species of special interest. Operations conducted included: visual surveys, biopsy sampling, photography, opportunistic retrieval of marine mammal body parts and bird specimens, passive acoustic sampling to locate and record organisms, oceanography, and El Nino biological sampling.[326]

Mission Requirements: CalCurCEAS 2014 consisted of 117 days at sea in five legs, plus three days of staging and set up (total 120 days), with 15 or 16 scientific personnel aboard for each leg. The mission departed from and ultimately

[322] Ibid.
[323] E-mail and personal communication with Kathleen O'Neil, National Weather Service, National Data Buoy Center. January 10 and 12, 2017.
[324] E-mail communication with Kathleen O'Neil, National Weather Service, National Data Buoy Center. April 26, 2017.
[325] Personal communication with Doug Russell, University of Washington and UNOLS Vessel R/V *Thomas G. Thompson*. February 23, 2017. See Appendix C for interview notes.
[326] NOAA. 2014. *Cruise Instructions – California Current Cetacean and Ecosystem Assessment Survey: CalCurCEAS*. National Marine Fisheries Service, Southwest Fisheries Science Center. July 17.

returned to San Diego with additional port stops between legs in Newport, Oregon, and San Francisco. Requirements for the vessel used to support the mission were the following:[327]

- Capable of operating for up to 24 days at sea.
- Accommodations and provisions for a NOAA scientific team of up to 16 people.[328]
- Observation platform (e.g., flying bridge) with canopy for visual surveys.
- Access to, and support in launching and recovering, one small rigid inflatable hull boat.
- Hydrographic winch with minimum 2,500 meter cable for net tows.
- Lab space including freezer space for biological samples, refrigerator for cell culture, and fume hood.
- Stowage for equipment supplied by NOAA including: expendable bathythermograph (XBT) launcher and 18 boxes of probes, two bongo net frames, three pallets of sonobuoys (125 square feet and 1,200 pounds), two boxes of acoustics equipment, acoustic winch (36 square feet and 1,200 pounds), 75 cubic feet of sample jars, four boxes of mammal sampling equipment, five drifting autonomous spar buoy recorder (DASBR), and additional electronics.
- Additional on-board equipment including: depth sounder, hydraulic power and connections for winches, power and global positioning system (GPS) connections for NOAA computers, deck hose with water supply, and grappling hook and line.
- Fuel for the voyage.
- Personnel to run the ship, navigate, and operate deck equipment.

NOAA Ship Cost: CalCurCEAS 2014 was originally planned for the NOAA ship *Reuben Lasker*, which would have supplied the requirements described above.[329] In 2015 dollars, at the marginal cost of $59,426 per day estimated in Section 2, the cost of using the *Reuben Lasker* for 120 days (including three days of staging and set up) would have been $7,131,120.

Cost of Contract Vessel Substitute: When the *Reuben Lasker* did not come on line as scheduled, the expedition was instead conducted aboard the R/V *Ocean Starr*, a contract vessel.[330] The *Ocean Starr* was a formerly the NOAA ship *David Starr Jordan*, which was decommissioned and sold in 2010.[331] During CalCurCEAS 2014, the 171-foot research vessel was owned and operated by Ocean Services LLC, a subsidiary of Stabbert Maritime.[332,333] The *Ocean Starr* supplied all of the requirements described above for the cruise, including staging and ship setup, provisioning for the scientific personnel, and a crew willing to do everything asked of them to support the research.

Data from USAspending.gov show that, in fiscal year 2014, NOAA had three transactions with Ocean Services LLC for a west coast charter for a trawl capable vessel, totaling $2,343,280.[334] A NOAA subject matter expert confirmed that the cost of using the *Ocean Starr* for CalCurCEAS was approximately $2.4 million. To escalate this 2014 cost to 2015 dollars, we used the producer price index (PPI) for the water transportation industry – specifically, for North American Industry Classification System (NAICS) category 483.[335] Applying the annual average values for 2014 and 2015 for this

[327] Ibid.

[328] This count includes up to two oceanographic science technicians, who were included as part of the NOAA scientific team on the mission as conducted. As discussed below, these additional personnel would not have been required had a NOAA ship been employed.

[329] In addition, it would have required fewer NOAA personnel in addition to the *Reuben Lasker's* permanent crew. As discussed below, the cost estimate of the charter substitute has been adjusted to accounts for this difference.

[330] Personal communication with Annette Henry, National Marine Fisheries Service, Southwest Fisheries Science Center. December 15, 2016.

[331] "David Starr Jordan." Office of Marine and Aviation Operations. Available at: http://www.omao.noaa.gov/learn/marine-operations/ships/decommissioned/david-starr-jordan. Accessed March 7, 2017.

[332] NOAA. 2014. *Cruise Instructions – California Current Cetacean and Ecosystem Assessment Survey: CalCurCEAS*. National Marine Fisheries Service, Southwest Fisheries Science Center. July 17.

[333] "Ocean Starr." Stabbert Maritime. Available at: http://www.stabbertmaritime.com/vessels/ocean-starr/. Accessed March 7, 2017.

[334] Data downloaded for National Oceanic and Atmospheric Administration for fiscal year 2014 from https://www.usaspending.gov/DownloadCenter/Pages/DataDownload.aspx. Accessed December 20, 2016.

[335] Time series data downloaded for producer price index for NAICS category 483 from https://www.bls.gov/ppi/data.htm. Accessed March 7, 2017.

industry-specific index to the contract cost results in an escalated cost of $2,350,048.[336] Although this adjustment is small, it reflects the change between 2014 and 2015 in prices received by producers in the NAICS category to which Ocean Services LLC belongs, allowing a consistent basis for comparison to the 2015 data on the cost of the NOAA fleet.

The data collected aboard the *Ocean Starr* were the same as would have been collected aboard the *Reuben Lasker*. There were, however, certain trade-offs that included the following:[337]

1. The *Reuben Lasker* has its own dedicated oceanographic science technicians; the cruise as conducted aboard the *Ocean Starr* required additional oceanographic technicians among the NOAA personnel.

2. Small boat operations were acceptable aboard the *Ocean Starr*, but more difficult than they would have been aboard the *Reuben Lasker*, primarily due to crew training and familiarity.

3. The *Reuben Lasker* is quieter, so passive acoustic data collection would probably have been improved due to less noise interference.[338]

4. The *Ocean Starr* is more maneuverable and the bow deck is closer to the water; these factors improved NOAA's ability to collect biopsy samples from animals near the bow.[339]

To account for the labor-related differences identified in items (1) and (2) above, we adjusted the estimated cost of using the *Ocean Starr* as discussed below. Data are not available to monetize the data collection/data quality differences identified in the other items. Because there are advantages to each ship, these latter items might offset one another to some extent.

The NOAA scientific team aboard the *Ocean Starr* for CalCurCEAS 2014 included one oceanographic technician. As noted in item (1) above, aboard the *Reuben Lasker*, the ship's existing complement of oceanographic science technician would have supplied this labor, the cost of which is included in the marginal cost for the *Reuben Lasker* estimated in Section 2. Therefore, in using the *Ocean Starr*, there was an additional labor cost to NOAA, over and above the contract cost. Data are not available on salary and benefits for the specific NOAA oceanographic technicians employed during CalCurCEAS 2014. To estimate the value of the additional NOAA labor, we used a rate of $503 per person-day. This rate reflects the average salary and benefits for fiscal year 2015 for crew serving aboard the NOAA fleet, calculated from the same data underlying the marginal cost estimates for the NOAA fleet in Section 2. Applying this average rate to the 120 person-days of additional NOAA oceanographic technician labor required aboard the *Ocean Starr*, results in an additional labor cost of $60,360.[340] Because this value is based on a 2015 labor rate, no escalation is required.

According to one NOAA subject matter expert, the difficulties with small boat operations aboard the *Ocean Starr* could have been alleviated by an additional contract deckhand. The subject matter expert estimated the cost of the additional deckhand would have been approximately $400 per day, based on an estimated salary of $200 to $250 per day and incorporating overhead and profit.[341] Applying this rate to 120 days at sea results in a labor cost of $48,000 in 2014 dollars.[342] Escalating this labor using the appropriate annual average employment cost index (ECI) increases the labor

[336] The annual average PPI for NAICS category 483 was 138.5 for 2014 and 138.9 for 2015. Applying these values to the contract cost results in the following calculation: $2,343,280 x 138.9/138.5 = $2,350,048.

[337] Personal communication with Annette Henry, National Marine Fisheries Service, Southwest Fisheries Science Center. December 15, 2016; and E-mail communication with Jeff Moore, National Marine Fisheries Service, Southwest Fisheries Science Center. February 15, 2017.

[338] Although not a requirement for CalCurCEAS 2014, the *Reuben Lasker* also has side-scanning sonar, which is often useful for mid-water detection.

[339] Note, however, that the *Reuben Lasker* does have observation decks of appropriate height.

[340] 120 person-days x $503/person-day = $60,360.

[341] Personal communication with Annette Henry, National Marine Fisheries Service, Southwest Fisheries Science Center. December 15, 2016

[342] 120 days x $400/day = $48,000.

cost to $48,946 in 2015 dollars.[343] Again, although this adjustment is small, it results in a consistent basis for comparison (2015 dollars).

Adding these labor adjustments to the escalated contract cost results in a total cost for using the *Ocean Starr* of $2,459,353 in 2015 dollars.[344] This estimated cost accounts for supplying all of the requirements discussed above.

Discussion: Exhibit B - 6 compares the cost of using the *Ocean Starr* for CalCurCEAS 2014 to the cost of using the *Reuben Lasker*. Even after accounting for the additional labor required to make the comparison equivalent, the cost of using the *Ocean Starr* for CalCurCEAS 2014 was much lower than the estimated cost of using the *Reuben Lasker*.

Exhibit B - 6: Cost-Effectiveness Comparison for CalCurCEAS 2014

Vessel Used	Cost ($)
Commercial contract vessel	2,459,353
NOAA ship	7,131,120

Notes:
- Contract vessel cost based on actual contract cost for the *Ocean Starr*, escalated to 2015 dollars and incorporating the additional labor costs described in the text.
- NOAA ship cost based on 120 days at sea using the *Reuben Lasker* at the marginal cost estimated in Section 2.

One explanation for the low cost of the *Ocean Starr* may be that she is nearing the end of her useful life and not being maintained for longevity, according to one NOAA subject matter expert.[345] The *Ocean Starr* was still in operation as of July 2016, however, when she completed a cruise supporting the California Cooperative Oceanic Fisheries Investigations program.[346] Ocean Services LLC did not respond to a request for an interview, so information about the vessel's future availability and price is not available.

