Challenges and Opportunities for Ocean Data to Advance Conservation and Management

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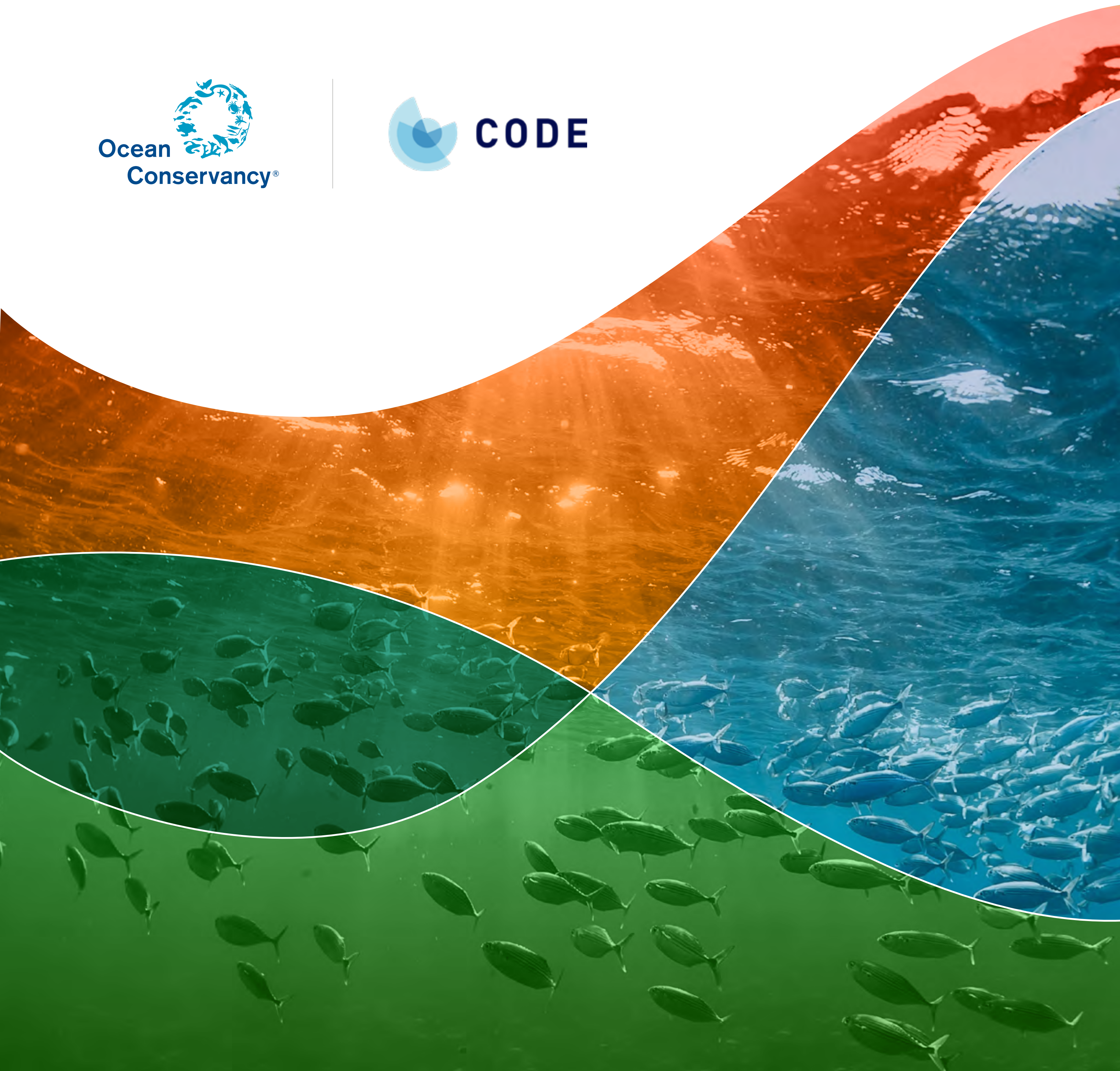
CODE



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Executive Summary

Ocean data collection and access are in the midst of a revolution with new technologies, new applications and renewed national commitments to understand and manage our ocean. We have an unprecedented ability to collect and analyze information about our environment and human uses of marine natural resources and to create significant opportunities for improvement in science and decision-making.

Government agencies currently have limits to their abilities to efficiently process and incorporate ocean data from new sources, including new technologies, into the decision-making process. In some cases, the data management infrastructure has not kept pace with the nearly exponential increase in data that the public and private sectors are now collecting. This problem is compounded by the reality that data-sharing programs are not always designed to benefit all stakeholders or the public equally, information is not accessible due to technical barriers, or longstanding cultural practices of withholding data to protect intellectual property, particularly in academia and industry.

Ocean data providers and stewards are beginning to address issues of data accessibility and discovery through frameworks such as FAIR (Findable, Accessible, Interoperable and Reusable) principles, which aim to facilitate the open and free exchange of data in the ocean observation community. However, even with the adoption of communities of practice, end users as well as Indigenous and coastal communities are not engaged to the extent they could be, and the federal government must continue to improve access and, in turn, allow for data sharing with and among these groups.

Other challenges must also be resolved if the ocean data revolution is to be impactful. Two examples of these challenges include chronic shortages of funding for the timely and efficient processing of data for ocean management and protecting the privacy and confidentiality of data providers while maximizing the use of new data streams from innovative technologies and from ocean industries (e.g., fossil fuel extraction, offshore wind).

Fortunately, solutions to these challenges are on the horizon, and the federal government is positioned to usher in a new era of improved data transparency, access and use to advance conservation, grow the blue economy, and support the sustainable management of ocean resources. The federal agency tasked to lead this ocean data revolution in the United States (U.S.) is the National Oceanic and Atmospheric Administration (NOAA). NOAA's mission is "to understand and predict changes in climate, weather, oceans, and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources."[i] The agency finalized a series of strategies in July 2020 to maximize the value of its data collection, processing and management assets, including Data, Cloud Computing, Artificial Intelligence (AI), 'Omics, Citizen Science and Unmanned Systems.

Beyond NOAA's commendable work and formidable capacity and expertise, the agency, along with its sister agencies at the Department of Interior (DOI), will need assistance from Congress and the White House in the form of sustained funding and political support to transform the ocean data ecosystem in service of marine conservation, the $373 billion blue economy, and sustainable and equitable use of marine resources.

The National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone (U.S. EEZ) (the National Strategy) is one example of an unprecedented opportunity to improve knowledge about ocean seafloor and water column ecosystems, guiding the appropriate types, locations and intensities of ocean use compatible with ecosystem health and function. The data to be collected, much less the enormity of new data to be processed, analyzed and applied to manage decisions, will require significant and sustained resources from Congress. Also, new partnerships among the federal government, private industry, academia and non-governmental organizations (NGOs) are needed to leverage survey assets and avoid duplication of effort. The National Strategy represents a microcosm of the challenges confronting ocean data custodians and end users and the opportunities for realizing the full potential of ocean data in service of sustainable and equitable management of ocean resources.

This paper reflects a comprehensive literature review, discussions from a February 2020 Ocean Data Roundtable hosted by the Center for Open Data Enterprise (CODE) in partnership with Ocean Conservancy, Esri, NOAA, Amazon Web Services, and Microsoft, and interviews with ocean data experts. Table 1 illustrates the technological, institutional, financial and cultural challenges faced by the ocean data community, from data providers to data stewards to end users, and some of the solutions available to alleviate them. The examples in Table 1 display a high-level summary of a more complete set of challenges and actionable solutions described in greater detail in the report.

i NOAA Mission and Vision. Science, Service and Stewardship [Internet]. Available from: noaa.gov/our-mission-and-vision

Table 1. Examples of ocean data challenges and solutions by issue area

Issue Area	Challenge	Solution
Equity and Transparency	Not all stakeholders, including Indigenous communities and coastal communities, have equal access to ocean data.	Retrofit or design open data and data-sharing programs that improve access to data for all who stand to benefit.
Funding	Data collection, management, sharing and use are expensive, and governments and other stakeholders are often resource-constrained.	Increase congressional funding commensurate with the growing volume and variety of ocean data that will need to be managed and shared via portals or the cloud. Develop new policies ensuring data management is equitably funded by taxpayers and private industry and access to data collected under federal permit is publicly available.
Forming partnerships	Federal government and regional data stewards are not fully leveraging their collective capacity to share or make data publicly available.	The Ocean Policy Committee (OPC) should examine data portals, products and services across federal agencies for improved collaboration and efficiency, namely through shared funding, combining duplicative efforts, and improving interagency, regional, state, Tribal and community collaboration identified in consultation with federal agencies and the broader ocean community.
Data sharing	There is a lack of available incentives and policy frameworks for private industry, academic scientists and other data collectors to share their data. Specifically, academic or industry ocean research data funded or required for regulatory reasons by NOAA are not always posted to publicly accessible platforms.	NOAA should evaluate the effectiveness of its Public Access to Research Results (PARR) plan and strengthen accountability measures for more timely and complete submission of data by researchers or federal permittees/lessees.
Privacy and confidentiality	New technologies enable the efficient collection and transmission of digital data for near real-time management, but federal laws err on the side of restricting such data releases to protect personal or proprietary information.	Balance privacy/confidentiality and open access of data by adapting approaches used in the health care industry to anonymize data while allowing it to be publicly accessed or allowing access under controlled conditions or for specific purposes.

Issue Area	Challenge	Solution
Integrating new data sources	New technologies are not always integrated into existing data collection and processing workflows, limiting their utility for broader public use.	Continue to expand the use of novel and efficient technologies such as Saildrones, electronic reporting and monitoring for collecting ocean and fisheries data while dedicating resources to integrate new and historical datasets so that long-term trends and shifting baselines in ocean conditions can be identified and future conditions predicted.
Data interoperability	Interoperability among different scientific domains and collaboration among data collectors and users are not fully implemented, thereby limiting data use.	The Office of Science and Technology Program (OSTP) should leverage ongoing collaboration with federal agencies on the National Strategy to advance FAIR principles. Coordination with new data providers on appropriate standards for public data systems should be initiated prior to research and monitoring efforts.
Data processing	Data processing can be costly, complicated and time consuming.	The development and use of consistent data standards and improved data interoperability will accelerate the processing of data that can be applied faster to management.
Cloud computing	Increasingly large datasets prevent users from downloading, processing or analyzing data due to lack of end-user computer power.	NOAA's Big Data Program (BDP) should be expanded to house ocean data and potentially fisheries data; the National Strategy could serve as a pilot to add ocean data to the BDP.
Stakeholder technical capacity	Not all ocean data stakeholders have the same level of technical capacity, making it difficult to achieve adoption of broad-based standards or embrace new technologies.	NOAA and regional data stewards should work with data users in remote areas to enable cloud-based data analysis that reduces the burden of accessing and using data.
Domain- and region-specific data gaps	Data domains and regions across the nation have different and sometimes unique data needs, although the following data gaps or needs are common across regions: marine species, commercial fishing vessel location, catch and effort, recreational fishing effort, bycatch and fish discards and bathymetry.	The OPC and federal partners, including NOAA, should create ongoing mechanisms to solicit input on regional data needs as was done in the 2018 Regional Data Platform scoping study conducted by NOAA and DOI's Bureau of Ocean Energy Management (BOEM). OPC should work with the regions to pursue data collection (and needed funding) in deficient, high-priority data categories identified in the scoping study, leveraging existing or new studies (e.g., the National Strategy).

Photo: Rafeed Hussain

Background and Introduction

Ocean Conservancy and CODE partnered to assess the challenges preventing decision-makers and the ocean community from maximizing the full potential of ocean data for advancing conservation, understanding the blue economy and sustainably managing ocean resources. While this assessment focuses on U.S. ocean data, the issues identified herein are potentially applicable to regions outside of the U.S. NOAA, the federal agency with primary responsibility for collecting ocean data and using it to track and forecast ocean conditions and manage marine resources, provided invaluable input toward this assessment.

Input for this report was based in part on a *Roundtable on Putting Ocean Data to Use* (Ocean Data Roundtable) held in February 2020 and co-hosted by NOAA, major online service providers including Amazon Web Services, Google, and Microsoft, Esri, CODE and Ocean Conservancy (Appendix V). At the Ocean Data Roundtable, more than 70 expert participants explored the use of ocean data and new data-driven strategies to improve ocean health and support the blue economy. CODE also gained a variety of perspectives from a series of interviews with ocean data experts from the public and private sectors, including NOAA, BOEM, regional ocean data experts and Shell.

This paper explores and builds on topics discussed at the Ocean Data Roundtable, mainly the current landscape of ocean data, impediments to optimizing the use of available ocean data in policymaking, and the various approaches to improving the management, archiving, dissemination and application of those data toward the twin goals of supporting a healthy marine ecosystem and a thriving, sustainable ocean economy. Solutions include advancements in ocean data partnerships, new resources, infrastructure, and policies needed to overcome the technical, social and legal obstacles of data sharing and management. The ocean data management challenges and associated set of recommended solutions are informed by CODE's involvement in addressing data transparency and accessibility issues in other industries (e.g., health care). CODE brings its unique perspective on data management problem-solving and lessons learned from other sectors to the ocean data ecosystem. Ocean Conservancy's long-standing work on conservation, ocean management and policy at the state, regional and national levels offers a perspective and link to data producers and those data users who rely on information to make informed management decisions. Ocean Conservancy's focus on federal ocean policy, federal appropriations, stakeholder engagement, fisheries management, ocean management and governance, science and policy expertise further informed this work.

Sources and Uses of Data

Data on America's oceans and coasts originate from a wide range of sources across many domains and have a tremendous number of applications. They are used to manage ocean ecosystems and fisheries, support the equitable and sustainable growth of the blue economy, protect endangered marine species, and help the global community mitigate and prepare for climate change.[1] Ocean data and models help us protect endangered species by understanding food sources and migration patterns, identify appropriate sites for offshore wind energy production facilities, develop better hurricane prediction models and plan for sea level rise and other impacts of climate change on coastal communities.

NOAA is responsible for one of the largest government data inventories, collecting, managing and publishing data ranging from the deep ocean to the atmosphere and outer space. The agency, along with other federal agencies, regional organizations, industry, academic partners, and data providers and users, manages a robust system of data on America's oceans, Great Lakes and coasts that has evolved significantly since its inception in 1807 as the U.S. Coast and Geodetic Survey. Additionally, private companies, community scientists, NGOs and others are leveraging new, inexpensive technologies such as drones and smartphones to add to the ever-expanding pool of ocean data.[2] These data may not be shared with government agencies or the public for a variety of legal, regulatory or technical reasons, thus limiting their application. The overall volume and complexity of ocean data types and sources further complicates their integration into portals for wider public use. Modern science is becoming increasingly computationally intensive and interdisciplinary, often additional requirements to make data accessible. This is leading to new approaches such as cloud technology being applied to ocean and atmospheric science.[3]

An opportunity exists to make more high-quality ocean data available for a wide range of applications and NOAA has initiatives underway that could lead to technological breakthroughs in how data it collects and manages is shared with researchers, managers and the public. In recent years, NOAA has developed collaborative opportunities with the private sector that promote and enable the public and commercial use of its data, specifically through its BDP via the cloud

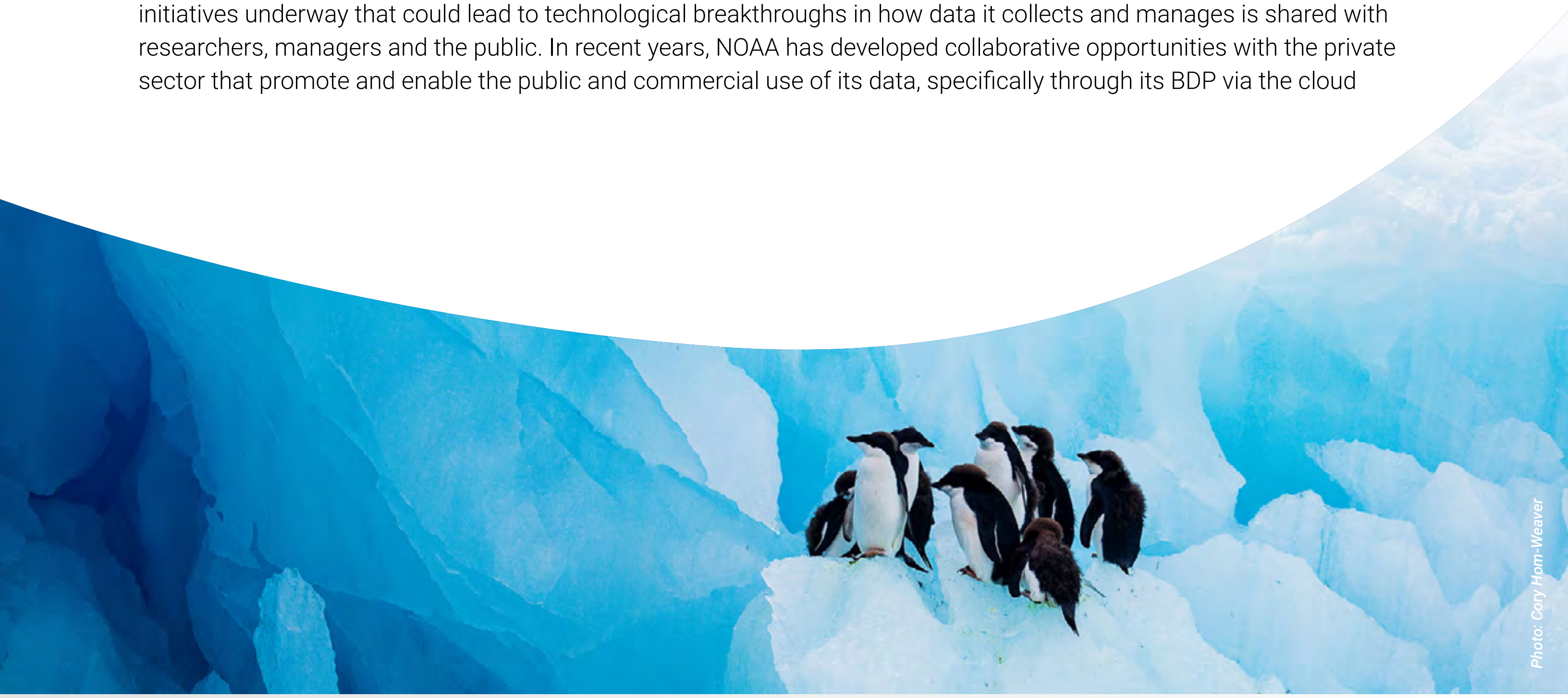


Photo: Cory Horn-Weaver

and a commitment to developing its AI capabilities. Other accomplishments in the area of improved ocean data availability and accessibility include the Marine Cadastre, a joint initiative managed by NOAA and BOEM (see page 18 for a description of Marine Cadastre), NOAA's National Center for Environmental Information (NCEI), and NOAA's Integrated Ocean Observing System (IOOS).

Complexity of Ocean Data

Ocean data, like the ecosystems they represent, are complex. This complexity presents significant challenges for data stewards—individuals who manage data at various points throughout its lifecycle—as they work to manage and share ocean data in usable ways. Reflecting this complexity is the landscape of public ocean data in the U.S., featuring national, regional and project-based data platforms, overarching data systems and individual datasets, real-time data and archival data assets, as well as a variety of data types covering domains as diverse as biology, chemistry, physics and economics.

This landscape is set to become more complex in the near future as new, inexpensive and autonomous ocean observation technologies become more widespread. Already, autonomous platforms that can take accurate measurements over the course of years-long deployments "are transmitting as much data in one year as has been acquired in the past century."[4] In fact, the amount of data held in NOAA's environmental data archives alone is expected to grow exponentially, exceeding 250 petabytes by 2030.[5] The increase in real-time data will require a transformation of network architecture and data management capabilities.

As ocean data stewards work to keep pace with this explosion of information, they will face a number of familiar challenges. These include funding and cost concerns, varying levels of technical capacity among stakeholders, data silos—data that are held by one office, program or agency and not effectively shared—regional data needs, privacy and confidentiality concerns, regional data gaps, a lack of incentives for data-sharing, challenges implementing data standards and data integration. To overcome these challenges, oceanographic institutions and data producers are encouraged to adopt FAIR principles. However, the effectiveness of implementation of FAIR principles will depend on data stewards modifying their data systems to support FAIR principles in practice.[6] The Intergovernmental Oceanographic Commission (IOC) convened global experts in September 2020 to discuss best practices for ocean observations and applications, recommending the use of FAIR principles, promoting adoption of metadata standards, and increasing outreach to the fisheries community, among other activities that would expand global interoperability of observations data.

Recent Federal Ocean Policy and Technological Initiatives

Ocean data has emerged as a federal priority in recent years both within Congress and the administration. In 2018 the Trump administration updated the federal ocean policy (Executive Order 13840) with a specific focus on making federal, unclassified data available to states and regions in a timely manner.[7] As part of this ocean policy framework, the White House OSTP and the Council on Environmental Quality co-hosted the White House Summit on Partnerships in Ocean Science and Technology in late 2019. The goal of the summit was to engage a cross section of the U.S. ocean community to discuss elevating, empowering and transforming how we work together to build and sustain partnerships, and to lay the foundation for a more broadly defined but commonly accepted direction to advance marine science, promote new technologies and explore the unknown ocean.[8]

These recent policy initiatives support building a robust ocean data ecosystem as part of a larger effort to fill gaps in our understanding of the ocean.[9] Meanwhile, regional ocean data stewards including the IOOS and Regional Ocean Partnerships (ROPs) have come together recently to discuss ways to boost data coverage and improve data sharing across the U.S.[10] Efforts to identify data gaps and needs at the regional level are helping to inform actions at the federal policy level, and vice versa. Beyond ocean policy, the Foundations for Evidence-Based Policymaking Act of 2018 imposes a broad legislative mandate on federal agencies to promote open data policies and inter-agency sharing of data. The cross-agency priority goal, Leveraging Data as a Strategic Asset, and the Federal Data Strategy further reinforce this mandate.[ii] Congress has also prioritized a number of bills related to ocean data, exploration, mapping, regional ocean data portals and federal ocean policy over the past few years, and this is expected only to increase as a renewed commitment to climate change advances under the Biden administration. The White House level OPC (Figure 1), made permanent as part of the National Defense Authorization Act at the end of 2020, provides a formal, interagency committee to advance ocean data challenges and strategic science and management opportunities.

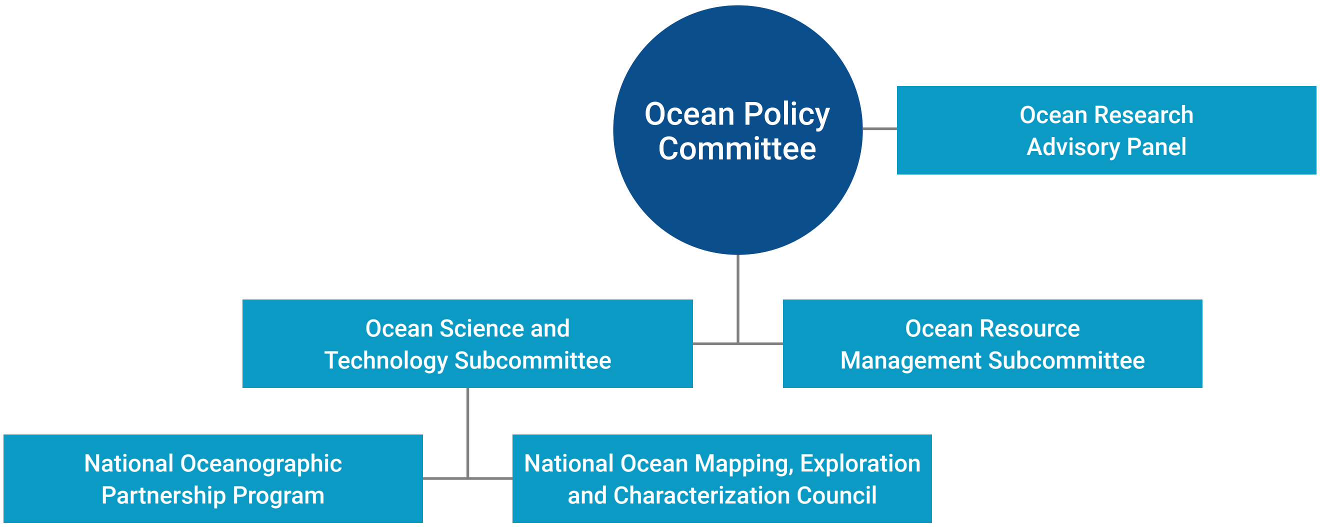


Figure 1. White House level interagency Ocean Policy Committee, co-chaired by the White House Council on Environmental Quality and the Office of Science and Technology Policy. All federal agencies with a stake in ocean and coastal management make up this Committee. The Ocean Resource Management Subcommittee coordinates policy related to ocean resource management across the federal government. The Ocean Science and Technology Subcommittee coordinates ocean science and technology and oversees a National Ocean Mapping, Exploration and Characterization Council and the National Oceanographic Partnership Program.

NOAA released six strategies in 2019-2020 in the areas of science and technology intended to help transform the agency's ability to disseminate information products in a timely manner: 1) Citizen Science; 2) Data; 3) Cloud; 4) Uncrewed Systems; 5) Artificial Intelligence and 6) 'Omics Strategy. These six strategies were in response to guidance from the administration and Congress and are interrelated and interdependent.[iii] The Data Strategy, for example, supports Citizen Science, Uncrewed Systems, AI and 'Omics,[iv] while Data is supported by the cloud and its platform for storing and making environmental data available to the public. NOAA's BDP, launched in 2015, exemplifies the agency's efforts to share its vast data holdings (so far limited to atmospheric data) with the public, leveraging cloud services as the platform for disseminating those data for free.

ii *See:* The Foundations for Evidence-Based Policymaking Act (Evidence Act; Pub. L. 115–435), performance.gov/CAP/leveragingdata/ and strategy.data.gov for more on government-wide open-data efforts.

iii *See: NOAA* Research Council, NOAA Science and Technology Focus Areas [Internet]. Available from: fisheries.noaa.gov/contact-directory/science-centers

iv 'Omics refers to a suite of advanced methods used to analyze material such as DNA, RNA, proteins or metabolites.

The Big Data Program—Harnessing the Cloud for Improved Data Dissemination

The BDP represents one approach to sharing ocean data more widely and cost-effectively by improving the "discoverability, accessibility, and usability" of NOAA's data resources."[11] NOAA initially framed the BDP as a pilot project to investigate whether or not the inherent value of NOAA's data could be used to underwrite the costs of commercial cloud storage while simultaneously driving innovation and new business opportunities for U.S. industry.[12] Under the original set of agreements, NOAA collaborated with Open Common Consortium and four commercial cloud service providers—Amazon Web Services, Google Cloud Platform, Microsoft Azure and IBM—to identify and publish select datasets of high value. The research phase of the project began in April 2015 under Cooperative Research and Development Agreements. In December 2019, NOAA moved beyond the research phase and operationalized the BDP through agreements with Amazon Web Services, Google Cloud Platform and Microsoft Azure.[13] As of June 2020, the BDP had published to the cloud about 120 NOAA files composed mostly of satellite, earth observation and atmospheric datasets.

While the BDP has thus far transferred relatively little ocean data to the cloud, the project's value can be seen in the posting of other major datasets. Next Generation Weather Radar (NEXRAD), for example, one of the most important systems of earth observation data, attracted much more user traffic in the months after it was published through the BDP. Before its migration to the cloud, the NEXRAD dataset had been extremely difficult to share due to its size and limitations on bandwidth.[v] Moving NEXRAD to the BDP made its data more accessible to users, with better user service, while also reducing the load on NOAA's systems.[14] Ocean data producers, consumers, managers and users could realize similar benefits by incorporating more ocean data into the BDP. Adding NOAA's ocean data to the cloud through the BDP would help centralize and consolidate datasets and make it easier to co-locate computation with data.

The universe of ocean data is broad, crossing numerous geopolitical boundaries and scientific disciplines. While there is no definitive system for categorizing ocean data, most major types of ocean data fall into at least one of five categories: biological, physical, chemical, geological/geophysical and socioeconomic. These data are all part of a broader set of oceanographic data, ranging from data on the organisms that live in the ocean, to the physical properties and processes of the ocean, to the chemical makeup of ocean waters.

v While the NEXRAD data was publicly available, the NCEI had to place limitations on time-series or large spatial download of the data. Order sizes were limited to 250GB to accommodate limited bandwidth and web server saturation. It was possible to order the data offline at the option of 0.5TB per day and $753 per TB. Prior to BDP, NOAA estimates that to download the NEXRAD Level II archive containing 270TB of data, a single user would have had to pay $203,310 over 540 days. See Ansari S, Greco SD, Kearns E, Brown O, Wilkins S, Ramamurthy M, et al. Unlocking the Potential of NEXRAD Data through NOAA's Big Data Partnership. Bulletin of the American Meteorological Society. 2018;99(1):194. Available from: doi.org/10.1175/BAMS-D-16-0021.1

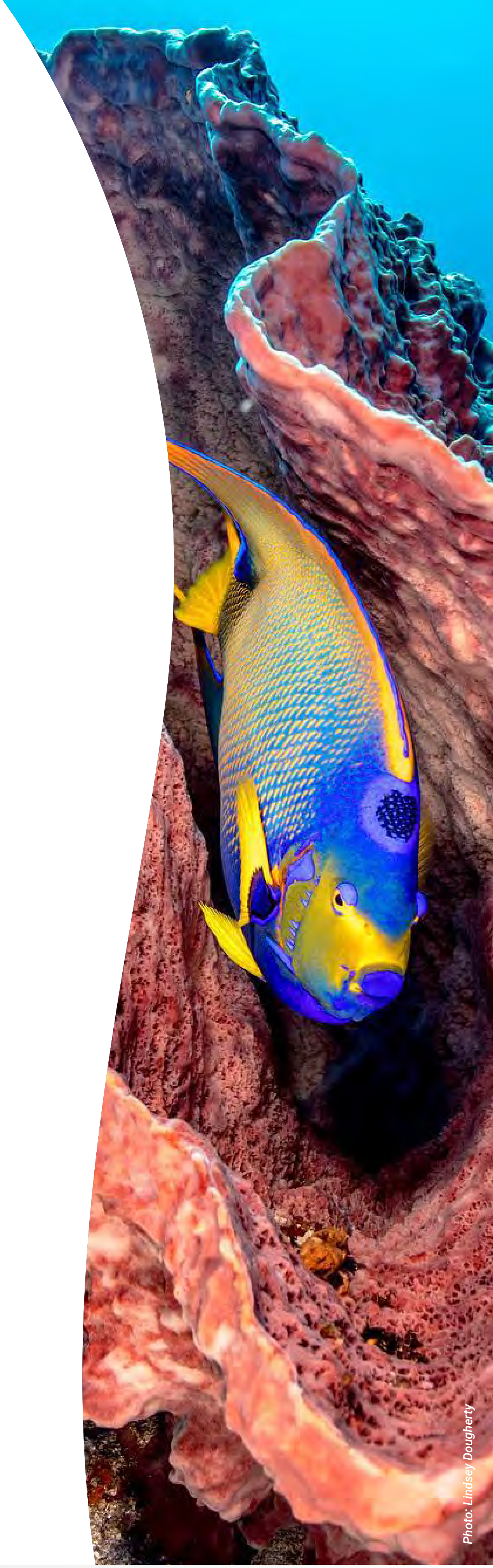


Photo: Lindsey Dougherty

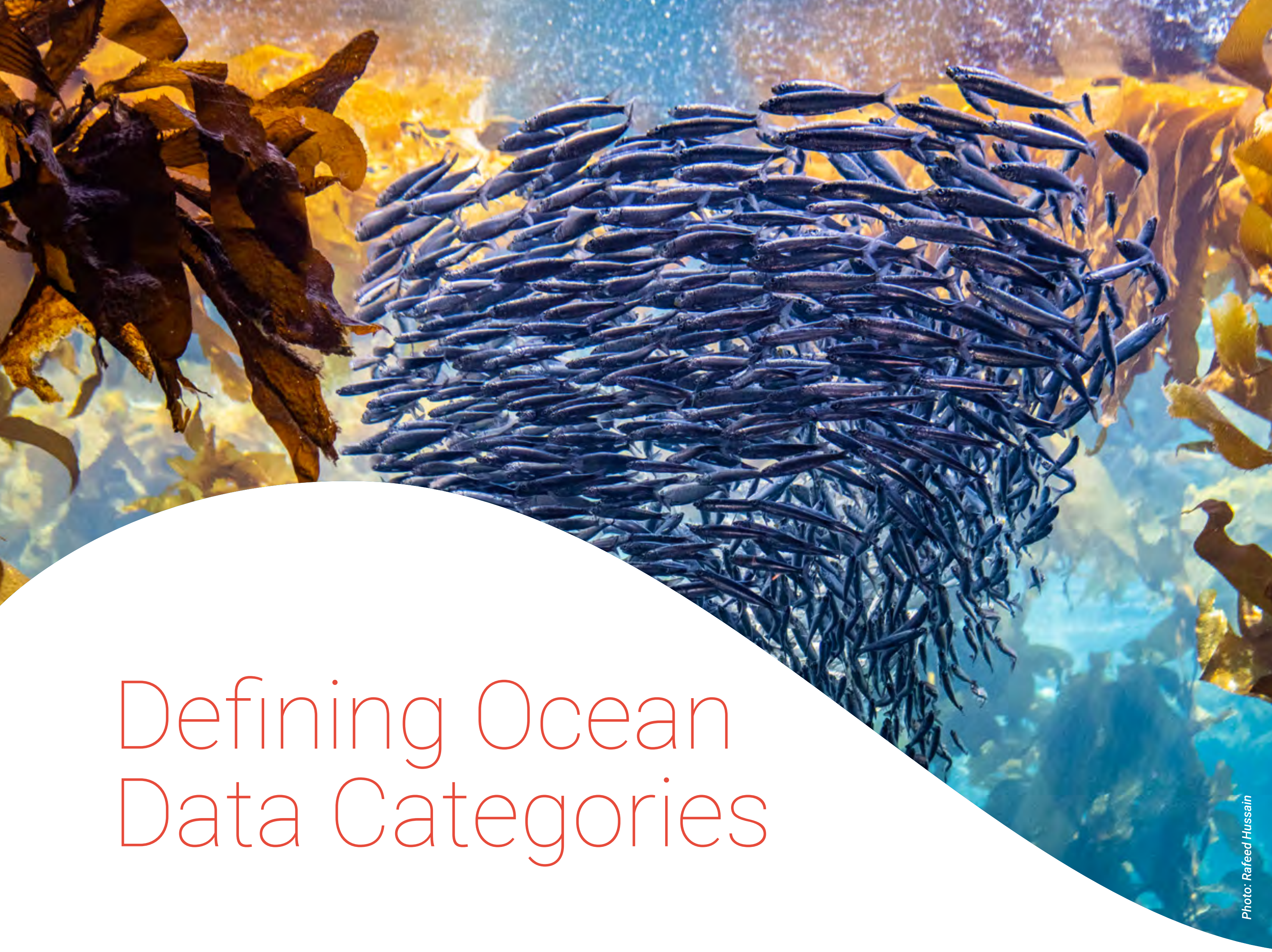


Photo: Rafeed Hussain

Defining Ocean Data Categories

Socioeconomic data are associated with blue economy (commercial, industrial) uses of the ocean and traditional (Indigenous, subsistence) uses of the ocean. They are used in combination with biological and chemical data to support decision-making in the areas of ocean planning and management as well as to monitor progress toward mandates under existing legislation (e.g., the Magnuson-Stevens Fishery Conservation and Management Act [MSA][15]).

A number of U.S. federal agencies collect and use a variety of ocean data, often driven by statutory mandates that specify the content, format and sharing requirements. Agencies collecting and relying upon ocean data to fulfill their missions include NOAA, BOEM, U.S. Coast Guard (USCG), U.S. Navy, Environmental Protection Agency (EPA), National Science Foundation (NSF), U.S. Army Corps of Engineers (USACE), Bureau of Transportation Statistics and National Aeronautics and Space Administration (NASA). State agencies also collect data in their territorial waters (generally 0-3 nautical miles with some exceptions), including fisheries data, which are important to management decisions. These federal and state agencies and the multitude of statutory mandates they must follow can make partnerships, coordination and management of ocean data a challenge, often resulting in silos and duplication of effort and, in some cases, lost opportunities to leverage observational assets for the benefit of multiple entities.

In addition to government data collection and stewardship programs, many industries collect ocean data for business purposes. Some of that data is now shared with the government per regulatory requirements, but the broader ocean data community would benefit if privately held data were shared more widely. Companies might be more willing to share their data if they were incentivized to do so and if their proprietary interests in those data were protected. For example, the oil and gas industry has a long history of investing substantial resources in seismic and seafloor data surveys throughout the life cycle of an oil field, from exploration to platform decommissioning, and these datasets could be useful to resource managers. The renewable energy industry—specifically offshore wind—is also emerging as a potential source of oceanographic and geological data that can serve the public.[16]

From an ocean-data management perspective, these five categories (biological, physical, chemical, geological/ geophysical and socioeconomic) present a number of challenges and interesting opportunities.

Biological Data

Biological ocean data applies specifically to marine organisms and how they interact with the ocean environment. Collection can be conducted using surveys that record the abundance, composition and/or behavior of marine life—or could include collections of specimens/individuals for later analysis. These data can be used to track and protect endangered species, achieve and maintain sustainable fisheries and boost ecosystem health.[17]

Biological data collection still occurs mostly at sea and is often conducted manually, requiring human input. While advances have been made in biological sensors, their wide use is not the norm. At-sea data collection requires heavy investment in human capacity as well as rigorous validation, data post-processing, synthesis and standardizations and, in many cases, physical archiving of samples. Examples of these types of data collection activities include scientific surveys using fishing gear, dockside collecting of landings information and at-sea observers. Improvements in electronic monitoring such as image recognition and environmental DNA (eDNA)[vi] could somewhat lessen the need for intensive human involvement in data collection but will still require ship time and may further increase the need for data storage and validation. Emerging monitoring technologies like eDNA, side-scan sonar, video monitoring aboard fishing vessels, and the use of AI are generating large data sets and computational requirements that require new management protocols.

Traditionally, biological data have been collected and managed differently from other types of oceanographic data. This has led to data interoperability challenges—including incompatible data standards and different data formats.[18] It is common to have a substantial delay in biological data publication (often up to five years) due to the processing difficulties associated with identification of samples and consultation of experts during peer review. Furthermore, the results of biological surveys tend to be highly dependent on survey methodology, and calibration across data sets can be challenging. Standardizing marine biological data through common metadata standards (e.g., Darwin Core) for sampling protocols has made it possible for users to model population monitoring, simultaneous counting and capture-recapture schemes.[19] (Metadata is the descriptive, contextual information about datasets and products that make them easier to discover, use and understand.)

vi eDNA techniques use a small sample of ocean water to monitor the abundance of fish and marine mammals. Scientists filter and copy the DNA for DNA sequencing. The sequencing technique allows scientists to look for many species by matching against a reference library of known species. See, *Tracking Marine Life with Invisible Clues: eDNA Enhances Ecosystem Monitoring [internet]. National Oceanic and Atmospheric Administration; 2020 Mar [updated 2020 March; cited 2020 April 2]*. Available from: fisheries.noaa.gov/feature-story/tracking-marine-life-invisible-clues-edna-enhances-ecosystem-monitoring. See also NOAA 'Omics Strategy (February 2020), available from: sciencecouncil.noaa.gov/NOAA-Science-Technology-Focus-Areas. 'Omics refers to a suite of advanced methods used to analyze material such as DNA, RNA, proteins or metabolites.

Efforts are underway in the U.S. to set standards for and consolidate data on the movement, behavior and habitat use of marine animals that are collected remotely via acoustic and satellite telemetry techniques. The Animal Telemetry Network is bringing a consistent approach to the national infrastructure that facilitates the collection, management and availability of marine animal telemetry data.[20] These data are used to minimize and mitigate impacts on marine wildlife resulting from interactions with human activities such as oil and gas, shipping, and fishing. As climate variability is also likely to drive changes in ocean conditions, animal migrations and human uses, managers will need the latest information on animal distributions to reduce harmful interactions.

Fishery-dependent (FD) data collection from the commercial and recreational fishing industries and government-led fishery-independent (FI) sampling are additional and somewhat unique sources of biological data. FD data include catch and fishing effort collected by fishing vessels or by third-party observers quantifying fish discards and bycatch of non-target species. FI data are those collected by NOAA researchers and partners involving a variety of sampling gears (e.g., bottom and pelagic longlines, plankton neuston and bongo nets, video camera array systems). Both FI and FD data can provide information on fish abundance, fish growth rates and natural mortality. Together, FD and FI data primarily are used in stock assessments to determine stock status and establish sustainable quotas. Varied data standards and formats, delay of data release, and need for Quality assurance (QA)/Quality control (QC)[vii] before release are among the challenges with FD data. Differences in data collection methods across fisheries and fishing sectors and the transition from paper logbooks to electronic reporting pose short-term challenges to the use of FD data. Additionally, management regulations may constrain the scope of data collection (e.g., to minimize the reporting burden on fishermen) or prevent the release of information due to confidentiality under the MSA. However, electronic reporting of FD data could potentially expedite the data flows for use in more timely fisheries management.

vii Quality assurance/Quality control is defined as quality management focused on providing confidence that quality requirements will be fulfilled. See National Institute of Standards and Technology. Information Technology Lab. Available from: https://csrc.nist.gov/glossary/term/Quality_Assurance_Quality_Control

A concerted international effort directed at improving biological observations is underway.[21] Biological data already appear in many data sources managed by the U.S. federal government—including the IOOS, NOAA Fisheries, U.S. Geological Survey (USGS) and the U.S. Fish and Wildlife Service (FWS)—as well as regional and international platforms like the Ocean Biogeographic Information System. These data, on their own or in combination with data from other disciplines, can be used to assess marine animals' habitat use, changes in migratory patterns due to deoxygenation, warming ocean temperatures and energy industry activity.[22]

USE CASE

Stock Assessment

NOAA Fisheries collects biological data, such as size and age of fish, growth rates and fecundity, on commercially and recreationally important fishes that are fed into stock status assessments for managing fisheries. Stock assessments are a regular part of the fishery management cycle in every region of the U.S. In the Gulf of Mexico, roughly three stock assessments are completed each year, coordinated by the Southeast Data Assessment and Review process that engages and coordinates dozens of data providers from NOAA and partner groups. Biological data are used to develop stock assessment (growth) models that are then used to estimate sustainable quotas for all of the managed species in the Gulf region. Gulf stock assessments help in the management of commercial fisheries valued at $900 million dollars and recreational fisheries totaling 19.5 million fishing trips and 2.7 million anglers.[23]

USE CASE

Sea Surface Temperature for Dynamic Management

NOAA Fisheries uses sea surface temperature (SST) measurements in a product called TurtleWatch that provides up-to-date information to prevent bycatch of loggerhead sea turtles, an endangered species. Fishermen on longline fishing vessels pursuing swordfish in the Pacific Ocean north of the Hawaiian Islands use this information in an effort to avoid catching turtles by mistake by avoiding areas of water that fall within the preferred thermal habitat for the turtles. In this way, SST measurements are deployed in dynamic fisheries management.[24]

Physical Data

Physical ocean data represent the "physical properties and dynamic processes of the oceans," including how the ocean interacts with the atmosphere, ocean temperature, currents, coastal dynamics and more.[25] These data are captured through variables including SST, subsurface temperature, surface and subsurface currents, sea surface salinity, subsurface salinity, ocean surface heat flux, wave conditions, ocean surface stress and sea ice.[26] Physical data also includes seafloor data—bathymetry, seabed forms, and sediment. These types of physical data tend to be managed and provided via the USGS, NOAA, NSF, states, and ROPs. Energy companies also maintain vast data holdings.

Physical ocean data play important roles in modeling larger systems and phenomena. For example, SST is used extensively in weather prediction models such as forecasting the *El Niño-Southern Oscillation* cycle and its associated effects on weather patterns, ocean conditions and marine fisheries. SST measurements are collected through different types of sensors as well as through a sustained operational stream of satellite imagery data.[27] SST is a key indicator in understanding marine ecosystem dynamics as the growth and reproduction of many species have thermal tolerance limits. A predicted increase in SST over the next century may result in poleward migration of fish species and have a profound effect on marine ecosystems.[28]

While oceanographers have used data from multiple sources for better spatial and temporal resolution, there are still opportunities to integrate additional data sources to improve real-time oceanographic information. For example, research cruises regularly sample water quality information to correlate the presence of marine species with ocean conditions. The same data could also be used to improve oceanographic models.

USE CASE

Ports and Navigation

Commercial vessels face navigational challenges such as shifting currents and tides and variable water levels, underscoring the importance of providing timely information to them for a safe and efficient passage to port. Physical ocean data will become more critical to safe navigation as maritime commerce and related vessel traffic are expected to grow and as ships continue to increase in size. The National Ocean Service (NOS) is meeting this data need through the Physical Oceanographic Real-Time System (PORTS®), a decision-support tool that monitors ocean and atmospheric conditions and disseminates information and predictions of currents, water levels, winds, air and water temperatures and salinity to approaching vessels. PORTS® could improve the economic efficiency of transporting goods and minimize collisions, groundings and oil spills by helping mariners avoid unnecessary delays and dangerous situations caused by rapid changes in ocean and weather conditions.