Another explanation for the large difference in cost may be that the estimated fiscal year 2015 marginal costs may not be representative of normal operations for the *Reuben Lasker*. The vessel was at the start of her service life and only executed 80 days at sea. Although more recent cost data for the *Reuben Lasker* might show the difference to be less dramatic, they are unlikely to change the conclusion. The cost of the *Ocean Starr* for CalCurCEAS 2014 was less than 120 days at sea even aboard the NOAA ship with the lowest fiscal year 2015 marginal cost.

4.3 Sanctuary Ecosystem Assessment Surveys (SEAS): Greater Farallones and Cordell Banks National Marine Sanctuaries

Mission Description: The Sanctuary Ecosystem Assessment Surveys (SEAS) for the Greater Farallones and Cordell Banks National Marine Sanctuaries was a project for the NOS Office of National Marine Sanctuaries conducted in 2016. The two sanctuaries were undergoing an administrative process for expansion to the north. The SEAS project was designed to collect data to identify nearshore or offshore pressures, characterize sensitive resources, and support development of management plans and regulatory actions in conjunction with this expansion.[347] This type of data is the same as that which informs National Marine Sanctuary Condition Reports, a product for which the main body of this report describes societal benefits. Activities conducted during the SEAS project included bird and marine mammal

[343] This calculation uses the employment cost index (ECI) for total compensation for private industry workers in construction, extraction, farming, fishing, and forestry occupations downloaded from https://www.bls.gov/eci/data.htm, March 8, 2017. The annual average of this ECI was 121.8 for 2014 and 124.2 for 2015. Applying these values to the 2014 labor cost estimate results in the following calculation: $48,000 x 124.2/121.8 = $48,946

[344] $2,350,048 contract cost + $60,030 of additional NOAA labor + $48,946 of additional contract labor.

[345] E-mail communication with Michael Gallagher, National Marine Fisheries Service. February 9, 2017.

[346] "2017 Cruise Schedule." California Cooperative Oceanic Fisheries Investigations. Available at: http://calcofi.org/cruises/561-cruise-schedule.html. Accessed March 8, 2017.

[347] Ship Time Request for Sanctuary Ecosystem Assessment Surveys: GFNMS and CBNMS v3. January 12, 2015.

observation, acoustic monitoring, habitat characterization, launch and recovery of CTDs, krill sampling during nighttime vertical migration of zooplankton, and corresponding sampling during daylight.

Mission Requirements: The SEAS project consisted of nine days at sea, departing from and returning to San Francisco, traveling into the northern expansion areas of the sanctuaries, distant from the nearest port. Requirements for the vessel used to support the mission were the following:[348]

- Capable of operating for nine days at sea, remaining on station for day and night sampling.
- Accommodations and provisions for a NOAA scientific team of 10 people.
- Observation platform for bird and marine mammal observation.
- Hydrographic winch for CTD with secondary cable of 500 meters for net tows.
- Lab space including fume hood, refrigerator, and freezer.
- Stowage for equipment supplied by NOAA including: CTD, hoop net, tucker trawl net, and computer and monitors (total 69 square feet and 1,600 pounds).
- Additional on-board equipment including: depth sounder and power and global positioning system (GPS) connections for NOAA computers.
- Fuel for the voyage.
- Personnel to run the ship, navigate, and operate deck equipment.[349]

NOAA Ship Cost: The Greater Farallones and Cordell Banks sanctuaries share the use of the ONMS vessel, R/V *Fulmar* with the nearby Monterey Bay National Marine Sanctuary. The *Fulmar*, however, typically is limited to about 40 miles offshore and cruises of 10 hours in length.[350] She berths a maximum of six scientists overnight.[351] Therefore, the *Fulmar* was not capable of supplying the requirements discussed above, especially given the need to investigate the distant northern expansion areas.[352] To meet the mission requirements, the project was instead conducted during nine days at sea aboard the OMAO ship *Bell M. Shimada*.[353] In 2015 dollars, at the marginal cost of $46,333 per day estimated in Section 2, the cost of using the *Bell M. Shimada* for nine days is $416,997.

Cost of Contract Vessel Substitute: Commercial contract vessels available nearby share similar endurance and/or berthing limitations similar to the *Fulmar*, such that multiple vessels or trips would be required to substitute for the *Bell M. Shimada*.[354] More capable vessels are generally located a greater distance away. For example, the UNOLS fleet in California does not currently include a regional class vessel.[355] The transit time involved in bringing in a more capable vessel would be significant, particularly compared to the relatively short nine-day project duration.

Given the limitations and/or distance away of other options, a NOAA subject matter expert suggested that a vessel operated by the nearby Monterey Bay Aquarium Research Institute (MBARI) might be an efficient substitute if the *Bell M. Shimada* were not available.[356] MBARI is a private, non-profit research institution that operates several research

[348] Ship Time Request for Sanctuary Ecosystem Assessment Surveys: GFNMS and CBNMS v3. January 12, 2015.
[349] Although not part of the SEAS project as conducted in 2016 and examined in this case study, piggyback research conducted on this mission can include: ocean acidification studies and exploration for deep sea corals and sponges using an autonomous underwater vehicle, remotely operated underwater vehicle, or camera sled. Both the NOAA ship and the contract vessel substitute can accommodate these types of vessels, although the cost of supplying this requirement is not included in the cost estimates here.
[350] Personal communication with Jan Roletto, Research Coordinator at the Gulf of the Farallones National Marine Sanctuary. January 10, 2017.
[351] "MBNMS: R/V *Fulmar* Specifications." NOAA Monterey Bay National Marine Sanctuary. Available at: http://montereybay.noaa.gov/marineops/about/fulmar/specifications.html. Accessed March 8, 2017.
[352] Ship Time Request for Sanctuary Ecosystem Assessment Surveys: GFNMS and CBNMS v3. January 12, 2015.
[353] "Project: Sanctuary Ecosystem Assessment Surveys (GFNMS and CBNMS)." NOAA Office of Marine and Aviation Operations. Available at: http://www.omao.noaa.gov/find/projects/3499-sanctuary-ecosystem-assessment-surveys-gfnms-and-cbnms. Accessed March 8, 2017.
[354] Ship Time Request for Sanctuary Ecosystem Assessment Surveys: GFNMS and CBNMS v3. January 12, 2015.
[355] Sanctuary Advisory Council, Monterey Bay National Marine Sanctuary. Letter supporting a new coastal research vessel for California. December 8, 2016.
[356] Personal communication with Jan Roletto, Research Coordinator at the Gulf of the Farallones National Marine Sanctuary. January 10, 2017.

vessels, including the 117-foot R/V *Western Flyer*. MBARI's Director of Marine Operations confirmed that the requirements of the SEAS project as described above are within the *Western Flyer's* capabilities.[357]

MBARI's current rate for using the *Western Flyer* is $31,100 per day.[358] Although the website lists this rate as corresponding to a 12-hour day, the same rate would apply for extended voyages like that for the SEAS project.[359] The rate would also cover all of the other requirements described above (e.g., including provisioning for the NOAA science party aboard). Although MBARI is located close to Greater Farallones and Cordell Banks sanctuaries, one day of transit time would still be required at both ends of the project. One day in port would also be required at each end for mobilization and demobilization.[360] Therefore, using the *Western Flyer* would require a total of 13 days (11 at sea and two in port). Using MBARI's current rates, the total cost for 13 days of using the *Western Flyer* would be $404,300.[361]

Discussion: Exhibit B - 7 compares the cost of using the *Western Flyer* as a substitute for the *Bell M. Shimada* for the SEAS project. Even with the additional days required to complete the mission, the *Western Flyer* would be slightly less costly (3 percent) than the *Bell M. Shimada*.

Exhibit B - 7: Cost-Effectiveness Comparison for SEAS: Greater Farallones and Cordell Banks National Marine Sanctuaries 2016

Vessel Used	Cost ($)
MBARI ship	404,300
NOAA ship	416,997

Notes:
- MBARI ship cost assumes 13 days to accomplish the mission at MBARI's current rates for the *Western Flyer*.
- NOAA ship cost assumes nine days at sea to accomplish the mission using the *Bell M. Shimada* at the marginal cost estimated in Section 2.

Although the results for this case study show the MBARI ship to be slightly more cost-effective, it is important to note that MBARI is not a commercial provider and does not actively seek out research assignments for its vessels from other organizations. MBARI does collaborate with staff from NOAA's Monterey Bay National Marine Sanctuary, who sometimes conduct piggyback research on MBARI vessels. The Institute has conducted two dedicated cruises for NOAA in the last decade, but usually only considers such missions on case-by-case basis, such as when the capabilities provided by MBARI not available elsewhere in the NOAA or academic fleet. Scheduling an MBARI ship would also require substantial lead time: approximately a year to guarantee availability for longer missions.[362]

In addition, budgetary constraints limit individual sanctuaries' options with regard to the use of contract vessels. When a sanctuary program receives ship time on the NOAA fleet, such as on the *Bell M. Shimada* for the SEAS project, that

[357] E-mail communication with Michael Kelly, Director of Marine Operations, Monterey Bay Aquarium Research Institute. March 6, 2017.
[358] "MBARI: Rates for Vessels, Vehicles, MARS, Labor, Test Tank." Monterey Bay Aquarium Research Institute. Available at: http://www.mbari.org/at-sea/mars-ship-rates/. Accessed March 2, 2017.
[359] Personal communication with Michael Kelly, Director of Marine Operations, Monterey Bay Aquarium Research Institute. March 2, 2017. See Appendix C for interview notes.
[360] E-mail communication with Michael Kelly, Director of Marine Operations, Monterey Bay Aquarium Research Institute. March 6, 2017.
[361] Note that this total is based on current rates, while the NOAA ship costs are in fiscal year 2015 dollars. It might be tempting to use the PPI for the water transportation industry, used elsewhere in this analysis, to de-escalate the MBARI costs to 2015 dollars for more accurate comparison. That PPI has actually decreased in in the last 12 months, however, whereas MBARI's rates have recently increased slightly, according to the MBARI's Director of Marine Operations. Therefore, applying this index would not be accurate for MBARI. Since MBARI is not a commercial organization, an appropriate industry-specific price index is not available. Applying a more general index of prices (e.g., the Consumer Price Index) to de-escalate the costs to 2015 dollars would result in a small decrease in the estimated cost for the MBARI ship, but would not change the conclusions about cost-effectiveness substantially.
[362] Personal communication with Michael Kelly, Director of Marine Operations, Monterey Bay Aquarium Research Institute. March 2, 2017. See Appendix C for interview notes.

allocation is paid out of the larger NOS budget, not out of the sanctuary's budget. If the NOAA ship time is not available, the sanctuary does not receive additional budget to replace that time using a contract vessel or vessels.[363]

4.4 Pacific Reef Assessment and Monitoring Program: American Samoa

Mission Description: The National Coral Reef Monitoring Program (NCRMP) is an integrated and focused monitoring effort with goals that include delivering high-quality data, data products, and tools to the coral reef conservation community.[364] The NCRMP is part of the Coral Reef Conservation Program, which is headquartered from the NOS Office for Coastal Management. The NCRMP provides scientific information required to track the health of coral reefs and delivers a variety of products to support resource managers and decision-makers, including coral reef Status and Trends Report Cards, a product for which the main body of this report describes societal benefits.