USE CASE

Search and Rescue

The USCG uses physical ocean data on the speed and direction of ocean surface currents from models and observations, including data from the IOOS' high frequency radar network. The USCG integrates national and regional models into its Search and Rescue Optimal Planning System through the Environmental Data Server (EDS) developed by RPS Applied Science Associates.[29] The ocean data delivered via the EDS supports national and international search and rescue missions.

Chemical, Biogeochemical, and Geological/Geophysical Data

Chemical ocean data relates to the chemical makeup, processes and cycles of ocean waters as well as how seawater interacts with the atmosphere and the seafloor.[30] Biogeochemical data relates to the cycling of nutrients from the biotic environment or biosphere (i.e., living organisms) to the abiotic environment, which includes the atmosphere, lithosphere and hydrosphere, and vice versa.

Data on these cycles can help researchers understand and monitor the ocean's role as a major carbon sink. The deep ocean, and its seafloor sediments in particular, plays a critical role in the global carbon cycle by acting as a long-term reservoir of most of the earth's carbon. The ocean acts as a biological pump by converting sunlight and carbon dioxide via photosynthesis into organic carbon through primary producers (phytoplankton), which in turn feed higher order animals from zooplankton to forage fish to whales. When phytoplankton and marine animals die and decay, the organic carbon falls through the water column, and much of it settles onto the seabed. The performance of this pump may be at risk as climate change affects ocean conditions.

In order to assess the biological pump and its ability to contain carbon dioxide from industrial and other emissions, scientists need to measure how carbon is transferred from living organisms and sequestered in deep ocean waters and sediments. Some of the chemical data needed to understand this process includes variables like oxygen, nutrients, inorganic carbon, particulate matter, nitrous oxide, stable carbon isotopes, dissolved organic carbon and ocean color.[31] These observations should be collected and analyzed over time with sufficient frequency to capture patterns on sub-seasonal, seasonal and even longer timescales.[32]

Geological/geophysical observations overlap with physical and chemical data, but are specifically related to the ocean seafloor or sub-seafloor features. By sampling these data, scientists are able to glean insights on seafloor spreading, plate tectonics, volcanic processes, magma genesis and other phenomena.

USE CASE

Ocean Acidification Data Use

Ocean acidification occurs as a result of increasing absorption of atmospheric carbon dioxide. It is measured by a decrease in pH levels of seawater and can adversely affect coral reefs, marine plankton and survival of larval marine species. Ocean acidification has a real impact on the marine shellfish industry because it reduces the growth rate of shellfish species or kills juveniles. The University of Washington and the Pacific Coast Shellfish Growers Association collaborate to disseminate ocean acidification data through the Northwest Association of Networked Ocean Observing System (NANOOS) web portal. Shellfish growers along the West Coast of the U.S. use this real-time data to improve production by choosing when to carry out specific functions like refilling hatchery tanks on land and deciding when to set out juveniles for grow-out.

Socioeconomic Data

The overall blue economy could generate $3 trillion in economic activity and employ 40 million people around the world by 2030.[33] Socioeconomic indicators of activity for ocean-based industries include turnover, employment, exports, number of enterprises, density, poverty, demographics and unemployment rates. This category includes data about industries like shipping, tourism, fishing and offshore renewable energy production as well as data on ways the ocean itself may have a socioeconomic impact—for example, as a source of natural resources and its provisioning of ecosystem services such as flood protection and carbon sequestration. These data represent an area of focus for federal and state agencies, coastal managers, industries, universities and ROPs. Socioeconomic data can also include data from the aforementioned oceanographic categories for use in planning, permitting and other ocean resource management decisions. Community impacts to a specific area can also be considered as part of this analysis using socioeconomic data.

At the federal level, NOAA and BOEM developed the Marine Cadastre to share data to "meet the needs of the offshore energy and marine planning communities."[34] The Cadastre has evolved and now includes data ranging from essential fish habitat composition and coverage to proposed and designated critical habitat that can be used in decision-making. Data hosted on the Marine Cadastre have been used for projects ranging from understanding how vessel noise impacts marine mammals to an offshore wind energy development project.[35] Additionally, NOAA's Economics: National Ocean Watch (ENOW) Explorer provides access to employment data and other economic information for local U.S. municipalities (e.g., counties) that border the ocean and Great Lakes.[36] OceanReports, a web-based tool developed jointly by NOAA's National Centers for Coastal Ocean Science and Office for Coastal Management and BOEM generates user-friendly, synthesizes reports derived from the Marine Cadastre that can be used by stakeholders in shipping, energy infrastructure development, permitting and conservation.[37]

Socioeconomic data are a critical component of ecosystem-based management, particularly as it applies to fisheries and tourism. Researchers are beginning to develop indicators derived from community-level socioeconomic data, such as community dependence on fishing and other marine industries. These metrics are in their infancy, and their advancement will help show how fishing communities may be vulnerable to changing ocean conditions, allowing fishery managers to monitor change and plan for the future of the fishery.[38] While NOAA collects an array of socioeconomic datasets, applications for other non-NOAA data sources are just starting to be explored. For example, a public health survey conducted by the Centers for Disease Control and Prevention has provided data on the health and well-being of people in the fishing industry which NOAA's National Marine Fisheries Service (NMFS) is analyzing to inform ecosystem-based fishery management.[39]

USE CASE

Ocean Activity Data

Data on ocean infrastructure and economic activity are used to plan new development and reduce potential conflicts among multiple ocean uses. For example, the American Waterway Operators, a trade association representing the tug and barge industry, is responding to increasing traffic and development by using data from the Mid-Atlantic Ocean Data Portal to plan routes that avoid new offshore wind energy sites and other potential obstacles.[40] The Automatic Identification System (AIS) used for tracking vessels via satellite- or shore-based stations is another data source that is increasingly seen as a tool for predicting collisions, oil spills, illegal fishing activity and potential interactions with marine mammals. More widespread deployment of AIS stations in the Arctic, where sea ice is decreasing due to warming waters and new shipping lanes are emerging, would be useful for improving vessel safety, facilitating enforcement of regulations, avoiding conflicts with subsistence users and avoiding marine mammal interactions.

USE CASE

Socioeconomic Data to Protect Coral

The New England Fishery Management Council (NEFMC) used spatial datasets and visualization tools from the Northeast Ocean Data Portal as it considered new management areas to protect deep-sea corals. Northeast Ocean Data Portal products helped fishermen and other stakeholders understand the issue and helped Council members facilitate the discussion. The NEFMC presented to stakeholders proposed management areas showing Northeast Ocean Data Portal data layers, including fishing vessel activity, enabling the public to provide and NEFMC to incorporate detailed feedback on proposals.[41] In the end, this process, heavily informed by socioeconomic data, achieved the twin objectives of protecting corals that provide habitat for numerous fish and invertebrates while minimizing fisheries interactions with corals that can result in damaged or lost commercial fishing gear.

Photo: Rafeed Hussain

NOAA's Ocean Data Holdings

Improvements in data-collecting infrastructure over the last few decades have increased the scale of ocean observations. The collection of data on our coasts, fisheries and deep seas has evolved to include a wide variety of technologically advanced ocean observation systems. Today's observation systems include underwater cables with fixed-point ocean observation infrastructure, crewed submersibles, autonomous underwater vehicles and more. This section describes various types of ocean data collected and maintained by NOAA and the programs, partnerships and other infrastructure in place to manage ocean data from the U.S. EEZ. NOAA maintains key pieces of the ocean observation infrastructure, including IOOS, 16 large oceanographic vessels and more than 400 small vessels.[42]

Table 2 presents a sample of ocean data products and elements of NOAA, federal agencies and regional organizational infrastructure along with information about who manages the data system and associated funding lines within the federal budget, including specific authorities. Data categories and key data sets are also included where applicable. This is not a comprehensive presentation, but serves to highlight the diversity and complexity of the ocean data ecosystem within NOAA, federal and regional partners.

Table 2. Data systems, federal organization, data categories and key data sources for U.S. federal agencies and partners. Funding mechanisms are included where appropriate under federal organization.

Ocean Data System	Federal Organization and Funding	Data Categories/ Products	Key Data Sources
Marine Cadastre	The Marine Cadastre was created via legislative directive to the Secretary of the Interior and is largely funded with funds from BOEM's Conventional Energy line. BOEM teamed with NOAA's NOS for the public-facing site. Related funding within NOAA NOS is cited as Regional Ocean Data Platforms.	Biological and physical oceanographic variables, jurisdiction and boundaries, ocean uses and planning areas, physical and oceanographic.	Federal agencies like NOAA, BOEM, Bureau of Indian Affairs, USGS, EPA, Department of Energy, academic and research institutions like Duke University, University of New Hampshire, regional ocean data portals like the Northeast Ocean Data Portal.
National Data Buoy Center	The office of the National Data Buoy Center is housed within NOAA's National Weather Service (NWS). Many activities, and their funding streams, trace back to NWS' Observations line. Data from the Atlantic Oceanographic & Meteorological Laboratory within NOAA's Office of Oceanic and Atmospheric Research (OAR) is also important, funded through OAR's Laboratories & Cooperative Institutes line.	Mostly physical oceanographic data like ocean currents, salinity, sea level pressure, water temperature.	Buoys maintained by NOAA and partners such as the IOOS Regional Associations (RAs), oil and gas companies, academic institutions and others.
Species Information Center *(Recently replaced by the Stock SMART Tool)*	The Species Information Center (SIC) is housed within NMFS' Office of Science and Technology (OST), with the data gathered by that office but reported by other parts of NMFS. The SIC is for internal NOAA use only while Stock SMART is the public-facing portal to some of that information. The OST and much of the data gathering is funded by lines under NMFS' Fisheries Science and Management.	An online clearinghouse for stock assessment data that tracks stock assessment results from across regions with respect to their current overfishing and overfished status, as well as historical trends in catch and biomass.	Regional stock assessments

Ocean Data System	Federal Organization and Funding	Data Categories/ Products	Key Data Sources
Comprehensive Large Array-data Stewardship System	The Comprehensive Large Array-data Stewardship System (CLASS) is maintained by NOAA's National Environmental Satellite Data and Information Service (NESDIS) and supported by funding that comes via their Satellite and Product Operations (SPO) line.	Environmental data for land, ocean and atmospheric applications	NOAA and Department of Defense (DOD) satellites.
National Center for Environmental Information	The NCEI is maintained by NOAA's NESDIS and has a dedicated funding line.	Range of products across ocean data categories with archival or near real-time data. Includes buoy data, satellite data products, and international projects like the global Argo network, World Ocean Database.	Federal agencies including unclassified data from the DOD, state and local governments, regional portals, private sector. Foreign data through direct bilateral exchanges with other countries and organizations, and through the facilities of the World Data System for Oceanography.
Earth Observing System Data and Information System	The Earth Observing System Data and Information System (EOSDIS) is the primary component of NASA's Earth Science Data Systems, which receives funds from NASA's Earth Science line.	Physical and chemical oceanographic variables.	Satellites, aircraft, field measurements and various other programs from various EOSDIS data centers such as Alaska Satellite Facility, Global Hydrology Resource Center, National Snow and Ice Data Center, among others.
Integrated Ocean Observing System Regional Associations	The U.S. IOOS RAs are coordinated by NOAA's NOS and receive their base support from a dedicated line under Navigation, Observation, and Positioning within NOS. RAs also compete for grants from and/or partner with federal, NGO, academic or industry entities.	Real-time observations, models and forecasts across different oceanographic categories. Custom-made data products reflect the priorities of each Regional Association. NCE archives IOOS data.	Platforms and stations maintained by the RAs, NOAA and other federal agencies, academic and research institutions, local and state governments.
Regional Ocean Partnerships and Associated Regional Ocean Data Portals	ROPs are comprised of representatives from various federal and state agencies, organizations, and IOOS RAs. NOAA is generally the lead federal funding agency, and has a dedicated funding line within the NOS Ocean and Coastal Management and Services.	Data made available through the different portals or platforms vary depending on the management needs of the ROPs.^	Federal and state agencies, industry, NGOs, IOOS RAs and other data sources unique to regional needs. Data may be from federal data sources but tailored to scale for regional management.

Ocean Data System	Federal Organization and Funding	Data Categories/ Products	Key Data Sources
The National Water Level Observation Network	The National Water Level Observation Network is managed by NOAA's Center for Operational Oceanographic Products and Services (CO-OPS), within the NOS. Funding falls under the Navigation, Observation and Positioning line.	Supports safe navigation through tide predictions and nautical charts and contributes to NOAA's forecast models, including tsunami and storm surge warnings. Real-time water level information is now available 24/7.	Approximately 210 shore-based stations monitor water levels across the country, with 100 in the Great Lakes region.
National Centers for Environmental Prediction	The National Centers for Environmental Prediction (NCEP) is housed within NOAA's NWS. NWS appropriations are divided into a few overarching funding streams: • Observations • Central Processing • Analyze, Forecast and Support • Dissemination • Science and Technology Integration. Many of the various NCEP centers and their functions can have their funding directly traced to various line items.+	NCEP comprises nine distinct centers, including the Climate Prediction Center and the Ocean Prediction Center, and provides a wide variety of national and international weather guidance products to NWS field offices, government agencies, emergency managers, private sector meteorologists and global meteorological organizations.	All available data from operational remote and in situ observing systems.*
Center for Operational Oceanographic Products and Services	NOAA's CO-OPS is one of the offices comprising the Navigation, Observation, and Positioning subactivity under the line item of the same name in the NOS.	CO-OPS provides accurate, reliable and timely information on tides, water levels, currents and other oceanographic information. Data products and services support safe and efficient navigation, sound ecosystem stewardship, coastal hazards preparedness and response, and the understanding of climate change.	Ocean observing infrastructure that includes: 1) in excess of 200 permanent water level stations along the U.S. coastline and in the Great Lakes and 2) an integrated system of real-time sensors clustered in busy seaports, and 3) temporary meters that collect observational data for making tidal predictions.

^For example, the Northeast Ocean Data Portal contains over 4,500 data layers on marine life, ecosystem function and human activity for ocean resource management.

+As NOAA describes it, "Each National Center depends on data from the Observations Subactivity, model output from the supercomputers in Central Processing, dissemination infrastructure from the Dissemination Subactivity, and innovations from the Science and Technology Integration Subactivity.... . The [Analyze, Forecast, and Support] Subactivity supports seven NCEP National Centers."[43]

* For example, the West Coast Operational Forecast System assimilates satellite SST and sea surface height (SSH) data sets and High Frequency Radar currents. The NWS Global Ocean Data Assimilation system uses SST, SSH, plus in situ temperature and salinity profiles.

Integrated Ocean Observing System (IOOS)

IOOS is a national-regional partnership of 11 RAs providing near real-time ocean observation data. IOOS is governed by the Integrated Coastal and Ocean Observation System Act of 2009 establishing statutory authority for the development of the U.S. IOOS.[44] The Act mandates the establishment of a national integrated system of ocean, coastal and Great Lakes observing systems coordinated at the federal level. The RAs provide modeling outputs and forecast information with data management capabilities and are the informational bridge between local/regional and national/federal levels, tailoring data products to the needs of the regions while providing higher resolution data to complement the federal system. IOOS is also the U.S. contribution to the Global Ocean Observing System (GOOS).

IOOS guides integration amongst the RAs, but each IOOS RA has its own governance structure that may include government, research institutions, industry and NGOs. The RAs maintain regional networks of ocean observation infrastructure and data management services following standardized IOOS requirements. They often present information through a data explorer, which tracks real-time observations from sensor networks and or historical information from archival datasets. These data are derived from a variety of sources, including federal and state governments. The Alaska Ocean Observation System (AOOS), for example, sources data from NOAA, USGS, the Department of Agriculture, and state agencies such as the Alaska Department of Fish and Game and the Alaska Department of Natural Resources.[45] In addition, AOOS relies on modeling outputs developed by academic institutions such as University of Alaska Fairbanks and the Alaska Pacific University.[46]

Academic and research institutions play a significant operations role in the RAs. The University of Maine maintains the observing systems for the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS). The Gulf of Maine Research Institute has developed the portal and products for NERACOOS. Similarly, the University of Washington, Oregon State University and the Oregon Health and Science University developed the data explorer for NANOOS.

IOOS has also partnered with the Ocean Observatories Initiative (OOI), maintained by NSF, on the development of new digital tools for improved access and use of ocean observing data through OOI's cyber-infrastructure. OOI is a highly adaptive platform of both well-established and experimental sensors that enable the research community to respond quickly to ocean events and to test emerging or novel ocean observation sensors that might one day be added to IOOS' network.

Regional Ocean Partnerships (ROPs)

ROPs are regional organizations convened by governors in collaboration with federal and Tribal governments and stakeholders to address ocean and coastal management issues unique to each region. ROPs and their associated regional ocean data portals are recognized in the federal ocean policy and within specific bills in Congress such as the Regional Ocean Partnership Act, BLUE Globe Act and federal appropriations.[47] ROPs currently include the Northeast Regional Ocean Council (NROC), the Mid-Atlantic Regional Council on the Ocean (MARCO), the Gulf of Mexico Alliance (GOMA) and the West Coast Ocean Alliance (WCOA).

Each ROP strategically addresses management challenges based on regional ecosystem needs and economic interests. NROC, for example, has prioritized ocean and coastal ecosystem health, coastal hazards resilience, and ocean data and planning. MARCO's focal areas are climate change adaptation, marine habitats, renewable energy, water quality, and ocean data and planning. GOMA concentrates on coastal resilience, data and monitoring, habitat resources, wildlife and fisheries, and ecosystem services. WCOA provides a forum for dialogue on common ocean management priorities such as compatible ocean uses, ocean and coastal data, transparent decision-making and Tribal rights.

Approaches to data collection and management, access to data and volume of data vary among the ROPs. The Northeast Regional Ocean Data Portal includes thematically organized data on marine life and habitat, commercial fishing, aquaculture, energy and infrastructure, and more to reflect its strategic regional priorities. Many sources of data form part of the workflows for portals (see Table 2), including IOOS RAs, federal and state agencies, industries and universities. Underlying workflows for these data portals involve multiple stages of rigorous subject matter review and quality control, representing opportunities for collaboration among federal agencies, the IOOS RAs, scientific experts, science and monitoring organizations forming around offshore renewable energy such as the Responsible Offshore Science Alliance and Regional Wildlife Science Entity, and ROPs to collectively advance all interests. Accessing federal data through the Marine Cadastre and tailoring for specific regional needs is also done by ROPs for each data portal. Collaboration among ROPs with federal data needs should continue to be a priority as well as improving data synthesis for geospatial data layers.

Other Data Sources

Research centers and academic institutions play a critical role in the ocean data ecosystem. In addition to maintaining ocean sensors and platforms that contribute to federal data, they also contribute to the IOOS RAs and ROPs as described above. They are also important sources of socioeconomic data, including through research consortia and networks like the Marine Social Sciences network and the ocean section of the Earth Systems Governance Global Research Project. The U.S. DOD, specifically the U.S. Navy, also holds an extensive amount of ocean data, most deemed classified and therefore not generally available to the public. However, some data are released for public use, such as those on marine mammals and unexploded ordinances. NGOs also help disseminate ocean data through platforms such as Resource Watch, Clean Swell, Fisheries Solutions Center and Global Fishing Watch. Community science platforms like iNaturalist are crowdsourcing platforms where marine life observations could be integrated into broader assessments.

Some Tribal Governments and Indigenous organizations gather data concerning marine ecosystems including humans. Often such data are regarded as proprietary and sensitive, but in some circumstances the data may be shared with others for specific purposes. Some Tribal and Indigenous data may be from instruments or sensors and thus in standard scientific formats. Other data may be held in a variety of forms, including maps, stories, songs, art, and more. Data management systems have been developed that are capable of handling such materials, and doing so with the appropriate protections of intellectual property, individual privacy, and cultural protocols.[viii] Working with Tribal Governments and Indigenous organizations can help develop partnerships for mutually beneficial sharing of data and information.

The maritime industry and companies in the blue economy sector more broadly collect data from a variety of sources such as geophysical or biological surveys associated with offshore energy exploration and mineral or metal extraction. These datasets are diverse including birds, fish, benthic ecology and seafloor sediment composition. The data are often unavailable or inaccessible outside these companies, but are useful to resource managers if companies or sectors had an incentive (or were required under lease agreements) to share data more widely. The offshore wind industry, working with RAs and ROPs in the Northeast U.S., is voluntarily sharing oceanographic and environmental data that could support the sustainable management of ocean or fishery resources. The industry's lease agreements with the U.S. government require that such data be collected and submitted to the relevant agencies as part of the review process, with BOEM as the lead permitting agency. Several companies, however, are voluntarily sharing this data more broadly than permitting currently requires.

With more such incentives and requirements, the private sector could ultimately share very large amounts of data. For example, the Marine Data Exchange, created to store and share offshore survey data in the United Kingdom, contains 167 terabytes of data from nearly 3,000 surveys.[48] New programs for sharing private sector ocean data will have to include plans for large-scale data management.

viii See, for example, the Exchange for Local Observations and Knowledge in the Arctic (ELOKA). Available from: eloka-arctic.org

USE CASE

Global Fishing Watch

Global Fishing Watch is a unique collaboration between corporate and NGO partners to collect and present data assets about global fishing from multiple sources. They aggregate vessel-tracking data from AIS and Vessel Monitoring Systems (VMS) and other sources to track roughly 65,000 vessels with a 72-hour time delay.[49] Global Fishing Watch's platform has supported Argentina's effort to establish its first Marine Protected Areas (MPAs), helped Indonesia seize a notorious illegal fishing vessel, been used to flag potential illegal fishing activities in numerous jurisdictions and provided data for dozens of published research articles.[50]

USE CASE

iNaturalist

iNaturalist is an app and community that helps community scientists identify the plants and animals they see in the wild and share their knowledge and observations with a large network of scientists and naturalists.[51] iNaturalist data has been used for a variety of scientific purposes including to identify new ocean species. For example in 2019, as part of an annual "BioBlitz" event, graduate students from Northeastern University spent one day collecting and identifying new species in Friday Harbor, Washington. They deposited their samples into Northeastern's Ocean Genome Legacy (OGL) collection and uploaded them to iNaturalist for crowd-sourced review and confirmation. In 2019, the project uploaded 60 samples, 25 of which represent new species in OGL's collection.[52]

USE CASE

Gulf of Mexico Coastal Ocean Observing System and Corporate Data Providers

Integrating private sector data into open-ocean data ecosystems is an ongoing challenge. The Gulf of Mexico Coastal Ocean Observing System has had success ingesting data from energy companies including Shell, BP, Chevron and others.[53] The companies collect data that, when combined with public data, can lead to improved models of hurricane intensity and other issues that are of great interest to regional stakeholders.[54]

Challenges and Recommendations

Data providers and users encounter fiscal, technical, cultural and social challenges to advancing ocean data. Here we outline solutions to address these challenges, including:

- Funding
- Forming partnerships
- Data sharing
- Privacy and confidentiality
- Integrating new data sources
- Data interoperability
- Data processing
- Cloud computing
- Stakeholder technical capacity
- Domain- and region-specific data gaps

Several of these challenges are cross-cutting in nature: for example, issues of privacy and confidentiality are interconnected with challenges in data sharing. Similarly, data processing challenges can be addressed through improvements in interoperability, cloud computing and enhanced stakeholder technical capacity.