The NCRMP relies on vessels to collect benthic and other habitat mapping data over a wide geographic region. The specific vessels that NCRMP uses, however, vary depending on the region of the world.[365] This case study provides a quantitative cost-effectiveness comparison specifically for an example mission in the Pacific. The discussion section below, however, also provides a qualitative discussion of the NCRMP's use of contract vessels for Atlantic coral reef areas.

The example mission considered here was conducted in 2015 under the Pacific Reef Assessment and Monitoring Program (which is NCRMP in the Pacific). The objective of the American Samoa Reef Assessment and Monitoring Program (RAMP) was to conduct ecosystem monitoring and research in the coral reef habitats of American Samoa and the Pacific Remote Islands Marine National Monument. Activities conducted included: self-contained underwater breathing apparatus (SCUBA) dives from small boats, towed-diver surveys of coral reef ecosystems and marine life, recovery and replacement of biological and oceanographic sea-floor instruments, collection and analysis of water samples, and coral reef mapping using multi-beam sonar. In addition to supporting the NCRMP, the data collected also supported NOAA's ocean acidification program to monitor and understand the effects of ocean acidification on coral reef ecosystems.[366,367]

Mission Requirements: The 2015 American Samoa RAMP consisted of 103 days at sea departing from and returning to Oahu, Hawaii, including a total of nine days of transit to and from the study area. The voyage was conducted in three legs with an intermediate port between legs in American Samoa. Requirements for the vessel used to support the mission were the following:[368]

- Global class endurance, capable of operating for 34 or more days at sea.
- Accommodations and provisions for a NOAA scientific team of 24 people.
- Stowage for equipment supplied by NOAA including: a lab van (80 square feet and 8,000 pounds), two 19-foot small boats and spare outboard (9,500 pounds total), SCUBA and survey gear for the NOAA science team including spare compressor (1,400 pounds), and additional electronics.
- Access to, and support in launching and recovering, three additional small work boats capable of carrying two to seven passengers with SCUBA and survey gear.
- Multi-beam sonar for reef mapping and access to a mapping launch capable of deploying multi-beam sonar in shallow waters.
- Access to on-board hyperbaric decompression chamber for emergency use.

[363] Personal communication with Jan Roletto, Research Coordinator at the Gulf of the Farallones National Marine Sanctuary. January 10, 2017.
[364] "NOAA's National Coral Reef Monitoring Program." NOAA Coral Reef Information System. Available at: https://www.coris.noaa.gov/monitoring/. Accessed March 9, 2017.
[365] Personal communication with Justine Kimball and Susie Holst, National Coral Reef Monitoring Program. December 21, 2016.
[366] "About: Hi'ialaki." NOAA Office of Marine and Aviation Operations. Available at: http://www.omao.noaa.gov/learn/marine-operations/ships/hiialakai/about. Accessed March 9, 2017.
[367] "Multi-agency Team of Scientists Conducting Interdisciplinary Monitoring of Coral Reef Ecosystems in American Samoa and the Pacific Remote Islands Marine National Monument." NOAA Pacific Islands Fisheries Science Center. Available at: https://www.pifsc.noaa.gov/cruise/ha1501.php. Accessed April 13, 2017.
[368] Ship Time Request for American Samoa and Pacific Remote Island Areas - Reef Assessment and Monitoring Program (RAMP). February 13, 2014.

- Certified operator for hyperbaric decompression chamber.
- Wet and dry lab space.
- Personnel support for operation of multi-beam sonar and electronics interface.
- Fuel for the voyage.
- Personnel to run the ship, navigate, and operate deck equipment.

NOAA Ship Cost: The 2015 American Samoa RAMP project was conducted using the NOAA ship *Hi'ialakai* in conjunction with the RAMP program's 25-foot mapping launch R/V *AHI* (Acoustic Habitat Investigator). With the exception of the mapping launch, the *Hi'ialakai* supplied all of the other requirements described above, including access to her three work boats and permanent hyperbaric chamber with dedicated operator.[369] In 2015 dollars, at the marginal cost of $31,350 per day estimated in Section 2, the cost of using the *Hi'ialakai* for 103 days is $3,229,050.

Cost of Contract Vessel Substitute: In the Pacific, the NCRMP does not use contract vessels and relies solely on the *Hi'ialakai* to conduct its mission. The NCRMP subject matter expert was unable to identify a commercial alternative to using the *Hi'ialakai*, given the remote locations and length of typical cruises.[370] Outside of the commercial sector, however, an alternative might be the R/V *Tangaroa*, operated by the New Zealand National Institute of Water and Atmospheric Research (NIWA). The 230-foot *Tangaroa* has multibeam sonar and dive support capabilities and operates throughout the Pacific.[371,372] Its listed endurance of 60 days is actually greater than the *Hi'ialakai's* (35 days).[373,374] Personnel with NIWA confirmed that the *Tangaroa* could supply the requirements described above.[375]

NIWA provided a detailed cost estimate for using the *Tangaroa* to conduct the mission and supply all of the above requirements. For example, NIWA's estimate includes the use of NIWA's 22-foot survey boat *Rukuwai* to conduct mapping in shallow waters. It also includes supplying an approved hyperbaric decompression chamber housed in a 20-foot container with a certified chamber operator. In addition to the 103 mission days, using the *Tangaroa* would require an additional 34 days, including mobilization and demobilization, in transit between Wellington, New Zealand and Hawaii. NIWA's estimate includes this additional transit, but it also includes a 20 percent discount, which NIWA would provide in the interest of continuing and strengthening its working relationship with NOAA. NIWA's estimate to supply all of the requirements above using the *Tangaroa*, including the additional transit and incorporating the discount, is 7,399,840 New Zealand dollars.[376]

At the current exchange rate of 0.6834 U.S. dollars to New Zealand dollars,[377] NIWA's estimate coverts to $5,131,049 (U.S.). To convert this current cost to 2015 dollars, we applied the annual average values for 2016 and 2015 for the PPI for the water transportation industry.[378] The resulting cost in 2015 dollars is $5,404,185.[379]

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369 Ibid.
370 E-mail communication with Justine Kimball, National Coral Reef Monitoring Program. February 13, 2017.
371 Personal communication with Rob Christie, Manager – Marine Resources, NIWA. February 24, 2017. See Appendix C for interview notes.
372 "Specifications and principal features." NIWA. Available at: https://www.niwa.co.nz/vessels/rv-tangaroa/specifications-and-principal-features. Accessed March 9, 2017.
373 Ibid.
374 "Specifications." NOAA Office of Marine and Aviation Operations. Available at: http://www.omao.noaa.gov/learn/marine-operations/ships/hiialakai/about/specifications. Accessed March 9, 2017.
375 E-mail communication with Greg Foothead, General Manager – Vessel Operations, NIWA. April 19, 2017.
376 "Preliminary Proposal for Marine Survey in American Samoa and the Pacific Remote Islands Marine National Monument." April 25, 2017.
377 "NZD to USD Exchange Rate – Bloomberg Markets." Bloomberg. Available at: https://www.bloomberg.com/quote/NZDUSD:CUR. Accessed May 2, 2017.
378 Although NIWA is a governmental organization, it operates like a business and tries to maintain its rates in line with the rest of the industry, according to NIWA's Manager of Marine Resources. Therefore, assuming that this industry-specific PPI could be applicable to NIWA's prices is reasonable. The analysis applies the annual average index value for 2016 to the current total because 2016 is the most recent full year for which data are available.
379 The annual average PPI for NAICS category 483 was 131.5 for 2016 and 138.9 for 2015. Applying these values to the total cost results in the following calculation: $5,131,049 x 138.9/131.5 = $5,404,185. Note that prices in this sector actually decreased between 2015 and 2016, resulting in a higher cost in 2015 dollars.

Discussion: Exhibit B - 8 compares the cost of using the *Tangaroa* as a substitute for the *Hi'ialakai* for the 2015 American Samoa RAMP. The cost of using the *Tangaroa* would be substantially higher than using the *Hi'ialakai*. Another factor to consider, if the *Tangaroa* were to be used, is scheduling. According to NIWA's Manager of Marine Resource, NIWA's vessels are committed to certain fisheries projects that have inflexible schedules.[380] Any use of the *Tangaroa* might have to be scheduled around these projects. NIWA's cost estimate further emphasizes that the *Tangaroa* has "a busy yet fluid schedule," so that scheduling her would require advance planning.[381] Thus, scheduling the *Tangaroa* could require substantial lead time for a mission of this length: possibly a year or more.[382]

Exhibit B - 8: Cost-Effectiveness Comparison for RAMP: American Samoa

Vessel Used	Cost ($)
NOAA ship	3,229,050
NIWA ship	5,404,185

Notes:

- NOAA ship cost based on 103 days at sea using the *Hi'ialakai* at the marginal cost estimated in Section 2.
- NIWA ship cost based on NIWA's cost estimate to supply the mission requirements, including 34 additional days of transit time, converted to U.S. dollars and de-escalated as described in the text.

The quantitative analysis presented here is specifically for an example coral reef mission in the Pacific, where the NCRMP has historically relied on NOAA ships, not contract vessels. In comparison, for Atlantic coral reef areas, the NCRMP has primarily used small contract vessels to collect data. The NOAA ship *Nancy Foster*, however, could also be an option for this region if it were available. In fact, at the time of this study, the NCRMP was considering making a ship time request for the *Nancy Foster* to collect coral reef data near Puerto Rico. If the *Nancy Foster* were available, one to two weeks of ship time might replace three to four months of sporadic sampling using small contract boats, entailing multiple transits and multiple contracts.[383] The NCRMP has not proceeded with the request for the *Nancy Foster*, however, because the program is allocated a limited budget for days at sea aboard NOAA ships. Using the *Nancy Foster* would take up part of that allocation and subtract from the days at sea available for the NCRMP's other missions (e.g., using the *Hi'ialakai* where options are scarce). The NCRMP subject matter expert has not yet identified the specific contract vessels that will be used as an alternative to the *Nancy Foster* in Puerto Rico or developed a cost estimate for them.[384] Therefore, a quantitative comparison of the two alternatives is not possible at this time.

[380] Personal communication with Rob Christie, Manager – Marine Resources, NIWA. February 24, 2017. See Appendix C for interview notes.
[381] "Preliminary Proposal for Marine Survey in American Samoa and the Pacific Remote Islands Marine National Monument." April 25, 2017.
[382] Personal communication with Rob Christie, Manager – Marine Resources, NIWA. February 24, 2017. See Appendix C for interview notes.
[383] Personal communication with Justine Kimball and Susie Holst, National Coral Reef Monitoring Program. December 21, 2016.
[384] E-mail communication with Justine Kimball, National Coral Reef Monitoring Program. February 13, 2017.