Open and Equitable Sharing of Data with the Public

Equity considerations will also be important in developing more open and useful ocean data systems. Data-sharing programs are not always designed to ensure that all stakeholders are able to benefit equally. There is always a risk that communities with more resources, better connections or a longer history of data use may have an advantage and gain the most. Overarching frameworks such as the FAIR principles aim to ensure data are open and freely available.

While this framework is important and underpins data accessibility, engagement with end users and Indigenous and coastal communities must continue to improve access and in turn allow for data sharing with and among these groups. For example, Indigenous and coastal communities have traditional, cultural or commercial ties to marine and fishery resources and are important end users of data about the status of those resources, but if they are not actively engaged in program development, they may not be able to access the data and data products. There are also cases where Indigenous communities have exclusive rights to their data and should be treated as full parties in discussions rather than simply expected to share data. It is important to design open-data and data-sharing programs that ensure access to data for all who stand to benefit. Robust and meaningful engagement with a diverse range of stakeholders to inform all levels of data collection, use and management is critical to success. Proactive communication and engagement provide the foundation for responsive decision-making that reflects the interests and needs of all parties.

Funding

While funding is a consistent challenge for data acquisition and management in any domain, ocean data are especially underfunded. Federal funding for ocean observation initiatives has been below the levels recommended in an independent analysis conducted by NASA's Jet Propulsion Laboratory.[ix] The current budget for NOAA's Ocean Exploration program is $42 million a year, less than one-fifth of the annual $218 million budget for the Lunar Discovery and Exploration program.[55] This is not to say that space exploration is not vital for our nation, but that investing more in our ocean and supporting investments in ocean science, data and management at NOAA is also critical.

NOAA needs additional and sustained funding to maintain current operations and enhance collection of oceanographic, biological and socioeconomic data for research, modeling, forecasting and management. The shortfalls in federal funding for ocean observation initiatives impact fisheries, climate applications, bathymetry, habitat classification, population health models for whales, fish, and turtles, and more. Funding is not keeping pace with the increasing cost of collecting biological data. This has implications for those involved in the life cycle of data, from researchers who collect information, to data managers who process information, to policymakers who need to make informed resource management decisions, and to the stakeholders who depend on the ocean for recreation, swimming, boating and fishing.

Beyond NOAA, BOEM, as one of the other federal agencies that amass large ocean datasets, is also resource-constrained for managing data collected by contractors or the energy industry. Funding constraints could be amplified as expanding offshore wind production and other forms of renewable energy create new data streams or increased interest in existing data for environmental assessments.

Underfunded data management—which is often funded at much lower levels than data acquisition—reduces the applied value of ocean observation and biological data collection because those needing it do not have access to it in a timely manner or useful format. Data may be collected, but not processed or formatted for interoperability.[56] The federal government needs the resources to manage a larger ocean data ecosystem, recognizing that more data will continue to be collected as new technologies improve the efficiencies and economies of scale of data collection. NOAA has reported to Congress that as data density increases and resolution improves with advances in technology, the amount of ocean data is projected to grow exponentially, exceeding 250 petabytes by 2030.[57] This growth is likely to differ by NOAA program but is a challenge for the agency and associated congressional budgets. Some Earth-observing organizations are already predicting that data will become "prohibitively expensive and complex to host within their own data centers."[58]

ix NASA's Jet Propulsion Laboratory (JPL) in 2012 estimated that $542 billion was needed for a 15-year period to fulfill both the federal and non-federal needs for observing, the major portion of which includes the cost of satellite observations. See Snowden J, Hernandez D, Quintrell J, Harper A, Morrison R, Morell J and Leonard L (2019) The U.S. Integrated Ocean Observing System: Governance Milestones and Lessons From Two Decades of Growth. Front. Mar. Sci. 6:242. Pg 2,8. doi.org/10.3389/fmars.2019.00242

Dedicated staffing and budgets for data management are critical to ensuring data management is not ignored and is instead advanced in tandem with resources for inevitable increases in data collection. Advancing broader data management efforts will boost overall data quality, usability and accessibility.

As a best practice, 5% to 10% of a scientific research proposal's budget should be dedicated to data management, although amounts needed could fall outside of this range depending on the complexities of the data collected.[59] This should serve as a minimum level of investment and apply across all projects funded by NOAA. Similarly, NOAA programs on the producing and receiving ends of data collection tasked with managing, distributing or using ocean data should have separate line items in their budgets for data management capacity. Dedicated staff are needed to ensure that data are collected and managed with the goal of reuse, interoperability and long-term preservation.[60] Congress should increase appropriations for NOAA's data management activities at the line-office level based on the justification that this funding will improve the accessibility and utility of the data for a broad range of stakeholders and help managers make more informed decisions about coastal or marine resources.

Ocean data stewards like IOOS have to strike a balance between investment in data management, including maintenance, storage and QC, and investment in emerging technologies and opportunities.[61] Funding for regional ocean data portals and spatial data, for example, are currently quite limited. While there is a demand among resource managers for spatial data to make more informed decisions, maintaining existing data sets and expanding capacity to accommodate the intake and management of additional data could result in decisions between maintenance of existing vs. adding critical new data sets. Regions have to balance costs to ensure the highest quality data are available, but not to the exclusion of new and informative data streams. Resources and innovative solutions to support the maintenance and acquisition of new data must be a priority for IOOS, ROPs and the broader ocean data community. Partnerships across sectors to address data management challenges of mutual importance should also be a priority for regional data stewards.

Bridging Funding Gaps through Regional Collaboration

Data stewards in different regions often share similar challenges. These similarities can lead to productive collaborations and solutions.[62] After a system was developed to help West Coast shellfish growers monitor the impacts of ocean acidification, information exchanges among IOOS RAs coupled with NOAA funding brought that system to other regions across the U.S.[63] While the nature of the IOOS program facilitates partnerships among its RAs, less structured collaborations on data between ROPs and IOOS RAs within a particular region also occur. The Mid-Atlantic Coastal

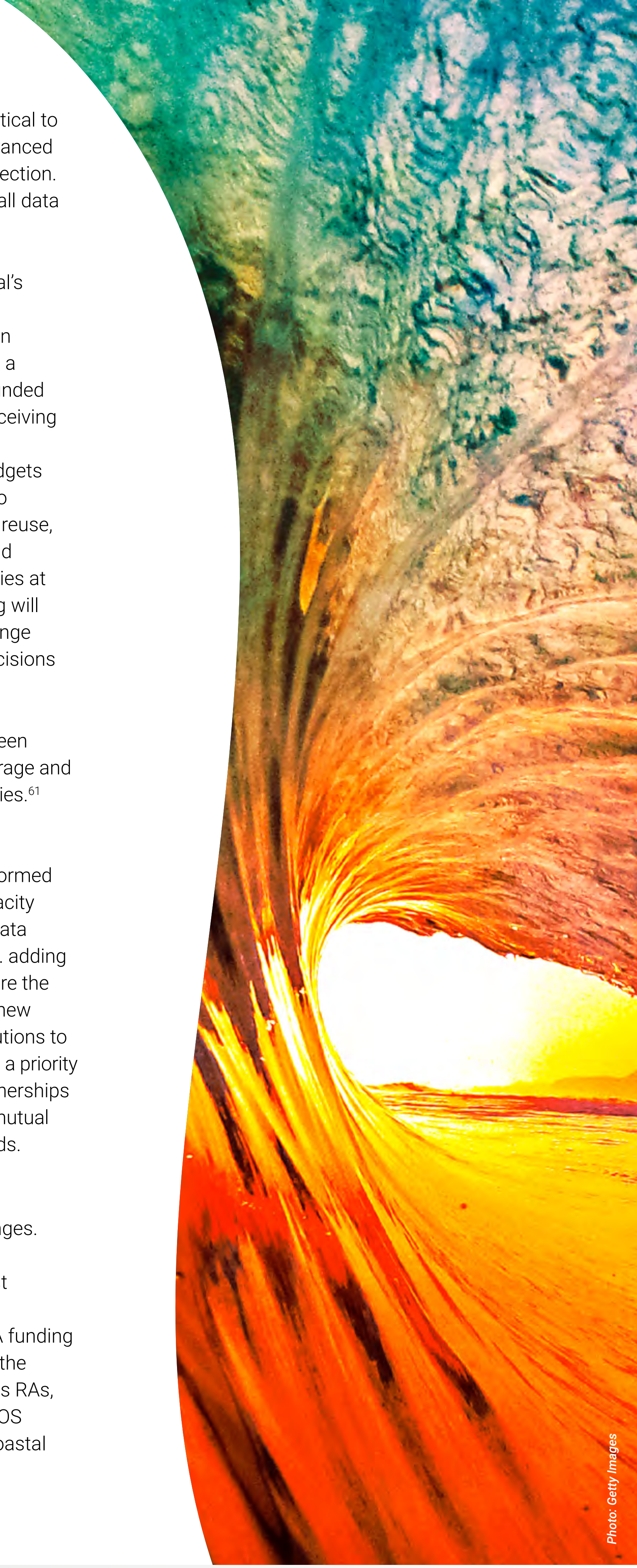


Photo: Getty Images

Ocean Observing System (MARACOOS) and MARCO have collaborated to create data products[64] and workshops on leveraging regional data to understand the impact of changing ocean conditions resulting from climate change.[65] Regional collaboration with the Fishery Information Networks are also used to leverage savings and compile data across regions such as the Atlantic Coastal Cooperative Statistics Program.[66]

It is more challenging to create and fund cross-regional collaborations either with IOOS RAs or ROPs based on the federal funding process and specific language directing investments that are often intended for a specific region. There are, however, some examples of successful cross-regional collaborations. The Caribbean Coastal Ocean Observing System (CARICOOS), for example, has worked with ocean data stewards in Maine and New Hampshire to access ocean observation technology and data.[67] Emphasis on collaboration and information-sharing could increase the value of the limited funding availability for these existing regional programs.

Fisheries

Data collection for sustainable fishery management faces funding deficiencies for both traditional and emerging data collection methods. Ship-based surveys have become costly, and ship days have decreased and will continue to decrease substantially as the NOAA fleet ages. Electronic technologies such as Electronic Reporting (ER) and Electronic Monitoring (EM) are encouraging technological advancements to improve efficiencies in data collection, but they can come at a high initial investment for implementation and often have long-term maintenance costs. In many fisheries, paper- or mail-based reporting is still common, and some fisheries currently do not even collect fishery-dependent data. ER represents a way to decrease the delivery time and administrative burden of data management while increasing the data available to scientists and managers, which results in improved in-season management. ER typically requires database planning in tandem with regulatory development, so that when implemented, the database infrastructure is in place and meets the specifications from the rulemaking. Investment in a strong communication rollout is instrumental to ensure users are comfortable with new technology changes and reporting requirements. Though the initial expense can be large, a strong rollout can ensure a successful and consistent program over the long term. Likewise, the use of EM via video data collection requires significant funding as programs are initiated; in many cases these technologies bring new and greater demands for data processing and storage that require additional long-term funding.

Beyond the core landings and biological data needed for stock assessment and catch compliance, the growing inclusion of habitat, environmental and socioeconomic data in fish stock assessments also necessitates more data management and coordination.

Congressional Leadership

Ultimately, it is the primary responsibility of Congress to allocate resources necessary to collect and manage federally sourced and curated ocean data—an especially pressing need as climate change creates greater uncertainty and shifts baselines for predicting future ocean conditions and proactively preparing resource management plans. With an exponential increase in ocean data gathering in the public and private sectors, funding to make data available in formats useful to resource managers and other stakeholders is a priority. Funding the continuation of important time-series data for status and trend assessments, as well as key data gaps, is essential and should be prioritized alongside data management.

Funding the acquisition and management of high-value ocean data will benefit ocean industries and coastal communities, protect marine resources and support ocean health. That said, it would not be equitable for taxpayers to pay entirely for these improvements. The private sector using public ocean resources should also contribute to the cost of managing ocean data from which it benefits commercially. One of the requirements of receiving a lease or license could be agreeing to provide all non-proprietary data to an agency.

Increased funding appropriations should support NOAA programs across budget lines that produce, use or manage ocean data as well as specific projects that tackle challenges identified in this paper. Congress should also work to promote and establish a more equitable cost-sharing approach between taxpayers and the private sector.

Actionable Opportunity: Federal agencies with a stake in ocean management and data collection should increase funding and support for data management in tandem with funding for data acquisition that will boost data quality, accessibility and usability while helping mitigate problems with processing and interoperability. To ensure existing and future data are publicly accessible in a timely and equitable manner to all stakeholders, the federal government should devote the resources commensurate with an ever- increasing stream of biological, oceanographic, socioeconomic and fisheries data. Recent coordination efforts among NOAA and other federal agencies on ocean exploration, characterization and mapping within the U.S. EEZ (the National Strategy) also have the potential to increase available data exponentially. Regional ocean data stewards should pursue opportunities to collaborate to overcome capacity shortages. Congress should increase its investment in ocean data management that is chronically underfunded to ensure we gain the full potential of collected information for the benefit of the ocean.

Recommendation:

Congress

- Work with NOAA and data stakeholders to understand the full suite of budget needs for data collection and management.
- Increase funding for regional ocean data portals through federal appropriations
- Provide dedicated funding for collaborative projects among ROPs and IOOS RAs and with other regional ocean data producers and consumers.
- Increase funding for IOOS RAs while tying awards to data management and integration programs.
- Develop new policies to ensure data management is equitably funded by taxpayers and private industry and that access to data collected by a federal agency or by private industry under permit or lease is publicly available.
- Facilitate and incentivize public-private partnerships to facilitate the cost-effective collection and acquisition of data through programs such as the National Oceanographic Partnership Program (NOPP).
- Direct the National Academy of Sciences or the Congressional Research Service to conduct an independent assessment of ocean data collection priorities relative to the information needs for climate adaptation and mitigation, marine ecosystem conservation, and the blue economy over the next decade, using the baseline analysis to help prioritize future funding for data collection activities.

Federal agencies

- NOAA requires its ocean data programs—including funds awarded through grants and contracts—to include a minimum of 5% to 10% for data management; make the necessary policy changes in consultation with stakeholders and factor these amounts into agency budget requests to Congress.
- The Office of Management and Budget (OMB) issues guidance to all federal agencies to allocate 5% to 10% of project budgets toward data management and best practices.

Key Stakeholders: Congress, NOAA, ROPs, IOOS RA, NOAA grantees and contractors, OMB, regional ocean data producers and consumers

Long-term Impact: Investments in ocean data are impactful relative to the natural resources they represent. With appropriate partnerships and coordination, duplication of data collection is limited. Improvements in the accessibility and delivery of data to end users are advanced. Stronger coordination between IOOS RAs and ROPs increases the impact of ocean data collections. Ocean management agencies are no longer constrained by resources for managing ocean data, providing data in formats that enable the ocean community to analyze data more effectively, and help move ocean managers closer to real-time management of marine resources. Best practices for data management are incorporated into federal grant and contract processes.

Photo: Debbie Tubridy

Forming and Advancing Partnerships

The long-term success of ocean data programs depends on partnerships among data producers and consumers both within the federal government and regionally. The ocean data ecosystem has several collaborative structures in place to build on. The IOOS structure and ROPs facilitate data flows between federal, regional and local stakeholders while providing opportunities for collaboration. There are also structures in place to help coordinate across federal agencies, including the Interagency Ocean Observation Committee (IOOC), which has representation from all federal agencies with a stake in ocean management: It includes19 bureaus and 12 federal agencies and has co-chairs from NOAA, NASA, NSF and the White House OSTP. The IOOC reports to the Subcommittee on Ocean Science and Technology (SOST) that is part of the White House OPC. Other structures, like the NOPP, exist to bring together government, science and technology partners.[68] The challenge, however, is that these structures are not always well known by ocean data stakeholders and in some instances have not had the mandate to engage the broader ocean data and science community.[69]

There are significant opportunities for improved collaboration among federal agencies, regional stewards, vendors, scientists, NGOs and data users.[70] Formal and informal mechanisms modeled after ones already in practice could be developed to improve transparency at the federal level and create robust partnerships. Formal mechanisms beyond the OPC like the NOAA-Google-Microsoft-Amazon Web Service partnership on Big Data and the NOPP, as well as informal mechanisms for collaboration around specific data types that occur frequently among regional ocean data portals, are concepts that could be built upon for enhanced partnerships. The marine life data work for the Northeast and Mid-Atlantic Ocean Data Portals, for example, involves NROC, MARCO, IOOS, NMFS, BOEM, U.S. FWS, the U.S. Navy, Duke University and academic scientists; similar models have proven successful to advance spatial data for management. Increased collaboration can lead to increased data availability, better data quality, more widely adopted standards, sharing of best practices and overall improvement in our understanding and management of the ocean. Often regions that engage states, federal agencies, Tribes, universities, industry and ocean stakeholders have expertise that can be replicated. There are great examples within regions where data priorities and needs have been outlined for a given topic and priority. Where this expertise lies should provide a model to start for collaboration mechanisms rather than building new ones. If a top-down collaboration or model is needed, federal agencies should look at the region where expertise or a given topic is a priority—this is the starting point for modeling partnerships.

Existing collaborative structures should be examined to ensure that the community is fully leveraging them, and new structures should be established, if necessary, where gaps exist. Experts identified several areas that need improved coordination. For example, there is no formal mechanism inside NOAA to coordinate NESDIS, NOS and OAR, even though they work on similar issues and often coordinate informally.[71] Non-governmental mechanisms could also be better leveraged to spearhead efforts among multi-stakeholders, community organizations and civil society groups.[72]

Several interagency agreements or memoranda form the basis of ongoing collaborations at the federal level. These include a Memorandum of Understanding (MOU) between NOAA and the NSF aimed at coordinating research, observation and data infrastructure as well as a long-term agreement between NOAA and BOEM to update and manage the Marine Cadastre. While federal agencies and data platforms are often collaborating effectively around ocean data and resource management, there are opportunities for further collaboration. One example is the advanced AIS analytics maintained by the USACE. This system would provide detailed traffic schemes and summary statistics for specific time periods, enhancing port and waterways management.[x] While these data are provided on request to other federal agencies, they are not publicly available.[73]

Recommendation: OSTP directs the SOST under the OPC to review and inventory existing interagency bodies that serve a role in creating, collecting, processing, managing, distributing and/or using ocean data. Improvements should be made, where necessary, to ensure that these interagency bodies are maximizing their utility and advancing collaboration with the broader ocean science community including:

- Identifying policies to advance partnerships for ocean data, science and technology.
- Defining formal and encouraging informal mechanisms for engagement with the ocean science community.
- Creating opportunities for collaboration with public, academic and private entities collecting, processing and managing ocean data to maximize the benefit for ocean research and understanding.
- Soliciting feedback on creating, collecting, processing, managing, distributing and/or using ocean data.
- Working effectively to meet the needs of end users including with regions, coastal managers, industry and Tribal and coastal communities, splicing feedback and data, where appropriate.

Recommendation: The OPC examines data portals, products and services across federal agencies for improved collaboration and efficiency. Recommendations should be developed with public comment and informal input from the ocean community. Improvements such as shared funding, combining duplicative efforts and improving interagency, regional, state, Tribal and community collaboration should be identified in consultation with federal agencies, ocean stakeholders and Tribal governments.

Recommendation: OSTP explores opportunities to expand and strengthen existing partnership mechanisms that already bring together government, industry, academic and philanthropic organizations, like the NOPP. The OPC should work to provide additional transparency surrounding federal actions on ocean research, science and management as it relates to data. A federal list or file system with public access should be explored as a means to outline ongoing research efforts occurring in the U.S. EEZ, identifying ways to leverage coordination with ocean science and technology communities and other organizations. Federal agencies and associated lead policy staff should be publicly displayed on an OPC website. In an effort to increase transparency and boost partnership engagement, committees and workgroups should make work plans and meeting summaries available.

x AIS is a communication protocol that is intended as a situational awareness tool and a means to exchange navigation information in near real-time. In addition to an integrated system of AIS data maintained by the USCG, federal agencies like the USACE use AIS data for navigation planning studies and enhanced reporting. Analytical tools developed by the USACE enable users to visualize vessel tracks, generate summary statistics of vessel activity, etc. See, Enhancing accessibility and usability of AIS data across the federal government and for the benefit of public stakeholders [internet]. Washington, DC: U.S. Committee on the Marine Transportation System; 2019 March. p. 19-20. Available from: https://www.cmts.gov/downloads/Accessibility_and_Usability_of_AIS_Data.pdf

Data Sharing

Oceanographic, biological and socioeconomic data collected by the research community and offshore energy industry are not always openly available to the larger community in the public domain. A large amount of ocean data are collected by scientists working on specific projects with short-term funding. This funding challenge is amplified by the fact that grants currently provide insufficient funding for data management and access. Data is also collected by private industry, but withheld due to concerns over privacy, confidentiality and competitive advantage (see Challenge: Privacy and Confidentiality page 34-36 for a discussion of confidentiality issues in the offshore industry). Further, data that is submitted for regulatory purposes are not integrated into ocean management and research in a systematic manner.

Scientists are highly incentivized to publish research results, but not necessarily to publish their underlying data, although mechanisms (e.g., data labels and grant requirements) now exist that encourage the latter.[74] As a result, only a small portion of potentially available ocean data is actually used, with a much larger amount still trapped in notebooks and laptops.[75] Scientific societies and journal publications are recognizing the need to boost data sharing. Both the American Geophysical Union and the American Meteorological Society, for example, have data policy statements highlighting commitments to full, open and transparent data, encouraging scientists to identify and appropriately archive their data.[76] In many grant and funding programs, resources are provided to collect data but not to support the platforms that house data and make them more publicly accessible. As a result, some data-sharing platforms are under-resourced or outdated. Sometimes data does not even make it onto public access platforms. Another challenge is that data are collected in a variety of spatial and temporal scales, levels of biological resolution or in different units, rendering them less relatable and comparable. Data quality might also not be apparent, if data are not provided with QC flags.

Efforts are underway to address these problems, but they could go further. The Digital Object Identifier (DOI) system, which provides infrastructure to register and use persistent interoperable identifiers on digital networks, represents a potential approach to incentivize data sharing.[77] Assigning a DOI allows for data to be shared widely and before manuscript publication while attributing it to the producer of the data. NOAA has made it mandatory for its own researchers and contractors to cite data using DOIs.[78]

NOAA's PARR plan lays out goals and requirements to meet the White House OSTP Memorandum Increasing Access to the Results of Federally Funded Scientific Research, issued in 2013 and targeted at increasing access to the results of federally funded scientific research.[79] As part of NOAA's plan, non-NOAA researchers who have been provided grants from NOAA have to make their research data publicly available within two years of publication. NOAA program offices have to evaluate data-sharing plans submitted in the proposals and ensure compliance.[80] It is unclear whether researchers are complying with these policies and if the scientific data is made publicly available as intended. OSTP is exploring updates to its original guidance that could prove useful to encouraging data sharing.[81] Other federal agencies are also grappling with this issue; the National Institutes of Health (NIH), for example, is considering updates to its data-sharing plan that would require all NIH grantees to share their scientific data in a timely manner.[82]

Actionable Opportunity: Ocean research data published by researchers funded by NOAA and other federal agencies are not consistently posted to publicly accessible platforms. NOAA's PARR plan that attempts to increase public access to ocean data by requiring researchers to publish data within two years is a potential solution.

Recommendation:

- NOAA evaluates the effectiveness of PARR since its implementation in 2016, focusing on researcher compliance with data sharing.
- NOAA updates the PARR plan and associated directives to align with future updates to the OSTP policy on public access to peer-reviewed scholarly publications, data and code resulting from federally funded research.
- NOAA strengthens accountability measures in the PARR plan by penalizing non-compliant researchers based on its PARR effectiveness review.
- NOAA makes data publicly available in appropriate formats—where there are no privacy or security restrictions on release—through an existing public mechanism such as the Marine Cadastre in a timely manner.

Stakeholders: NOAA program offices, NOAA grants management divisions, extramural researchers.

Long-Term Impact: Timely access to ocean research and scientific data funded by federal grants that can inform scientific discovery, conservation and sustainable ocean management.

The offshore energy industry collects ocean data but, with the exception of some data-sharing arrangements, these data are not widely available and are not integrated into ocean management.[83] While there are instances of collaboration between the research community and oil and gas companies, as well as offshore wind companies with IOOS and ROPs, these arrangements have been ad hoc in nature and dependent upon individuals, researchers or companies. Further, efforts at integrating private data by federal agencies have been driven by specific programs rather than any broad strategy. Individual companies are hesitant to lose their competitive advantage or undertake additional risk. However, there is strong user demand for non-proprietary biological and oceanographic data collected by the energy industry, which has an obligation to openly share data as a beneficiary of public trust resources.

Overall, industry can justify sharing data if they are submitted as part of regulatory requirements or if companies are able to realize a tangible benefit like improved nautical or helicopter charts.[84] Under the Outer Continental Shelf Lands Act of 1953 and the Energy Policy Act of 2005, BOEM regulates and manages offshore oil and gas and renewable energy resources, respectively. In the case of offshore renewable energy, companies that have been granted leases are required to submit extensive survey data as part of site assessment plans and construction and operational plans. Regulations allow for BOEM to publish such data as long as it does not result in "substantial competitive harm or disclosure of trade secrets."[85] For proprietary data, an embargo of three years is applicable, after which BOEM can publish such data if the harm no longer persists.[86] Environmental data are also being submitted to federal agencies like NOAA under laws such as the Marine Mammal Protection Act and Endangered Species Act. BOEM has historically exercised its regulatory power to instruct energy companies to share oceanographic data with regional stakeholders.[87] Energy companies operating in the Gulf of Mexico, for example, share oceanographic data with the regional IOOS association that helps create better hurricane prediction models.[88] This data sharing could be expanded through language in lease agreements requiring companies to share data throughout the time that they operate in an area.

Achieving the unrestricted sharing of industry oceanographic and biological data will require changing the culture, allocating resources to create public-private sector partnerships, and updating policies requiring that data collected under federal leases or contracts be publicly shared. Even though the underlying regulatory framework to support data sharing exists in a number of ways, both federal agency and private industry stakeholders are reluctant to collaborate on longer-term and more institutional data-sharing projects. Federal agencies must collaborate and create sustainable data management systems that allow for private sector data to feed into ocean resource management decisions. It is important to recognize the extensive costs associated with processing data, and federal agencies should identify a distinct applied purpose for data that are not part of regulatory requirements.

A precedent exists in the Gulf of Mexico whereby oil and gas companies share certain oceanographic data as part of their lease agreements.[xi] This model has not yet been fully replicated in the offshore wind industry, which is less mature with most sites still in the research and development phase, but will be a useful template as the industry matures.[89] Offshore wind companies are beginning to voluntarily share data within the Northeast and Mid-Atlantic regions; the hope is that this will continue with a comprehensive approach to data sharing and partnerships with industry. At this point, however, existing data-sharing agreements are not necessarily comprehensive. Even in the Gulf of Mexico, for example, data on oceanographic variables like water temperature are available, but seismic data that are considered commercially sensitive are not. Successful models implemented globally (for example, the Marine Data Exchange and the UKBenthos database) point to the possibility of implementing data-sharing mechanisms with offshore energy companies in the United States.[90]

Actionable Opportunity: Oil and gas companies share some data from their offshore facilities, but those data are far from comprehensive and not always in the public domain. There is an opportunity to institutionalize a culture of data sharing with emerging industries like offshore renewable energy that are in the early development phases. NOAA and BOEM should require all non-proprietary biological and oceanographic data collected by energy companies operating in the U.S. EEZ to be made available to the public.

Recommendation: BOEM should strengthen data-sharing requirements in lease agreements with energy companies (including oil, gas, wind and other renewables) operating offshore facilities within the U.S. EEZ. Energy companies would share all such non-proprietary ocean data such as oceanographic conditions, seafloor bathymetry and sediment, biological observations, maritime activities (via private AIS monitoring) and socioeconomic assessments of different industry sectors from the start of their projects through decommissioning as a leasing term. Where administrative directives cannot be achieved based on existing statute, congressional action should be taken. Data should be collected and shared with standard metadata conventions used by the Marine Cadastre, IOOS, regional ocean data portals or other long-term collaborative data-management efforts. Discussions should begin before data collections efforts are initiated with these entities. This is important to ensure data collection and standards are aligned with appropriate systems. The cost of managing energy-sector data should be factored into a portion of Outer Continental Shelf rental receipts or cost-recovery fees, with those funds set aside by BOEM for long-term data management in coordination with relevant IOOS RAs and ROPs, where applicable. Data should be provided in appropriate formats, regionally standardized and synthesized where applicable for distribution through public data systems.

Stakeholders: NOAA, BOEM, IOOS RAs, offshore energy companies, Congress

Long-term Impact: Marine industries, including the offshore renewable energy sector, adopt extensive data-sharing practices for non-proprietary data. Federal agencies adopt collaborative arrangements and use industry data to help fill knowledge gaps with the goal of a better understanding of the ocean and more effective ocean management.

xi Data Portal, Gulf of Mexico Coastal Ocean Observing System, data.gcoos.org/fullView.php; National Data Buoy Center, ndbc.noaa.gov

Privacy and Confidentiality

Privacy must be considered as part of any data-sharing program. Government-derived oceanographic and biological research generally captures less sensitive information than other sources, but, with the rise of smartphones as monitoring tools, data streams are increasingly collecting personally identifying information through metadata. Data-sharing practices need to be evaluated and clearly communicated to data contributors, managers and anyone granted data access. Guaranteeing privacy and allowing the collection of important information for management purposes through electronic means require a system that can do both. For example, a smartphone with access to social media can reveal the exact location of rare or endangered species in real time that could attract unwanted attention and put them at risk, yet the information is valuable to management agencies.

All data passing through federal agencies are subject to the Privacy Act and the Freedom of Information Act, which provides a baseline framework for handling and disclosing personally identifying details. For fisheries data, the MSA adds explicit provisions around privacy and confidentiality. NMFS has interpreted the MSA requirements as a "rule of three" where any public summary data must be aggregated to include at least three entities (i.e., three people, three vessels, three businesses) and individually identifiable information may not be released without a court order. Access beyond this interpretation requires an MOU with NMFS.[91]

New technologies in fisheries are testing the practical limits of this interpretation. VMS transmit a vessel's location by satellite at mandated time intervals to enforce fishery closures or other spatial management regulations. The data are collected and monitored by NOAA's Office of Law Enforcement at NMFS. VMS data are highly restricted for privacy, even within the agency, and typically provided to non-NOAA stakeholders in formats that are not easily deciphered, rendering these data less useful to end users.[92] In addition to their use for enforcement by NOAA, NMFS, USCG and fishery management councils,[93] the data from such systems could be used for scientific research and management. Strategies and techniques employed in the health care sector might be adapted to improve the utility of electronic fisheries data for decision-makers and end users, while protecting the anonymity of fishermen (see CODE sidebar immediately below).

Photo: Aurora Giorgi

Cross-cutting Recommendation: Learning and Adapting from Other Sectors

CODE has explored strategies for protecting individual privacy while maximizing data sharing both broadly across federal agencies and in specific industries such as health care. There are technical and other approaches that are often adopted together to mitigate risk. A number of best practices from other areas should be considered in the ocean data space, including:

Technical approaches to anonymization seek to remove sensitive personally identifiable information from individual-level and population-level data or otherwise make it difficult to identify an individual's information. These can include:

- **Providing anonymized identifiers:** These identifiers allow researchers to connect disparate datasets while preserving the privacy of individuals (addressed in the ocean space related to VMS and vessel trip report (VTR) data).
- **Removing non-critical information:** Researchers must remove key variables such as ZIP code digits, part or all of social security numbers, account information and other identifying information (addressed in the ocean space related to VMS and VTR data).
- **Leveraging synthetic data:** Synthetic data is produced by a complex statistical model that generates a simulated population that has the same general features as the original data.
- **Applying differential privacy:** Differential privacy places constraints on algorithms that rely on inputs from a database of information. This masks the personal information so an external user cannot determine if an individual's information was used in the computation process.

Restricted or Differential Access approaches are designed to make sensitive information, such as individual health information, accessible to institutions under controlled conditions and for specific purposes, when release to the public is not appropriate or could negatively impact privacy. This approach can be used to make data available to academic researchers and others in the public, private or nonprofit sectors. It requires balancing privacy risk against the benefit of making the data accessible and ensuring the trustworthiness of the people or institutions with access to it.[94]

In the context of fisheries, catch, survey and habitat data can be useful for developing fishing location apps while also aiding in educational and outreach activity to help fishermen comply with regulations such as marking closed areas.[95] As one example, commercial fishermen in New England have been participating in a cooperative research pilot to record their catch and the environmental conditions at depth with the aid of the Fisheries Logbook Data Recording Software (FLDRS or "Flounders"). FLDRS data will be available to commercial fishermen and vessel operators through the Graphic Offshore Fishing Information System Homepage (GOFISH) app, enabling them to map, graph and analyze the data they have entered through FLDRS. Temperature-depth plots, bycatch analysis graphics, and other visualizations will be possible using GOFISH, assisting in fishing operations and helping researchers study marine ecosystems.[96]

Data produced from electronic monitoring and reporting technologies will provide fishery managers, researchers and the public with new opportunities, but they will have to be navigated in the context of statutory confidentiality requirements and privacy considerations. Ocean data stakeholders should evaluate approaches adopted in other government and industry sectors to address privacy challenges. Data providers and NMFS will need to develop clear guidance on the privacy-preserving approaches they are adopting and how confidentiality provisions will be interpreted and upheld. When providing public-facing data products, such as spatial fishing effort and bycatch hot spots, data providers will need to share data in ways that do not violate privacy but also do not require MOUs.

Confidentiality issues also come into play in the context of private industry data. While there are some examples of private industry sharing ocean data with the government, it is not a common practice as confidentiality concerns limit businesses' willingness to freely share the information they collect. Industry data submitted through the regulatory process, such as oil and gas lease bidding, may be treated as confidential information even if the lease is not secured. Unless there is an immediate economic gain or a regulatory requirement, companies find it difficult to justify sharing data that has specific business value or that was expensive to acquire.[97] However, making ocean data, like the public trust ocean resources they represent, available to the public in the interest of transparency and equity is an important consideration as the federal government balances confidentiality and open access (see Challenge: Data Sharing for a discussion of issues in the offshore industry page 31-33). As opportunities to identify overlapping partnerships, increased collaboration and data sharing are identified, strategies to manage privacy and confidentiality issues should be analyzed as part of this work.

Leveraging and Integrating New Data Sources

As ocean data stewards work to engage data users and overcome technical challenges, the increasing availability and deployment of new ocean-observing technologies will greatly expand the volume and diversity of ocean data.[98] These new technologies include autonomous sensors, Unmanned Aerial Systems, high-frequency radar, gliders, imaging bots, and eDNA species identification technologies. The technology is evolving in multiple contexts ranging from miniaturization of sensors and the evolution of power-harvesting systems for platformsxii such as Wave Glider or Saildrones, to improve data-transmission systems through better acoustic modems and fiber-optic cables.[99] Concurrently, new technical approaches to data analysis are emerging, including cloud computing, big data analytics, machine learning and AI.[100]

USE CASE

Autonomous Technologies

Scientists are increasingly using autonomous technologies like profiling floats, gliders and Saildrones to complement data collected by ship-based researchers. These technologies are unlikely to replace ship-based research, but they can add complexity and context to benefit research while saving researchers money and time. For example, Saildrones, which are essentially autonomous sailboats, can cover significantly more ground than larger manned ships and other autonomous vehicles—a significant advantage in the Arctic where unpredictable weather provides smaller time windows for scientists to conduct research than in other ocean areas. These technologies are helping significantly expand the amount of data available related to carbon dioxide and other chemicals in the ocean. For example, NOAA's Pacific Marine Environmental Laboratory uses a Saildrone to take readings in the Arctic Ocean, providing a much broader picture of carbon dioxide levels there than would otherwise be available.[101]

These new technologies present significant opportunities, including the potential to improve existing data collections and add new ones in areas as diverse as water chemistry and human use.[102] Technological opportunities also come with challenges as data consumers work to manage data flowing from these new technologies and ensure that they are interoperable with existing ocean data systems and standards.[103] Integrating historical data with newer or future data streams will be important for documenting how and what changes in the ocean have occurred and understanding the implications for resource management and ocean-based industries going forward.

xii Such platforms are able to harvest wind and solar energy to power the platforms for a longer period of time.

As new technology companies and NGOs enter the community, they may be able to facilitate multi-party data licensing, access and sharing agreements across data creators and users in government, academia and industry. Global Fishing Watch offers an example of a data-sharing partnership among Google, Skytruth (an NGO) and country-level governing bodies.[104]

In fisheries, electronic monitoring (EM) and electronic reporting (ER) provide concrete and relatively new opportunities for more effective fisheries management by improving data reliability, timeliness, accuracy and sharing. Traditionally, fisheries observers have been used in many commercial fisheries to collect biological data and conduct catch and bycatch monitoring. EM programs represent an opportunity to supplement the work of observers. EM programs employ the use of cameras installed on fishing vessels that provide additional catch-related information, such as bycatch, predation and size data. ER has been implemented in many fisheries to improve the timeliness of data collection, as fisheries data can be transmitted electronically. If effectively implemented, EM and ER programs can reduce reporting burdens on fishermen, observers, agency personnel and others who collect or process fishery-dependent data. However, if there are limited or no reporting or observer requirements already in place at the time EM or ER is implemented, then fishermen might face increased burdens or costs associated with these new systems. Regardless, if these technologies are to be effectively used, the EM and ER data must have consistent standards and be validated, calibrated and comprehensively integrated with existing, traditional data collection methods.

Traditionally, EM and ER data have been used for catch monitoring and enforcement, however, technological innovations have created new avenues for data analysis and use. Both EM and ER data can be used directly by fishermen in the seafood marketplace, for example, to increase product credibility and consumer interest. In addition, EM and ER data can be used by scientists to better inform management decisions.[105] An example of how modern EM hardware and software work to improve data collection is the partnership between the Alaska Fisheries Science Center and NOAA's Fisheries Information System Program. These agencies have automated video analysis of Pacific halibut discards from longline vessels, improving overall catch accounting.[106] Continued refinements in the data collected can be achieved through updated technologies, such as improved sensor and camera capabilities that can capture clearer images of species caught and discarded at sea as part of EM systems.

USE CASE

Integrating Electronic Monitoring Data into Fish Stock Assessments

Regional Fishery Management Councils (FMC) can partner with the fishing community to expand EM and use catch data and, where relevant, geolocation data, more efficiently in management decisions while protecting fishermen privacy. For example, an experimental project in the Gulf of Mexico snapper-grouper fishery is using video data to improve multiple aspects of management. Using specialized cameras, computer processors and sensors installed on participating commercial fishing vessels, the project has collected and confidentially reviewed more than 60,000 species-level catch, bycatch and discard records including, their catch and or release dispositions, to inform management.[107] The data from these pilot projects are making their way into stock assessments.

The use of EM to collect data can be cost-effective relative to human observers and can be especially valuable by supplementing the work of observers in cases where there are significant safety risks to people. In addition, EM could be used to monitor compliance with fisheries and worker safety laws, removing from observers the burden of reporting regulatory infractions, potentially improving working conditions for observers who can be harassed for serving in that capacity.

Recommendation: NOAA, FMCs and the fishing industry should modernize fisheries monitoring programs through expanded use of electronic technologies that can improve the timeliness and accuracy of information for management. At the core of modernization should be efforts to accelerate the use of EM and ER programs in fisheries while ensuring production and use of high-quality data through enumeration of data standards and improved data management and infrastructure.

Actionable Opportunity: The ocean remains largely unknown with more than 80% of the ocean unmapped, unobserved and unexplored.[108] Resource managers cannot effectively manage ocean resources without information on the diversity, abundance, distribution and inherent sensitivities of biological and geological resources. Allocating the necessary resources to explore, map and characterize the U.S. EEZ outlined by NOAA and federal partners through the National Strategy is critical to filling gaps in knowledge. As part of this effort, high volumes of data will be generated and available to the public. Cloud computing could help ensure large amounts of data are readily available and, specifically, cloud computing under the NOAA BDP and other line office efforts should be further investigated as options.

Recommendation: NOAA's topline budget must be increased to fully address our nation's ocean and coastal scientific and management questions that are necessary for our nation. Funding should be appropriated to explore, map and characterize the U.S. EEZ, with a portion allocated to support cloud computing for the data generated, including funding to offices within NOAA that oversee exploration, characterization and mapping, such as NOAA's NOS and Office of Ocean Exploration. Data collected through these programs should be made available for access and analysis via the cloud. Without robust and sustained, multi-year funding in these programs, investments in advanced research technologies as well as investment in NOAA's at-sea infrastructure, this work will not be successful. NOAA must have the resources to undertake the National Strategy and produce the data needed for the nation to protect ecosystems and promote a sustainable blue economy, supporting related activities such as nautical charting, sand and gravel assessments, essential fish habitat restoration and wind energy siting.

Stakeholders: NOAA, OPC, Congress, ocean science and technology community.

Long-term Impact: NOAA and other federal agencies are able to leverage the computing power of cloud technology to address objectives under the National Strategy and to address long-term coastal scientific and management questions. Making cloud technology critical to the data infrastructure for such programs will enable sustainable data management as well as make it more accessible for a range of ocean stakeholders.

Data Interoperability

Data interoperability can be defined as the “degree to which two or more systems, products or components can exchange information and use the information that is exchanged”.[109] Some of the necessary elements to achieve interoperability for ocean data include file standards, common data and metadata models, controlled vocabularies, and ontologies that define the terms and relationships.[110] The challenge is that it is not simply a national, regional and local observing context that the U.S. operates in but also a loosely coordinated Global Observing System that adds additional complexity on interoperability.

The myriad of data collectors, data publishers, software and tool builders that provide data analysis and processing services, federal agencies, and the ocean science and management community create complexity overall.[111] This is coupled with the ongoing desire and need for interlinking datasets to better understand ocean and coastal systems and make decisions. Open and free data policies are increasing, and interoperability challenges are pushing the use of FAIR principles. FAIR principles provide a framework for guiding the ocean-observing community toward the establishment of an integrated, sustained ocean-observing system with fit-for-purpose data and information streams for societal and scientific benefit.[112] FAIR principles are interlinked with making data interoperable.