5. Capacity, Availability, and Other Factors Affecting the Use of Contract Vessels

This section discusses the capacity of contract vessels to support NOAA, including the factors affecting the availability of individual vessels. It also presents available information on future prices for contract vessel services. It concludes by touching on other factors that could affect NOAA's use of contract vessels.

A primary source for this section is a set of informal, voluntary interviews with contract vessel providers conducted specifically for this study. **Exhibit B - 9** identifies the providers interviewed, along with some summary information on the services they provide. Appendix C lists the questions that guided the interviews, along with detailed notes from each interview.

All of the providers interviewed have performed services for NOAA in the past. The interviewees are evenly split between commercial providers and research institutions. They represent a range of vessel capabilities, from small coastal vessels to large research ships with global range and multi-mission capabilities. A limitation is that the interviews only encompassed providers serving the U.S. west coast and Pacific Ocean. Providers serving the east coast, Gulf of Mexico, or Atlantic did not respond to requests for interviews. Note, however, that given the voluntary nature of the interviews and the small sample size, the interview process was not designed to be a statistical survey, only to collect qualitative information.

Exhibit B - 9: List of Contract Vessel Providers Interviewed

Organization	Vessels	Geographic Region
Commercial Providers		
Alaska Charter Boats	Broker for fleet of research vessels	Southeast Alaska
Auklet Charter Services	R/V *Auklet*	Southeast Alaska
Homer Ocean Charters	Broker for fleet of research vessels	Southeast Alaska
Miss Linda Charters	R/V *Miss Linda*	Oregon, Washington, and California
Research Institutions		
MBARI	R/V *Western Flyer*, R/V *Rachel Carson*, and R/V *Paragon*	Canada to Mexico and Hawaii (*Western Flyer*, *Rachel Carson*), Monterey Bay (*Paragon*)
NIWA	R/V *Tangaroa*, R/V *Kaharoa*, and R/V *Ikatere*	Pacific and Indian Ocean (*Tangaroa*, *Kaharoa*), New Zealand coast (*Ikatere*)
Oregon State University	R/V *Elakha*, R/V *Pacific Storm*, and UNOLS R/V *Oceanus*	Oregon coast (*Elakha*), Alaska to Mexico (*Pacific Storm)*, Pacific Ocean (*Oceanus*)
University of Washington	UNOLS R/V *Thomas G. Thompson* and R/V *Clifford A. Barnes*	Pacific Ocean
Acronyms and Abbreviations: MBARI = Monterey Bay Aquarium Research Institute; NIWA = New Zealand National Institute of Water and Atmospheric Research; UNOLS = University National Oceanographic Laboratory System		

Another source used in this section is data from USAspending.gov, a publicly accessible U.S. government website that provides searchable, transaction-level information on federal contracts and grants.[385] Specifically, this study uses data downloaded from USAspending for NOAA contracts for fiscal year 2015.[386] To identify contracts specifically for vessels, the analysis examined contract descriptions in conjunction with the vendor's NAICS code and the product or

[385] "About: USAspending.gov." Available at: https://www.usaspending.gov/about/usaspending/Pages/default.aspx. Accessed March 10, 2017.

[386] Data downloaded for National Oceanic and Atmospheric Administration for fiscal year 2015 from https://www.usaspending.gov/DownloadCenter/Pages/DataDownload.aspx. Accessed November 18, 2016.

service code identified in the system. Because USAspending's contract descriptions are brief, this approach is imperfect and was not able to identify all of NOAA's vessel contracts. **Exhibit B - 10** compares the value of contracts identified in the USAspending data with NOAA's actual spending on contract vessels presented in Section 3.

Exhibit B - 10: Completeness of Vessel Contract Data from USAspending for Fiscal Year 2015

Program	Actual ($)	Identified in USAspending ($)	Percent Identified
NMFS	13,231,360	12,024,810	91%
NOS Hydrographic Services	19,804,427	381,284	2%
Other NOS Programs	278,000		
NWS	6,854,000	6,823,830	>99%
OAR	3,841,852	418,225	11%
NESDIS	257,300	0	0%
TOTAL	44,266,939	19,648,149	44%
Total excluding Hydrographic Services	24,462,512	19,648,149	80%

Notes:

- Actual spending is as presented in Section 3.
- NOS Hydrographic Services contracts are structured as data buys instead of traditional charters, covering services above and beyond vessel use.
- Spending identified in USAspending is the total base and all exercised options value of transactions filtered as described in the text from all NOAA contracts for fiscal year 2015.

Acronyms and Abbreviations: NESDIS = National Environmental Satellite, Data, and Information Service; NMFS = National Marine Fisheries Service; NOS = National Ocean Service; NWS = National Weather Service; OAR = Oceanic and Atmospheric Research

For NMFS and NWS, the value of contracts identified in the USAspending data for fiscal year 2015 accounts for more than 90 percent of the actual spending on contract vessels by each of these programs. For NOS, on the other hand, the approach used to identify vessel contracts appears to miss most of the spending on hydrographic services. This result is not unexpected, given that these contracts are structured as data buys instead of traditional charters. The approach also misses most contract vessel spending by Oceanic and Atmospheric Research and the National Environmental Satellite, Data, and Information Service. Even with these limitations, however, the data extracted from USAspending capture 44 percent of NOAA's total spending on contract vessels, and 80 percent of the total if hydrographic services are excluded. Therefore, data derived from examining the selected contracts may be reasonably representative of the majority of NOAA's vessel contracts, especially for NMFS and NOS. This representativeness is important because the USAspending data allow examining details about NOAA's vessel contracting that are not readily available elsewhere (i.e., number of vendors used, number of offerors).

5.1 Capacity and Availability

Collection of comprehensive information on the total number of vessels with capabilities useful to NOAA that might be available under contract was beyond the scope of this analysis. Databases do exist that identify research ships or certain types of fishing vessels. For example, the Ocean Information Center at the University of Delaware maintains a database of international research ship specifications and schedules.[387] Similarly, the Inter-American Tropical Tuna Commission has a database of vessels, by country of origin, authorized by their government to fish for species under the purview of

[387] "Research Vessel Specifications Search." Ocean Information Center, University of Delaware. Available at: http://www.researchvessels.org/qryshipinfo.asp.

the Commission.[388] These databases, however, do not provide information regarding whether the vessels are available for use under contract or have capabilities suitable for NOAA's purposes.

In addition to being suitable for the mission and available for hire, vessels used by NOAA under contract must meet certain minimum safety standards and regulatory requirements, particularly if NOAA staff are to be aboard as passengers. The process of determining the specific requirements applicable to a given contract vessel can be complex.[389] Requirements can include that the vessel has a U.S. Coast Guard (USCG) Letter of Designation as an oceanographic research vessel, a USCG Certificate of Inspection, or a USCG Certificate of Documentation as a fishing vessel and Commercial Fishing Vessel Decal.[390] These requirements may limit the pool of available contract vessels.

The data on charter contracts filtered from USAspending show that NOAA had transactions with more than 130 individual vendors under approximately 200 unique contracts in fiscal year 2015. **Exhibit B - 11** shows data on the number of bids received for each of these contracts. Although a few contracts had a large number of bidders, just over half received only one offer and almost 70 percent had two or fewer offers.[391] Therefore, while the overall size of the charter industry may be large, these data suggest that the number of vendors with the capability to support the specific requirements of a given project can be small (i.e., one or two).

Exhibit B - 11: Number of Offers Received for NOAA Charter Vessel Contracts Active in Fiscal Year 2015

Program	Number of Contracts	Offers Received per Contract		Percent of Contracts	
		Average	Range	Only one offer	One or two offers
NMFS	151	2.1	1 to 9	51%	70%
NOS	20	2.2	1 to 8	55%	70%
NWS	17	4	1 to 18	41%	53%
OAR	4	1.25	1 to 2	75%	100%
TOTAL	192	2.3	1 to 18	51%	69%

Acronyms and Abbreviations: NESDIS = National Environmental Satellite, Data, and Information Service; NMFS = National Marine Fisheries Service; NOS = National Ocean Service; NWS = National Weather Service; OAR = Oceanic and Atmospheric Research

The interviews with charter providers also addressed several topics related to capacity and availability. All of the vendors interviewed expressed interest in NOAA work and a willingness to continue supporting it. Nearly all of them predicted they would have very good availability to do so, both in the immediate future and in coming years.

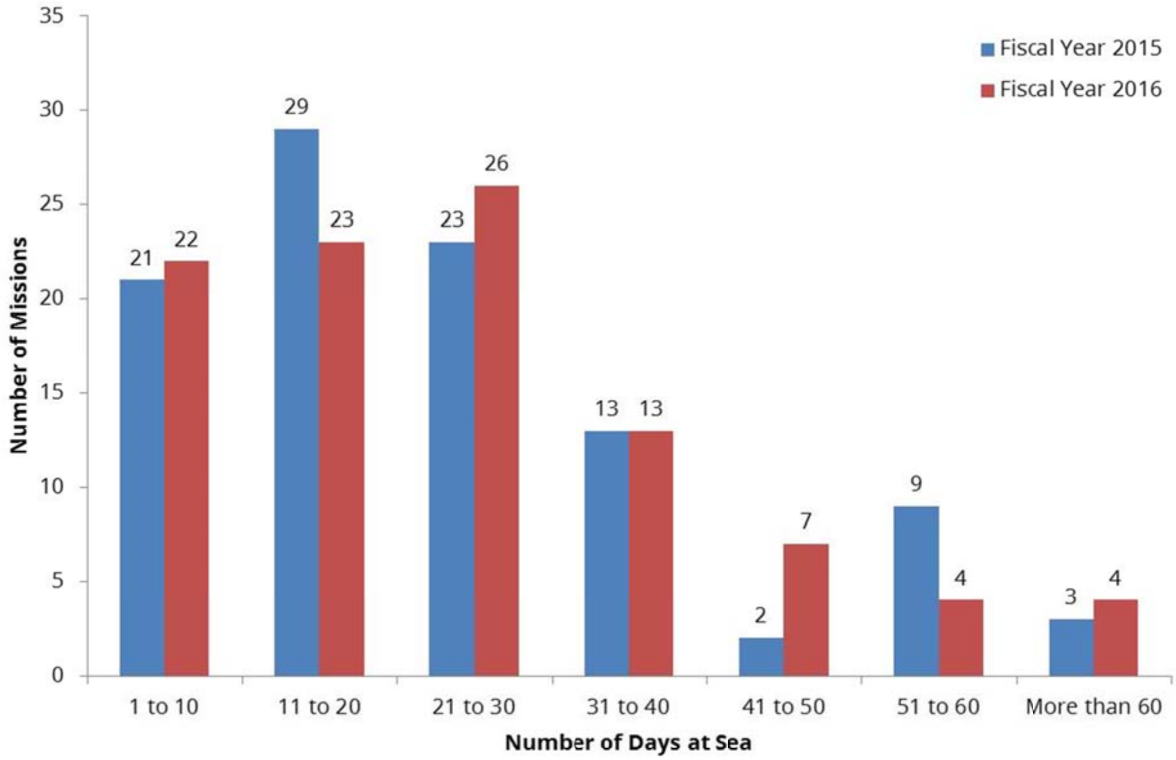
A key exception to the generally high availability is among the larger ships of UNOLS fleet, where there are competing demands for limited ship time. In particular, the R/V T*homas G. Thompson* just completed a mid-life maintenance overhaul that reduced her availability during the past year. The R/V *Roger Revelle* is scheduled for mid-life maintenance during 2018, which will likewise limit availability.[392] A commercial vessel broker also indicated that, while overall availability is good, it is dependent on vessel capability, specifically size. Smaller vessels are always more available.[393]