In the ocean data context, it is important that scientific data formats are “self-describing” or formatted to include metadata that describes the data as well as the file structure. The adoption of self-describing file standards and common data models is not simple and requires significant resources. In the last two decades, the Network Common Data Form (netCDF) data model and Climate and Forecast conventions have emerged as the most widely used self-describing file formats in oceanography. The need for controlled vocabulary for metadata arises from the fact that different datasets may use different terms to describe a variable (e.g., salinity can be described as psal, salinity, Salinity, sal).[113] Controlled vocabularies are vital to ensure valid interpretation of values by human users and to enable correct compilation of datasets.[114]

The diversity of types of ocean data makes it particularly difficult for interoperability. Further, related science domains use different metadata models to represent the same types of data and are not necessarily interoperable.[115] Biological data are especially challenging for interoperability. Fisheries trawl data, for example, are significantly linked to management, but challenges remain with interoperability among other data sets that could inform management. Among biological data sets, there is likely an increased cost associated with making data interoperable including added staff time and coordination needed to define best practices for specific data sets rather than applying a standard across all biological data.[116] Challenges are also found with many metadata standards defining detail geospatially but may not fully capture the granularity needed for biological data sets. Technical experts also cite challenges with the resources necessary to fully engage data producers on data management that is necessary and crucial for improving data interoperability across the life cycle of individual data sets collected.[117]

Data portals, which are taking in data from producers, face technical and resource challenges associated with integrating biological and ecological data standards into their existing metadata catalogs. While work is being done to develop methods to achieve better interoperability, funding and other resources are limited for ocean data portals.[118] Adding to the complexity, social science data are not easily integrated with natural science data, but can be critical, for example, to adapting to future conditions for fisheries or for port-related infrastructure. ROP-managed ocean data portals are often seeking these types of data sets for management decisions. IOOS RAs have noted that they have to manually input metadata information in lieu of an automated process. This challenge is improving with netCDF files or others such as Esri files generating metadata that can be automated.[119]

Metadata standard challenges occur with moving from one form to another and with the variety of ocean data types. Engaging the ocean data community to encourage metadata usage also adds to the complexity. Ocean data standards are relevant to both the platforms that collect observations and to portals that distribute data. Platform manufacturers do not necessarily build their products and the underlying software with data standards in mind.[120] Manufacturers of new ocean observation technologies also need to ensure that their instruments produce data in standard formats that are commonly used and metadata that conforms to commonly accepted standards.[121]

The underlying nature of data managed by regional data stewards adds a level of complexity to the issue of interoperability. While some types of ocean data are presented and used in real time, other data represent a longer time series. Combining these data would have great value, but has proven difficult. ROPs, states, USGS, EPA, BOEM, FWS and certain parts of NOAA focus on geospatial data that could be aggregates of time-series data or a characterization of the current extent of resources and activities. IOOS RAs focus more on standardized ocean observations in real time while also providing time-series data for certain oceanographic, climatological and weather data. Given the difference in underlying technology used by oceanographers from systems that manage geospatial data, these time-series datasets may follow different metadata conventions and lack clear interoperability with real-time data observational data.[122] The use of netCDF and other standard data formats has, however, made it much easier for software companies to handle temporal data; Esri's work adopting netCDF as a data format in maintaining the geographic information system, ArcGIS, is an example.[123]

Despite multiple data portals managed by federal, regional, academic and other organizations, end users often point to the lack of a single resource that can help them find data across these sources. Given the proliferation of ocean data, portals and applications, data consumers will need to ensure that users can find the data sets they may want to combine. Current efforts to integrate interoperability with cross-enterprise data management are reflected in NASA's Common Metadata Repository and NOAA's OneStop system. These data management systems integrate standards-compliant metadata across distributed data sources, enabling unified search and access to a wide range of scientific data.[124] The ability to improve search mechanisms for end users is expected to evolve with greater interoperability and emerging technology such as AI. Rather than directing investments and full-time staff towards developing a single data hub or portal (which has been attempted at many different times and organizational levels), data producers and consumers should prioritize and focus on improving interoperability and search technology. Further, an emphasis on making data publicly available in easy-to-understand formats through the Marine Cadastre and regional ocean data portals should continue to be a priority.

The National Strategy for Mapping, Exploring, and Characterizing the U.S. EEZ presents a potential opportunity to apply lessons learned to address other data interoperability challenges across the federal government.[125] The National Strategy includes commitments to establish a national ocean mapping protocol. It contemplates development of national data standards and best practices as required by the Geospatial Data Act of 2018 including specifications for bathymetry data as well as timelines and protocols for data management and availability.[126]

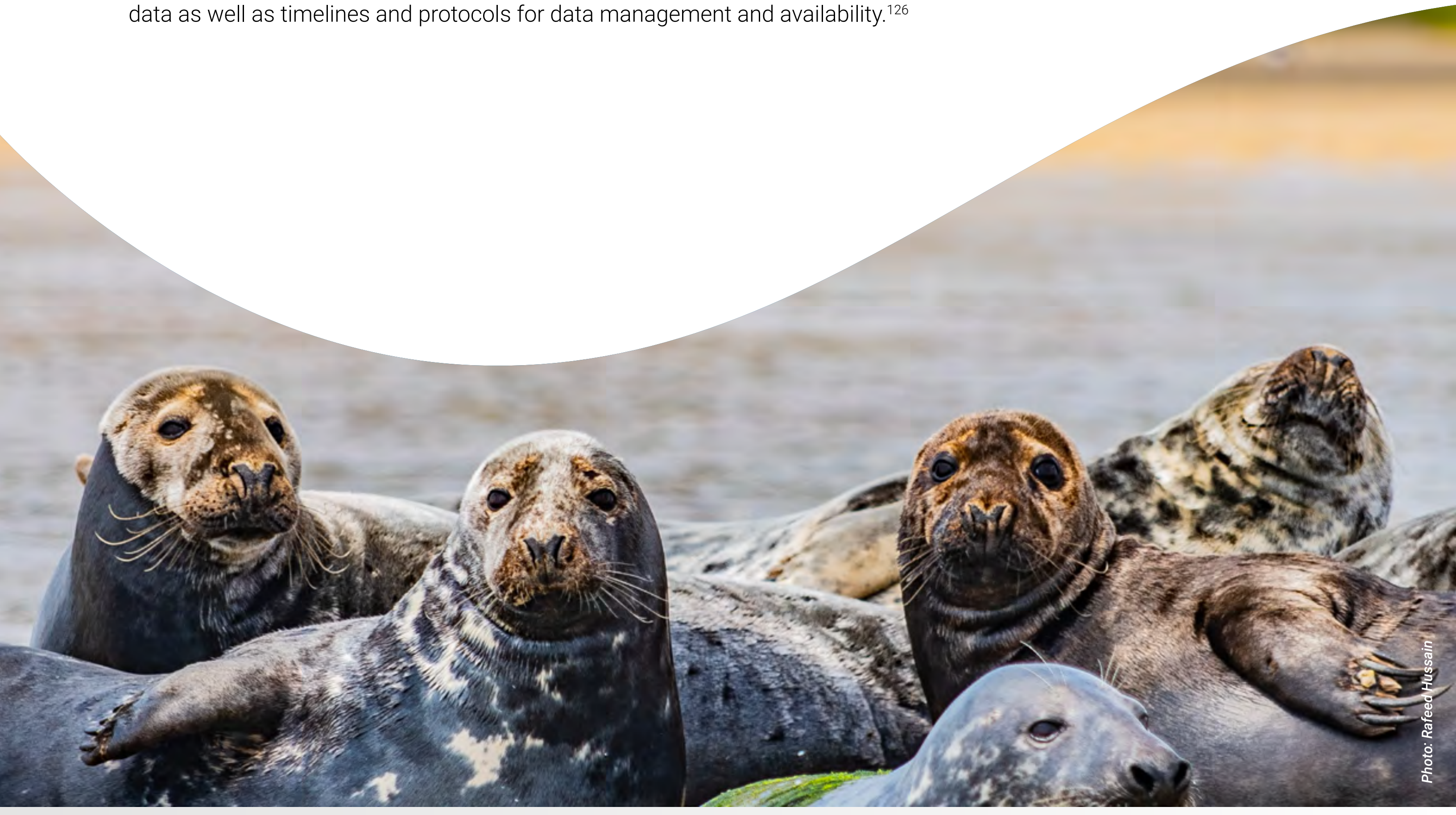


Photo: Rafeed Hussain

Recommendation: Ocean data are not used to their full potential unless standards are adopted and data interoperability addressed. FAIR principles should be advanced, as well as funding for educating and working with non-technical data producers to incorporate metadata standards and collectively improving the biological components of ocean observing.

OSTP could use the ongoing collaboration with federal agencies as part of the National Strategy to outline best practices to improve and adopt standards across the ocean data ecosystem, recognizing that standards vary across disciplines. Leveraging the OPC's OST committee that coordinates across federal agencies on ocean science and technology is a good starting place for this work.

As partnerships and new technologies advance, different stakeholders with needs for data and the ability to use that data to make decisions will increase. Interoperability challenges are likely to increase as new technologies are advanced. Clear direction and use of standards templates and coordination in advance with partnerships on these challenges are key. Beyond ocean exploration and mapping, OSTP could work with NOAA and BOEM to require new data providers like offshore wind companies to coordinate on appropriate standards needed to share with public data systems such as IOOS and regional ocean data portals before research and monitoring plans are initiated.

Following recommendation development by the OPC, OSTP should provide guidance to agencies to integrate standards into agency ocean-data collection protocols to improve interoperability of systems across the federal ocean data ecosystem.

Recommendation: Congress should allocate resources to NOAA so that staff can educate and train researchers, data managers and other key stakeholders to advance data interoperability.

Interoperability issues represent a technical hurdle to increased ocean-data sharing, but cultural hurdles stand in the way as well. Specifically, there are limited incentives currently as we have outlined for researchers, private industry and even individuals to share ocean data. Funding and prioritization of data standards are also part of this interoperability challenge.

Data Processing

Data processing is an important part of ocean data management. Significant time and expertise are required to process the raw data and make ocean data useful for analysis that can inform management decisions, clarify long-term trends and answer major scientific questions. The requirements vary across different types of data and are often a function of how the data were collected, for example, through the proprietary software associated with sensors or the extended time needed to analyze biological samples. The steps taken to process the data also need to be documented properly to enable scientific reproducibility across studies using the same data.[127]

Ocean-data best practices are defined as a description of a methodology, often by an individual organization. There are many forms of ocean-data best practices, yet there is a common goal of improving the quality and consistency of processes, measurements, data and applications.[128] The Ocean Best Practices System under the IOC, with NOAA and IOOS as part of the contributing network, aims to have agreed and broadly adopted methods across research, operations and applications.[129] The Quality Assurance/Quality Control of Real Time Oceanographic Data (QARTOD) is run by IOOS with collaboration from federal agencies, universities and other partners representing the oceanographic observing and data management communities. The QARTOD works to sustain a process for authoritative QA/QC procedures including developing expert-vetted QA/QC manuals for real-time ocean variables.[130] To advance data processing there must be a consistent following of best practices, use of QARTOD or other manuals and use of QA/QC data quality flags.

Challenges with data processing can limit the utility of data for understanding the ocean. Lack of data standards, inadequate funding for data management and cumbersome policies and procedures around data collection and processing can make real-time data sharing impossible. Ocean datasets are often large and resource-intensive to process, with larger volumes of data collected every day.[131]

The challenges that arise in data processing are addressed through improvements in data interoperability, cloud computing and stakeholder technical capacity. Recommendations identified in those sections will also indirectly address issues in data processing.

Cloud Computing

Cloud computing[xiii] has great potential to change the way ocean data are received, processed, used and archived. The ability of cloud resources to "burst" to meet varying demands can help many of the challenges mentioned above. Using the cloud provides resources to tackle the four Vs of big data—veracity, volume, velocity and variety.[132] NOAA is exploring the cloud for uses from direct ingest of sensor data to making data available via the BDP to archiving in the cloud. IOOS has created a cloud sandbox to allow researchers to develop and test ocean and coastal models with data co-located in the cloud. Future work on AI and machine learning will likely use data and computing resources in the cloud. NOAA's Pacific Marine Environmental Laboratory is exploring the use of AI to understand hydroacoustic data gathered by Saildrones.

The cloud presents a huge opportunity, but it is not a solution to all challenges. Emerging cloud technologies provide new opportunities for long-term efficiency but may pose high, short-term costs as legacy systems are re-engineered for the cloud and new data formats and workflows are developed to best utilize the cloud's potential. Data stewards may ultimately achieve significant benefits by moving to the cloud through lower costs associated with capital improvements, storage and ongoing maintenance as well as potentially increased security, reliability and computing power. In the short term, cloud migration for ocean data may be seen as a cost-prohibitive option or in some cases require new skills with the potential to slow a research project in the beginning.[133] Cloud computing, however, offers the opportunity for researchers to address larger and more complex problems without the cost associated with building and maintaining local computational infrastructure.[134] Vance et al. (2019) outline opportunities and challenges as they relate to ocean data and the cloud as well as current examples on the IOOS RAs.[135] Ocean data experts at the Ocean Data Roundtable recognized the potential for smaller ocean-modeling projects to realize cost savings by hosting data on the cloud instead of relying on supercomputers for all predictive forecasting.[136]

The full utility of cloud computing to different stakeholders is still in the exploratory phase. NOAA recently released its Data Strategy and Cloud Strategy that have broad application for the agency and are interrelated with the Unmanned Systems, AI and 'Omics Strategies.[137] One way that NOAA has attempted to encourage and scale collaboration in data sharing and enable cloud computing is through its focus on the BDP. The BDP is a public-private collaboration between NOAA and three cloud service providers—Amazon Web Services, Google Cloud Platform and Microsoft Azure—to publicly disseminate NOAA open data on their cloud computing platforms. The BDP deploys an open-data transfer scheme that allows a single copy of data to be securely transferred to the three cloud service provider platforms where all users may gain access to NOAA open data. At the Ocean Data Roundtable, various ocean data users and stakeholders made recommendations for priority data categories to be added to the BDP (Appendix III).

The ability to increase data throughput via more powerful processing and analysis may ultimately be a more important use of the cloud than data hosting. Participants at the Ocean Data Roundtable, which had a strong focus on the BDP,

xiii Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. See: National Institute of Standards and Technology. The Definition of Cloud Computing: Recommendations of the National Institute of Standards and Technology [Internet]. Washington DC: U.S. Department of Commerce; 2011 September. 7 p. 2-3. Available from: nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf identified the potential of the cloud to improve data quality, leverage new technologies to process raw data and utilize AI to streamline data imports. Migrating data processing and analysis functions to the cloud may help compensate for limited resources for data processing or the lack of computing power to analyze large datasets. In addition, as users increasingly access and use open datasets through cloud environments, they can provide feedback or report errors in the data. There are other ongoing cloud activities at NOAA including NESDIS cloud initiative, IOOS, other NOS work and AI efforts, especially at Pacific Marine Environmental Laboratory.

As challenges around ocean data are addressed, the utility of cloud computing can be realized and improved. Butler and Merati (2016) outline an analysis pattern for data providers and project managers to determine cloud needs for a given research endeavor upfront based on potential computing needs.[138] The National Strategy, under which large amounts of bathymetry and ecosystem-characterization data will be collected and stored, can apply cloud computing to improve the value of the data for scientific studies and resource management by automating QA/QC. As the National Strategy is implemented and updated through 2030, attention should be given to collaborations and engagement with the ocean community that advance new technological solutions, improve management through data accessibility and transparency, and advance our understanding of the deep ocean. Determining the use and function of the cloud at the beginning of a project with federal partners and researchers up front will lead to success of this effort.

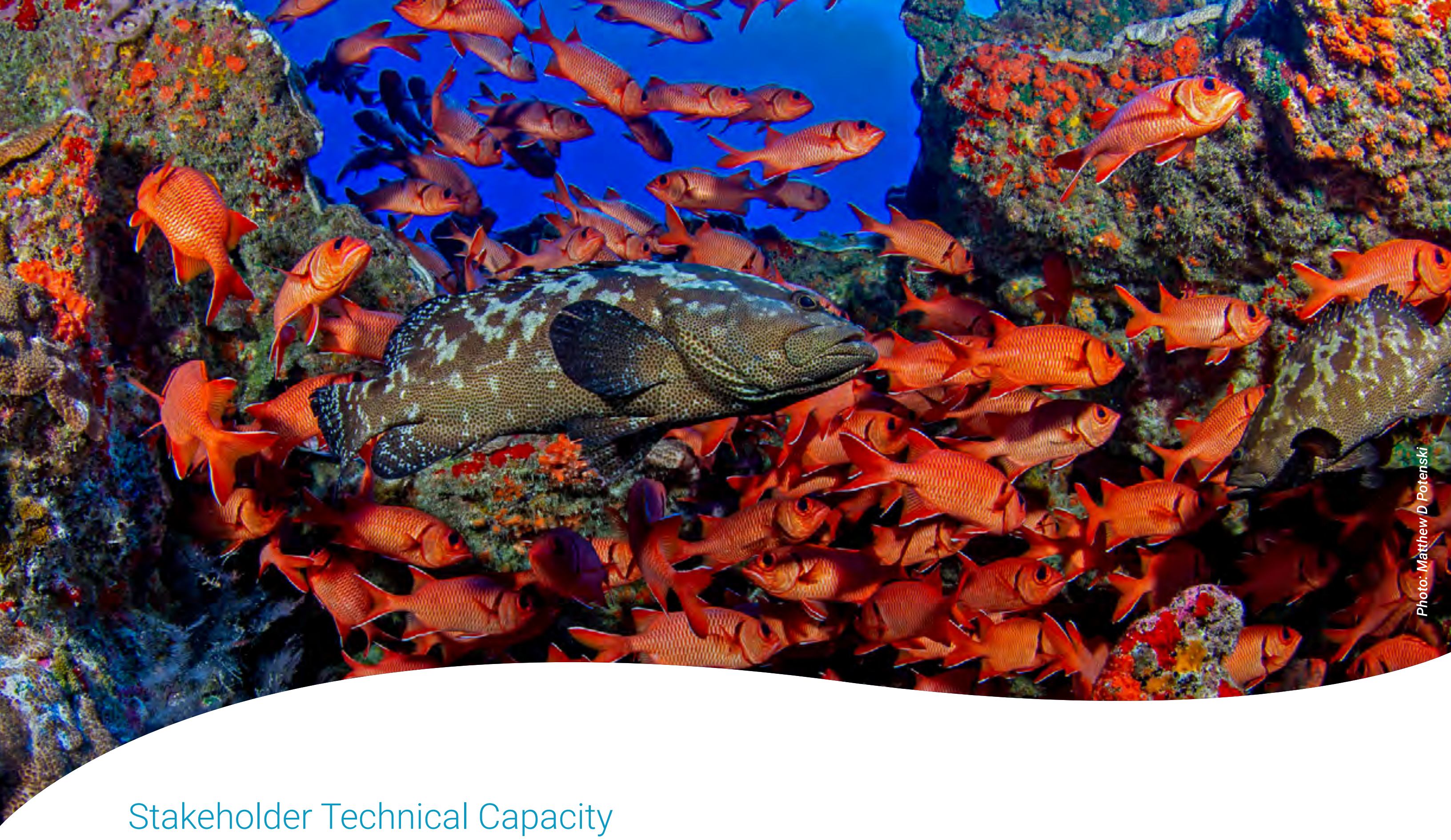
Actionable Opportunity: Ocean data stakeholders have identified a number of datasets that are not publicly available or that could be made more useful by being aggregated at a national level. Cloud computing has been identified as an opportunity to bring these data together and make them available to a wider audience. NOAA's BDP has been identified as a potential tool to address these data gaps and priorities. The BDP is a cloud-based public-data dissemination service and was designed to ease access to the terabytes of data produced by NOAA satellites, radar, ships and weather models every single day.[139] Adding more ocean data to the BDP could prove valuable as it moves into this new phase.

Recommendation: NOAA's BDP team and cloud service providers (Amazon Web Services, Google Cloud Platform and Microsoft Azure) should clarify a process to enable data managers at the federal and regional levels to provide data on marine species and also VMS, VTR, AIS and bathymetry data for incorporation into the BDP. This will enable the integration of state and federal data and facilitate standardization and interoperability. For example, it will ease integration of existing bathymetry data collections with data collected by the National Strategy discussed earlier.

Stakeholders: NOAA, cloud service providers, ROPs, IOOS, Fisheries Councils, OSTP, OPC

Long-Term Impact: Ocean data stakeholders are able to use previously inaccessible or difficult-to-use datasets in research and for ocean resource management.

Recommendation: Action to implement the use of the cloud within NOAA BDP, NESDIS cloud pilot, AI, machine learning and other NOAA line-office cloud pilot projects is needed. NOAA at the operational level has security concerns that in some instances limit the ability of staff to explore cutting-edge cloud and technological applications. Working outside NOAA boundaries with the intent of creating tools that can be brought back into the agency once fully developed is a good option to address some of the operational level sercutity concerns. Additional funding and support to NOAA from Congress and direction within the agency to advance and suppot partnerships with academia and commercial entities would help NOAA cloud efforts. Support to explore cloud tools and participation in communities of practice such as Earth Science Information Partners and NSF National Center for Atmospheric Research led initiatives on archiving of model data in the cloud is also important for NOAA cloud advancement. NOAA staff should also be encuraged to explore the equity and access ramifications of moving data to the cloud.



Stakeholder Technical Capacity

Some data users cannot access or leverage data as easily as others. Scientists collecting data may lack the necessary technical skills to convert them into interoperable formats while potential end users may be intimidated when faced with raw data downloads. The challenges can include a lack of technical capacity for data cleaning, software development or standards adoption. For example, despite the advantages of the netCDF format, a self-describing data format, many research groups lack the capacity to use it consistently.[140] Researchers in the field have to run custom software routines—often multiple times—to convert and validate data sets. The challenge of using data standards is even more difficult for data users who are not academics or researchers. They often lack the necessary technical skills, and project-data management plans rarely provide the resources they need.[141] More broadly, it is often difficult to encourage stakeholders to adopt common standards, due to a lack of understanding of their importance or lack of ability to adopt and use them. Accounting for these varying levels of technical capacity is a significant challenge for ocean data stewards working to make data more available to interested stakeholders. It is incumbent on data producers and consumers to recognize the data ecosystem and user limitations through the design of user-friendly, data-delivery mechanisms. New technologies such as QA/QC as a service in the cloud or automated reformatting of data and translation of metadata formats could go a long way to answering these challenges.

Ocean data producers and consumers at the regional level have recognized the need to build products with and for user groups with varying levels of technical capacity or interest. Work done by the ROPs can serve as models for engaging stakeholders and developing products and tools tailored to data-user needs. The Northeast and Mid-Atlantic ROPs, for example, have ensured that data relating to human use activities, from the maritime industry to recreational boating, are displayed meaningfully. The ROPs' success in displaying geospatial data can be attributed in large part to robust and continual engagement with stakeholders. Working to develop trust and understanding among ocean groups, the ROPs work to identify appropriate characterization of human activity for each sector, group or community to properly display a given activity. These ocean data portals also characterize spatial-use activity that corresponds to industry trends and use across spatial and temporal scales that enable management decisions. Similarly, data producers and consumers like the IOOS RAs serve a variety of end users ranging from shellfish growers to surfers, who have unique data needs.[142] The Pacific NANOOS and other IOOS RAs have worked with their various stakeholders to develop a range of tailored apps, serving specific data sets to the users who need them most.[143] Similarly, CARICOOS is focused on getting their data out to non-scientists who may face challenges finding the data or may be intimidated when faced with raw data.[144]

Other capacity challenges include technical issues like spotty Internet access or lack of specialized software. For example, ocean data stakeholders in Alaska cited a wide variance in Internet bandwidth in different areas of the state as a major challenge for accessing large quantities of data.[145] Ocean datasets vary significantly in size.[146] The largest include video files and detailed bathymetric data that may be difficult for users without consistent, high-speed Internet access to manage. Meanwhile, data users in the Pacific Islands cited a lack of access to proprietary Geographic Information System (GIS) mapping software and a need for open-source data formats as a key challenge.[147]

Capacity issues can be addressed in a number of ways. Targeted funding for training, data management and user engagement can help data consumers ensure interoperable data and tailor products directly to end-user needs. Cloud-based projects like the BDP could help alleviate some of the challenges caused by large file sizes and lack of access to fast Internet or adequate computing power. Researchers and other stakeholders with limited Internet access, computing power or physical storage space can host their data and conduct research entirely on the cloud without having to download, process and store large data sets. By giving users access to the data and enabling them to analyze them in the cloud, these services make big data both more accessible and more computable. The cloud can also host “labeled” training data to improve predictive ability and make it easier for scientists with limited access to computing power to analyze large data sets.

Actionable Opportunity: Scientists and other ocean data users with limited access to computing power and Internet bandwidth need ways to analyze large datasets. Cloud technology makes this possible by giving end users the opportunity to analyze large datasets without needing to download them or pay for local storage.

Recommendation: NOAA and regional data consumers should work with data users in remote areas to enable cloud-based data analysis. Data consumers should use cloud technology to develop algorithms that allow both basic and specific analysis. Regional data consumers should continue to engage ocean data users in development of tailored products. They should consider opportunities to integrate cloud into their underlying data infrastructure for better processing, management, analytics and public access for users with varying capacity.

Stakeholders: NOAA, ROPs, IOOS RAs, cloud service providers, scientists.

Long-term Impact: Ocean data users with varying access to resources are able to leverage ocean data for their research, resource management, commercial and other needs. Ocean data users with varying levels of technical capacity eventually benefit from better stakeholder engagement as a result of regional data consumers using cloud technology for better processing, management and analysis.

Domain- and Region-Specific Data Gaps

Due to the nature of ocean data collection and management and the sheer challenge of collecting data across the vast ocean, there are many gaps in ocean data across regions in the U.S and even across states within those regions. Examples include a variance in the amount of data on recreational and commercial fishing among the Northeast, Mid-Atlantic and South Atlantic regions, a lack of bathymetry data for the Gulf Coast states, and inconsistent and non-standardized data on species across states (see Appendix IV page 57-59 for additional data gaps identified by regions in a scoping study).[148] In some instances, ROPs or their regional functional equivalent such as AOOS have research and science agendas with critical data gaps that could advance our understanding and management decisions. The Arctic has many challenges and data limitations that have impacts for the region from both management of the area to broader weather predictions associated with melting sea ice. Arctic data needs include long-term data to support fisheries management including treaty obligations under the Central Arctic Ocean Fisheries Agreementxiv, real-time ice and marine mammal information to reduce risks to and impacts from commercial vessel traffic[149], ecosystem data to monitor and understand the rapid change taking place in Arctic waters[150], data to support effective management of offshore oil and gas activities[151], and more. Ice-covered areas have traditionally been difficult to sample and result in data gaps that are compounded with satellite data that present difficulties distinguishing snow and ice from clouds.[152] Argo floats are the backbone of the Global Observing System, and there is a need to extend this Argo network with advances to a variety of autonomous profiles and gliders that can operate in ice-covered areas to advance our understanding of the Arctic.[153] There are a variety of new technologies that can help address data gaps; partnerships and enhanced coordination are key to these endeavors.[154] As more work is done to map, explore and characterize the ocean and the National Strategy advanced, regions should be consulted to guide decisions on data needs, focusing on data needed for management decisions and to better understand changing ocean conditions as a result of climate change.

In addition to gathering appropriate ocean data, data management and access systems must be capable of providing access to data in ways useful to decision-makers and other users. Planning for data gathering should be done in conjunction with planning for data use, recognizing a diversity of uses and users, including those whose willingness to share data may depend in large part on whether their needs are being met and their interests respected.

Specific data needs and gaps have been identified for different ocean data categories. Ecosystem and habitat data lack adequate standardization, preventing comparisons and analyses of the data across regions and federal agencies (although the Coastal and Marine Ecological Classification Standards may address some of these concerns). While some bathymetry data is generally available, there are major gaps, and the data that are available are located in various places across multiple federal agencies.[155]

xiv T.I. Van Pelt, H.P. Huntington, O.V. Romanenko, F.J. Mueter. 2017. The missing middle: Central Arctic Ocean gaps in fishery research and science coordination, *Marine Policy* 85:79-86, https://doi.org/10.1016/j.marpol.2017.08.008.

Photo: Rafeed Hussain

In a scoping study led by NOAA and BOEM to inform the OPC, stakeholders from regional ocean platforms and data portals identified a number of high-priority data sets in need of improvement.[156] Experts at the Ocean Data Roundtable identified opportunities to use cloud computing to more efficiently process, manage and disseminate key data sets.[157] Significant priority data categories that emerged across these conversations include:

- Abundance and distribution of marine species.
- Commercial fishing vessel location (VSM and AIS data, catch and effort VTR data).[xv]
- Recreational fishing effort.
- Bycatch and discards from fishing.
- Bathymetry.

Additionally, there are a number of known sources of data that are not currently available due to national security concerns or concerns over competitive advantage. The DOD collects data on bottom habitat, bathymetry, acoustic imagery and more that they do not currently share.[158] Ocean data stakeholders also have a need for data that have been collected by private companies for commercial purposes but are not shared widely.[159]

With investment in research from NOAA and other federal agencies, conversations with regional experts and coastal managers are essential to ensure data collection efforts and later tool development are serving those entities who need the information to make decisions. As with many themes of this report, the potential challenges and solutions require collaboration with a wide, diverse, and inclusive set of constituents, including Tribal Governments through government-to-government consultation.

Actionable Opportunity: ROPs and IOOS RAs have a unique perspective on the data needs of a given region. Consultation on regional data gaps as well as opportunities for better integration with the OPC will ensure that data gaps are addressed in a way that prioritizes the need to solve management challenges and advance the scientific understanding of an area. Regions have direct connections to the broader ocean community including universities, industry, communities and managers as well as producers and consumers. Improving collaboration with ROPs, IOOS RAs, Tribal Governments and federal agencies will collectively advance many of the challenges related to domain- and region-specific data needs.

Recommendation: The OPC and federal partners such as NOAA should create ongoing mechanisms to solicit input on regional data needs as was done in the recent scoping study. OPC should outline priority data sets and an associated work plan for advancement for each fiscal year. The OPC's Ocean Resource Management Subcommittee should be tasked with implementing and improving the availability of data and should consult with the OST Subcommittee where specific data gaps exits that could be advanced through targeted research and defined priority areas for additional research and technological advancements.

Stakeholders: OPC, relevant federal agencies for data gaps identified, ROPs, IOOS, ocean data stewards

Long-Term Impact: A comprehensive plan is developed from the OPC that drives federal agency action and prioritization for research, analytics, staff time and associated budgets. Regional data gaps are filled and progress is made to fully understand the most pressing questions within ocean science and management. The process is transparent, and there is an understanding of what is needed from all parties.

xv These categories were identified by the regions in response to the administration's commitment to direct resources in FY 2020 towards four data themes: vessel traffic, marine species, fishing and offshore infrastructure. Also see, *Ocean Policy Committee: Ocean Resource Management Subcommittee Implementation Plan to Increase Public Access to Marine Data and Information. Washington, DC: The White House*; 2019 September. 3 p. Available from: https://trumpwhitehouse.archives.gov/wp-content/uploads/2017/11/20191009-FINAL-ORM-Marine-Data-IP-Sep2019.pdf

Photo: Emily Brauner

Conclusion

The blue economy, accounting for $373 billion of U.S. gross national product, is powered by ocean uses that include shipping, fishing, tourism and offshore energy development. All of these sectors are both providers and users of ocean data used to inform business and operational decisions, placement of new infrastructure and sustainable resource management policies. The amount of data now collected from the deployment of new technologies and crowdsourcing is staggering, yet these data are underutilized because the systems of characterizing, managing and sharing data have not been standardized, modernized or updated to keep pace with the exponential growth in data while guaranteeing confidentiality and privacy. If the private and public sectors are to fully realize the potential of ocean data, various technical, cultural, institutional and economic impediments preventing stakeholders from accessing and optimizing data need to be overcome.

The set of solutions to ocean data management and sharing challenges described in this report are not exhaustive, but reflect top priorities that, when implemented, will improve the transparency, quality, consistency and accessibility of data for use in ocean conservation, business and management decisions. This need is punctuated by the climate crisis, which is driving changes in ocean conditions that must be monitored and studied closely for responsive and timely management actions. For example, species are shifting their distributions, potentially disrupting fisheries or increasing the potential for vessel-marine mammal interactions in new shipping routes with decreasing sea ice. Another priority is expanding equitable, public access to ocean data and recognizing that the Indigenous community and local stakeholders have much to offer (and gain) by sharing traditional ecological knowledge not captured through instrumentation or structured surveys. Anecdotal observations can be used in models, along with empirical data, to provide a richer understanding of marine ecosystem function and health.

Detailed recommendations, with emphasis on the U.S., are provided in the report, but the following is a high level summary of conclusions and priorities.

- The open and equitable sharing of data with the public should be improved. Lessons learned from the health care industry suggest confidential and private data can be aggregated or anonymized to protect proprietary claims and identities while maximizing their benefit for sustainably managing the oceans.

- Federal funding has not kept pace with the exponential increase in ocean data and should be increased for relevant federal agencies, particularly NOAA. Ocean data, like the marine resources they represent, are a valuable, virtual commodity that enable public officials to make informed management decisions and help businesses from shipping to fishing understand changes in ocean conditions or resource abundance or distribution that affect their operations.

- Partnerships among data collection and custodial organizations such as IOOS and ROPs facilitate data flows from the source through distribution channels such as portals for public access. Taking stock of existing collaborative efforts with the goal of improving their relevance and reach to end users and stakeholders is a priority, as is expanding and strengthening partnership mechanisms like the NOPP across industry, academia and philanthropic organizations.

- A culture of competitiveness is a significant reason why academics and industry have historically withheld data from timely or public disclosure. Technical advances now allow data to be tagged and shared with attribution provided to original owners, incentivizing release of data before publication. Some federal agencies now require federally funded researchers to share their data, although to what extent rules are enforced is unclear. NOAA should review its enforcement of its data-sharing rules and consider accountability measures to improve compliance. BOEM should strengthen data-sharing requirements in lease agreements with energy companies operating offshore facilities within the U.S. EEZ.

- Technology is giving humanity an unprecedented window into ocean processes, but the prolific amount of data generated by a growing network of disparate sensors, gliders and smartphones is not always comparable or analyzable because of the different systems and currencies used. Ocean observation entities, including those run by government agencies and private institutions, should formally adopt a common framework that ensures data are open, freely available, discoverable and comparable across platforms. The FAIR principles are gaining acceptance as a framework for establishing an integrated, sustained ocean-observing system with fit-for-purpose data and information streams for societal and scientific benefit.

- Cloud computing is a technological advancement that enables data to be stored, accessed and analyzed (using AI) with greater efficiency, accuracy, speed and eventual economies of scale. NOAA's BPP is an experiment in cloud computing provided by Amazon Web Services, Google, and Microsoft Azure focusing initially on migrating atmospheric data collected via satellites, radar, ships and weather models. NOAA should consider expanding the BDP to include more ocean data collected from in situ and remote platforms.

- The oceans remain underexplored, hindering scientific discovery and efforts to manage marine habitats and species at a time of intensifying climate change and increasing ocean use (e.g., deep sea mining, aquaculture). Leveraging new data streams and expanding ocean exploration and research to fill gaps in ecosystem knowledge are priorities. Significant, specific priority data categories that emerged are: 1) abundance and distribution of marine species; 2) commercial fishing vessel location and catch and effort; 3) recreational fishing effort; 4) bycatch and discards from fishing; and 5) bathymetry. Launched in 2020, the National Strategy for Mapping, Exploring, and Characterizing the U.S. EEZ, under which large amounts of bathymetry and ecosystem characterization data will be collected, is an unprecedented opportunity to inform resource management or policymaking that permits offshore commercial activities (e.g., wind farms) while maximizing conservation values. Sustained government funding for this initiative is a priority, as is leveraging intergovernmental (e.g., NOAA and DOD) and private-public partnerships that would maximize government and commercial shipping and fishing fleets for data collection.

The U.S. led by NOAA and its sister agencies and in cooperation with the international community, is well positioned to transform ocean data collection, management and use in service of the ocean-based economy and ocean conservation. This can be achieved using 21st century technologies, forging new public-private partnerships, engaging communities thoughtfully, and overcoming cultural and institutional barriers to data sharing in academia and industry. Perhaps most importantly, however, these outcomes require political will and funding commensurate with the challenges that lie ahead.

Appendices

Appendix I: Acronyms

AI	Artificial Intelligence
AIS	Automatic Identification System
AOOS	Alaska Ocean Observation System
BDP	Big Data Program
BOEM	Bureau of Ocean Energy Management
CARICOOS	Caribbean Coastal Ocean Observing System
CODE	Center for Open Data Enterprise
CO-OPS	Center for Operational Oceanographic Products and Services
DoI	Department of Interior
DOI	Digital Object Identifier
eDNA	Environmental DNA
EDS	Environmental Data Server
EM	Electronic monitoring
ENOW	Economics: National Ocean Watch
EOSDIS	Earth Observing System Data and Information System
EPA	Environmental Protection Agency
ER	Electronic reporting
FAIR	Findable, Accessible, Interoperable and Reuseable
FD	Fishery-dependent
FI	Fishery-independent
FLDRS	Fisheries Logbook Data Recording Software
FMC	Fishery Management Council
FWS	Fish and Wildlife Service
GOFISH	Graphic Offshore Fishing Information System Homepage
GOMA	Gulf of Mexico Alliance
GOOS	Global Ocean Observing System
IOC	Intergovernmental Oceanographic Commission
IOOC	Interagency Ocean Observation Committee
IOOS	Integrated Ocean Observing System
MARACOOS	Mid-Atlantic Coastal Ocean Observing System
MARCO	Mid-Atlantic Regional Council on the Ocean
MOU	Memorandum of Understanding
MPA	Marine Protected Area
MSA	Magnuson-Stevens Fishery and Conservation Management Act
NANOOS	Northwest Association of Networked Ocean Observing Systems
National Strategy	National Strategy for Mapping, Exploring, and Characterizing the U.S. Exclusive Economic Zone
NCEI	National Center for Environmental Information

NCEP	National Centers for Environmental Prediction
NEFMC	New England Fishery Management Council
NERACOOS	Northeastern Regional Association of Coastal Ocean Observing Systems
NESDIS	National Environmental Satellite Data and Information Service
netCDF	Network Common Data Form
NEXRAD	Next Generation Weather Radar
NGO	Non-governmental Organization
NIH	National Institutes of Health
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOPP	National Oceanographic Partnership Program
NOS	National Ocean Service
NROC	Northeast Regional Ocean Council
NSF	National Science Foundation
NWS	National Weather Service
OAR	Oceanic and Atmospheric Research
OGL	Ocean Genome Legacy
OMB	Office of Management and Budget
OOI	Ocean Observatories Initiative
OPC	Ocean Policy Committee
OST	Office of Science and Technology
OSTP	Office of Science and Technology Program
PARR	Public Access to Research Results
PORTS®	Physical Oceanographic Real-Time System
QA	Quality assurance
QARTOD	Quality Assurance/Quality Control of Real-Time Oceanographic Data
QC	Quality control
RA	Regional Association
ROP	Regional Ocean Partnerships
SIC	Species Information Center
SOST	Subcommittee on Ocean Science and Technology
SPO	Satelite and Production Operations
SSH	Sea surface height
SST	Sea surface temperature
U.S.	United States
U.S. EEZ	United States Exclusive Economic Zone
USCG	United States Coast Guard
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
VMS	Vessel Monitoring Systems
VTR	Vessel Trip Reports
WCOA	West Coast Ocean Alliance

Appendix II: Ocean Data Platforms and Portals

Marine Cadastre
marinecadastre.gov
The Cadastre is an integrated marine information system that provides data, tools and technical support for spatial use and planning. Originally designed to support renewable energy efforts on the Outer Continental Shelf, it now supports other ocean management and conservation efforts.

National Data Buoy Center (NDBC)
ndbc.noaa.gov
The NDBC is a unit of the National Weather Service's Office of Operational Systems in NOAA. It operates ocean observing networks of data collecting buoys and coastal stations.

Comprehensive Large Array-Data Stewardship System (CLASS)
avl.class.noaa.gov/saa/products/welcome
CLASS provides a repository of environmental data from a variety of ground-based and remotely-sensed observing systems. It is a multi-site system which ingests data from a number of satellites including the Geostationary Operational Environmental Satellites (GOES) and the Polar-orbiting Operational Environmental Satellites (POES). It also contains data from continuing operating reference stations and derived products.

National Center for Environmental Information (NCEI)
ncdc.noaa.gov/data-access
NCEI hosts and provides access to archival oceanic, atmospheric and geophysical data. It maintains a number of datasets and portals including the World Ocean Database and the World Ocean Atlas.

Earth Observing System Data and Information System (EOSDIS)
earthdata.nasa.gov
EOSDIS is an end-to-end data management system for NASA's earth science data from various sources such as satellites, aircraft, and field measurements. It operates Distributed Active Archives Centers which produce and archive the earth science data products.

Integrated Ocean Observing System Regional Associations
Integrated Ocean Observing System (IOOS) consists of 11 regional associations. Among other objectives, regional associations aim to develop and host data portals that integrate data from multiple sources and build tailored products specific to the unique characteristics of the region. The design of the portals and tools and nature of archival datasets published vary among the different regional associations.

- Alaska Ocean Observing System portal.aoos.org
- Caribbean Coastal Ocean Observing System caricoos.org
- Central and Northern California Ocean Observing System data.cencoos.org
- Great Lakes Observing System portal.glos.us
- Gulf of Mexico Coastal Ocean Observing System data.gcoos.org
- Mid-Atlantic Regional Association Coastal Ocean Observing System oceansmap.maracoos.org
- Northeastern Regional Association of Coastal Ocean Observing Systems neracoos.org/datatools
- Pacific Islands Ocean Observing System pacioos.hawaii.edu
- Pacific Northwest Association of Networked Ocean Observing Systems nvs.nanoos.org
- Southeast Coastal Ocean Observing Regional Association portal.secoora.org
- Southern California sccoos.org/observations

Regional Ocean Partnerships

Regional Ocean Partnerships (ROPs) are regional organizations voluntarily convened by governors to address ocean and coastal issues of common concern among states and in collaboration with federal agencies, Tribes, academic institutions, and ocean stakeholders. While many ROPs have worked to address ocean and coastal management challenges for over a decade, the federal ocean policy, Executive Order 13840 (July 2018), recognized the function of ROPs and their associated regional ocean data portals as providing interagency collaboration on cross-jurisdictional ocean and coastal matters. Several ROPs have developed ocean data portals to provide a common platform where spatial ocean data can be displayed for planning and resource management.

Data found on these platforms come from a variety of sources including federal agency data sources (like the Marine Cadastre), individual agencies, states, industry, IOOS Regional Associations, universities and non-governmental entities. Platforms and data sets are unique to the needs of the states and region but often similar in the spatial nature of the data displayed. In some regions that do not currently have ROPs, the IOOS observing system is also used to provide information on resource management in addition to the other services the system provides. Those regions include: Alaska, Caribbean, Southeast, Great Lakes and Pacific Islands.

Northeast Regional Ocean Council (NROC) – Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, Department of Interior, Environmental Protection Agency, National Oceanic and Atmospheric Administration, Department of Agriculture, Army Corps of Engineers and Coast Guard

Northeast Ocean Data Portal: northeastoceandata.org

Mid-Atlantic Regional Council on the Ocean (MARCO) – New York, New Jersey, Delaware and Virginia

Mid-Atlantic Ocean Data Portal: portal.midatlanticocean.org

Gulf of Mexico Alliance (GOMA) – Alabama, Florida, Louisiana, Mississippi and Texas

Gulf of Mexico Alliance manages a number of tools and portals to support management: gulfofmexicoalliance.org/our-priorities/priority-issue-teams/data-and-monitoring-team

West Coast Alliance (WCOA) – California, Oregon, Washington and 11 Tribal governments

West Coast Ocean Data Portal: portal.westcoastoceans.org

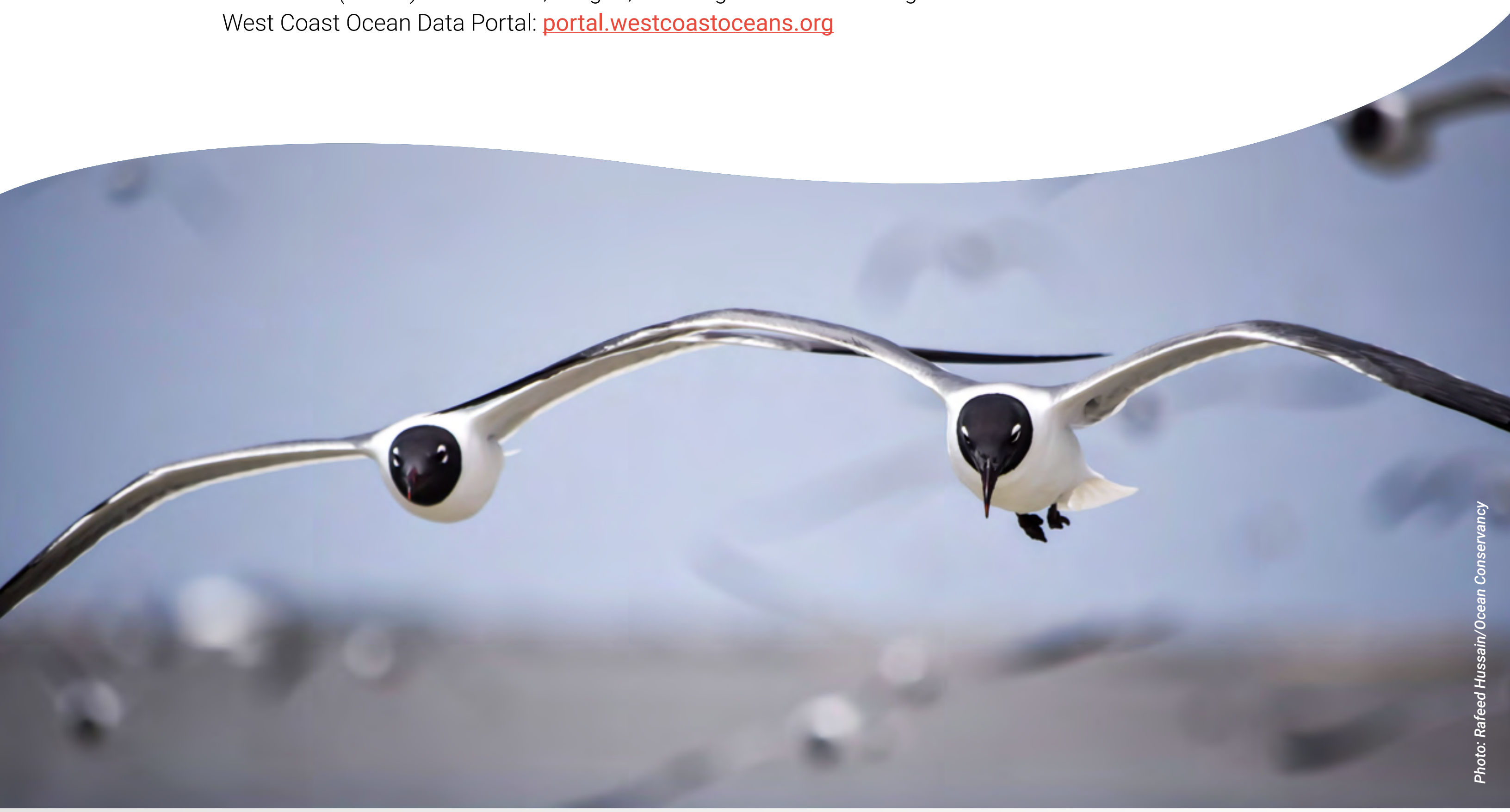


Photo: Rafeed Hussain/Ocean Conservancy

Appendix III: Priority Ocean Data Categories and Types Identified at the Roundtable on Putting Ocean Data to Use

The Center for Open Data Enterprise (CODE) hosted a roundtable in partnership with Ocean Conservancy, NOAA, Esri, Amazon Web Services and Microsoft in February 2020 to discuss the use of ocean data and development of data driven strategies to improve ocean health and promote the Blue Economy. Roundtable participants were requested to identify categories and types of datasets that would prove useful for inclusion as part of the Big Data Program.