Most of the vendors (six of the nine) reported that their availability is greater with more advance planning. The lead time required to access charter services varies depending on the length of the project and on the size of the vessel. Operators of

[388] "IATTC Vessel Database." Inter-American Tropical Tuna Commission. Available at: https://www.iattc.org/VesselRegister/VesselList.aspx?List=RegVessels&Lang=ENG#United_States.
[389] For example, see the Minimum Requirements Flowchart available at: https://www.omao.noaa.gov/sites/default/files/documents/Visio-Vessel%20Chartering%20Requirements%20Flowchart%20V4.pdf.
[390] "Vessel Chartering Info." Office of Marine and Aviation Operations. Available at: http://www.omao.noaa.gov/learn/headquarters/safety-environmental-compliance/vessel-chartering-info. Accessed January 12, 2017.
[391] Data are not available on the number of solicitations that received no bids.
[392] Personal communication with Doug Russell, University of Washington and UNOLS Vessel R/V *Thomas G. Thompson*. February 23, 2017. See Appendix C for interview notes.
[393] Personal communication with Linda Kadrlick, Alaska Charter Boats. March 2, 2017. See Appendix C for interview notes.

smaller vessels report that planning early in the year for operations in the summer is ideal. Some of these operators also report being able to respond very quickly when needed, within a week or even a day. For longer projects aboard larger vessels, more planning is required, however: often a year or more in advance. For context, the average length of missions conducted by NOAA's fleet in fiscal years 2015 and 2016 was approximately 25 days at sea.[394] **Exhibit B - 12** shows the distribution of these missions by length.

Exhibit B - 12. Length of Missions Conducted by NOAA Fleet



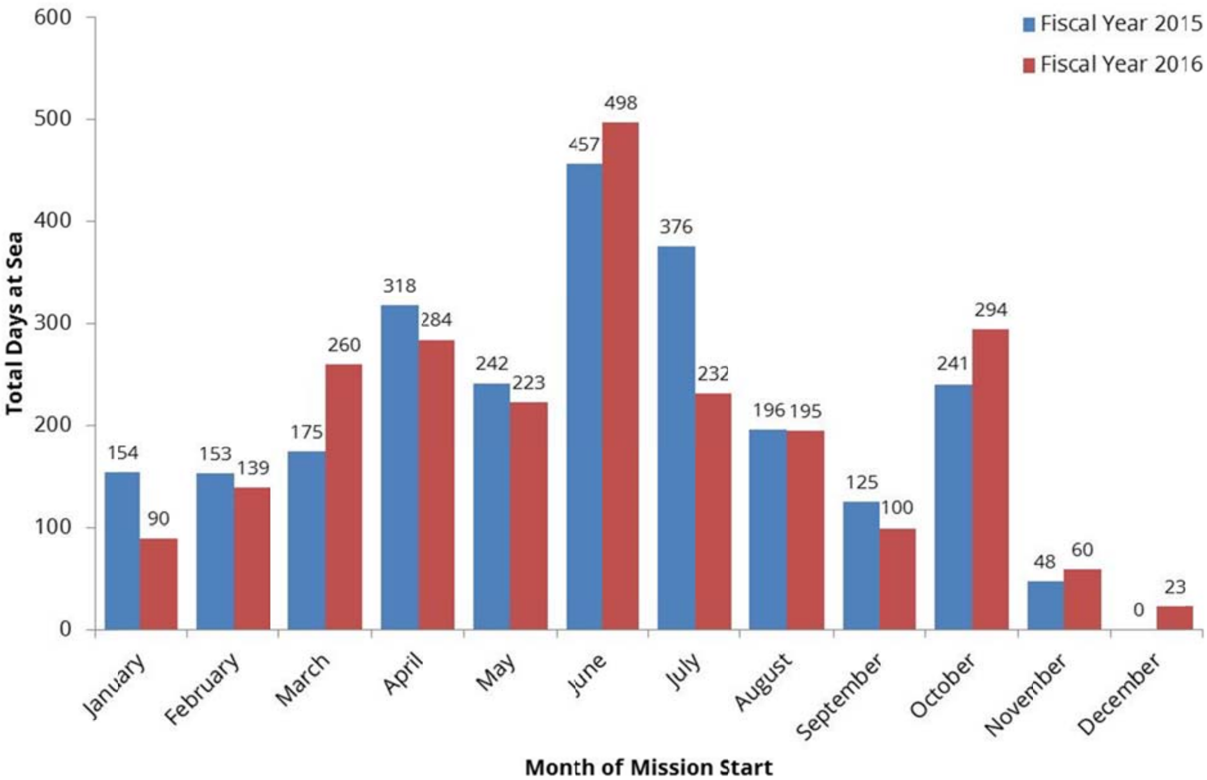
Source: data provided by OMAO
Note: Excludes fleet services and program support activities (e.g., inspections, shakedowns, sea trials, and transit not assigned to a specific line office) and scheduled missions where actual days at sea were reported as zero.

The majority of the providers (five of the nine) reported that their vessels are busiest during the summer months. Only one of the interviewees specifically mentioned fishing season.[395] A NOAA subject matter expert, however, identified this competing obligation as particularly important in the scheduling of NMFS charters, most of which are commercial fishing vessels.[396] Based on the interviews, research vessels, like fishing vessels, also have greater availability outside of summer. Even during summer, however, the interviewees reported good availability, particularly with advance planning. **Exhibit B - 13** shows the total days at sea executed by the NOAA fleet in each month of fiscal years 2015 and 2016. NOAA ships execute missions year-round, but, like charter vessels, they are busiest during the summer (particularly June). The NOAA fleet, however, also executes a significant number of days at sea outside of summer (particularly

[394] Based on data provided by OMAO. Excludes fleet services and program support activities (e.g., inspections, shakedowns, sea trials, and transit not assigned to a specific line office) and scheduled missions where actual days at sea were reported as zero.
[395] Personal communication with Roark Brown, Homer Ocean Charters. February 15, 2017. See Appendix C for interview notes.
[396] E-mail communication with Michael Gallagher, National Marine Fisheries Service. February 9, 2017.

March through April and October).[397] These schedule data suggest there may be opportunities to utilize charters when those vessels have greater availability.

Exhibit B - 13. Days at Sea Executed by NOAA Fleet by Month



Source: data provided by OMAO
Note: Excludes fleet services and program support activities (e.g., inspections, shakedowns, sea trials, and transit not assigned to a specific line office) and scheduled missions where actual days at sea were reported as zero.

Most of the providers, particularly the commercial vendors, also reported a willingness to modify their vessels to support project requirements, more so for longer-term projects and contracts. One commercial vendor even noted that his vessel evolved into its current research configuration precisely because of modifications based on customer recommendations.[398] One research institution, on the other hand, reported a more conservative approach. Although willing to make changes, this institution considers safety carefully before making major modifications, including engaging the services of a marine architect when needed.[399]

Examining the information from interviewees in conjunction with the data from USAspending suggests the following conclusions about capacity and availability. The overall size of the charter vessel industry is large and NOAA successfully contracts with a variety of different providers. Individual vendors are generally willing and available to provide support, even to the extent of modifying their vessels to suit project needs. Specific projects, however, may have requirements (e.g., vessel capabilities, project scheduling, or location) that are not a good match for a very large number of vessels. The number of such projects may be large, based on the available data about the number of bids received.

[397] Based on data provided by OMAO. Excludes fleet services and program support activities (e.g., inspections, shakedowns, sea trials, and transit not assigned to a specific line office) and scheduled missions where actual days at sea were reported as zero.
[398] Personal communication with Bob Pedro, Miss Linda Charters. March 6, 2017. See Appendix C for interview notes.
[399] Personal communication with Monita Cheever, Oregon State University. February 28, 2017. See Appendix C for interview notes.

5.2 Future Prices

All of the charter providers interviewed identified fuel prices as the major factor that would affect future prices for their services. Changes in fuel prices would, of course, affect both charter vessels and the NOAA fleet. Therefore, the impact of such changes on relative cost effectiveness would be limited to some extent.

Outside of major changes in fuel prices, most interviewees, including all of those willing to make a prediction, predicted only small increases in the prices for their services. The most common prediction was in the range of a two to three percent annual increase. As a point of reference for their predictions, two of the interviewees noted that prices have not changed substantially recently. These statements are generally consistent with the trends observed in the PPI for the water transportation industry, used elsewhere in this analysis. PPIs measure the average change over time in the selling prices received by U.S. producers of goods and services. The U.S. Bureau of Labor Statistics publishes PPIs for various industries and groups of products. In this case, we examined the PPI for the water transportation industry (NAICS category 483, which is the category to which many of NOAA's contract vessel providers belong). PPIs measure price changes with respect to a base period, for which the index is set to 100. The PPI for the water transportation industry specifically measures price changes in relation to a base period of December 2003. Thus, the difference between the current value of the index and 100 reflects the percent change in prices since December 2003.[400] So, if the annual average PPI for 2016 was 131.5, it means that prices in 2016 were, on average, 31.5 percent higher than in December 2003.

Exhibit B - 14 shows annual average values for the PPI for the water transportation industry for the last five years.[401] With the exception of a moderate decrease in 2016, prices in this industry have remained fairly stable.

Exhibit B - 14: Producer Price Index (PPI) for the Water Transportation Industry

Year	Annual Average Index Value	Change from Previous Year
2012	136.4	2.2%
2013	135.1	-1.0%
2014	138.5	2.5%
2015	138.9	0.3%
2016	131.5	-5.3%

5.3 Other Barriers and Incentives

Three of the case studies presented in Section 4 identified institutional factors that affect NOAA's use of charter vessels. These factors differ across NOAA programs. For example, the NDBC has a marine services contract vehicle that allows it to access commercial vessels to perform mooring maintenance. Because of this mechanism, when contract vessels can meet the mission requirements (e.g., ancillary science is not required), NDBC finds it easy to access and schedule them.[402] Other programs, however, do not have the mechanisms or budget to readily access charters. For example, when an individual marine sanctuary receives ship time on the NOAA fleet, that allocation is paid out of the larger NOS budget, not out of the sanctuary's budget. If the NOAA ship time is not available, the sanctuary does not receive additional budget to replace that time using a charter vessel or vessels.[403] For still other programs, the fleet allocation process may create an incentive to use charters. Specifically, the NCRMP did not proceed with a ship time request for the

[400] "Producer Price Index Frequently Asked Questions." U.S. Bureau of Labor Statistics. https://www.bls.gov/ppi/ppifaq.htm. Accessed May 24, 2017.
[401] Time series data downloaded for producer price index for NAICS category 483 from https://www.bls.gov/ppi/data.htm. Accessed March 7, 2017.
[402] E-mail and personal communication with Kathleen O'Neil, National Weather Service, National Data Buoy Center. January 10 and 12, 2017.
[403] Personal communication with Jan Roletto, Research Coordinator at the Gulf of the Farallones National Marine Sanctuary. January 10, 2017.

Nancy Foster, because using the *Foster* would take up part of the program's ship time allocation and subtract from the days at sea available for the NCRMP's other missions.[404]

From the vendor perspective, the charter providers interviewed did not identify major barriers to working for NOAA. A few interviewees identified paperwork requirements as a minor issue that they have learned to handle. They specifically mentioned difficulties with invoicing procedures that can require additional effort and result in delays in payment of up to several months.[405,406] One vendor noted that they account for this effort and the potential delays in their pricing.[407]

Several interviewees identified incentives to working for NOAA. Most frequently identified was the detailed planning that NOAA does in advance of its projects. Two of the interviewees specifically noted that this planning is better than that of other science parties or organizations, making it easier to work with NOAA.[408,409]

[404] E-mail communication with Justine Kimball, National Coral Reef Monitoring Program. February 13, 2017.
[405] Personal communication with Monita Cheever, Oregon State University. February 15, 2017. See Appendix C for interview notes.
[406] Personal communication with Roark Brown, Homer Ocean Charters. February 28, 2017. See Appendix C for interview notes.
[407] Ibid.
[408] Personal communication with Doug Russell, University of Washington and UNOLS Vessel R/V *Thomas G. Thompson*. February 23, 2017. See Appendix C for interview notes.
[409] Personal communication with Bob Pedro, Miss Linda Charters. March 6, 2017. See Appendix C for interview notes.

6. Appendix C: Interviews with Charter Providers

As discussed in Appendix B, this project included informal interviews with charter providers in order to gather information capacity within the contract vessel industry to support NOAA and the cost of that support. The following substantive questions guided each of these interviews:

1. Can you provide a brief description of the services that you have provided for NOAA in the past?
2. Do you have additional current or planned capabilities (e.g., additional vessels, other services that that NOAA might not have used in the past) that you'd be interested in making NOAA aware of?
3. How willing would you be to modify your vessel (e.g., adding hull mounted transducers, adding oceanographic winches, etc.) to make it more suitable for NOAA charter work? Would the possibility of long term contracts (multi-year) make you more amenable to modifying the vessel?
4. Given competing requirements or requests for your services, what do you predict your availability and capacity to support NOAA might be in the future (i.e., in the next year, in the next five years)?
5. What is the lead time required for NOAA to access your services (i.e., from initial scheduling through issuance of a contract to actually going to sea)?
6. Are there limitations on the geographic region in which you can provide support?
7. Are there specific periods of the year when you can or cannot provide support (e.g., seasons where you have other priorities)?
8. Are there other barriers to or incentives for working with NOAA?
9. What are typical prices of the services you've provided NOAA in the past?
10. How do you expect these prices to change in the future (i.e., in the next year, in the next five years)?
11. What factors drive these prices?

This appendix provides the detailed notes from each of the interviews.

Interview with Roark Brown, Homer Ocean Charters, Homer, Alaska

(907) 399-1269, homer.ocean.charters@gmail.com, 2/15/2017

1. *Can you provide a brief description of the services that you have provided for NOAA in the past?*

Homer Ocean Charters owns/operates a fleet of vessels up to 60 feet and contracts out for additional vessels, including larger ships. Some example projects for NOAA have included deployment of tidal current meters and deployment of a weather buoy. The weather buoy project used a 100 foot vessel when NOAA had difficult scheduling time using a USCG vessel. Projects usually involve at least one NOAA person aboard.

2. *Do you have additional current or planned capabilities (e.g., additional vessels, other services that that NOAA might not have used in the past) that you'd be interested in making NOAA aware of?*

Willing to do just about any type of mission.

3. *How willing would you be to modify your vessel (e.g., adding hull mounted transducers, adding oceanographic winches, etc.) to make it more suitable for NOAA charter work? Would the possibility of long term contracts (multi-year) make you more amenable to modifying the vessel?*

They often make modifications. For example, they installed a hull-mounted acoustic Doppler current profilers. This definitely depends on the duration of the contract. For a one-day project, they are not likely to make extensive modifications, but they are willing to "saw the boat in half" if the contract is long enough.

4. *Given competing requirements or requests for your services, what do you predict your availability and capacity to support NOAA might be in the future (i.e., in the next year, in the next five years)?*

Good, they are almost always able to find an appropriate vessel.

5. *What is the lead time required for NOAA to access your services (i.e., from initial scheduling through issuance of a contract to actually going to sea)?*

[This question was not answered]

6. *Are there limitations on the geographic region in which you can provide support?*

Their vessels operate in Cook Inlet and throughout the Gulf of Alaska.

7. *Are there specific periods of the year when you can or cannot provide support (e.g., seasons where you have other priorities)?*

June to August is always busy in the region because of salmon season. There are also Navy exercises that have engaged a large number of private vessels during late June for the last few years.

8. *Are there other barriers to or incentives for working with NOAA?*

Not really, although Federal government contracts are always a paper shuffle, although state contracts are sometimes worse. Changing invoicing procedures can result in months of delays in getting paid. They often anticipate this and build a premium into their pricing because of it.

9. *What are typical prices of the services you've provided NOAA in the past?*

Varies depending on the project, but $3,000 to $8,000 per day is typical, including for the buoy deployment project.

10. How do you expect these prices to change in the future (i.e., in the next year, in the next five years)?

Expect small annual increases, but nothing significant unless there are substantial changes in fuel prices.

11. What factors drive these prices?

See above regarding fuel prices.

Interview with Captain Doug Russell, University of Washington and UNOLS Vessel R/V Thomas G. Thompson, Seattle, Washington

(206) 543-5062, dgruss@uw.edu, 2/23/2017

1. *Can you provide a brief description of the services that you have provided for NOAA in the past?*

The Thompson has supported NOAA extensively over the last few years through the UNOLS ship time request process. Projects have included dedicated NOAA cruises, as well as smaller NOAA projects that piggyback on other cruises. The NOAA exclusive cruises include 40 day mooring maintenance projects (primarily TAO buoys). On these cruises, the University supplies two marine technicians to do the actual maintenance, in addition to the ship time. There will also be a NOAA science team of up to ten people aboard to do ancillary science. When supporting piggyback projects, the University ends up charging NOAA for a portion of the total cruise costs (e.g., one to two days of a 20 to 40 day cruise). The University's partnership vehicle with NSF makes the charge-back process easy.

2. *Do you have additional current or planned capabilities (e.g., additional vessels, other services that that NOAA might not have used in the past) that you'd be interested in making NOAA aware of?*

The University also has a smaller (55 foot), older vessel (the Barnes) that NOAA has occasionally used. They are partnering with NOAA on design of a new smaller vessel to support fisheries projects and hope for a contribution from NOAA on the construction costs through UNOLS. They also have a pool of scientific equipment available and often consider potential NOAA uses when investing in new equipment.

3. *How willing would you be to modify your vessel (e.g., adding hull mounted transducers, adding oceanographic winches, etc.) to make it more suitable for NOAA charter work? Would the possibility of long term contracts (multi-year) make you more amenable to modifying the vessel?*

They have made modifications, albeit minor, for NOAA in the past. They are more than willing to do large modifications. For example, they added large through-ports to support NASA projects during the recent overhaul. It all depends on lead time and funding.

4. *Given competing requirements or requests for your services, what do you predict your availability and capacity to support NOAA might be in the future (i.e., in the next year, in the next five years)?*

The Thompson is just coming out of a major, mid-life maintenance overhaul which reduced her availability during the past year. Her sister ship, the Revelle, will be in her mid-life maintenance during 2018. This means there will be high demand during 2018-2019. NOAA is involved in the UNOLS ship time process, although it sometimes comes to the table later in the process. The prioritization process is complex. The Navy and NSF get a slightly higher priority in the process, but as a federal agency NOAA also has high priority over other competing organizations. The TAO (and DART) cruises get high priority, in particular, because they are consistently funded from year-to-year.

5. *What is the lead time required for NOAA to access your services (i.e., from initial scheduling through issuance of a contract to actually going to sea)?*

Ideally, requests are made in February, and firmed up during March and April, for operations during the following year (e.g., requests in early 2017 are made for cruises during 2018). The ship scheduling process is dynamic and changes during the course of a year, but plans made earlier in the calendar year have the best chance for the following year. The lead time, however, can depend on the length of the project. Small projects may be piggybacked in, if the opportunity is there once the major projects have been decided.

6. *Are there limitations on the geographic region in which you can provide support?*

The Thompson operates primarily in the Pacific, sometimes the Indian Ocean. The Revelle operates more frequently in the Indian Ocean. Of the other class UNOLS ships:

- The Atlantis travels back and forth between the Atlantic and Pacific
- The Kilo Moana (University of Hawaii) is primarily near Hawaii in the Pacific
- The Sikuliaq is in Alaska in the summer and fall, the rest of the Pacific during the remainder of the year

The new ocean class vessel planned for UNOLS will support the northern Pacific. It won't have quite the endurance of the Thompson.

7. Are there specific periods of the year when you can or cannot provide support (e.g., seasons where you have other priorities)?

Summer, really May through October, is jam packed and the Thompson operates mostly in the Washington and Oregon region during this period. In November, it is usually dedicated to student cruises in the same region -- the ship spends a total of 45 days a year, of its usually 260 to 300, supporting University of Washington research. During other parts of the year, the Thompson operates farther out of the region.

8. Are there other barriers to or incentives for working with NOAA?

NOAA is easy to work for, because their detailed planning is often better than that of other science parties. The only barrier can be uncertain funding (especially early in the planning process), but the TAO and DART cruises have been consistently funded.