Roundtable participants suggested a variety of high priority data types that could support conservation and the blue economy, promoting sustainable ocean stewardship. Participants noted that the BDP presented a unique opportunity to help create new systems to streamline data collection and to improve high priority data areas like fisheries, Coast Guard data, and weather patterns data. NOAA and the Cloud Service Providers can use this input to investigate specific datasets for the BDP as appropriate.

Biological Data

The BDP does not currently host explicit biological datasets nor does it host any datasets from the National Marine Fisheries Service (NMFS). Roundtable participants suggested that the BDP host both the critical species and marine life data from the NMFS, and include commercial fishing data.

Abundance and Distribution of Marine Species Data

The current NOAA "OneStop" Data Portal links to a number of datasets that directly feature biological assessments of marine resources, species identification in select geographic zones, and overall biological surveys of key species.[xvi] Roundtable participants stressed the importance of tracking species to support planning efforts for preserving and monitoring habitat and species diversity. The Regional Scoping Study notes that marine species data provides planners with important information for aquaculture planning, evaluating project impacts on habitats, and monitoring invasive species. Coral reef assessments, for example, can provide ocean planners with tangible data to evaluate species health or the impact of ecotourism on these endangered environments.

Vessel Monitoring Systems Commercial Fishing Effort

Current Producer: National Marine Fisheries Service and NOAA Office of Law Enforcement
NOAA already compiles and aggregates fisheries statistics each year which help track 474 fish stocks across 46 different fisheries management plans.[xvii] Data on fishing effort, catch, and other information are directly gathered through Vessel Monitoring Systems (VMS), Automated Integration Systems (AIS), and other sources like logbooks, and help quantify the value of the Blue Economy. Vessel Monitoring Systems or VMS specifically provides remote monitoring of fishing vessel positions in relationship to maritime boundaries and other key regulatory areas and were first used for compliance and enforcement. This data ensures the vitality of sustainable fisheries, reliable seafood sources, and general conservation of important ecosystems. Roundtable participants noted that if VMS/location information is allowed to be reported, particularly in conjunction with catch information, it provides value by potentially evaluating the effects on species habitats, and also assessing catch and bycatches. Most fisheries data collected through VMS Derived Products have considerable privacy issues given that this information includes specific GPS location data. Data collected through Fishery Management Councils may be disparate and not collectively aggregated at the national level. Roundtable participants recognized that the BDP could prioritize key fishing datasets and work with ROPs to identify and address regulatory restrictions that may impede access to fishing data. NOAA would also need to spearhead an effort to better train regional planners on coding, processing and engagement.

xvi One Stop. National Oceanic and Atmospheric Administration; [cited 2020 Mar 3]. Available from: data.noaa.gov/onestop/collections
xvii NOAA Fisheries. About Us [Internet]. National Oceanic and Atmospheric Administration; [cited 2020 February 21]. Available from: fisheries.noaa.gov/about-us

Physical Data

Many of the recommended physical data types are derived from satellites, ships, buoys and underwater technologies (e.g., gliders). There are several valuable datasets hosted on the BDP. For example, Ocean Heat Fluxes is produced by the National Environmental Satellite, Data and Information Service (NESDIS). It provides a high quality climate data record that captures heat fluxes using a special sensor microwave imager and sea surface temperature. Roundtable participants also identified several additional high-value physical datasets that should be hosted by CSPs for their potential commercial and research value.

Acoustic Doppler Current Profiler (ADCP) Data

Current Collector or Producer: NOAA Ocean Explorer

Acoustic data helps measure ocean currents using the principle of the "Doppler Shift", which emits a sequence of pulses that measures the pitch of particles either moving towards or away from the ADCP. Although the NCEI is attempting to share ADCP data, a number of Roundtable participants recognized that the BDP could streamline this process and feature a single hosting location for ADCP data on its cloud platforms. Roundtable participants also noted that high frequency radar data is valuable in measuring the speed and direction of ocean surface currents in real time.

Real-Time Tide Gauge Data

Current Collector or Producer: NOAA Tides and Currents

NOAA Tides and Currents is developed and supported by the Center for Operational Oceanographic Products and Services, and provides a series of dataset products that capture water levels, sea level trends, and other critical data. The real-time tide gauge data measures water level information every six minutes from a series of active stations across different regions of North America, including the Great Lakes, the Gulf Coast, the Caribbean, and the West Coast.[xviii] Many of these stations are operated by IOOS and are part of its mandate to report ocean observations. This oceanographic parameter can provide critical information to coastal authorities and can also be extrapolated into time-series products that measures sea level rise caused by seasonal weather and global sea level rise.

Synthetic Aperture Radar (SAR)-derived High Resolution Wind Products

Current Collector or Producer: NOAA CoastWatch

Synthetic Aperture Radar (SAR) uses the surface microwave radar to create its own illumination and profile surface conditions regardless of the weather. Roundtable participants noted that several key physical parameters can be derived from SAR, including the ability to measure sea surface wind speed. Current users of SAR data and its derived products are the US National Ice Center, the Alaska Weather Service and the Naval Oceanographic Office.

Other High-Value Datasets:

- ***Imagery Response Data*** for faster response times to major weather events like Hurricanes
- ***Glider data*** features underwater drone data that can share information back with key NOAA centers.

xviii Tides & Currents Products [Internet]. National Oceanic and Atmospheric Administration; [cited 2020 Mar 3]. Available from: tidesandcurrents.noaa.gov/products.html

Chemical Data

The BDP does not currently host any pure chemical datasets apart from Ocean Heat Fluxes which may be used to extrapolate certain features about ocean chemical composition. Roundtable participants noted several key datasets that should be considered for upload to the BDP for their commercial value.

NOAA Gap Free Ocean Color Data

Current Producer: NOAA CoastWatch
Ocean Color satellite sensors measure visible light at specific wavelengths as it is reflected from the surface of the ocean into the atmosphere. These wavelengths can be analyzed for ocean properties such as the concentration of certain chemicals like chlorophyll, which can be used to determine the amount of phytoplankton biomass in the water.xix The Gap Free Ocean Color Data set allows scientists and researchers to better comprehend changing levels of chemicals and other key elements.

Harmful Algal Bloom (HAB) Data

Current Producer: NOAA's Center for Operational Oceanographic Products and Services (CO-OPS)
Harmful Algal Blooms (HABs) are the rapid growth of algae which can produce toxins harmful to humans, mammals, birds and local economies. NOAA currently produces and monitors data from the Great Lakes and the Gulf of Mexico, with weekly forecasts provided as conditions favor the rise of HABs.xx Roundtable participants noted that NOAA has already helped develop tools to better measure HABs, and these tools are deployed in high-risk areas like the Great Lakes.

Socioeconomic Data

Socioeconomic data are often released in annual or semiannual intervals and may be difficult to combine with daily physical, biological, or chemical oceans observations.

Ocean Economy Satellite Account Data

Current Producer: NOAA and the Bureau of Economic Analysis
The Ocean Economy Satellite Account is a collaboration between NOAA and the Bureau of Economic Analysis (BEA) to gather better data and establish new infrastructure to measure how the Blue Economy contributes to the nation's Gross Domestic Product. This working group is producing valuable economic data on commercial fishing, aquaculture development, and other key measures.

Vessel Density Maps

Current Producer: Marine Cadastre
Vessel Density or vessel traffic can be developed with AIS and displayed geospatially. Vessel density supports coastal and marine planning by showing vessel traffic patterns and potential conflicts with other uses. These data help decision makers manage coastal development such as port siting and development, identify threats to species, and inform renewable energy leasing. In addition to the Marine Cadastre, the Digital Coast, produced by the Office of Coastal Management, uses AIS to show the locations and types of vessels in U.S. and international waters.

xix Jiang L, Wang M. Improved near-infrared ocean reflectance correction algorithm for satellite ocean color data processing. Opt Express. 2014 [cited 2021 Mar 2]; 22(18):21657–78. Available from: doi.org/10.1364/OE.22.021657

xx Harmful Algal Bloom Forecasts [Internet]. Tides & Currents. National Oceanic and Atmospheric Administration; [cited 2020 May 5]. Available from: https://trumpwhitehouse.archives.gov/wp-content/uploads/2020/01/20200611FINALOcean-Strategies-and-recommendations_press-release-1.pdf

Appendix IV: High Priority Data Categories and Needed Improvements

Categories and improvements were identified in the Regional Data Platform Scoping Study: Federal Data Task Report conducted by Dewberry Engineers for the NOAA Office for Coastal Management.xxi The discussion convened both IOOS and ROPs to disucuss regional proirities and data needs.

Data Category and Improvements

Jurisdictions and Regulated Areas

- Boundaries are currently being digitized from descriptions published in Acts, Code of Federal Regulations (CFR), treaties and permit documents. Authoritative agencies should be publishing geospatial data in addition to the published documents.
- Additional details about regulatory restrictions, when or why changed, duration of regulation or agreement, status of permit (e.g. proposed, planned, approved) should be included as attributes in the geospatial data.
- Thresholds for project size and update frequency should be agreed upon with the authoritative agency.
- More detailed data are needed for military areas instead of broad areas of restriction (e.g. unexploded ordnance) if such information can be released.

Abundance and Distribution of Marine Species

- Synthesis of observation data is needed from the multiple entities that collect data.
- Modeled data, derived products and documentation of methodology are also needed (e.g. time series, heat or density maps, and trends over time)
- Dependable and continuous updates to models and products.

Synthesized Oceanographic Parameters

- Synthesis of monitoring and observation data is needed from the multiple regional entities that collect data.
- Derived products from the raw data (e.g.forecasts, change over time).
- In some regions, densification or winterizing of monitoring devices would greatly improve usability of the collected data.
- Standardized, seasonal, annual or decadal products, as applicable, at an ocean-basin scale for temperature, salinity, oxygen, biomass and productivity.

Commercial Fishing Effort – Vessel Monitoring System (VMS)

- Processing and publication of data derived from VMS is conducted by regional partners at considerable cost and effort. Annual agency sponsored products are needed, and in more regions than are currently available.
- Consultation with the Fisheries Management Council (FMC) and regional experts by NOAA National Marine Fisheries Service (NMFS) is needed to define appropriate planning products compatible with existing efforts.
- Improvements to the consistency and completeness of declaration, gear type and other codes.
- Data on recreational fishing, including locations and type of fish caught.
- Having access to economic ata so the economic importance of fishing areas can be quantified would add considerable value to derived products.

xxi Dewberry Engineers, Inc. Regional data platform scoping study. Fairfax, VA: National Oceanic and Atmospheric Administration Ocean Prediction Center; 2018 October 35 p. Available from: https://coast.noaa.gov/data/docs/marinecadastre/regional_scoping_study.pdf

Vessel Traffic – Automatic Identification System (AIS)

- Publication of data derived from raw AIS data is currently performed by the Marine Cadastre.
- Stronger efforts by U.S. Coast Guard (USCG), Maritime Administration (MARAD) and the U.S. Army Corps of Engineers (USACE) could stabilize, expand and improve this resource for the broader ocean community.
- Improvements to the identity and characteristics of vessels, higher frequency access and ready-to-use products. Better access to satellite AIS data is needed where land-based receiver are not available.

Human and Cultural Use Areas

- Uniform and complete data are not readily available and data gathering is intensive.
- Derived products (e.g. summary of use, hot spots, recreation patterns) are needed.
- Data on Tribal Protected Areas need to be updated and made publicly available.
- National Historic Preservation Act data need to be updated.
- Improved documentation of provenance and procedures is needed in the metadata.

Commercial fishing effort - Vessel Trip Report (VTR)

- Processing and publication of data derived from VTR is conducted by regional partners at considerable cost and effort. Annual agency sponsored products are needed, and in more regions than are currently available.
- Consultation with the FMC and regional experts by NMFS is needed to define appropriate planning products.
- Improvements to the consistency and completeness of original codes, documentation, and products interpolated at a spatial resolution to support energy and aquaculture leasing (i.e. ~2.5nm x ~2.5nm or less).
- Data on recreational fishing, including location, type of fish caught, and shore-based access location.

Bathymetry

- Bathymetry data are collected and distributed in a patchwork form and are difficult to find and use at scales beyond individual surveys. Additional high resolution/full bottom surveys are needed for complete coverage in priority areas of interest, especially near shore. Seamless 'best available' products and more up to date bathymetry data products are needed.
- Seafloor characterization by sediment texture and physiographic zones.

Sand and Borrow Sites

- Current information on sand and borrow sites is not complete, is not synthesized, and can be difficult to find. The forthcoming BOEM Marine Minerals Information System will address many issues when published.
- Historic data may not be available in digital format.

Species and Habitat Locations, Including Benthic Habitat

- Synthesis and normalization of data is needed from the multiple entities that collect data.
- Modeled data, derived products and documentation of methodology are needed (e.g. seasonality of occurrence, gear types, high use areas, endangered species).
- Interpretation of bathymetry into bottom habitat information.

Appendix V: Roundtable on Putting Ocean Data to Use: Agenda, Participating Organizations and Partners

Overview of Roundtable Putting Ocean Data to Use, February 2020

The Roundtable on Putting Ocean Data to Use was hosted by the Center for Open Data Enterprise (CODE) on February 10, 2020 in partnership with the Ocean Conservancy, NOAA, Esri, Amazon Web Services and Microsoft. It sought to develop new strategies, action plans and collaborations to improve ocean data collection, sharing, and analysis to support ocean ecosystems and the Blue Economy. The National Oceanic and Atmospheric Association (NOAA) is responsible for one of the largest data inventories of any federal agency, collecting, managing and publishing data for many different users. NOAA has embraced innovative approaches to data distribution, notably through the Big Data Program (BDP). The BDP contracts with Amazon Web Services, Microsoft Azure and Google Cloud as Cloud Service Providers (CSPs) to make a variety of NOAA datasets—including atmospheric and earth observation data that are widely used by the weather industry—publicly accessible and computable in the cloud.

NOAA and other federal agencies and offices have continued their longtime efforts to collaborate to make ocean data more accessible, usable and broadly applied for purposes ranging from environmental studies to resource management decisions. In June 2018, the White House issued an Executive Order (EO 13840) that advanced a federal ocean policy and prioritized the release of federal ocean data to states and regions. As part of the EO, NOAA conducted a Regional Portal Scoping Study to identify regional data gaps, challenges, and opportunities and the White House held its first Ocean Summit in November 2019 to encourage new partnerships in ocean research and to review emerging technologies to improve the ocean data ecosystem. Following the Summit and continuing the theme of advancing ocean data, a Presidential Memorandum on Ocean Exploration was released at the end of last year and in June, the White House Ocean Policy Committee subsequently released several strategies and recommendations to advance the exploration of the EEZ.

The Roundtable on Putting Ocean Data to Use built on this work and brought together nearly 70 stakeholders including members of Regional Ocean Partnerships (ROPs), Integrated Ocean Observation System Regional Associations (RAs), federal policymakers, civil society, scientists and researchers, and members of the private sector. The Roundtable also convened the contracted CSPs, including Microsoft Azure, Amazon Web Services and Google Cloud, to better understand high-value datasets that should be published publicly on behalf of NOAA's BDP. The Roundtable had several objectives:

- Identify ways to leverage the Big Data Project and other emerging strategies and technologies to expand the frontiers of ocean data collection, sharing and processing and analysis.
- Identify challenges and opportunities in partner collaboration for ocean data and data integration.
- Build on the first two objectives to identify new strategies and opportunities to reimagine the ocean data ecosystem within NOAA and more broadly.

Some of the key findings in this White Paper come directly from outputs identified at the Roundtable, including actionable opportunities for NOAA, regional stakeholders and other key ocean data users.

Agenda

Roundtable on Putting Ocean Data to Use
Washington, DC | Monday, February 10, 2020

Roundtable Purpose: To identify emerging opportunities to improve data collection, sharing and analysis across key ocean data stakeholders to support the Blue Economy.

CODE

9:30	**Registration and Networking**
10:00	**Welcome** Joel Gurin, *President, Center for Open Data Enterprise (CODE)* Pat Cummens, *Government Strategist, Esri*
10:10	**Opening Remarks: Envisioning the Future of Ocean Data** Craig McLean, *Acting Chief Scientist, NOAA*
10:20	**Big Data Project: Overview and Panel** ***Big Data Project Overview:*** Jena Kent, *Big Data Project Communications Lead, NOAA* ***Panel Moderator:*** Ed Kearns, *Acting Chief Data Officer, U.S. Department of Commerce* ***Panelists:*** Jon O'Neil *(BDP)*, Ana Pinheiro Privette *(Amazon)*, Erin Gallagher *(Microsoft)*, Eric Pennaz *(Google)*
10:50	**Structure of the Day** Joel Gurin, President, *CODE*
10:55	**Lightning Talks: Opportunities and Challenges to Improve the Ocean Data Ecosystem** Deerin Babb-Brott, *Principal Assistant Director of Oceans and Environment, White House OSTP* Nick Napoli, *Ocean Planning Director, Northeast Regional Ocean Council* Keith VanGraafeiland, *Product Engineer, Esri* Amy Trice, *Director of Ocean Planning, Ocean Conservancy*
11:15	**BREAKOUT SESSION 1:** ***Emerging Strategies and Technologies to Better Collect, Share, Process, and Analyze Ocean Data***
12:15	**Networking Lunch** *(Lunch will be provided)*
1:15	**BREAKOUT SESSION 2:** ***Partner Collaboration and Data Integration: Challenges and Opportunities***
2:15	**Networking Break**
2:30	**BREAKOUT SESSION 3:** ***Reimagining the Ocean Data Ecosystem: Solutions and Recommendations***
3:30	**Presentation of Highlights**
4:00	**Group Discussion: The Potential for an Ocean Data Consortium**
4:15	**Closing Remarks & Next Steps** Ed Kearns, *Acting Chief Data Officer, U.S. Department of Commerce*
4:30	**Adjourn**

Roundtable Partners

The Roundtable on Putting Ocean Data to Use was hosted by the Center for Open Data Enterprise (CODE) in partnership with NOAA, Ocean Conservancy, Esri, Amazon, and Microsoft.

The National Oceanic and Atmospheric Administration's products and services support economic vitality and affect more than one-third of America's gross domestic product through daily weather forecasts, severe storm warnings and climate monitoring, to fisheries management, coastal restoration and supporting marine commerce. NOAA's dedicated scientists use cutting-edge research and high-tech instrumentation to provide citizens, planners, emergency managers and other decision makers with reliable information they need when they need it.

Ocean Conservancy educates and empowers citizens to take action on behalf of the ocean. From the Arctic to the Gulf of Mexico to the halls of Congress, Ocean Conservancy brings people together to find solutions for our water planet. Informed by science, their work guides policy and engages people in protecting the ocean and its wildlife for future generations. Ocean Conservancy works with stakeholders to create science-based solutions for a healthy ocean, and the wildlife and communities that depend on it.

Esri is the global market leader in GIS and has helped customers improve results since 1969. They build ArcGIS, the world's most powerful mapping and spatial analytics software. ArcGIS connects everyone, everywhere through a common visual language. It combines mapping and analytics to reveal deeper insight into data, helping organizations create positive change in industry and society.

Microsoft is an American multinational technology company with headquarters in Redmond, Washington. It develops, manufactures, licenses, supports and sells computer software, consumer electronics, personal computers and related services. Its best known software products are the Microsoft Windows line of operating systems, the Microsoft Office suite, and the Internet Explorer and Edge web browsers.

Amazon Web Services began offering IT infrastructure services to businesses in the form of web services -- now commonly known as cloud computing. The AWS cloud computing platform provides the flexibility to launch your application regardless of your use case or industry. Today, Amazon Web Services provides a highly reliable, scalable, low-cost infrastructure platform in the cloud that powers hundreds of thousands of businesses in 190 countries around the world.

Roundtable Participating Organizations
The Center for Strategic and International Studies
Consortium for Oceans Leadership
Global Fishing Watch
Greenpeace
Oceana
World Resources Institute

Federal Government
Federal Maritime Commission
National Aeronautics and Space Administration (NASA)
National Oceanic and Atmospheric Administration
- Climate Program Office (CPO)
- The National Centers for Environmental Information (NCEI)
- The National Ocean Service
- NOAA Fisheries
- The Office of Oceanic and Atmospheric Research (OAR)
- U.S. Integrated Ocean Observing System

U.S. Census Bureau
- The Opportunity Project

U.S. Department of Commerce
White House Office of Science and Technology Policy
- Subcommittee on Ocean Science and Technology

Private Sector and Technology Companies
Google
Epsilon Innovation Group
Axiom Data Science
Conservation X Labs
CVision Technologies Inc.
Development Seed
Kongsberg Underwater Technology Inc.
RPS Group North America
Terradepth

Regional Entities
Alaska Ocean Observing System
Great Lakes Observing System
Mid-Atlantic Coastal Ocean Observing System
Northeastern Regional Association of Coastal Ocean Observing Systems
Northwest Association of Networked Ocean Observing Systems
Northeast Regional Ocean Council

Academic Science and Research
Gulf of Maine Research Institute
OCEARCH
The Schmidt Ocean Institute
University of Washington Joint Institute for the Study of the Atmosphere and Ocean (JISAO)
Woods Hole Oceanographic Institute


Photo: Rafeed Hussain/Ocean Conservancy

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