9. What are typical prices of the services you've provided NOAA in the past?

Rates for the TAO cruises are around $35,000 per day for the ship plus $4,500 per day for the marine technicians (a total of $39,500 per day). Because NOAA requires day rates to be set up front, instead of adjusted at the time of billing (which is the practice NSF employs), there is a 5 percent markup included in what we charge NOAA. Also, there is some fee involved in passing the money through NSF.

10. How do you expect these prices to change in the future (i.e., in the next year, in the next five years)?

The prices were high this past year because the Thompson was out of service for a time, meaning increased demand. However, typical increases are in the 2 to 3 percent range per year.

11. What factors drive these prices?

Fuel is the key factor. For UNOLS in general, there are differences because of the overhead of the different university systems and the geographic regions of operation. The Revelle is more expensive, for example, both because of the University of California system and costs in California in general.

Interview with Rob Christie, New Zealand National Institute of Water and Atmospheric Research (NIWA), Wellington, New Zealand

+64-4-386-0881, Rob.Christie@niwa.co.nz, 2/24/17

1. *Can you provide a brief description of the services that you have provided for NOAA in the past?*

NIWA is a government-owned organization, but operates like a business. Their research includes atmospheric, marine, freshwater, fisheries, geophysical science, etc. About the only thing they don't do is deep sea geology; in New Zealand, that particular capability is held by a different organization. NIWA consists of about 605 people in 14 offices. About half of their work is through contracts with organizations in New Zealand and the other half with organizations throughout the rest of the world.

NIWA operates three vessels: the 70-meter (330-foot) R/V Tangaroa, the 28-meter (92-foot) R/V Kaharoa, and a smaller, coastal vessel, the R/V Ikatere. NIWA has had very few direct contracts with NOAA, but NOAA has accessed its vessels through subcontracts with the University of Washington and Scripps. NIWA's vessels have conducted 19 previous cruises for NOAA. They are currently planning the next cruise for NOAA, 15 percent of which will be funded by Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia's equivalent to NOAA. NIWA meets annually with NOAA leadership and attends the International Research Ship Operators' (IRSO) conference to talk about collaborating on research worldwide.

2. *Do you have additional current or planned capabilities (e.g., additional vessels, other services that that NOAA might not have used in the past) that you'd be interested in making NOAA aware of?*

NIWA's ships have permanent crews of their own employees, not contractors. Their crews have long-standing tenures with the organization, an average of 15 years. Their crews are not unionized, so they are quicker to deploy and more responsive. NIWA potentially has a new 35-meter (115-foot) vessel in the pipeline, which will add the capability to deploy ROVs. They currently have a cost-effective drone that can get seabed imagery, but the new ship will add full ROV capability. They also have warehouses of equipment with their own technicians, so they can provide turnkey services.

3. *How willing would you be to modify your vessel (e.g., adding hull mounted transducers, adding oceanographic winches, etc.) to make it more suitable for NOAA charter work? Would the possibility of long term contracts (multi-year) make you more amenable to modifying the vessel?*

NIWA modifies its vessels all the time, sometimes extensively, but financial viability is the bottom line. For big modifications, it's necessary to have a long-term contract or be reimbursed directly.

4. *Given competing requirements or requests for your services, what do you predict your availability and capacity to support NOAA might be in the future (i.e., in the next year, in the next five years)?*

Both the Kaharoa and Tangaroa have about 150 to 160 days a year available. The limitations are a couple of voyages that are set in stone and unmovable, usually fisheries work set around repeated trawling. Most other projects are not time-specific, which offers some flexibility.

5. *What is the lead time required for NOAA to access your services (i.e., from initial scheduling through issuance of a contract to actually going to sea)?*

Lead time depends on the complexity of the voyage. NIWA is pretty agile. The geographic region requested and the number of permits required are big factors in determining lead time. This year they already have quite a few months tied up. Ultimately, lead time could be a year for a longer or more complex voyage, two months for less complex trips.

6. Are there limitations on the geographic region in which you can provide support?

NIWA's ships can travel across the Pacific and the Indian Oceans, as far west as Mauritius, including voyages of 45 days at sea without returning to port. They have done about 13 voyages to the Antarctic. They would not rule out working in the Atlantic, but this would require considering the next projects on the schedule because of transit time.

7. Are there specific periods of the year when you can or cannot provide support (e.g., seasons where you have other priorities)?

Except for the set fisheries voyages, they are available year-round. Each ship has two crews that alternate months on and off, year-round.

8. Are there other barriers to or incentives for working with NOAA?

No real barriers. NIWA has a lot of respect for NOAA. Working for NOAA is seen as a prestige job that offers good exposure, so there is an incentive to do it.

9. What are typical prices of the services you've provided NOAA in the past?

Prices are dependent on the project. The last subcontracted project for NOAA on the Kaharoa was deploying ARGO floats and the rate was 11,500 New Zealand dollars per day including fuel. The Tangaroa has not worked recently for NOAA, but has in the past. Their current target day rate for the Tangaroa is 57,500 New Zealand dollars per day including fuel. These prices are ship rates only. Additional science support and equipment would increase the price, possibly up to 80,000 New Zealand dollars per day.

10. How do you expect these prices to change in the future (i.e., in the next year, in the next five years)?

Prices will change in line with the rest of the industry. The new 35-meter vessel would probably replace the Kaharoa and be more expensive.

11. What factors drive these prices?

Fuel and demand from other missions/cruises.

Interview with Monita Cheever, Oregon State University, Newport, Oregon

541-867-0295, hantzecm@oregonstate.edu, 2/28/17

1. *Can you provide a brief description of the services that you have provided for NOAA in the past?*

Oregon State owns and operates the 84 foot R/V Pacific Storm and the 54 foot R/V Elakha. It also operates the UNOLS R/V Oceanus. NOAA has used all of these ships for many different projects, including trawls, CTD deployment, water flow measurement, buoy deployment (including DART buoys), and equipment recovery. The vessels have supported both daytime and nighttime operations for NOAA.

2. *Do you have additional current or planned capabilities (e.g., additional vessels, other services that that NOAA might not have used in the past) that you'd be interested in making NOAA aware of?*

The University is not planning any major vessel acquisitions. They are, however, enhancing the Pacific Storm to install a flow-through seawater system for sampling like that on the Oceanus and Elakha. They are installing interface systems that will allow equipment to be transferred and used across vessels. They are installing a new crane at their jetty to support equipment loading. They also have another small vessel (17 foot).

3. *How willing would you be to modify your vessel (e.g., adding hull mounted transducers, adding oceanographic winches, etc.) to make it more suitable for NOAA charter work? Would the possibility of long term contracts (multi-year) make you more amenable to modifying the vessel?*

Modifications are possible, but safety is the key factor. In the past, when major modifications were requested, they have engaged a marine architect to evaluate the proposal. Thus, modifications require careful planning; they are not done in a day. But the University is willing to make modifications, subject to this planning, particularly if there is a long term contract involve or the installed equipment could be of future benefit to other projects. For example, after evaluation, they have added major equipment in the past to support a project for researchers from another college.

4. *Given competing requirements or requests for your services, what do you predict your availability and capacity to support NOAA might be in the future (i.e., in the next year, in the next five years)?*

There is currently availability on their ship schedules and that availability is not expected to change that much. Weather is a bigger challenge than competing demands. The availability of the Elakha has actually increased over the last five years, due to certain projects ending or losing funding. The Pacific Storm also now supports year-round operations.

5. *What is the lead time required for NOAA to access your services (i.e., from initial scheduling through issuance of a contract to actually going to sea)?*

The Pacific Storm and Elakha are normally ready to go, since they do maintenance during bad weather. The University has even supported projects on one-day notice in the past. And they are willing and able to reschedule projects, even long-term ones, for example, when there are weather delays. Ideally and typically, though, a couple of weeks lead time is required. For NOAA specifically, it is typical to plan and schedule, for example, in January or February for operations in May or June.

6. *Are there limitations on the geographic region in which you can provide support?*

The Elakha supports coastal operations (out to 50 nautical miles) close to home, from the Columbia River to Coos Bay. The Pacific Storm has travelled from Baja, Mexico up to Alaska. The Oceanus is global, although it stays on the Pacific side for the most part, because other UNOLS vessels support the Atlantic. Voyages have included South America and the Galapagos Islands, west of Hawaii, the Orient, Dutch Harbor, and Mexico.

7. *Are there specific periods of the year when you can or cannot provide support (e.g., seasons where you have other priorities)?*

For the larger vessels, summer (April through August) is busy. The Pacific Storm is mostly scheduled for long blocks starting in April, but has open availability for short periods (4 to 5 days) here and there. November through January are less busy, weather permitting. The Elakha has availability all year round, currently scheduled for no more than 15 days a month.

8. *Are there other barriers to or incentives for working with NOAA?*

NOAA is easy to work for, and provides cruise plans in advance. Paperwork and invoicing can be challenging with the federal government in general. There are varying invoicing procedures for different groups within NOAA, and some make post-cruise invoicing smoother than others. There can sometimes be delays in payment (a worst case has been six months), which require follow-up effort.

9. *What are typical prices of the services you've provided NOAA in the past?*

Oregon State's rates for the Pacific Storm and Elakha are available at: https://fees.oregonstate.edu/. NOAA uses the external rates.

10. *How do you expect these prices to change in the future (i.e., in the next year, in the next five years)?*

Fuel drives pricing, so it is difficult to forecast. The University's marine operations are not meant to make huge profits or support the expansion of services, so prices are meant to reflect what the market will bear.

11. *What factors drive these prices?*

See above.

Interview with David Janka, Auklet Charter Services, Cordova, Alaska

info@auklet.com, answers received via e-mail, 2/28/17

1. *Can you provide a brief description of the services that you have provided for NOAA in the past?*

Auklet Charter Services provides vessel support for extended periods of time throughout the Pr. Wm. Sound region of Alaska. Licensed captain, cook/crew, meals & snacks, bunking w/bedding, skiff use, open deck with hydraulic boom and block, shuttle crews ashore, communications, navigation, general assistance and logistical support. See www.auklet.com for further descriptions and photos.

2. *Do you have additional current or planned capabilities (e.g., additional vessels, other services that that NOAA might not have used in the past) that you'd be interested in making NOAA aware of?*

Possible portable wet lab on deck. Additional hydraulics on the boom. Possibly a transducer well.

3. *How willing would you be to modify your vessel (e.g., adding hull mounted transducers, adding oceanographic winches, etc.) to make it more suitable for NOAA charter work? Would the possibility of long term contracts (multi-year) make you more amenable to modifying the vessel?*

I have done this for the Pr. Wm. Sound Science Center and would be more than willing to do it for NOAA. Long-term contracts: definitely.

4. *Given competing requirements or requests for your services, what do you predict your availability and capacity to support NOAA might be in the future (i.e., in the next year, in the next five years)?*

Our charter season is made up of about 80 percent research/work trip support trips. I try to keep the vessel available throughout the year and always look forward to working with federal agencies especially those I have worked with in the past; NOAA, NMFS, USFWS, USGS, USFS, NRCS, USCG.

5. *What is the lead time required for NOAA to access your services (i.e., from initial scheduling through issuance of a contract to actually going to sea)?*

If available, very little, less than a week.

6. *Are there limitations on the geographic region in which you can provide support?*

Prefer inland waters, especially within Pr. Wm. Sound but depending on the nature, time of year and duration of the charter - Kenai Fiords, Kodiak Is. area, Southeast Alaska, Glacier Bay, Yakutat Bay, Icy Bay. Again, prefer inland waters.

7. *Are there specific periods of the year when you can or cannot provide support (e.g., seasons where you have other priorities)?*

We operate year-round although winter does have its limitations.

8. *Are there other barriers to or incentives for working with NOAA?*

Not really. Paperwork is paperwork.

9. *What are typical prices of the services you've provided NOAA in the past?*

Basic rate is $1200.00 per day with up to 4 passengers. $100.00 per day each additional passenger. Six passenger maximum. Possibly more if a great deal of running time is required, if odd hours are required, if extra assistance is needed on my or my crew's part, if any special, if location is distant from our homeport of Cordova or additional equipment is needed for me to purchase. More Sept-March (off season for regular insurance). An additional $300.00 per day if more than 12 hours of running time is required (second captain required). Possibly more.

10. How do you expect these prices to change in the future (i.e., in the next year, in the next five years)?

We expect prices to change very little unless fuel prices rise substantially or inflation sets in.

11. What factors drive these prices?

Fuel, food, insurance, location, time of year, nature of work.

Interview with Linda Kadrlick, Alaska Charter Boats, 907-523-0897, Juneau, Alaska

linda@alaskacharterboat.com, 3/2/2017

1. *Can you provide a brief description of the services that you have provided for NOAA in the past?*

Alaska Charter Boats owns and operates one vessel, but primarily represents a fleet of vessels, including research vessels, fishing vessels, and pleasure vessels, as a broker. Their fleet has worked for several groups within NOAA. Alaska Charter Boats watches the federal procurement process and prepares bids for the vessels they represent.

2. *Do you have additional current or planned capabilities (e.g., additional vessels, other services that that NOAA might not have used in the past) that you'd be interested in making NOAA aware of?*

Alaska Charter Boats replies to specific requests for proposals. If nothing in their fleet matches the requirements, they sometimes try to locate a vessel for specific projects, although this is not typical of the process for NOAA. A key advantage of the vessels they represent is that their captains and crews are knowledgeable of local waters.

3. *How willing would you be to modify your vessel (e.g., adding hull mounted transducers, adding oceanographic winches, etc.) to make it more suitable for NOAA charter work? Would the possibility of long term contracts (multi-year) make you more amenable to modifying the vessel?*

Most of the time, Captains are willing to modify their vessels, if the changes are not too radical. There is definitely more willingness with longer-term contracts.

4. *Given competing requirements or requests for your services, what do you predict your availability and capacity to support NOAA might be in the future (i.e., in the next year, in the next five years)?*

There's always availability for the types of vessels NOAA uses. Vessel size is key, though. The smaller vessels are more available. It is hard to predict, though, what the makeup of the fleet of vessels they represent will be in the future.

5. *What is the lead time required for NOAA to access your services (i.e., from initial scheduling through issuance of a contract to actually going to sea)?*

Alaska Charter Boats reacts to the requirements of the specific request for proposal. More lead time is better, though. Four or five months is ideal for planning, longer for longer jobs.

6. *Are there limitations on the geographic region in which you can provide support?*

They represent vessels that serve Prince William Sound, Kodiak, and southeast Alaska waters.

7. *Are there specific periods of the year when you can or cannot provide support (e.g., seasons where you have other priorities)?*

The primary determinant is weather, so obviously there are limitations to going to sea in winter.

8. *Are there other barriers to or incentives for working with NOAA?*

Most of the time, the contracting process works well. The specificity of the contracts is helpful in finding the right vessel.

9. *What are typical prices of the services you've provided NOAA in the past?*

Prices depend greatly on the specific vessel. For the larger research vessels it is around $5 to $6 thousand per day dry rate (without fuel).

10. *How do you expect these prices to change in the future (i.e., in the next year, in the next five years)?*

Prices have remained stable over the last few years. It’s difficult to predict the future, but prices might go up a little.

11. What factors drive these prices?

Fuel.

Interview with Michael Kelly, Director of Marine Operations, Monterey Bay Aquarium Research Institute (MBARI), Moss Landing, California

831-775-1902, mkelly@mbari.org, 3/2/2017

1. *Can you provide a brief description of the services that you have provided for NOAA in the past?*

MBARI owns and operates the 117 foot R/V Western Flyer and the 135 foot R/V Rachel Carson. It also operates the smaller (32-foot) near-coastal vessel R/V Paragon under lease from the University of California, Santa Cruz. MBARI collaborates with NOAA's Monterey Bay National Marine Sanctuary, so there are sometimes one to two NOAA staff from the Sanctuary conducting piggyback research on MBARI cruises. NOAA has used the MBARI ships for dedicated cruises only twice in the last decade, in 2006 and 2010. The more recent project supported mapping a wreck using an autonomous underwater vehicle (AUV).

2. *Do you have additional current or planned capabilities (e.g., additional vessels, other services that that NOAA might not have used in the past) that you'd be interested in making NOAA aware of?*

With the exception of collaborating with the Sanctuary, MBARI usually only supports NOAA when they have capabilities that are not available elsewhere in the NOAA or academic fleet. The Institute does not actively seek out dedicated research missions for other organization.

3. *How willing would you be to modify your vessel (e.g., adding hull mounted transducers, adding oceanographic winches, etc.) to make it more suitable for NOAA charter work? Would the possibility of long term contracts (multi-year) make you more amenable to modifying the vessel?*

MBARI's existing vessels have some adaptability in configuration. More extensive modification would have to be evaluated on a case-by-case basis.

4. *Given competing requirements or requests for your services, what do you predict your availability and capacity to support NOAA might be in the future (i.e., in the next year, in the next five years)?*

If NOAA requested support from MBARI ships, short-term availability would be questionable. Their schedules do include contingency days, so shorter projects (5 to 6 days) might be feasible in the short term. For longer cruises, a one year lead time would be best.

5. *What is the lead time required for NOAA to access your services (i.e., from initial scheduling through issuance of a contract to actually going to sea)?*

See above.

6. *Are there limitations on the geographic region in which you can provide support?*

The Western Flyer and Rachel Carson support research along the entire West Coast from Canada to the Gulf of California in Mexico. Occasionally, they have travelled as far west as Hawaii.

7. *Are there specific periods of the year when you can or cannot provide support (e.g., seasons where you have other priorities)?*

Winter would be more available.

8. *Are there other barriers to or incentives for working with NOAA?*

Not to note.

9. *What are typical prices of the services you've provided NOAA in the past?*

MBARI's rates for the Western Flyer and Rachel Carson are available at: http://www.mbari.org/at-sea/mars-ship-rates/. These rates have been very recently updated (in the last several days). Note that although the rates for the Western Flyer are listed as for a 12 hour day, these same rates would apply to extended time at sea without returning to port and could include some nighttime work, subject to crew rest regulations. The rates for the Rachel Carson do reflect a 10 to 12 hour day.

10. How do you expect these prices to change in the future (i.e., in the next year, in the next five years)?
The recent update to their prices did not incorporate a large change, maybe a 3 percent increase. MBARI would not anticipate huge changes in the future unless there are dramatic changes in fuel prices.

11. What factors drive these prices?
See above.

Interview with Bob Pedro, Miss Linda Charters, Charleston, Oregon

541-888-2128, misslindacharters@gmail.com, 3/6/2017

1. *Can you provide a brief description of the services that you have provided for NOAA in the past?*

The Miss Linda is 76 foot charter research vessel. Her biggest projects for NOAA have involved the deployment and retrieval of current measurement devices (upwelling and subsurface) in the San Francisco Bay and adjacent rivers. With a NOAA scientific team aboard, she deployed the devices and retrieved them after a few weeks to change batteries, download data, and redeploy them at new locations.

2. *Do you have additional current or planned capabilities (e.g., additional vessels, other services that that NOAA might not have used in the past) that you'd be interested in making NOAA aware of?*

The Miss Linda has also done research charters for Oregon State University, the Navy, and the States of Oregon and California. She has bid on additional work for NOAA in the Puget Sound region. She is well configured for the deployment and retrieval of remotely operated underwater vehicles (ROVs) and autonomous underwater vehicles (AUVs). For example, she just recently finished a project deploying and testing wave gliders for a private company.

3. *How willing would you be to modify your vessel (e.g., adding hull mounted transducers, adding oceanographic winches, etc.) to make it more suitable for NOAA charter work? Would the possibility of long term contracts (multi-year) make you more amenable to modifying the vessel?*

Absolutely willing: modifications to better support customers are how the ship has evolved to its current configuration. For example, the A-frame was installed to support the Navy. Existing davits and winch were based on customer recommendations.

4. *Given competing requirements or requests for your services, what do you predict your availability and capacity to support NOAA might be in the future (i.e., in the next year, in the next five years)?*

The ship is dedicated to supporting research projects, so is generally available as needed. There aren't competing uses (e.g., fishing) and no current long-term research commitments.

5. *What is the lead time required for NOAA to access your services (i.e., from initial scheduling through issuance of a contract to actually going to sea)?*

NOAA typically plans early in the year for operations in the summer and this is ideal; the earlier the better. The ship is not always totally booked, though, so there is the potential for quick turnaround.

6. *Are there limitations on the geographic region in which you can provide support?*

Oregon, Washington, and California.

7. *Are there specific periods of the year when you can or cannot provide support (e.g., seasons where you have other priorities)?*

Winter is not busy because most users don't want to put their equipment in jeopardy, although Miss Linda has done and is currently doing projects during winter. Spring and summer are busier.

8. *Are there other barriers to or incentives for working with NOAA?*

NOAA projects are well organized and the NOAA science teams are professional. This makes them much easier to work with than some other organizations.

9. *What are typical prices of the services you've provided NOAA in the past?*

The Miss Linda has standard day rates for a minimum of 6 hours with hourly rates beyond that. However, for multi-day projects like NOAA's, they typically incorporate a discount, especially on transit days.

10. *How do you expect these prices to change in the future (i.e., in the next year, in the next five years)?*

There haven't been major price changes recently because fuel hasn't changed much. Miss Linda's standard fuel rate (about $20/hour) is not likely to change much unless there's a major spike in fuel prices (e.g., $1/gallon).

11. What factors drive these prices?
See question 10 above.

Appendix D: Acknowledgements

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